Technical Report 2006–1

PUGET SOUND NEARSHORE PARTNERSHIP

RESTORING OUR ECOSYSTEM HEALTH

COASTAL HABITATS IN PUGET SOUND:
A Research Plan in Support of the Puget Sound Nearshore Partnership

Prepared in support of the
Puget Sound Nearshore Partnership

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science for a changing world

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Cover: Oblique aerial photograph of Skagit River delta. (Photograph taken by Guy Gelfenbaum, U.S. Geological Survey, September 5, 2003.)

Contents

1. Executive Summary

The purpose of this research plan is to identify high-priority research goals and objectives and delineate the critical questions and information gaps that need to be addressed to provide natural-resource managers and policy- and decision-makers with tools to effectively undertake restoration planning and adaptive management of the nearshore ecosystems of Puget Sound.

Puget Sound is the second largest estuary in the United States, supporting abundant fish and wildlife populations and a vibrant economy. The Sound is home to more than 200 species of fishes, including several native salmon species and 10 species of marine mammals, including orca whales. Major port facilities located here support billions of dollars of trade between the United States and the rest of the world. Military installations of National importance depend on the Sound. The overall health of the Puget Sound estuary has steadily decreased as human population and development has increased in the Puget Sound Basin. Impairment of nearshore processes and degradation of ecosystem functions in the Sound, extending along more than 2,000 miles of shoreline, is believed to be a critical factor in the declining nearshore ecosystem health of Puget Sound. However, the complex role of geological, biological, and hydrological processes in maintaining nearshore ecosystem health remains poorly understood.

In response to these critical issues, the Washington Department of Fish and Wildlife and U.S. Army Corps of Engineers joined with other State natural resource agencies, other Federal agencies, Tribes, the commercial sector, non-governmental organizations, universities, and numerous local governments to form the Puget Sound Nearshore Ecosystem Restoration Project (PSNERP). PSNERP represents a science-based approach to restoring and preserving nearshore ecosystems of the Puget Sound and to preventing additional damage. There is a fundamental need for restoration projects at a landscape scale to achieve sustainable, long-term restoration of the entire system. It is critically important that (a) both individual nearshore restoration and preservation actions be coordinated regionally and prioritized on the basis of their expected impact on the Sound; and (b) large-scale restoration programs such as envisioned by PSNERP must be strategically designed and located for maximum impact. To enable the selection of optimum management options, the physical and biological processes that create and maintain nearshore ecosystems must be well understood so that the regional impacts of proposed small-scale restoration and preservation options can be anticipated and evaluated. This requires that the processes be understood at multiple spatial and temporal scales, knowledge that is currently limited at any scale. Once management options have been implemented, outcomes must be monitored to verify how well restoration and preservation projects have achieved their intended results and to guide adjustments as needed through adaptive management. This adaptive management approach to ecosystem rehabilitation requires a clear understanding of the ecological function of nearshore Puget Sound. To support this science-based approach and guide scientific research in support of nearshore ecosystem restoration in Puget Sound, the USGS and PSNERP Nearshore Science Team developed six high-priority goals:

> Goal 1—Understand nearshore ecosystem processes and linkages to watershed and marine systems.
>
> Goal 2—Understand the effects of human activities on nearshore ecosystem processes.
>
> Goal 3—Understand and predict the incremental and cumulative effects of restoration and preservation actions on nearshore ecosystems.
>
> Goal 4—Understand the effects of social, cultural, and economic values on restoration and protection of nearshore ecosystems.
>
> Goal 5—Understand the relations of nearshore processes to important ecosystem functions including human health and protection of at-risk species.
>
> Goal 6—Understand the roles of information—its representation, conceptualization, organization, and interpretation—in restoring nearshore ecosystem processes.

Natural resource managers need to have reliable predictive tools and information about the effects of different management actions on the ecosystem in order to help make wise restoration and preservation decisions. Such tools and information will

- Reduce the risk of unintended consequences associated with uncertainty.
- Provide an assessment of the potential interactive effects of multiple actions at various spatial and temporal scales.
- Allow selection of beneficial restoration and preservation actions.
- Provide direction for management decisions by suggesting which action or combination of actions is most likely to meet specific objectives within specific limitations.

The strategy for achieving these goals includes conducting both inter- and multi-disciplinary research incorporating such scientific disciplines as geology, hydrology, biology, geography, oceanography, atmospheric science, and social science. Elements in a research approach should include such commonly agreed-upon techniques as the use of conceptual and numerical models, reference sites, and careful scientific peer review, not only of the results and products, but of research proposals.

The overarching goal of this research plan is to help reduce uncertainty in decisions regarding what and how much to protect and restore. This goal will be accomplished as individual academic researchers and local entities, as well as State resource agencies and the Federal and Tribal research community understand the information needs, seek funding, and develop specific research plans. Multiple avenues of implementation should be followed, including: (1) prioritization of funding for Demonstration Projects and Early-Action Projects to learn from planned and opportunistic restoration activities. Federal, State, and local agencies that fund restoration activities should actively seek opportunities to monitor and study the changes that occur as a result of the restoration actions; (2) directing and focusing ongoing agency science efforts to seek opportunities to leverage internal funding, as in the successful Coastal Habitats in Puget Sound (CHIPS) science program; (3) communicating information needs to the academic and private research community through reporting at national, regional, and local scientific conferences and workshops such as the Georgia Basin / Puget Sound Research Conference; and (4) collaborating through sharing of existing and new data and information, coordinating the collection of new data and information, prioritizing research needs, and pooling and leveraging resources. Progress in restoration will accelerate only if there are opportunities to learn from restoration efforts that are ongoing. This requires adding hypothesis-based research and monitoring components to restoration projects while they are in the design phases. This will require a commitment of funding research at a level directly proportional with the level of restoration funds. Continued failure to appropriately support research and monitoring in association with funded restoration projects leaves the restoration and resource agency community short on informed vision and is an opportunity lost.

2. Introduction

The beautiful and productive inland marine waters and shorelines of Puget Sound[1] in Washington State are considered a National treasure. This fjord-like arm of the Pacific Ocean, nestled between the Olympic and Cascade Mountains, contains more than 8,000 square kilometers (2 million acres) of marine waters and nearshore environment, and more than 33,000 square kilometers (8.3 million acres) of watershed with 4,020 kilometers (2,500 miles) of shoreline as the interface between the land and water.

Roughly 4 million people, 70 percent of the Washington State population, live in the Puget Sound watershed, concentrated in the metropolitan areas of Seattle, Tacoma, Everett, Bellingham, and Olympia. The population is growing by about 50,000 people per year (1.5 percent per year) and is expected to reach 5.33 million before 2020 and double by 2040 (Puget Sound Regional Council, 2004). To visualize this, one might imagine the current (2005) Puget Sound watershed's population spaced evenly along the shoreline; they would be only 3 feet apart, jostling nearly shoulder to shoulder. Under current projections, the 2040 population would be squeezed back to back.

Despite these population pressures, Puget Sound is still home to tremendous biological richness that includes more than 200 species of fish, 100 species of birds, 26 different marine mammals, and perhaps 7,000 species of marine invertebrates, including the world's largest octopuses and more than 70 kinds of sea stars. This biological richness is supported by an equally diverse community of primary producers, with more than 625 species of marine algae (seaweeds), 6 species of seagrasses, and hundreds of species of phytoplankton.

These resources provide goods and services of high economic value to the people of Washington State and the United States. Shellfish growing areas in Puget Sound contribute 70 percent of shellfish harvested in Washington State. Annual shellfish production in Puget Sound from 1979 to 1993 increased from about 4.5 to 9.6 million pounds; wholesale value (not adjusted for inflation) more than quadrupled during the same period. Shellfish production in Puget Sound has helped make Washington

State the second largest oyster-producing region in the country now worth about $50 million per year (Puget Sound Action Team, 2004). Geoduck harvest has generated $60 million of public funds through auctions of harvest quotas (Washington Department of Natural Resources, 2004). The total revenue from commercial fish harvesting in Puget Sound in 1998 was more than $12 million, and the industry employed nearly 900 people (Puget Sound Action Team, 2004).

The Sound also serves as one of the most important shipping and transportation routes in the world (Sommers and Canzoneri, 1996). Taken together, the Ports of Seattle and Tacoma are the third largest container complex in the United States. More than $40 billion worth of goods travel through the ports of Puget Sound each year leading to tens of thousands of direct and indirect jobs (Trade Development Alliance of Greater Seattle, 2004).

Visitor and recreation activity in Puget Sound generates $5.2 billion in revenue and 62,000 jobs (Puget Sound Action Team, 2004). The 4 million people living in the Puget Sound watershed own nearly 500,000 boats, sailboats, and other watercraft that are moored in more than 280 marinas (Puget Sound Action Team, 2004).

The Puget Sound shoreline provides tremendous allure as an esthetic amenity. Single-family residences on waterfront property now occupy nearly one-quarter of Puget Sound shorelines. Because coastal real estate near Puget Sound is limited, land value has tripled in some areas in the past 10 years (John L. Scott Real Estate, 2004).

Unfortunately, this bounty and beauty are in jeopardy.

[1]Puget Sound is broadly defined to include Hood Canal and the U.S. portions of the Strait of Juan de Fuca and Georgia Strait.

Problem Statement

The apparent beauty and richness of Puget Sound belie real problems. Like other U.S. coastal ecosystems that suffer serious problems, the decline of the Puget Sound and its adjoining basin has been described as a death from a thousand cuts inflicted over the past 150 years. The cumulative effects of such activities as over harvesting, resource extraction, dredging, diking, filling, discharges of industrial and municipal wastes, deforestation, and paving are all taking their toll. Evidence is growing of declining fish and wildlife populations, toxic contaminants, eutrophication, habitat-loss, exotic species, and altered hydrologic regimes.

The symptoms of these problems are a reduction in goods and services produced in Puget Sound, such as listed species or reductions in forage fish. However, the real problem to be addressed is change in the ecological processes that create and maintain habitats, which in turn produce the ecosystem resources that are so highly valued (fig. 1).

Direct loss of the historical nearshore ecosystems has been profound. It is estimated that 73 percent of the original salt marshes of the Sound have been destroyed, as have virtually all river delta marshes in urbanized areas. More than 800 of the 2,500 miles (33 percent) of shoreline have been modified in the Puget Sound region (Puget Sound Action Team, 2002a, *Puget Sound Update 2002*: p. 27. Figure 2-13 Shoreline Modifications and Table 2-2 Shoreline Modifications by county). The percentage of armored shoreline more than doubled in Totten Inlet and more than tripled in Nisqually Reach between 1977 and 1993 (Morrison and others, 1994). There has been a nearly complete loss of eelgrass habitat in Westcott Bay and several other small embayments (Mumford and others, 2003; Wyllie-Echeverria and others, 2003).

The cumulative effects of these multiple human-induced stressors is overwhelming the ability of naturally occurring ecosystem processes to maintain structures, biological resources, and ultimately the goods and services provided by the ecosystem. Although nearshore[2] ecosystems have been affected directly, they also are subject to impacts from upland and marine environments—impaired water quality, invasive species coming from offshore, and most importantly, impacts downhill and downstream of the watershed, such as reduced water quantity and quality, altered sediment transport, and disrupted landscape linkages.

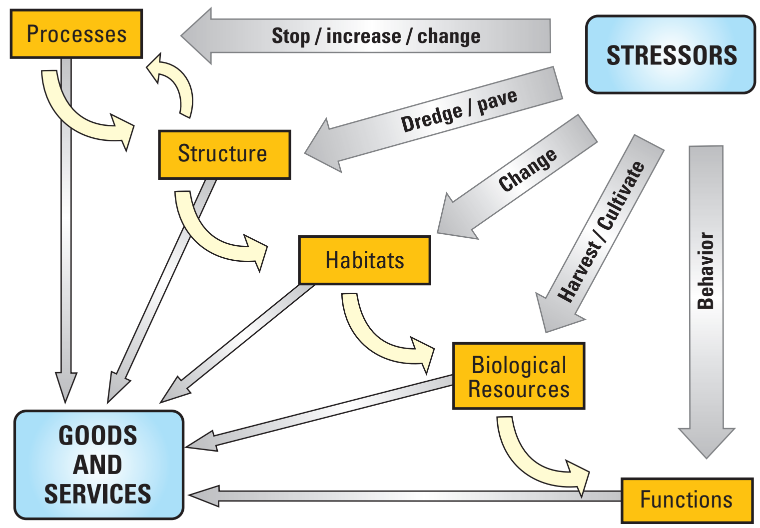


Figure 1. Conceptual model of relation of process, structure, habitat, biological resources, and good and services.

These visible effects and long-term impacts have been described and discussed in numerous documents (Wilson and others, 1994; West, 1997; McMurray and Bailey, 1998; Washington Department of Natural Resources, 1998; Washington Department of Natural Resources, 2000; Heinz Center for Science, Economics, and the Environment, 2002; Mumford, 2002; Puget Sound Water Quality Action Team, 2002a; Puget Sound Action Team, 2002b; Puget Sound Action Team, 2004).

Multiple fish and wildlife species—including orcas, Chinook and chum salmon, diving birds, rockfish, and Pacific herring—have experienced dramatic population declines in recent years (West, 1997; Puget Sound Action Team, 2002). For example, the largest stock of Pacific herring in Washington State (the Cherry Point stock) declined by 84 percent over the past decade. Surf scoters declined by more than 50 percent and western grebes by more than 85 percent over the past 25 years. Common murres and marbled murrelets also have declined more than 50 percent during this period (Nysewander and others, 2001; Puget Sound Action Team, 2005).

The number of marine species listed or proposed to be listed under Endangered Species Act and State regulations continues to increase and now includes bull trout, Puget Sound Chinook salmon, summer chum salmon, rockfish, birds, and marine mammals such as orca (National Oceanic and Atmospheric Administration Fisheries, 2004; Northwest Salmon Recovery Planning, 2004; Washington Department of Fish and Wildlife, 2004b).

[2]Puget Sound nearshore ecosystems encompass the bluffs, beaches, tide flats, estuaries, rocky shores, lagoons, salt marshes, and other shoreline features and shallow water habitats of the marine and estuarine areas of Washington State east of Cape Flattery and north to the Canadian border.

The number and diversity of the species in decline in Puget Sound suggest systemic rather than isolated problems. Because nine of the ten Puget Sound species identified as endangered or threatened rely on nearshore environments, the declines are, at least in part, likely related to problems in nearshore ecosystems of Puget Sound. Although some of these declines are the result of over-harvesting, loss of habitat and degradation of water quality likely are the results of disruption of ecosystem processes supporting those habitats.

Other warning signals include the chemical contamination of marine food chains (Determan, 1999a; Schmidt and Johnson, 2001; Ross, 2003). Although overall discharge of toxic chemicals appears to be declining (Washington State Department of Ecology, 2004), persistent chemicals and fecal contamination continue to affect the ecosystem, especially in the higher portions of the food web in such animals as orcas (Wiles, 2004), salmon, and geoducks (Washington Department of Natural Resources, 2004). Some constituents, such as ambient concentrations of Polycyclic Aromatic Hydrocarbons (PAHs) in Puget Sound waters are equal to or greater than concentrations shown to be detrimental to fish eggs and embryogenesis (Carls and others, 1999; Heintz and others, 1999).

Early signs of eutrophication are becoming more evident (Briker and others, 1999). There is an increase in the occurrence of green tides (Valiela and others, 1997; Frankenstein, 2000). The frequency and distribution of harmful algal blooms causing shellfish closures from paralytic shellfish poison (PSP) and domoic acid are increasing (Determan, 1999b). Hood Canal, a historically fragile area, has been plagued by an increase in hypoxia (Newton, 2004; Puget Sound Action Team, 2004; Washington State Department of Ecology, 2004). This is viewed as a sign of eutrophication, or over-enrichment of inorganic nitrogen (Thom and others, 1988).

Another alarming trend is an increased threat of alien and invasive plant and animal species such as four species of *Spartina* (cordgrass), *Sargassum*, green crab, and dozens of poorly understood invertebrate species (Cohen and others, 1998; Cohen and others, 2001). Such species can cause extensive ecological damage and economic costs by depressing or eliminating valuable native species or requiring expensive measures to limit the species or its impact. The invasive tunicate, *Didemnum lahillei,* was discovered in Puget Sound in late 2004 and is causing alarm among biologists and the public. This tunicate forms dense mats over firm substrates, overgrowing sea scallops and mussels, and probably affecting numerous other species (http://www.nefsc.noaa.gov/press_release/2004/news04.19.htm).

Poorly documented but thought to be of great importance are the alterations to the hydrology of rivers, streams, and ground-water flow into Puget Sound (Staubitz and others, 1997; Washington Department of Natural Resources, 1998). Little is known of inputs of nutrients and toxics by aerial deposition to the aquatic environment, and especially to the sea surface microlayer (Hardy and others, 1987a; Hardy and others, 1987b; Gardiner, 1992; Hardy, 1997).

Climate change will have profound effects in the future on the Puget Sound ecosystem (Mote and others, 1999; Whitfield and others, 2003). These include changes in the timing and quantity of freshwater inputs, changes in ocean circulation affecting upwelling, and sea-level change. The compounding affect that future climate change will have on Puget Sound ecosystems is largely unknown.

The presence of these multiple stressors are believed to be early signs of a system in serious decline. Many of the symptoms of declining ecosystem health described here were noted in other major estuarine environments such as Massachusetts (Valiela and others, 1997), Chesapeake Bay (The Chesapeake Bay Program, 2001; Boesch and Greer, 2003), and the Baltic Sea (Gren and others, 2000). These symptoms became more widespread over time and were in fact early indicators of later, system-wide collapses.

Several nationally conducted review efforts, including the Heinz Center for Science, Economics, and the Environment (2002), the Pew Oceans Commission (2003), the U.S. Commission on Ocean Policy (2004), the Millennium Ecosystem Assessment (2005), and have come to a similar conclusion, "…America's oceans are in crisis and the stakes could not be higher." "Unfortunately, our use and enjoyment of the ocean and its resources have come with costs, and we are only now discovering the full extent of the consequences of our actions" (U.S. Commission on Ocean Policy, 2004). And the root cause is clear: "Our failure to properly manage the human activities that affect the Nation's oceans, coasts, and Great Lakes is compromising their ecological integrity, diminishing our ability to fully realize their potential, costing us jobs and revenue, threatening human health, and putting our future at risk" (U.S. Commission on Ocean Policy, 2004).

Around Puget Sound, many scientists, as well as Federal and State resource agencies, fear the path the Sound is taking is similar to that observed in these other coastal settings. The nearshore region in particular is both ecologically sensitive and the region where many of the human impacts take place or are manifested. For example, docks and piers, dredging and filling, shoreline protection structures, waterfront development, stormwater outfalls, and beach harvesting are all located in the nearshore. As the interface between the terrestrial and the marine, the nearshore concentrates much of what people value in the Sound, including the beaches, views, and entryway to boating and fishing. In addition, the impacts in this region are felt throughout the marine ecosystem. Direct removal of intertidal habitat, modification of valuable forage fish spawning grounds, and contamination of nearshore waters and sediments have both a direct and indirect effect on the larger Sound ecosystem.

This research plan is based on the premise that these many indicators of ecosystem stress are related to an underlying cause: disruption or elimination of the natural processes that control the delivery and distribution of sediment, water, energy, organic matter, nutrients, and other chemicals in Puget Sound's nearshore environments. Because these nearshore processes are essential to the proper functioning of the Puget Sound ecosystem, restoring them is considered of highest priority.

Need for a Sound-Wide Nearshore Science Plan

In response to these past and ongoing stresses on nearshore Puget Sound, the U.S. Army Corps of Engineers has joined State natural resource agencies, other Federal agencies, Tribes, the commercial sector, non-governmental organizations, universities, and numerous local governments to form the Puget Sound Nearshore Ecosystem Restoration Project (PSNERP). The PSNERP partnership is working to restore and preserve nearshore ecosystems to help rehabilitate the ecosystem health of Puget Sound and prevent additional damage in the future as the human population in the basin continues to increase (Appendix 1 describes PSNERP in greater detail).

At the direction of the PSNERP Executive Committee, the PSNERP Nearshore Science Team was asked to produce a Strategic Science Plan. This research plan is one component of an overall science strategy supporting ecosystem restoration in Puget Sound. Other components include a peer-review plan, a monitoring plan, an information management plan, scientific workshops, and an outreach plan (fig. 2). Together, these components form the foundation of a science-based restoration plan that can help insure use of best-available science, broad communication, and adaptive management strategies that will lead to long-term success of the restoration activities.

Estuarine restoration projects are being undertaken in Puget Sound by various agencies and partners. A limited number of projects have been completed and still others are in planning stages. Examples of current projects include reconnection or improved connection of coastal wetlands to tidal influence through the removal of dikes or culverts in Skagit, Nisqually, Skokomish estuaries, and Hood Canal. Examples of completed projects include rehabilitation of tidal marshland in limited areas along the lower Duwamish River and at Deepwater Slough at the mouth of the South Fork of the Skagit River. Projects under consideration include restoration of tidal marshlands at the mouths of the Nisqually, Skagit, and other rivers. These projects generally are small (fewer than about 300 acres) and planned and implemented as independent, local

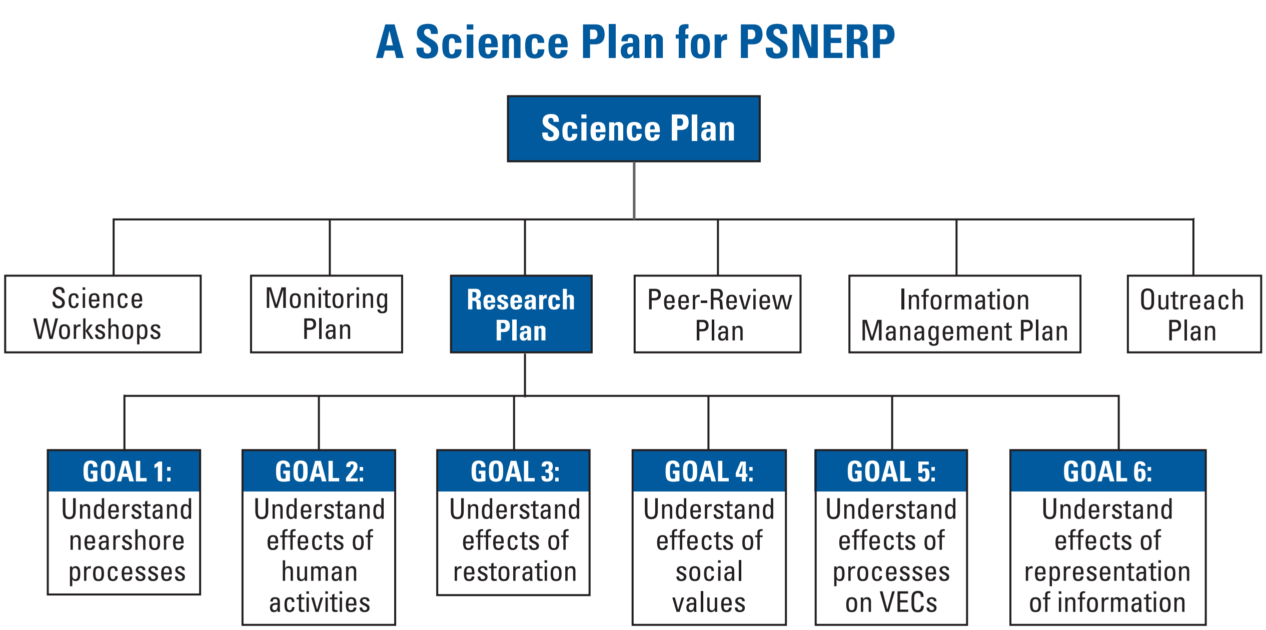


Figure 2. Relation of research plan described in this report to the Strategic Science Plan for PSNERP.

efforts. Although these smaller projects may have achieved important results at the local scale, there has been little consideration of how multiple small-scale efforts may affect each other or how they may cumulatively affect the restoration of the greater Puget Sound ecosystem.

There is, in addition, a critical need for restoration projects at a landscape scale to achieve sustainable, long-term restoration of the entire system. It is critical that (a) both individual nearshore restoration and preservation actions be coordinated regionally and prioritized on the basis of their expected impact on the Sound, and (b) large-scale restoration programs such as envisioned by PSNERP be strategically designed and located. To enable the selection of optimum management options, the processes that create and maintain nearshore ecosystems must be understood so that the regional impacts of proposed small-scale restoration and preservation options can be anticipated and evaluated. This requires that the processes be understood at multiple spatial and temporal scales, and this knowledge is currently limited at any scale. Once management options have been implemented, outcomes must be monitored to verify that restoration and preservation projects have achieved their intended results and can be adjusted as needed through adaptive management.

Many different agencies over the years have collected and analyzed monitoring data and scientific information for different aspects of the Puget Sound ecosystem, including nearshore habitat. To date, however, this information has not been integrated to develop a comprehensive understanding of nearshore ecosystems, including the natural and human factors that have changed conditions over time. Gaps in critical information must be identified to be able to anticipate ecosystem responses to different options for nearshore ecosystem restoration and preservation.

Successful restoration and preservation of the Puget Sound nearshore involves a long-term societal commitment that requires substantial resources. Natural resource managers need to have reliable predictive tools and information about the effects of different management actions on the ecosystem in order to help make restoration and preservation decisions.

Such tools and information will

- Reduce the risk of unintended consequences associated with uncertainty.
- Provide an assessment of the potential interactive effects of multiple actions at various spatial and temporal scales.
- Allow selection of beneficial restoration and preservation actions.
- Provide direction for management decisions by suggesting which action or combination of actions is most likely to meet specific objectives within specific limitations.

Purpose, Scope, and Approach

The purpose of this research plan is to identify high-priority research goals and objectives and important questions and information gaps that need to be addressed to assist natural-resource managers and policy and decision makers with restoration planning and adaptive management of nearshore ecosystems of Puget Sound. This plan relies heavily on the data and information gaps reports recently published by the Northwest Straits Commission (1999; 2000) and by King County Department of Natural Resources (2001). This plan identifies six overall goals, and strategies for achieving those goals through the collaboration of multiple partners. The research plan provides a prioritization for posing detailed and coordinated research questions by multiple agencies and organizations with the common goal of developing the scientific information and tools that support adaptive management of the Puget Sound nearshore (see table 1). The research goals, objectives, and hypotheses are presented in detail in Section 4. These objectives and hypotheses are formulated to support critical information needs through scientific studies. In addition, the research plan includes the development of research questions that could best be answered through detailed studies of nearshore ecosystem restoration projects. Appendix 3 lists important questions that could best be addressed through monitoring and analysis of Demonstration Projects and Early-Action Projects. Demonstration Projects are those restoration projects designed specifically to address important information needs that will ultimately help to decrease uncertainty in future restoration decisions. Early-Action Projects are those restoration projects designed primarily for restoration that also will serve to address major information needs.

The research questions identified in this plan focus on understanding the processes that create and maintain nearshore ecosystems and the natural and human factors that affect those processes. Current knowledge and understanding of nearshore ecosystem processes is limited, and the lack of understanding of the processes prevents natural-resource managers and policy and decision makers from effectively managing coastal ecosystems.

The answers to questions identified in the research plan will explain observed ecosystem conditions by relating those conditions to natural and human factors, by defining the causes of spatial and temporal variations, and by predicting the effects of proposed nearshore restoration and preservation. Improved scientific information will assist decision makers in their efforts to balance the protection and restoration of the Puget Sound nearshore ecosystem with future sustainable development.

Research goal	Examples of information needs
1. Understand nearshore ecosystem processes and linkages to watershed and marine systems	• Variability, rate, distribution, and quality of river and stream discharge to the nearshore, including sediment discharge • Frequency, volume, and type of non-riverine sediment input to nearshore beaches • Temporal and spatial variability of nearshore sediment erosion, transport, and deposition • Rate, distribution, and quality of ground-water discharge to the nearshore • Frequency, intensity, and type of nearshore disturbances resulting from storms and other episodic events (freshwater discharge, sediment and detritus sources and transport, plant and animal distributions) • Spatial and temporal distributions of nearshore plants and animals, including the different stages of the life cycles of species • Spatial and temporal variability of foodweb characteristics in the nearshore • Spatial and temporal variability of marine waters from deep to shallow water, including temperature, salinity, turbidity, nutrients, other • Causes of variability in foodweb characteristics, species distributions, physical, chemical, and other biological variables • Linkages between physical, chemical, and biological processes in the nearshore • Linkages between nearshore biological diversity and abundance and those factors elsewhere in the Puget Sound estuary and watersheds
2. Understand the effects of human activities on nearshore ecosystem processes	• Distribution of exotic species in Puget Sound • Changes in the diversity and abundance of native species in response to the presence of exotic species • Effects of individual and cumulative ecosystem stressors, both naturally occurring stressors and those resulting from human activities, including harvest, development, other • Effects of land use on freshwater inputs to the nearshore, including contaminants, pathogens, nutrients, and sediments • Effects of shoreline modifications and other development on beaches and nearshore substrates • Effects of climate and sea-level change • Distribution and fate of persistent contaminants in the nearshore foodweb
3. Understand and predict the incremental and cumulative effects of restoration and preservation actions on nearshore ecosystems	• Spatial and temporal scales at which effects of nearshore restoration can be measured • Nearshore physical, chemical, and biological effects of sample restoration projects, including dike breaching, dam removal, estuarine wetland restoration, other • Short- and long-term ecological effects of restoration and preservation actions
4. Understand the effects of social, cultural, and economic values on restoration and protection of the nearshore	• Societal values associated with different aspects of the nearshore, including recreation, harvest, cultural significance, tourism, development, land use, other, and trends in those values • Attitudes, perceptions and beliefs regarding restoration, and cost-benefit relationships of different restoration and preservation options, expressed in socially relevant terms • Demographic patterns of use of shorezones, projected trends, and how they affect and are affected by restoration • Governance and institutions for restoration
5. Understand the relationships of nearshore processes to important ecosystem functions such as support of human health and at-risk species	• Cycling and accumulation of contaminants in the nearshore foodweb, of which humans and at-risk species are components • Factors that alter parts of the foodweb relied on by at-risk species, such as orca whales, salmon, other • Effects of restoration actions on nearshore foodweb characteristics
6. Understand the roles of information —its representation, conceptualization, organization, and interpretation—related to nearshore ecosystem processes on the preservation and restoration potential of Puget Sound	• Most effective methods to educate the public so it can engage in informed nearshore restoration decision-making • Needs for information and tools that allow resource managers to analyze the costs and ecological impacts of different nearshore restoration and preservation options • Most effective methods for storing and processing new and existing nearshore data and information for use by the public, decision-makers, and scientists

Table 1. Information needs for research goals.

Conceptual Model of Nearshore Ecosystem Processes

A cornerstone to the development of this research plan is a conceptual model that describes key drivers in ecosystem change, and the inter-relationships among those drivers. Process-based nearshore restoration relies on a sound conceptual understanding of the complex interactions of multiple physical, chemical, and biological processes. This conceptual model of nearshore ecosystem processes developed by Puget Sound Nearshore Ecosystem Restoration Project (fig. 3) is one useful tool to help describe "how Puget Sound works" (PSNERP-NST Conceptual Model Working Group, 2004). One purpose of the model is to guide understanding of how ecosystem processes respond to specific stressors within and across the nearshore. Examples of such stressors are shoreline armoring, introduction of exotic species, and excess nutrient loading. Another purpose of the model is to help identify gaps in the understanding of critical processes, as well as interactions among processes. In some cases, specific processes or interactions are well known; in many other cases, little is known about what may be important processes. Successful restoration of coastal ecosystems depends on identifying and understanding these critical processes, the effects of these processes on a healthy functioning ecosystem, and the effects that human activities have on these processes.

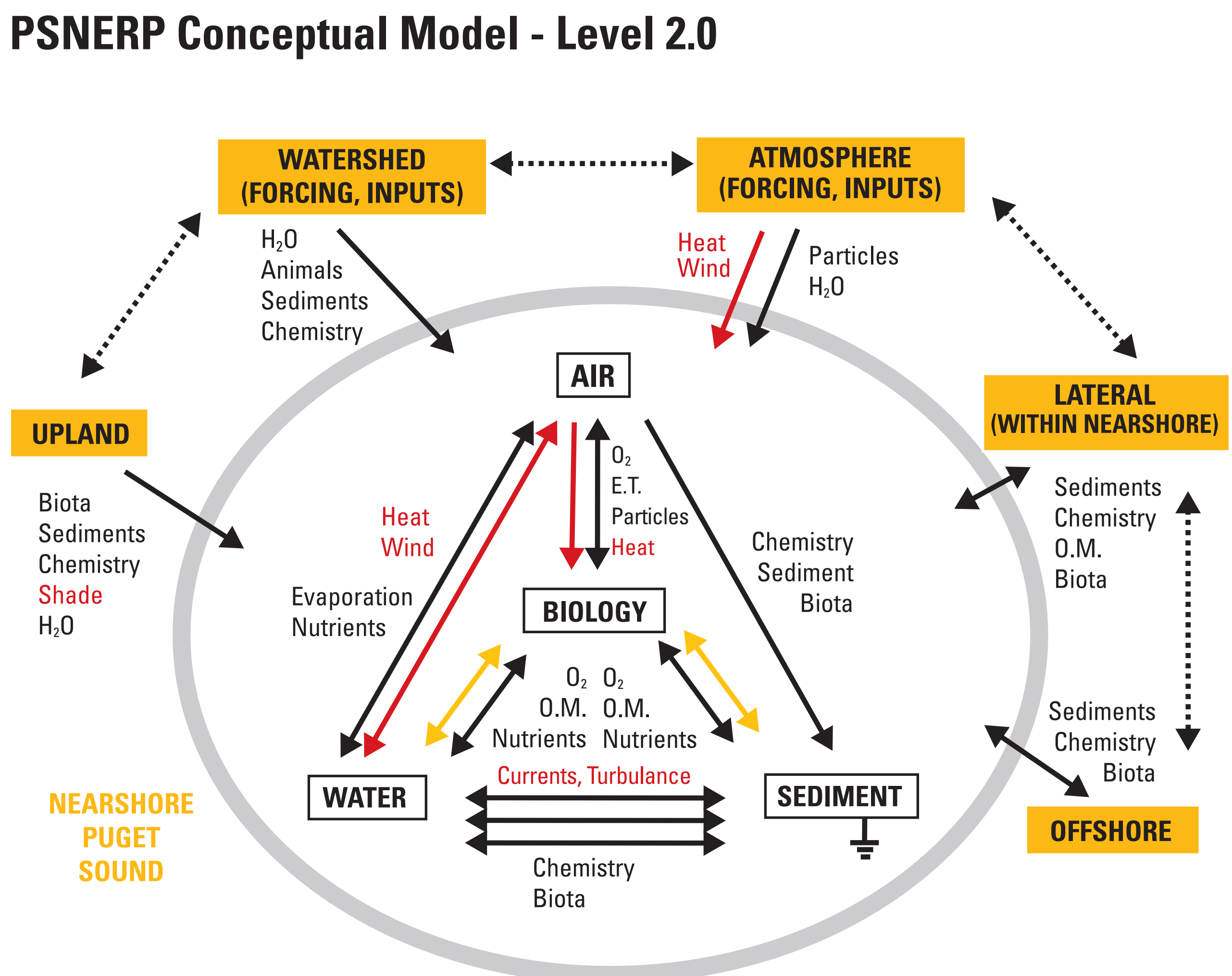


Figure 3. Conceptual model of nearshore ecosystem processes developed by Puget Sound Nearshore Ecosystem Restoration Project (PSNERP) to support strategic restoration planning (from Simenstad et al. 2006). (O.M., organic matter.)

3. Description of Puget Sound

Environmental Setting

The Puget Sound estuary is a glacial fjord (fig. 4) covering 7,250 square kilometers (2,800 square miles within a watershed of 44,000 square kilometers (17,000 square miles). The Puget Sound estuary is connected and interdependent with Canadian waters and watersheds of the Strait of Juan de Fuca and the Strait of Georgia to the north.

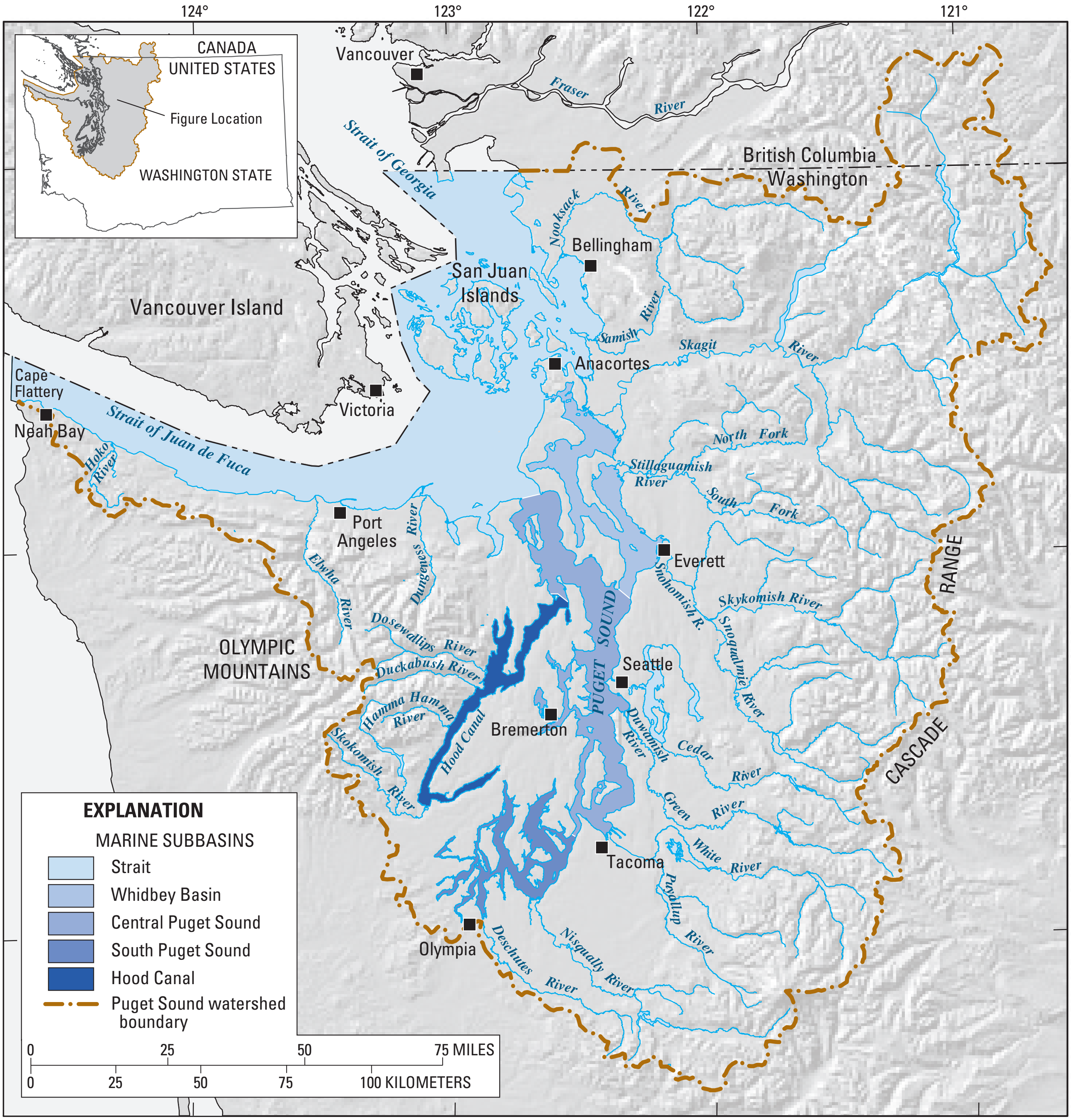
The region has a temperate maritime climate with average annual precipitation ranging from about 100 centimeters per year [cm/yr] [40 inches per year (in/yr)] in the Puget Lowland to about 230 cm/yr (90 in/yr) in the mountains (Staubitz and others, 1997).

Puget Sound waters generally are cold, nutrient-rich, and support abundant marine life. Surface waters range in temperature seasonally from 7ºC (45ºF) to 13ºC (55ºF) and have an average salinity of 27 psu (practical salinity units). Deep waters are about 6ºC (43ºF) throughout the year and have an average salinity of 30 psu (Puget Sound Water Quality Authority, 1988), which approaches salinities of oceanic waters. The tidal range increases from about 2.5 to 4.5 meters (8 to 15 feet) from northern to southern Puget (Gustafson and others, 2000).

Puget Sound was formed by glaciers that carved previously deposited glacial and interglacial sediments during the last glacial period about 10,000 to 14,000 years ago. This process created deep and narrow channels divided by islands and peninsulas that can be subdivided into several distinct oceanographic basins on the basis of water depths and circulation characteristics (fig. 1). As is typical for fjords, water depths in the Puget Sound increase rapidly from shore, with an average depth of 62 meters (205 feet) (Staubitz and others, 1997), and a maximum depth of about 370 meters (1,200 feet) (Burns, 1985; Puget Sound Water Quality Authority, 1987).

The glacial carving that shaped the deep channels of Puget Sound also helped shape the steep coastal bluffs, beaches, and relatively narrow, shallow marine terraces that form the terrestrial-marine interface of Puget Sound, transitioning from the deep fjord to the gently rolling elevated terrain of the Puget Sound Lowland. The lowlands are dissected by a system of rivers and coastal streams that supply freshwater, nutrients, and sediments to Puget Sound. Additional freshwater is supplied by diffuse ground-water discharge. Since sea level began to stabilize after the last glacial period, rivers and streams have built deltas, estuaries, and marshlands at their mouths. The coastal geomorphology continually evolves through landslide failures of coastal bluffs and longshore transport of sediments driven by wave action. This process combined with the irregular shorelines of Puget Sound leads to the segregation of beaches into many discrete littoral cells that each define a beach-sediment system with distinct sediment sources and sinks (Downing, 1983; Schwartz and others, 1989; Finlayson and Shipman, 2003).

Although some of these landscape-scale processes are gradual, the Puget Sound also is shaped by naturally occurring catastrophic events. For example, selected river deltas expanded rapidly following volcanic eruptions in the Cascade Range (Collins and others, 2003) and portions of the shoreline have been dramatically uplifted or submerged during earthquakes (Haugerud and others, 2003). River deltas, salt-marshes and estuaries also are shaped by large floods, and beaches and spits are altered and formed by severe storms. Nearshore ecosystems have evolved in response to these natural events and, in many cases, are maintained by them (King County Department of Natural Resources, 2001).



PSNERP base map from U.S. Geological Survey digital data 1:2,000,000, 1972
Albers Equal-Area Conic Projection
Standard parallels 47° and 49°, central meridian 122°
Washington shaded relief, USGS, 30 meter DEM
British Columbia shaded relief, NASA, SRTM 90 meter

Figure 4. Physiographic map of Puget Sound, with drainage basin and major oceanographic subbasins delineated.

Nearshore Environments

Puget Sound contains a diverse assemblage of nearshore environments, each formed and maintained by a characteristic suite of geomorphic processes, and each associated with distinct aquatic and riparian ecosystems. Puget Sound's vast shoreline of beaches and narrow marine terraces generate much of its intertidal and shallow subtidal ecosystems. The most common shoreline type consists of mixed sand and gravel beaches backed by high coastal bluffs. Rocky-bottom habitat is less common than soft-bottom habitat and is largely confined to northern Puget Sound. Other shoreline environments include large river deltas, tidal flats, salt-marshes, and estuaries (King County Department of Natural Resources, 2001). In addition to geomorphic and substrate characteristics, nearshore environments also are characterized by wave energy, water quality, aquatic vegetation, and faunal structure.

The nearshore environments of Puget Sound are maintained by a complex interplay of biological, geological, and hydrological processes that interact across the terrestrial-marine interface. Many of these processes have been significantly impacted by human activities, and nearshore habitats have been altered and lost since the start of industrial and agricultural development in the late 1800s (Bortleson and others, 1980). Dikes built to create farmland and reduce flooding have altered nearshore sedimentation patterns and eliminated the tidal influence that forms salt-marshes; dams built to manage water supplies and generate power have reduced the magnitude and frequency of floods and limited sediment inputs that sustain river deltas; and seawalls and bulkheads built to protect shoreline properties have reduced sediment supplies that feed beaches from naturally eroding bluffs. Examples of other changes in nearshore environments resulting from development include the elimination of small estuaries to create developable land, degradation of sediment quality due to the discharge of pollutants, generation of dangerously low oxygen levels from algal blooms fed by excess nutrient input, and modification of the structure of biological communities resulting from harvesting aquatic plants and animals and introducing exotic species. Successful restoration of coastal ecosystems depends on identifying, understanding, and restoring the nearshore ecosystem processes where possible.

Marine Biota

Puget Sound supports diverse communities of marine plant and animal species, ranging from phytoplankton and zooplankton to marine mammals (Simensted and others, 1979).

The marine vegetation of Puget Sound includes many species of seaweed and seagrasses critical in providing food, shelter, and rearing habitat for numerous aquatic animals. Some of the more important plants include species of kelp (bull kelp, *Nereocystis luetkeana*, and giant kelp, *Macrocystis integrifolia*), surfgrass (*Phyllospadix* spp.) and native eelgrass (*Zostera marina*). Non-indigenous vegetation (*Zostera japonica*, *Sargassum muticum*, and *Spartina* spp.) is suspected of displacing native vegetation (Washington Sea Grant Program, 2000). Shoreline modifications, such as bulkheading, diking, and dredging and filling, also have adverse affects on native aquatic vegetation (Center for Marine Conservation, 1998).

Assemblages of benthic invertebrates vary seasonally and annually throughout the Sound (Gustafson and others, 2000). These include polychaetes (worms), echinoderms (sand dollars, sea stars), mollusks (clams, snails), and crustaceans (crab, shrimp). Of these invertebrates, several are harvested commercially, such as Dungeness crab (*Cancer magister*), native littleneck clam (*Protothaca staminea*), Pacific geoduck (*Panopea abrupta*) and others, including non-indigenous species such as Pacific oyster (*Crassostrea gigas*) and Manila or Japanese littleneck clam (*Venerupis philippinarum*) (Washington Department of Fish and Wildlife, 2004a).

More than 200 species of fish have been identified in Puget Sound (Palsson and others, 1997). These include resident species of demersal and pelagic fish that use Puget Sound habitats during a portion of their life cycle (Miller and Borton, 1980a; 1980b; 1980c). The most common of these are Chinook (*Oncorhynchus tshawytscha*), Coho (*O. kisutch*), chum (*O. keta*), pink (*O. gorbuscha*), and sockeye salmon (*O. nerka*), anadromous steelhead (*O. mykiss*), and cutthroat trout (*O. clarki clarki*) (Miller and Borton, 1980a; 1980b; 1980c). Commercial marine fish species include Pacific hake (*Merluccius productus*), Pacific cod (*Gadus macrocephalus*), walleye pollock (*Theragra chalcogramma*), Pacific herring (*Clupea harengus pallasi*), spiny dogfish (*Squalus acanthias*), lingcod (*Ophiodon elongatus*), English sole (*Pleuronectes vetulus*) and various rockfish species (*Sebastes* spp.) (Miller and Borton, 1980a; 1980b; 1980c).

Many marine birds depend on Puget Sound, the most common of which are rhinoceros auklet (*Cerorhinca monocerata*), glaucous-winged gull (*Larus glaucescens*), pigeon guillemot (*Cepphus columba*), cormorants (*Phalacrocorax* spp.), marbled murrelet (*Brachyramphus marmoratus*), and brant (*Branta bernicla*).

In order of abundance, the most common species of marine mammals that live in Puget Sound year-round or migrate through the Sound for part of the year are harbor seal (*Phoca vitulina*), California sea lion (*Zalophus californianus*), Steller sea lion (*Eumetopias jubatus*), Northern elephant seal (*Mirounga angustirostris*), harbor porpoise (*Phocoena phocoena*), Dall's porpoise (*Phocoenoides dalli*), orca (*Orcinus orca*), gray whale (*Eschrichtius robustus*), and minke whale (*Balaenoptera acutorostrata*) (Gustafson and others, 2000).

Multiple fish and wildlife populations—including orcas, salmon, diving birds, rockfish, and Pacific herring— have experienced dramatic declines in recent years (West, 1997; Puget Sound Action Team, 2002). Marine species listed or proposed to be listed under Endangered Species Act and State regulations continues to increase. Bull trout, Chinook salmon, and Hood Canal summer chum salmon are currently listed as threatened under the Endangered Species Act. Several rockfish species, diving bird species, and orca whales also are depleted to the point where either State or Federal listing is being considered (National Oceanic and Atmospheric Administration Fisheries, 2004; Northwest Salmon Recovery Planning, 2004; Washington Department of Fish and Wildlife, 2004b).

The diversity of the species in decline in Puget Sound suggests systemic rather than isolated problems. Because many of these declining species rely on nearshore environments, the declines are, at least in part, likely related to problems in nearshore ecosystems of Puget Sound. Although some of these declines are the result of overharvesting—direct losses through poor management—these declines also can be viewed as symptoms of underlying causes: loss of habitat, degradation of water quality, and in turn, from the disruption of ecosystem processes supporting those habitats.

Human activities and development patterns have harmed, and continue to threaten, nearshore ecosystems by disrupting or eliminating the processes that control the delivery and distribution of sediment, water, energy, organic matter, nutrients, and other chemicals in Puget Sound's nearshore environments. Exotic species that have been introduced have displaced native species and this phenomenon is likely to get worse in the future.

Cultural Setting

Prior to permanent settlement by non-Native Americans in the mid-1800s, the Puget Sound Lowland was inhabited by Native Americans, who lived in small communities along rivers and saltwater shores. The population probably was about 10,000 to 20,000 people (Washington State University, 2004), who lived on marine and terrestrial plants and animals harvested in the lowlands. In 1853, when the Territory of Washington was established, there were fewer than 5,000 settlers in the Puget Sound Lowland (Vaccaro and others, 1998). The lowlands population rapidly expanded to about 350,000 people by 1890, 800,000 by 1960, and almost 4 million by 2000. By 2020, the population is expected to exceed 5 million (Transboundary Georgia Basin-Puget Sound Environmental Indicators Working Group, 2002). The rapid increase in population has been accompanied by extensive urbanization, agricultural development, and natural-resource extraction that have dramatically altered the pre-settlement landscape, much of it highly concentrated along Puget Sound's shorelines.

By the 2^{nd} half of the 19^{th} century, the effects of development on ecosystems were readily recognized. Congress established the National Fish Hatchery System in 1871 to produce fish for domestic consumption to replace declining native fish populations. In 1895, Washington State installed its first fish hatchery in southwest Washington to compensate for land-use changes that altered fish habitat (Washington Department of Fish and Wildlife, 2004c). At present, an extensive system of Tribal, State, and Federal fish hatcheries is operated in Puget Sound. With the passing of the Endangered Species Act in 1973, the purpose of salmon and steelhead fish hatcheries in the Sound and elsewhere evolved to not only support sustainable harvest opportunities but also help recover and conserve naturally spawning fish populations (modified from Washington Department of Fish and Wildlife, 2000; 2004c; and 2004d, U.S. Fish and Wildlife Service, 2004). There is no similar Federal or State-initiated cooperative management process for protecting and restoring coastal ecosystems. Nonetheless, many organizations and agencies are actively engaged in nearshore restoration and preservation efforts because they recognize the importance of doing so. In Puget Sound, these efforts generally are small-scale and not coordinated amongst each other. Scientific information on which to base restoration plans is limited, and follow-up monitoring to ascertain whether restoration efforts have their intended effects usually does not occur. For nearshore ecosystems to be restored and preserved so they will be self-sustaining without costly interventions in the future as the population and development in the Puget Sound Lowland continue to increase, it is critical that these efforts restore and preserve natural ecosystem processes and not solely ecosystem structure or function.

4. Research Goals

Goal 1: Understand Nearshore Ecosystem Processes and Linkages to Watershed and Marine Systems

Problem Statement

Nearshore ecosystems functions that provide ecological and other "goods and services" ultimately depend on the interaction among physical, chemical, and biological processes that sustain desirable nearshore structure, attributes, and communities. These processes dictate the mode and strength of interactions among nearshore ecosystems and watershed, marine, and atmospheric systems. However, at present, our scientific understanding of these processes is insufficient to determine mechanisms of nearshore degradation or the likelihood of ecosystem restoration, particularly when multiple stressors are involved.

Existing Work

Previous investigations of Puget Sound have focused on the structure of nearshore ecosystems rather than the underlying nearshore ecosystem processes. When processes have been investigated, the objective has been to resolve responses to a stressor (e.g., excess nutrient input) rather than the mechanisms accounting for the stress. For example, there are a considerable number of investigations of intertidal benthic macroinvertebrate assemblages along Puget Sound and the Strait of Juan de Fuca (e.g., Long and others, 1983; Thom and others, 1984; King County Department of Natural Resources and Parks, 2002). Although these investigations included some assessments of corresponding biotic and abiotic beach characteristics (e.g., grain size, salinity, and contaminant concentrations), the actual processes structuring these assemblages and especially ecological processes have not been a focus of such investigations. Such studies typically are limited to a few nearshore ecosystems and sites, are short-term (Staude, 1979), and are seldom published in peer-reviewed scientific journals (exceptions include Armstrong and others, 1976 and 1981; Thom and others, 1976; Schoch and Dethier, 1996).

As a result of these limitations, fundamental nearshore processes in Puget Sound are understood at only the most general level. Some processes, such as critical physical processes of erosion and transport of sediments by waves that impact the beach, are somewhat understood conceptually and are much less understood categorically or mechanistically. Limited studies are being conducted on the faunal structure of Puget Sound beaches (e.g., on-going Washington Department of Natural Resources SCALE studies (Schoch and Dethier, 2001), but none of these address the "forcing" processes that regulate faunal structure, or even whether the most important regulating factors are physical (e.g., wave exposure and sediment structure) or ecological (e.g., predators and competitors) across the range of Puget Sound's nearshore environments. NearPRISM research (Puget Sound Regional Synthesis Model, 2004) is presently being conducted to describe the variation in Puget Sound beach geomorphologies and to ascertain some of the underlying physical processes. This work is conducted in concert with other Puget Sound Regional Synthesis Model (PRISM) research in watershed, marine, and atmospheric domains, but none of this research addresses biological responses to the processes being studied.

Objectives

Basic objectives of research to address this goal include:

1. Identify key nearshore ecosystem processes, which are defined as dominant and most human impacted, and set priorities for filling information gaps.
2. Characterize the spatial and temporal scales over which key ecosystem processes prevail and vary.
3. Define how physical and chemical processes interact and affect biological processes.
4. Define and evaluate the strengths of linkages between nearshore ecosystems and their associated watershed and marine systems.

Relevance and Impact

Process-based restoration can only succeed by significantly increasing the understanding of the nearshore processes that are affected by restoration and their role in the broader Puget Sound landscape. A fundamental understanding of nearshore ecosystem processes and linkages to stressors in surrounding watershed and marine systems is critical to determine the impacts of and plans for the expected growth of the population and infrastructure of Puget Sound over the next 50 years.

Hypotheses and Studies

The following are examples of high-priority hypotheses and corresponding studies that serve to illustrate how scientific investigations might be focused on critical linkages between nearshore ecosystems processes and adjoining watersheds and open waters of the Sound.

Hypothesis 1: Upland areas such as coastal bluffs and banks are the primary source of sediments that nourish Puget Sound beaches.

Study 1a: Document the frequency, volume, and composition of non-river/stream sediment input to Puget Sound beaches.

Study 1b: Determine under what conditions and at what rates sediments are transported from the upper shore to the lower beach terrace.

Hypothesis 2: Eelgrass (*Zostera marina*) and certain benthic invertebrate assemblages moderate wave energy and affect nearshore sediment stability and structure.

Study 2a: Evaluate the wave energy and sediment structure and mobility in nearshore areas with and without eelgrass.

Study 2b: Evaluate the effects of differences in eelgrass density, blade length, and epiphyte growth on wave energy.

Study 2c: Determine what benthic and epibenthic organisms are associated with or contribute to sediment stability.

Hypothesis 3: Nutrient-cycling processes in the nearshore are regulated by the structure and turnover of sediments in the lower intertidal platform.

Study 3: Document what sediment processes promote the greatest nutrient uptake and transformations of nitrogen and phosphorus species.

Hypothesis 4: Nearshore ecosystems are both influenced by and have the capacity to significantly modify the structure and processes of adjacent watershed and marine systems.

Study 4a: Determine the capacity of different beach biota to consume food particles, such as phytoplankton and detritus that originate in adjacent watershed and marine systems.

Study 4b: Evaluate the forcing of nearshore ecosystem processes by watershed and marine systems, and the nearshore mediation of those systems.

Study 4c: Characterize the nutrient dynamics in different nearshore environments, their linkages to watershed and offshore marine sources, and how restorative actions may affect nearshore nutrient dynamics.

Goal 2: Understand the Effects of Human Activities on Nearshore Ecosystem Processes

Problem Statement

Human activities are creating stressors or change agents (table 2) that affect nearshore ecosystem processes (table 3) and components (e.g., Newton and others, 2000). Many of these ecological processes are unmeasured or poorly understood. The linkages between processes, structures, stressors, and activities also are poorly understood; either conceptually or quantitatively. Much of the existing research and knowledge is about single stressors and responses. An emphasis on cumulative effects and multiple stressors, and the interactions among stressors and ecosystem response is needed. (See also Goal 3.)

The key to answering these and similar questions will be to develop predictive capability through understanding the linkages between past and present physiochemical and biological processes and then project this knowledge into the future. Knowledge about past and present ecosystem processes, when integrated with studies of land use and development activities, will equip decision makers with the tools to guide policy development and natural-resources management.

Toxics
- Add toxic
- Contribute fecal coliform bacteria
- Increase marine debris
- Increase air deposition
- Increase sediment loadings

Input changes
- Decrease sediment loading
- Alter freshwater input
- Alter runoff timing
- Increase strength of peak flow

Ambient changes
- Alter light transmissivity from turbidity
- Cause shading (structures)
- Produce noise
- Create physical disturbance via intrusion
- Change depth or shoreline slope
- Alter sediment type, including via water transport
- Physically disturb the sediments
- Resuspend sediment
- Reduce endemic benthic habitat area
- Sea level change
- Add constructed habitat
- Alter seawater temperature regime
- Impede water circulation

Biota
- Extinction/threatening of marine species
- Introduction of exotic marine species
- Alter local marine species composition
- Change marine organism abundance

Table 2. Stressors and change agents.

Regional
- Atmospheric and climatic
  - Deposition of precipitation
  - Energy sources
- Geologic
  - Earthquake
  - Volcanic
  - Glacial
- Hydrological
  - Tidal
  - Sea-level rise
  - Freshwater
  - (Sea) wave

Local
- Hydrological
  - Tidal
  - Freshwater inflow
  - (Wind) wave
- Sedimentologic/geomorphologic
  - Erosion
  - Accretion/entrainment
  - Transport

Finite
- Geochemical transformation and translocation
  - Dissolved organic to particulate organic
  - Inorganic to organic form
  - Inorganic species change
  - Contaminant species change and uptake
- Food web
  - Primary production and reproduction
  - Production of seeds and other propagules
  - Primary consumption
  - Excretion and respiration
  - Decomposition and detritus consumption
  - Secondary and tertiary production
  - Consumption
  - Growth
  - Reproduction
  - Predation
  - Competition
- Ecological
  - Recruitment
  - Symbiosis
  - Behavior

Table 3. Nearshore ecosystem processes (from Simenstad, 2004).

Existing Work

Much of the existing data and information about the Puget Sound region is scattered and fragmented. This is partly because of the many institutions and jurisdictional boundaries associated with human and natural-resource management activities in the Sound. In the Puget Sound nearshore, many large multidisciplinary research projects were undertaken following the passage of legislation in the 1970s: National Environmental Policy Act, Clean Water Act, Comprehensive Environmental Response, Compensation, and Liability Act, Endangered Species Act, MESA (Simensted and others, 1979). As a result of this legislation, many of the existing research and monitoring projects have been mission oriented, and scientific efforts have been focused on environmental assessments, impact analysis, and regulatory compliance. Most research and monitoring projects have been based on resource or habitat. More recently, large-scale efforts, such as the University of Washington's PRISM program (Puget Sound Regional Synthesis Model, 2004) have focused on understanding the ecosystem through information synthesis, research and monitoring, modeling, and visualization of human effects. The proposed work would provide complementary scientific coverage of the nearshore waters of Puget Sound.

Objectives

Basic objectives of research to address this goal include:

1. Understand types and ranges of human activities and the relation to stressors/change agents the activities have created or caused.
2. Link stressors/changes to ecosystem structure processes.
3. Factor in the role of hypothetical changes in climate and sea level to ecosystem components and processes.
4. Use a holistic approach to consider multiple and cumulative activities and stressors/change agents as the link to multiple processes and ecosystem structure.
5. Consider human activities and their impacts over multiple temporal and spatial scales.

Relevance and Impact

Resource managers and politicians need objective scientific information to determine and guide the course and effectiveness of restoration projects and programs to address these issues and, ultimately, to restore ecosystem health and integrity in the Puget Sound. This work also will promote an understanding of human effects at multiple scales on the Puget Sound nearshore, and improve human and ecosystem health by understanding the sources, transport, and fate of anthropogenic contaminants that are mediated by natural processes.

Hypotheses and Studies

Hypothesis 1: Increased sediment and nutrient loading due to silviculture, agriculture, septic systems, and storm drains affect the processes, structure, and function of nearshore ecosystems.

Study 1a: Document the frequency, volume, and composition of non-river/stream (bluff, bank) sediment input to beaches along Puget Sound.

Study 1b: Link land-use practices and water quality.

Study 1c: Determine the effects of increased stressors on nearshore plankton communities (e.g., derived from benthic and pelagic sources).

Hypothesis 2: Changes in fish abundance and habitats in upstream reaches affect the productivity and species composition of estuarine communities.

Study 2: Document the reduction of marine-derived nutrients (from gametes and carcasses of adult salmon) from before the 1800s (fishing, dams, and urbanization) and link to productivity for salmon and other species of interest.

Hypothesis 3: Diking and draining tidal delta ecosystems or construction of jetties and piers in delta or coastal areas affect coastal processes.

Study 3a: Collect and synthesize monitoring information from existing dike removal projects (Nisqually, Spencer I., Jimmy-Come_Lately, Skagit, etc.)

Study 3b: Document off-site changes in deltaic processes and delta morphology resulting from dike removal.

Hypothesis 4: Invasive species affect ecosystem processes.

Study 4: Document the effects of *Spartina anglica* invasion on community structure, sediment movement, and habitat functions (for fish, birds, and invertebrates).

Hypothesis 5: Multiple stressors act synergistically or cumulatively on nearshore processes.

Study 5: Changes in parasite loads, contaminant levels, and competition with invasive species have cumulatively reduced herring populations at Cherry Point.

Goal 3: Understand and Determine the Incremental and Cumulative Effects of Restoration and Preservation Actions on Nearshore Ecosystems

Problem Statement

Effective restoration management of nearshore ecosystems requires an improved understanding of the interactive effects of multiple restorations, preservation, and other management actions and an increased ability to determine these effects. Incremental effects are those that emerge as a series of successive management actions and begin to build on each other. In some instances, initial actions may need to be taken to reinitiate ecosystem processes that are required to support future actions. Cumulative effects are those that result from the interaction between either successive or simultaneous actions. These effects may emerge as synergistic, being greater than or different from the additive effects of multiple actions considered separately. To date, evaluations and modeling of effects of restoration actions have been focused largely on single actions and the resultant effects within the boundaries of the project area. Expanded evaluations and ecosystem modeling are needed that determine short- and long-term incremental and cumulative effects at scales ranging from project areas to the greater Puget Sound.

Existing Work

Nearshore ecosystem restoration in Puget Sound has largely focused on estuarine wetlands, especially those associated with large river systems. Much of the work has occurred relatively recently, with few large projects more than 10 years old. Monitoring of these projects has evaluated structural responses, such as vegetation community changes, production of invertebrate prey resources important to salmonids, and the presence of targeted fish species within the project area (Cordell and others, 2001; Tanner and others, 2002; Hood and Hinton, 2003; Hood, in press). Although these results are useful in formulating hypotheses about the relation between restoration actions and ecosystem processes as evidenced by structural response, little direct investigation of these relations has been completed.

Over the past few decades, a number of numerical models have been and continue to be developed by different agencies and institutions that simulate selected ecosystem processes across the Puget Sound Basin at the landscape scale. For example, the U.S. Geological Survey developed a

hydrodynamic, sediment transport, and morphological change model to explore alternative restoration scenarios for the Deschutes River Estuary Feasibility Study (George and others, 2005).

Other examples include:

- Models that simulate marine circulation (Kawase, 1998);
- Watershed and ground-water models that simulate freshwater discharge to Puget Sound for different land-use alternatives;
- Water-quality and sediment-transport models that simulate the loading of nutrients, contaminants, and sediments to Puget Sound for different land-use alternatives; and
- Models that examine the fate of those inputs once they enter the marine waters of the Sound.

The existing models simulate conditions at a range of scales, with some models simulating conditions at the sub-watershed or river-mouth scale within specific watersheds (George and others, 2005) and others simulating conditions throughout the entire Puget Sound Basin. The integration of disparate numerical models into one unifying modeling system has started as part of the University of Washington's Puget Sound Regional Synthesis Model (PRISM), as well as other more localized efforts.

Objectives

Basic objectives of research to address this goal include:

1. Determine ecosystem response to management actions using rigorous, hypothesis-based evaluation of restoration projects and other management actions.
2. Develop methods to test hypotheses about the effects of management actions on nearshore ecosystems, including short- and long-term effects at multiple spatial scales.
3. Determine the interactive and cumulative effects of multiple management actions on nearshore ecosystem processes.
4. Develop tools to project and evaluate the incremental and cumulative effects of possible future alternatives of restoration, protection, and other management actions on the condition of the Puget Sound nearshore.

Relevance and Impact

Nearshore restoration projects typically are costly and there may be significant uncertainty in the outcome, especially considering improvements to higher order ecosystem functioning. It is therefore important to be able to predict the outcome of restoration actions, and in particular the outcome of various restoration scenarios, to help decision makers select the most favored or likely to succeed scenario. Improving the understanding of restoration and preservation actions on nearshore ecosystem processes, structure, and function will provide the basis for better predictive models that can be used for selecting amongst several restoration scenarios or prioritizing one management action versus another. In fact, strategic restoration planning requires some ability to prioritize amongst various options, thus an improved ability to predict these linkages will always be needed.

The ability to predict the outcomes of various restoration scenarios provides managers, decision makers, and the public the ability to make informed decisions about which restoration action they prefer. For example, for the Deschutes River Estuary Feasibility Study, at least four restoration scenarios have been considered. Hydrodynamic and sediment transport models of each of the scenarios provides input for a biological assessment of the likely response to those different scenarios. Each of the scenarios can then be evaluated for physical, biological, and aesthetic response, and compared against the range of values expressed by the various interest groups. Decision makers can then make more informed choices.

Benefits from an improved understanding and prediction of incremental and cumulative effects of restoration and preservation actions will increase over time, as more and more restoration projects are carried out, and as the expected increase in population in the region requires evermore carefully balanced management of natural resources.

Hypotheses and Studies

Hypothesis 1: Management actions affect nearshore ecosystems at multiple spatial and temporal scales.

Study 1a: Assess the detectable effects on ecosystem processes at various spatial and temporal scales associated with large restoration actions (e.g., dike breaching in the Skagit or Nisqually River estuary and dam removal in the Elwha River system).

Study 1b: Conduct hypothesis-based evaluations of recently completed restoration projects by comparing projected and actual ecosystem responses.

Hypothesis 2: Multiple management actions have interactive and cumulative effects on nearshore ecosystems.

Study 2a: Evaluate the interactive and cumulative effects of multiple restoration actions (e.g., restoration of estuarine wetlands of the Snohomish River).

Study 2b: Develop numerical models to simulate the incremental and cumulative effects of restoration and preservation actions.

Goal 4: Understand the Effects of Social, Cultural, and Economic Values on Restoration and Protection of the Nearshore

Problem Statement

Human activities and development patterns reflect the social, cultural, and economic values of the societies, communities, and individuals that resided in, used, and influenced these nearshore ecosystems over time. Therefore, restoration of nearshore processes must consider the social, cultural, and economic values held by Puget Sound residents. It is imperative to understand the motivation for those values and the degree of flexibility and willingness to change in order to bring about an improved future condition for the nearshore ecosystem. To date, little or no social science study of nearshore resource use and development has been conducted in the Puget Sound. In addition, current social science tools and methods are not adapted for complex systems and need to be refined and/or applied in innovative ways for developing, analyzing, and assessing qualitative and quantitative data.

Existing Work

A draft National Social Science Research Strategy for Marine Protected Areas (Wahle and others, 2003) has been developed by National Oceanic and Atmospheric Administration (NOAA) and the U.S. Department of Interior that may be appropriate for application to Puget Sound and PSNERP. The strategy was developed through a series of focused meetings, workshops, and reviews with broad stakeholder participation, and used several existing social science plans including: *Usable Knowledge: A Plan for Furthering Social Science and the National Parks; A Social Science Plan for South Florida National Park Service Units; Report on the Socioeconomic Roundtable Convened by the Chequamegon and Nicolet National Forests; and the South Florida Action Plan for Applied Behavioral Sciences.*

A regional effort of more local relevance was from The Pacific Northwest Coastal Ecosystem Regional Study (PNCERS), in which they conducted a survey of resident's attitudes on a number of natural resource issues in the Grays Harbor estuary on the West Coast of Washington (Pacific Northwest Coastal Ecosystems Regional Study, 2000).

Within the Puget Sound Basin, in a 2003 proposal funded by the U.S. Department of Energy, the Tulalip Tribes of Washington identified the need to document the "environmental and tribal social, cultural, and economic benefits" as part of a proposal to determine the feasibility of a Biomass-Powered Renewable Energy Generation project on Tribal lands in Snohomish County, Washington. (http://www.eere.energy.gov/tribalenergy/projects/fy03_tulalip.html, accessed June 2005).

Objectives

The purpose of Goal 4 is to provide the scientific basis for better understanding the effects of social, cultural, and economic values on restoration and protection of the Puget Sound nearshore. The specific objectives are to:

1. Determine how human governance, institutions, and social/political processes affect important nearshore ecosystem attributes such as habitats or biotic components.
2. Determine how human use patterns directly or indirectly affect and are affected by nearshore ecosystem attributes.
3. Determine how human attitudes, perceptions, and beliefs directly or indirectly affect and are affected by nearshore ecosystem attributes.
4. Determine how economic and demographic trends affect nearshore ecosystem attributes and human values.
5. Determine how communities (geographic and stakeholder) associated with nearshore marine areas in Puget Sound affect ecosystem attributes including how these communities relate to the use and conservation of these attributes.
6. Characterize and provide the science needed to protect cultural heritage and resources (historical and traditional artifacts) of the Puget Sound nearshore ecosystem.
7. Understand the role of the Puget Sound nearshore ecosystem in both historic and contemporary cultural heritage of Native American and non-Native American communities.
8. Understand ways to improve communication of scientific information regarding nearshore restoration, and ways that community attitudes, perceptions, and beliefs can shape and inform restoration science.

Relevance and Impact

Process-based restoration and protection of nearshore environments likely will not achieve acceptable performance levels without significant increases in understanding the behaviors of individuals and human institutions that use and manage ecosystem attributes. To date, the vast majority of research and literature on nearshore ecosystems has focused on natural science, with largely anecdotal social scientific references and few rigorous projects or programs evaluating the complexities of their socioeconomic social scientific aspects. As with any policy or management issue, decisions regarding nearshore ecosystems always involve tradeoffs between the natural and human environments. Both must be adequately described and analyzed and integrated for sound decision making processes to occur (National Research Council, 1995).

Hypotheses and Studies

Hypothesis 1: Local and regional governance, institutions, and social/political processes and policies directly affect important nearshore ecosystem attributes such as habitats or biotic components and constrain restoration opportunities.

Study 1a: Examine the nature of intra-agency, interagency, and intergovernmental interactions in relation to nearshore restoration and protection planning, management and evaluation in order to design optimal structures and avoid inter-jurisdictional incompatibilities and conflict.

Study 1b: Explore alternative models for meaningful integration of the public into decision making about nearshore restoration and protection.

Study 1c: Evaluate information, resources, legal authorities, processes, and structures that are needed to plan, manage, and evaluate a site or network of nearshore restoration and protection areas and effectiveness of past designation processes.

Study 1d: Analyze and understand governmental and nongovernmental institutional cultures and how they influence and constrain decision making.

Hypothesis 2: Human use patterns directly or indirectly affect nearshore ecosystem attributes and constrain or condition restoration opportunities.

Study 2a: Collect baseline data on human ecology of use at various spatial and temporal scales.

Study 2b: Assess the ecology of nearshore-related use patterns by conducting studies of the legislative institutional, social, environmental, and economic dimensions of decision making, as well as of legal and historic frameworks that depict the "rights and responsibilities" of resource use.

Study 2c: Assess the historical political ecology of nearshore-related use patterns by conducting studies combining biophysical and human dimensions data describing patterns of human use from prehistoric to present time.

Hypothesis 3: Human attitudes, perceptions, and beliefs directly or indirectly affect nearshore ecosystem attributes and constrain or condition restoration opportunities.

Study 3a: Collect data on constituents and stakeholders' attitudes, perceptions, and beliefs regarding habitats, species, spaces, and ecological processes, relationships between people and restoration and protected areas, current environmental status, and the effects of restored and protected areas on quality of life.

Study 3b: Assess traditional and local knowledge regarding habitats, species, spaces and ecological processes, develop validation frameworks and incorporation of traditional and local ecological knowledge, and assess the value manager's place on this knowledge.

Study 3c: Assess the conditions under which people volunteer collective action in the name of ecological restoration and protection and how they perceive cause and effect linkages of these actions, including primary, secondary, and cumulative impacts.

Study 3d: Examine aesthetic ideals as they derive from or drive human/environment interactions and assess the relations between aesthetics and the development and maintenance of sense of place.

Study 3e: Assess individuals' and community's principles and ethics regarding the environment, and examine how "ways of thinking" influence decision making and behavior regarding restored and protected areas.

Hypothesis 4: Economic conditions and trends affect nearshore ecosystem attributes.

Study 4a: Develop a regional inventory of socioeconomic data and analyses on groups and measures pertinent to restored and protected areas including: commercial and recreational fisheries, shore-side support industries and coastal communities and associated infrastructure; coastal development; associated tourism and recreation and non-consumptive use and existence value.

Study 4b: Adapt and apply cost benefit analysis to restored and protected nearshore areas, including definition of costs and benefits; give consideration to basic groups (recreational, business, and tourism, etc.), different kinds of Resource Protection Areas (RPAs), specific scenarios, cultural values, and net costs and benefits to current and future generations.

Study 4c: Develop methods for estimating non-market values, in order to compute total economic value.

Hypothesis 5: Communities (geographic and stakeholder) associated with nearshore areas affect ecosystem attributes and are in turn shaped by real of or perceived ecosystem attributes.

Study 5a: Develop descriptive and explanatory information regarding social, cultural, and economic aspects of communities and stakeholder groups of particular regions and subregions in association with particular habitat or ecosystem characteristics.

Study 5b: Develop community capacity and skills related to issues such as determining the best ways to empower communities to articulate and develop their own visions and tools, and to assess existing capacity and skills in relation to environmental protection.

Study 5c: Analyze community decision making patterns and processes, determining indicators of community resiliency and identifying sources of power as they influence political change.

Study 5d: Identify mechanisms designed to reach marginalized groups, determining incentives for community compliance with ecosystem restoration guidelines, determining which management structures and processes allow for flexibility and adaptation, and impacts of various management practices on communities.

Study 5e: Assess the historic social construction of RPAs, and interdisciplinary studies of RPA "successes and failures."

Study 5f: Develop and test means for protecting maritime cultural resources including archeological, historical and ethnographic resources, including the creation of databases for these resources.

Goal 5: Understand the Relations of Nearshore Processes to Important Ecosystem Functions Including Human Health and Protection of At-Risk Species

Problem Statement

Nearshore ecosystems support or provide a large number of valuable attributes or goods and services. These goods and services are collectively referred to here as Valued Ecosystem Components (VECs). Some structural features of nearshore ecosystems, such as low gradient beaches, are valued because these beaches can be directly enjoyed by humans (e.g., a beach to walk on and water to swim in). Nearshore environments provide habitat and other supporting functions for many species of plants, fish, and wildlife for part or all of their life cycles. Some of these species are valued because they are commercially and recreationally harvested or because they can simply be viewed (e.g., eagles). Salmon are the most obvious example of a valued ecosystem biotic component that is economically important.

The number and types of VECs is dynamic. VECs that are valued today may decrease in value in the future while other ecosystem goods and services may increase in value. The ability of nearshore ecosystems to support and sustain VECs depends on the interaction of a wide variety of physical, geological, chemical, and biological processes. These ecosystem processes create and maintain structural features (e.g., habitats) of the ecosystems specifically important to different species in different ways, which then support the ecosystem functions that are valued. In addition, ecosystem processes in some cases can directly support functions, such as human health.

The basic intent of this goal is to understand the interactions among ecosystem processes, structure (i.e., attributes defining habitat for particular organisms), and functions because these interactions generate VECs. Because attributes of nearshore ecosystems that are valued will be dynamic, the study of the interaction between processes, structure, and function must be similarly dynamic and incorporate our changing values. We generally have some knowledge of many VECs associated with nearshore ecosystems including habitats that they occupy, trophic relations, and so on. Much of this information is descriptive. For example, we understand much about how salmon use nearshore ecosystems. In addition, we understand in a general sense how ecosystem processes may work. We lack a quantitative understanding of the rates, frequency, duration, and magnitude at which many processes operate and the linkages between processes, structure, and function. The lack of such knowledge is critical because increasing human activity has significantly modified many nearshore ecosystem processes and thereby compromised their ability to support important structural and functional aspects of ecosystem.

Valued Ecosystem Components (VECs)

- Salmon
- Forage fish
- Native shellfish
- Eelgrass and kelp
- Coastal forests
- Beaches and bluffs
- Orcas
- Marine and shore birds
- Great Blue Herons

Existing Work

Basic information is available on many of the species of plants and animals that use nearshore ecosystems and the functions their nearshore habitats may provide for these species. For example, we understand the types of nearshore environments that constitute Pacific herring, Pacific sand lance, and surf smelt requirements for spawning habitats, and we know some of the key habitats of juvenile salmon. The functions of their nearshore habitats vary both within and among species as a function of time of year, size, and so on. Some species such as eelgrass are associated with specific nearshore habitats for much or all their lives while other species depend on nearshore habitats only for parts of their lives. However, the relative role or importance of nearshore ecosystems in "producing" these VECs for many of the VECs associated with nearshore ecosystems for parts of their life cycles. For example, Puget Sound salmon populations have experienced widespread declines and these declines are not due to changes in any one ecosystem they occupy. Although degradation of nearshore ecosystems plays a role in declines of these populations, recovery of this VEC will require actions across a broader landscape.

Although human health can be affected by nearshore processes in several ways, a primary concern is with consumption of contaminated fish and invertebrates. Many of these contaminants are known, where they can be found in the water and in sediments, and how they enter nearshore ecosystems (e.g., stormwater runoff). Although the structure of many nearshore food webs based on diet studies are well understood, structure of these food webs need to be quantified. Furthermore, how most contaminants enter food webs, how the contaminants are processed or cycled, and how they eventually end up in nearshore biota are not clear.

Objectives

To address this science goal, a greater understanding of ecosystem processes is needed, what nearshore ecosystem attributes are important features of VEC habitats, and how VECs use their habitats. Thus, the ability to address this science goal will depend in part on the science conducted to address other goals in this research plan. Conceptually, the major objectives of work conducted under this goal will be to focus on defining linkages between ecosystem processes, ecosystem structure, and ecosystem functions. Support of human health and support of species in decline such as salmon and orca whales will be an initial focus of the research plan.

More specifically, the following objectives are identified:

1. Determine how nearshore processes directly affect the quantity and quality of nearshore habitats.
2. Determine the direct linkages between nearshore processes and key VECs.
3. Determine how changes in ecosystem processes such as those brought about restoration or development affect nearshore habitats and other VECs.
4. Understand how variability in nearshore habitats affects the ability of these ecosystems to support VECs, such as salmon, orca whales, and baitfish.
5. Determine the role of nearshore ecosystems in supporting key ecosystem components.
6. Determine economic values in relation to VECs and other aspects of the restoration process.

Relevance and Impact

Process-based restoration must be based on a significant increase in our understanding of nearshore ecosystem processes. By defining those attributes that are of most importance, attention can be focused on defining linkages between specific nearshore processes in specific regions. With this type of understanding, we can better understand what restoration actions to take. Planning for Puget Sound population and infrastructure growth over the next 50 years, and specifically along the shorelines, will not solve many of the predictable impacts without such a fundamental understanding of the relations between nearshore ecosystem processes and attributes of these systems that are most valued. Understanding how food webs function is especially critical because it will help track how contaminants enter food webs and how they are cycled, which will aid in the evaluation and management of Puget Sound water- and sediment-quality issues.

Hypotheses and Studies

Hypothesis 1: Nearshore processes and key VECs are directly and indirectly linked.

Study 1a: Develop and populate numeric models (e.g., using bioenergetics approaches of food web relations) to define pathways of contaminant uptake.

Study 1b: Determine the beach and bluff processes that are necessary for successful forage fish spawning.

Hypothesis 2: Changes in ecosystem processes brought about by restoration or development affect nearshore habitats and other VECs.

Study 2a: Determine which nearshore processes are affected by bulkheading, and how those altered processes affect nearshore habitats that support salmon and herring.

Study 2b: Determine the affect of dike breaching and/or removal on intertidal wetland processes and how those restored processes may affect juvenile salmon survival.

Hypothesis 3: Impaired or stressed ecosystem processes impact human health.

Study 3a: Determine how contaminants are processed and cycled and how they end up in biota we consume.

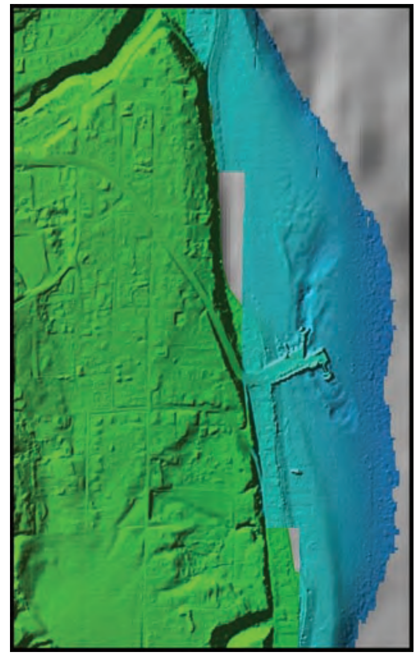
Study 3b: Investigate the role altered ground water and surface hydrology play in the development of harmful algal blooms.

Goal 6: Understand the Roles of Information—Its Representation, Conceptualization, Organization, and Interpretation—in Restoring Nearshore Ecosystem Processes

Problem Statement

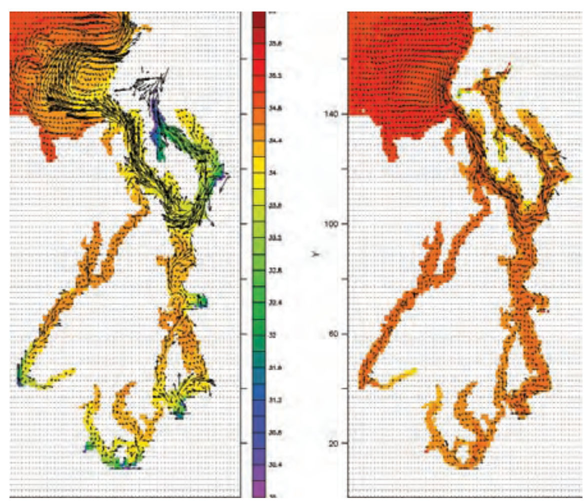
There is no specific research regarding how information is presented and organized in support of process-based restoration of the Puget Sound nearshore ecosystem. A formal framework is needed that addresses: (1) the acceptance of analysis and conclusions drawn by science-based restoration research; (2) guidance for public policy; and (3) public support for long-term, system-wide restoration.

With data as the principle building block in constructing a knowledge pathway to informed decisions, the tasks required to manage large and complex database systems have become a central focus of many planning and research activities. Numerous initiatives need to be developed, both query-based and autonomous learning systems, to satisfy the information needs of many potential users, including individual investigators, decision makers, project managers, and publicly active collaborative groups.



Existing Work

Data represent specific values, objects, or ideas that can convey meaningful information when properly interpreted. This distinction (interpretation to convey meaning) propels the task of “information management” into both technical (operative) research domains. Information systems seek to combine data access in a timely manner with quality and appropriate context. The body of knowledge that informs the usefulness of information is referred to as information science.



In recent years, scientists have developed strategies for the management and visualization of data in an effort to “reconceptualize” both spatial and temporal patterns in ecosystem data. Little is known of (1) how visual-spatial abilities are invoked when analyzing geographically or temporally distributed data; (2) how to design inquiry experiences that connect users with data from field instruments (e.g., remotely sensed data, continuous monitoring data, high resolution measurements); (3) how to link the users’ interpretation of data with discipline-specific theories; and (4) what types of skills are necessary to support inquiry using visualization of scientific data in the classroom, boardroom, or courtroom.

As Latour (1990) has explained, scientists do not spend the majority of their time working with observations. Rather, they work most often with representations of observations including tables, graphs, drawings, mathematical formulae, maps, and output from instruments or models. These representations serve as a language of science (Garfinkel and others, 1981; Knorr-Cetina and Amann, 1990); however, users seldom participate in creating these representations and thus may have trouble following the language (Roth and McGinn, 1998). Yet ecosystem scientists rely on the users to construct meaning from various forms of data representation. The ultimate effective use of data on nearshore ecosystems requires a theoretical foundation for facilitating those cognitive reconstructions.

Objectives

Both basic and applied research in information science share a common set of fundamental questions that are relevant to a broad range of communities (academic, governmental, professional, and the public-at-large). These specific objectives are:

1. Determine how choices of measurements affect misconceptions regarding ecosystem processes.
2. Determine how the accessibility and exchange of data (driven by trends in technology) impact the distribution of knowledge and the socioeconomic benefit of improved information.
3. Determine how the design of an information distribution system or the inequality in interpretive skills may ultimately restrict access to that information and thus affect the success of individual restoration projects.

Relevance and Impact

The long-term results of an information science research program that addresses the complexities of nearshore ecosystem studies are:

- A theoretical model of how "learners" use various visual-spatial-temporal abilities to make meaningful connections between actions and consequences in the nearshore ecosystem.
- A greater understanding of the knowledge and skills needed by users (program managers, project designers, decision makers, teachers, researchers, and the involved public) to support scientific inquiry of the nearshore ecosystem.
- A generalized model for constructing long-term information services.

Hypotheses and Studies

Hypothesis 1: Exaggeration in visual representations of spatial data creates misconceptions about ecosystem process relations.

Study 1: Investigate how misconceptions about linkages between nearshore ecosystem processes and physical structure vary among people at different educational levels. Design a questionnaire to administer to selected K-12, high-education, and to attendees to existing nature center sites that investigates the impact of graphic representation of the nearshore.

Hypothesis 2: Increased access to real-time information about nearshore physical conditions prior to project design will (a) alter project design, and (b) increase potential for successful restoration of processes.

Study 2: Using a case study approach, investigate the strategic role that access to data and information plays in restoration projects that use adaptive management as a design tool.

Hypothesis 3: The errors that propagate when data recorded at different spatial scales are aggregated are less significant in forming misconceptions than the aggregation of data at different temporal scales.

Study 3: Select a series of field measurements that may be acquired across a gradient of both space and time scales (such as temperature and wave energy). Develop and administer (both pre and post) a survey questionnaire for the data collector, analyst, and "learner" that investigates the significance of measurement units and resolution in portraying nearshore processes. Record attributes of nearshore processes taken in different units, projections, and protocols may result in a cumulative error that leads to misinterpretation of ecosystem relations.

5. Strategy for Achieving Research Goals

The PSNERP Research Plan research goals are complex, interrelated, and span a range of scientific disciplines. To achieve the goals, both inter- and multi-disciplinary research in such disciplines as geology, hydrology, biology, geography, oceanography, atmospheric science, and social science are required. Much of the research described here will be fundamental to understanding nearshore ecosystems anywhere, and thus will have wide applicability, although other research will be more applied and site-specific.

The plan was developed with input from scientists and managers to assure that all research will be useful, relevant, and relate directly to the needs of natural-resource managers and policy and decision makers. The plan encourages building decision support tools that assist resource managers to better relate scientific studies to end users. Study designs should be flexible to take advantage of research opportunities that vary in relation to active restoration, preservation, and adaptive management of nearshore ecosystems. For example, if researchers have advance knowledge of a pending restoration action (an Early-Action Project), the area to be restored could serve as a "living laboratory" for learning about the effects of the restoration on nearshore ecosystem processes. Lessons learned in one restoration site can be applied in other similar sites yet to be restored to ensure optimum restoration based on the best available science (see Appendix 2). In order to take advantage of "living-laboratory" opportunities, it is critical that restoration, preservation, and adaptive-management actions be communicated among decision makers and scientists in Tribal, local, State, and Federal agencies and that monitoring and scientific analyses of the actions be conducted in collaboration when possible.

The fundamental ecosystem processes that this plan seeks to elucidate occur at multiple spatial and temporal scales, ranging from local to regional over periods of hours to decades and longer. This range of scales should be addressed by short- and long-term small- to landscape-scale studies and monitoring. Long-term monitoring at multiple spatial scales is particularly important to understanding and predicting cumulative effects of multiple restoration and preservation actions. Studies will synthesize and integrate new data and existing information collected for other purposes in the past but that contain important information for understanding nearshore ecosystem processes.

Rather than dictate or suggest specific research approaches, these should be left to the principle investigator(s). However, elements in a research approach should include such commonly agreed-upon techniques as the use of conceptual and numerical models, reference sites, and careful peer review, not only of the results, but of research proposals.

6. Implementation of Research Plan

The overall goal of this research plan is to help reduce uncertainty in decisions regarding what and how much to protect and restore. This goal will be accomplished as individual academic researchers and local entities, as well as State resource agencies and the Federal and Tribal research community understand the information needs, seek funding, and develop specific research plans. Especially important to the success of this goal will be the prioritization of funding for Demonstration Projects and Early-Action Projects to learn from opportunistic and planned restoration activities. Federal, State, and local agencies that fund restoration activities should actively seek opportunities to monitor and study the changes that occur as a result of the restoration actions. Because there is little incentive for a local entity to fund monitoring and research studies, State and Federal agencies, through the auspices of restoration programs such as PSNERP and the Puget Sound and Adjacent Waterways (PSAW) should fund such activities. Another avenue for encouraging studies to address the research goals and objectives described in this plan is to direct and focus ongoing agency science efforts. National Oceanic Atmospheric and Atmospheric Administration, the U.S. Geological Survey (USGS), Washington Department of Natural Resources, and others all have staff with the expertise to address important information needs. Agency research programs could seek opportunities to leverage internal funding by augmenting ongoing studies with additional funds from large restoration programs, individual restoration projects, or local entities. The USGS, for example, has successfully directed its research efforts by funding the Coastal Habitats in Puget Sound (CHIPS) project. This multi-disciplinary project includes studies of ecosystem processes of large river deltas, effects of urbanization on nearshore ecosystems, and effects of dam removal on nearshore ecosystems. Washington Department of Natural Resources has augmented an ongoing effort directed at monitoring eelgrass. Another avenue for encouraging research on Puget Sound nearshore issues is to communicate the information needs to the academic and private research community through reporting at scientific conferences. Conferences such as the Georgia Basin Puget Sound Research Conference, the Restore America's Estuaries conference, the Estuarine Research Federation conference amongst others are excellent forums to inform scientists of the interesting and important issues in Puget Sound.

Implementation of this research plan depends upon close collaboration of multiple Tribal, local, State, and Federal agencies, universities, non-governmental organizations, and private industry. Many of these groups contributed to this plan through the PSNERP partnership and jointly identified the research goals described herein. Collaboration through sharing of existing and new data and information, coordinating the collection of new data and information, prioritizing research needs, and pooling and leveraging resources to achieve the research goals will benefit all interested parties.

The research plan is best used for posing detailed and coordinated research questions by individual researchers or lead entities, or multiple agencies and organizations with the common goal of developing the scientific information and tools that support adaptive management of nearshore Puget Sound. Because the Plan identifies complex research needs, encompassing several fields of scientific study, implementation will not be quick or inexpensive. Implementation of the plan will take multiple years, and funding should be sought from multiple sources. By the same token, restoration and preservation activities should not wait for the research studies identified in the plan to be complete. Just as restoration and preservation activities will be ongoing for a long time, so should research continue to improve understanding and to reduce uncertainty. In fact, progress will accelerate if there are opportunities to learn from restoration efforts that are ongoing, and by adding hypothesis-based research and monitoring components to restoration projects that are currently in the design phases.

This research plan should be considered a living document that will be updated as significant scientific findings or new organizational structures or opportunities warrant refinements or changes of the plan.

7. References Cited

Armstrong, J.W., C.P. Staude, R.M. Thom, and K.K. Chew. 1976. Habitats and relative abundances of the intertidal macrofauna at five Puget Sound beaches in the Seattle area. Syesis. 9:277-290.

Armstrong, J.W., R.M. Thom, and K.K. Chew. 1981. Impact of a combined sewer overflow on the abundance, distribution, and community structure of subtidal benthos. Marine Environmental Research. 4:3-23.

Boesch, D.F., and J. Greer (eds.). 2003. Chesapeake Futures: Choices for the 21st Century. Chesapeake Research Consortium, Inc., Edgewater, Maryland. 160 p.

Bortleson, G.C., M.J. Chrzastowski, and A.K. Helgerson. 1980. Historical changes of shoreline and wetland at eleven major deltas in the Puget Sound Region, Washington. U.S. Geological Survey Hydrologic Investigations Atlas, HA-617, 11 sheets.

Burns, R. 1985. The shape and form of Puget Sound. Washington Sea Grant Program. University of Washington Press. Seattle, Washington. 100 p.

Carls, M.G., S.D. Rice, and J.E. Hose. 1999. Sensitivity of fish embryos to weathered crude oil. Part I. Low level exposure during incubation causes malformations, genetic damage, and mortality in larval Pacific herring (*Clupea pallasi*). Environmental Toxicology and Chemistry 18:481-493.

Center for Marine Conservation, 1998, Marine resources. A citizen's guide to the northwest straits, 40 p.

Cohen, A.N., C. Mills, H. Berry, M. Wonham, B. Bingham, B. Bookheim, J. Carlton, J. Chapman, J. Cordell, L. Harris, T. Klinger, A. Kohn, C. Lambert, G. Lambert, K. Li, D. Secord and J.Toft. 1998. Puget Sound Expedition: A rapid assessment survey of non-indigenous species in the shallow waters of Puget Sound. Prepared for the Nearshore Habitat Program, Aquatic Resources Division, Washington State Department of Natural Resources. Olympia, Washington and U.S. Fish and Wildlife Service, Lacey, Washington. Available at URL: http://www2.wadnr.gov/nearshore/textfiles/pdf/exotics1998.pdf, accessed June 2005.

Cohen, A.N., H.D. Berry, C.E. Mills, D. Milne, K. Britton-Simmons, M.J. Wonham, D.L. Secord, J.A. Barkas, B. Bingham, B.E. Bookheim, J. E. Byers, J.W. Chapman, J.R. Cordell, B. Dumbauld, A. Fukuyama, L.H. Harris, A.J. Kohn, K. Li, T.F. Mumford Jr., V. Radashevsky, A.T. Sewell, K. Welch. 2001. Washington State Exotics Expedition 2000. A rapid survey of exotic species in the shallow waters of Elliot Bay, Totten and Eld Inlets, and Willapa Bay. Prepared for the Nearshore Habitat Program, Aquatic Resources Division, Washington State Department of Natural Resources. Olympia, Washington. Available at URL: http://www2.wadnr.gov/nearshore/textfiles/pdf/exotics2000.pdf, accessed June 2005.

Collins, B.D., D.R. Montgomery, and A.J. Sheikh. 2003. Reconstructing the historical riverine landscape of the Puget Lowland. p. 79-128 *in* D.R. Montgomery, S.M. Bolton, D.B. Booth, and L. Wall (eds.), Restoration of Puget Sound Rivers. University of Washington Press, Seattle, Washington.

Cordell, J.R., L.M. Tear, and K. Jensen. 2001. Biological monitoring at Duwamish River Coastal America restoration and reference sites: A seven-year retrospective. University of Washington, School of Aquatic Fishery Sciences SAFS-UW-0108. Seattle, Washington. 75 p. Available at URL: http://www.fish.washington.edu/research/publications/pdfs/0108.pdf, accessed June 2005.

Determan, T.A. 1999a. Trends in fecal coliform pollution in eleven Puget Sound embayments. Office of Shellfish Programs. Washington Department of Health. Olympia, Washington. 102 p.

Determan, T.A. 1999b. Temporal and spatial distribution of paralytic shellfish poisoning in Puget Sound. Olympia, Washington. Office of Shellfish Programs, Washington State Department of Health. Olympia, Washington.

Downing, J. 1983. The coast of Puget Sound: Its processes and development. University of Washington Press, Seattle, Washington. 126 p.

Finlayson, D. and H. Shipman. 2003. Puget Sound drift cells: The importance of waves and wave climate. Puget Sound Notes No. 47, p. 1-4. Puget Sound Action Team. Olympia, Washington. Available at URL: http://www.psat.wa.gov/Publications/psnotes_pdf/ps_notes_47.pdf, accessed June 2005.

Frankenstein, G. 2000. Blooms of ulvoids in Puget Sound. Puget Sound Water Quality Action Team. Olympia, Washington.

Gardiner, W.W. 1992. Sea surface films: deposition and toxicity in intertidal habitats. M.S. Thesis. Western Washington University. Padilla Bay National Estuarine Research Reserve Reprint Series No. 16.

Garfinkel, H., M. Lynch, and E. Livingston. 1981. The work of discovering science construed with materials from the optically discovered pular. Philosophy of the Social Sciences 11:131-158.

George, D., G. Gelfenbaum, G. Lesser, B. Barnard, S. Morrison, P. Lund. 2005, The Deschutes Estuary Restoration Feasibility Study: development of a process-based morphological model. Puget Sound Georgia Basin Research Conference Proceedings.

Gren, I.-M., R.K. Turner, and F. Wulff (eds.). 2000. Managing a sea: The ecological economics of the Baltic. Earthscan Publications, Inc. London, England.

Gustafson, R.G., W.H. Lenarz, B.B. McCain, C.C. Schmitt, W.S. Grant, T.L. Builder, and R.D. Methot. 2000. Status review of Pacific Hake, Pacific Cod, and Walleye Pollock from Puget Sound, Washington. U.S. Department of Commerce, NOAA Technical Memorandum NMFS-NWFSC-44, 275 p. Available at URL: http://www.nwfsc.noaa.gov/publications/techmemos/tm44/tm44.htm, accessed July 12, 2004.

Hardy, J.T. 1997. Biological effects of chemicals in the sea-surface microlayer. Pages 339-370 *in* P. Liss and R. Duce (eds.), The Sea Surface and Global Change. Cambridge University Press, United Kingdom.

Hardy, J.T., E.A. Crecelius, C.W. Apts, and J.M. Gurtisen. 1987a. Sea-surface contamination in Puget Sound: Part II. Concentration and distribution of contaminants. Marine Environmental Research. 23:251-271.

Hardy, J.T., S.L. Kiesser, L.D. Antrim, A.I. Stubin, R. Kocan, and J.A. Strand. 1987b. The sea-surface microlayer of Puget Sound: Part I. Toxic effects on fish eggs and larvae. Marine Environmental Research. 23:227- 249.

Haugerud, R.A., D.J. Harding, S.Y. Johnson, J.L. Harless, C.S. Weaver, and B.L. Sherrod. 2003. High-resolution lidar topography of the Puget Lowland, Washington—A Bonanza for Earth Science. GSA Today. 13(6): 4-10.

Heinz Center for Science, Economics, and the Environment. 2002. The State of the Nation's Ecosystems: Measuring the lands, waters, and living resources of the United States. Cambridge University Press, United Kingdom. 270 p. Available at URL http://www.heinzctr.org/ecosystems/intro/toc.shtml, accessed June 2005.

Heintz, R.A., J.W. Short, and S.D. Rice. 1999. Sensitivity of fish embryos to weathered crude oil: Part II. Incubating downstream from weathered Exxon Valdez crude oil caused increased mortality of pink salmon (*Oncorhynchus gorbuscha*) embryos. Environmental Science and Technology. 18:494-503.

Hood, G. in press. Deepwater slough restoration project monitoring report. Skagit Systems Cooperative. La Conner.

Hood, G., and S. Hinton. 2003. Baseline Monitoring: Planning, Design, and Prediction for Estuarine Habitat Restoration. Puget Sound Georgia Basin Research Conference Proceedings, 14 p.

John L. Scott Real Estate. 2004. San Juan Island Office. Available at URL http://johnlscottsji.com/P53.cfm, accessed July 22, 2004.

King County Department of Natural Resources and Parks. 2002. Water quality status report for marine waters, 2001. Marine and Sediment Assessment Group, King County Department of Natural Resources and Parks. Seattle, Washington.

King County Department of Natural Resources. 2001. Reconnaissance assessment of the State of the Nearshore Ecosystem: Eastern shore of Central Puget Sound, including Vashon and Maury Islands (WRIAs 8 and 9). Available at URL: http://dnr.metrokc.gov/wlr/watersheds/puget/nearshore/sonr.htm, accessed June 2005.

Knorr-Cetina, K.D., and K. Amann. 1990. Image dissection in natural scientific inquiry. Science, Technology, and Human Values. 15(3):259-283.

Kawase, M. 1998. A numerical model of Puget Sound circulation. Proceedings Puget Sound Conference, p. 209-216.

Latour, B. 1990. Drawing things together. p. 19-68 *in* M. Lynch and S. Woolgar (eds.). Representations in Scientific Practice. MIT Press, Cambridge, Massachusetts.

Long, E.R., A.B. Benedict, R.D. Everitt, B.S. Miller, C.F. Nyblade, C.A. Simenstad, S.M. Speich, T.R. Wahl, and H.H. Webber. 1983. A synthesis of biological data from the Strait of Juan de Fuca and northern Puget Sound. U.S. Environmental Protection Agency EPA-600/7-82-004. Washington, D.C. 295 p.

McMurray, G.R., and R.J. Bailey (eds.). 1998. Change in Pacific Northwest Coastal Ecosystems. NOAA Coastal Ocean Program. Decision Analysis Series No. 11. Troutdale, Oregon. 342 p.

Millennium Ecosystem Assessment. 2005. Ecosystem and Human Well-Being: Synthesis, Island Press, Washington, D.C.

Miller, B.S., and S.F. Borton. 1980a. Geographical distribution of Puget Sound fishes: Maps and data source sheets. Volume 1. Family Petromysontidae (Lampreys) through Family Syngnathidae (Pipefishes). University of Washington, Fisheries Research Institute. Seattle, Washington. 681 p.

Miller, B.S. and S.F. Borton. 1980b. Geographical distribution of Puget Sound fishes: Maps and Data Source Sheets. University of Washington, Fisheries Research Institute. Seattle, Washington. v. 2.

Miller, B.S., and S.F. Borton. 1980c. Geographical distribution of Puget Sound fishes: Maps and data source sheets. Volume 3. Family Cottidae (sculpins) through Family Molidae (Molas). University of Washington, Fisheries Research Institute. Seattle, Washington.

Morrison, S.W., J.K. Kettman, and D. Haug. 1994. Inventory and characterization of shoreline armoring, Thurston County, Washington, 1977-1993. Coastal Erosion Management Studies Volume 3. Shorelands and Coastal Zone Management Program, Washington Department of Ecology.

Mote, P., D. Canning, D. Fluharty, R. Francis, J. Franklin, A. Hamlet, M. Hershman, M. Holmberg, K.G. Ideker, W. Keeton, D. Lettenmaier, R. Leung, N. Mantua, E. Miles, B. Noble, H. Parandvash, D.W. Peterson, A. Snover, and S. Willard. 1999. Impacts of variability and change in the Pacific Northwest. A Report of the Pacific Northwest Regional Assessment Group, for the U.S. Global Change Program. By the JISAO/.SMA Climate Impacts Group, University of Washington, Seattle. JISO Contrib. No. 175. 109 p.

Mumford, T. F. Jr. 2002. Emerging issues: Changing paradigms, unseen trends, neglected science. *In* T.W. Droscher (ed.). Proceedings of the 2001 Puget Sound Research Conference. Puget Sound Action Team. Olympia, Washington. 9 p. Available at URL http://www.psat.wa.gov/Publications/01_proceedings/sessions/oral/7b_mumfo.pdf, accessed June 2005.

Mumford, T.F., Jr., S. Wyllie-Echeverria, R.T. Thom, and D.E. Penttila. 2003. Loss of eelgrass (*Zostera marina* L.) in small embayments, Puget Sound, Washington: Similarity to worldwide early signs of collapse. Proceedings of the Estuarine Research Foundation Conference. Estuaries on the Edge: Convergence of Ocean, Land and Culture. Sept. 14-18, 2003. Seattle, Washington. Available at URL http://fish.washington.edu/news/erf/Program_9-17.pdf. (abstract only).

National Research Council (NRC), 1995a. Improving Interactions Between Coastal Science and Policy: Proceedings of the Gulf of Maine Symposium, National Academy Press.

National Research Council (NRC), 1995b. Science, Policy, and the Coast: Improving Decisionmaking, National Academy Press.

Newton, J. 2004. Hood Canal dissolved oxygen concentrations at historically low values during winter 2003-2004. Available at URL: http://www.hoodcanal.washington.edu/observations/winterconditions03-04.html, accessed July 2004.

Newton, J., T. Mumford, J. Dohrmann, J. West, R. Llanso, H. Berry, and S. Redman. 2000. A conceptual model for environmental monitoring of a marine system. Developed for the Puget Sound Ambient Monitoring Program. Olympia, Washington. 12 p., 2 appendixes. Available at URL: http://www.psat.wa.gov/Publications/conceptual%20model.pdf, accessed June 2005.

Northwest Salmon Recovery Planning. 2004. Final report of updated status of listed ESUs of salmon and steelhead. Available at URL: http://www.governor.wa.gov/gsro/publications/sosreport/2004/puget.pdf, accessed June 2005.

Northwest Straits Commission. 1999. Report from the Northwest Straits Workshop to identify gaps and information needs. Available at URL: http://www.nwstraits.org/PageID/162/default.aspx, accessed June 2005.

Northwest Straits Commission. 2000. Northwest Straits Overview: A Science Gap Report References. Available at URL: http://www.nwstraits.org/PageID/162/default.aspx, accessed June 2005.

Nysewander, D.R., J.R. Evenson, B.L. Murphie, and T.A. Cyra. 2001. Status and trends for a suite of key diving marine bird species characteristic of greater Puget Sound, as examined by the Marine Bird Component. Puget Sound Ambient Monitoring Program (PSAMP). Poster presentation for Puget Sound Research Conference, Feb. 12-14, 2001, Bellevue, Washington.

Pacific Northwest Coastal Ecosystems Regional Study. 2000. Coastal Resident Survey, Basic Summary of Responses.

Palsson, W.A., J.C. Hoeman, G.G. Bargmann, and D.E. Day. 1997. 1995 status of Puget Sound bottomfish stocks (revised): Washington Department of Fish and Wildlife, Report No. MRD97-03. Olympia, Washington. 98 p.

Pew Oceans Commission. 2003. America's Living Oceans: Charting a course for sea change. A Report to the Nation. Pew Ocean's Commission, Arlington, Virginia.

PSNERP-NST (Puget Sound Nearshore Ecosystem Restoration Program, Near-Shore Science Team) Conceptual Model Working Group. 2004. Conceptual model for assessing restoration of Puget Sound nearshore ecosystems: Conceptual Model Narrative. Available at URL: http://sal.ocean.washington.edu/nst/private/products/conceptmodel/CM%20narrative%20(121702)_HMS.doc, accessed July 2004.

Puget Sound Action Team. 2004. Puget Sound Index. Available at URL: http://www.psrc.org/datapubs/pubs/trends/d7jul04.pdf, accessed June 2005.

Puget Sound Action Team. 2005. State of the Sound, 2004. Puget Sound Action Team, PSAT 05-01, Olympia, Washington.

Puget Sound Regional Council. 2004. Population change and net migration. Puget Sound Trends No. D7. Available at URL: http://www.psrc.org/datapubs/pubs/trends/d7jul04.pdf, accessed July 2004.

Puget Sound Regional Synthesis Model. 2004. "What is PRISM?" University of Washington. Available at URL: http://www.prism.washington.edu/, accessed July 23, 2004.

Puget Sound Water Quality Action Team. 2002a. 2002 Puget Sound Update: Eighth Annual Report of the Puget Sound Ambient Monitoring Program. Puget Sound Water Quality Action Team. Olympia, Washington.

Puget Sound Water-Quality Action Team. 2002b. Puget Sound Georgia Basin Ecosystem Indicators Report. Terrestrial Protected Areas. Available at URL: http://wlapwww.gov.bc.ca/cppl/gbpsei/terrestrial/graph1.html, accessed July 22, 2004.

Puget Sound Water Quality Authority. 1987. Puget Sound Environmental Atlas, Volumes 1 and 2. Prepared by Evans-Hamilton, Inc. and D.R. Systems, Inc. Seattle, Washington.

Puget Sound Water Quality Authority. 1988. State of the Sound 1988 report. Puget Sound Water Quality Authority. Seattle, Washington. 225 p.

Ross, P.S. 2003. Life at the top of the food chain: Seabirds, seals and whales as sentinels of environmental contamination in Puget Sound and Georgia Basin (abs.). *In* T.W. Droscher and D.A. Fraser (eds.). Proceedings of the 2003 Georgia Basin/Puget Sound Research Conference. Available at URL: http://www.psat.wa.gov/Publications/03_proceedings/PAPERS/ORAL/4e_ross.pdf, accessed June 2005.

Roth, W.M., and M. McGinn. 1998. Inscriptions: Toward a theory of representing as social practice. Review of Educational Research. 68(1):35-59.

Schmidt M., and P. Johnson. 2001. Toxics in the Puget Sound food web. People for Puget Sound. Seattle, Washington. Available at URL: http://www.pugetsound.org/index/cms-filesystem-action?file=publications/2001_toxics_food_web.pdf, accessed June 2005.

Schoch, G.C., and M. Dethier. 1996. Scaling up: the statistical linkage between organismal abundance and geomorphology on rocky intertidal shorelines. Journal of Experimental Marine Biology and Ecology, v. 201; Number 1/2, p. 37-72.

Schoch, G.C., and M. Dethier. 2001. The intertidal biota of Puget Sound gravel beaches: Part 1. Spatial and temporal comparisons between 1999 and 2000, and Part 2. Recommendations for future sampling. Washington State Department of Natural Resources Nearshore Habitat Program, Olympia, Washington.

Schwartz, M.L., R.S. Wallace, and E.E. Jacobsen. 1989. Net shore-drift in Puget Sound. Engineering Geology in Washington, Volume II. Olympia, Washington. Washington Division of Geology and Earth Resources Bulletin 78. p. 1137-1145.

Simenstad, C. 2004. Nearshore processes. Paper prepared for PSNERP NST (Puget Sound Nearshore Ecosystem Restoration Program, Near-Shore Science Team). 5 p. Available at URL: http://sal.ocean.washington.edu/nst/private/review/NearshoreProcessesDFT1.doc, accessed July 22, 2004.

Simenstad, C.A., M. Logsdon, K. Fresh, H. Shipman, and J. Newton. 2006. Conceptual Model for Assessing Restoration of Puget Sound Nearshore Ecosystems. Puget Sound Nearshore Partnership. Tech. Re. 2006-03. Olympia, Washington. 43 p.

Simenstad, C.A., B.S. Miller, C.F. Nyblade, K. Thornburgh, and L.J. Bledsoe. 1979. Food web relationships of northern Puget Sound and the Strait of Juan de Fuca; a synthesis of available knowledge. U.S. Environmental Protection Agency, Washington, D.C., Report #EPA-600/7-79-259. 335 p.

Sommers, P., and D. Canzoneri. 1996. The Sound Economy: Puget Sound Region's industries and their relationship to the Sound. People for Puget Sound. Seattle, Washington. Available at URL: http://www.pugetsound.org/index/cms-filesystem-action?file=publications/1996_industries_report.pdf, accessed June 2005.

Staubitz, W.W., G.C. Bortleson, S.D. Semans, A.J. Tesoriero, and R.W. Black. 1997. Water-quality assessment of the Puget Sound Basin, Washington—Environmental setting and its implications for water quality and aquatic biota. U.S, Geological Survey Water-Resources Investigations Report 97-4013. 76 p. Available at URL: http://pubs.er.usgs.gov/pubs/wri/wri974013, accessed June 2005.

Staude, C.P. 1979. Changes in the intertidal macrofauna and macroflora near Seattle's West Point Sewage Treatment Plant from 1971 to 1975. M.S. Thesis. University of Washington, 161 p.

Tanner, C.D., J.R. Cordell, J. Rubey, and L.M. Tear. 2002. Restoration of freshwater intertidal habitat functions at Spencer Island, Everett, Washington. Restoration Ecology. 10(3):564-576.

The Chesapeake Bay Program. 2002. Where are we and where are we going? Available at URL: http://www.chesapeakebay.net/pubs/Snapc2k.pdf, accessed June 2005.

Thom, R.M., J.W. Armstrong, C.P. Staude, K.K. Chew, and R.E. Norris. 1976. A survey of the attached marine flora at five beaches in the Seattle area, Washington. Syesis. 9:267-275.

Thom, R.M., R. Albright, C.A. Simenstad, J. Hampel, J. Cordell, and K.K. Chew. 1984. Intertidal and shallow subtidal benthic ecology. v. IV *in* K.K. Chew and Q.J. Stober (eds.). Renton sewage treatment plant study: Seahurst baseline study. FRI-UW-8413, Final Report to Municipal. Metro. Seattle, Fish. Res. Inst., University of Washington, Seattle, Washington. 172 p.

Thom, R.M., A.E. Copping, and R.G. Albright. 1988. Nearshore primary productivity in central Puget Sound: A case for nutrient limitation in the nearshore systems of Puget Sound. Proceedings of the First Annual Puget Sound Research Conference. Puget Sound Water Quality Authority. Seattle, Washington. p. 378-391.

Trade Development Alliance of Greater Seattle. 2004. Trace Stats & Information: http://www.seattle.gov/tda/trade_info/stats_info.htm.

Transboundary Georgia Basin-Puget Sound Environmental Indicators Workgroup. 2002. Georgia Basin-Puget Sound Ecosystem Indicators Report. Georgia Basin Ecosystem Initiative Pub. No. EC/GB- 01-034, Washington Department of Ecology Pub. No. 02-01-002.

U.S. Commission on Ocean Policy. 2004. An Ocean Blueprint for the 21st Century, Final Report. Washington D.C.

U.S. Fish and Wildlife Service. 2004. Critical habitat proposed for Washington's Coastal Puget Sound population of bull trout. News Release, June 22, 2004. Available at URL: http://pacific.fws.gov/bulltrout/jcs/documents/cps_NR.pdf, accessed June 2005.

Vaccaro, J.J., A.J. Hansen, and M.A. Jones. 1998. Hydrogeologic framework of the Puget Sound aquifer system, Washington and British Columbia. U.S. Geological Survey Professional Paper 1424-D. 77 p.

Valiela, I., J. McClelland, J. Hauxwell, P.J. Behr, D. Hersh, and K. Foreman. 1997, Macroalgal blooms in shallow estuaries: controls and ecophysiological and ecosystem consequences. Limnology and Oceanography. 42(5, Part 2):1105-1118.

Wahle, C., S. Lyons, K. Barba, L. Bunce, P. Fricke, E. Nicholson, M. Orbach, C. Pomeroy, H. Recksiek, and J. Uravitch, 2003. A Social Science Research Strategy for Marine Protected Areas, NOAA Marine Fisheries Service.

Washington State Department of Ecology. 2004. Chemicals in Washington State summary report 2002. Toxics release inventory and tier two - Emergency and hazardous chemical inventory. Hazardous Waste and Toxics Reduction Program Publication Number 04-04-020. 95 p. Available at URL: http://www.ecy.wa.gov/pubs/0404020.pdf, accessed June 2005.

Washington State Department of Ecology. 2004. Oxygen at historic low in Hood Canal waters. News release, June 8, 2004. Available at URL: http://www.psat.wa.gov/News/releases/DOE_04_106.htm, accessed June 2005.

Washington Department of Fish and Wildlife. 2000. The dual role of Washington's hatcheries: conservation of wild stocks, sustainable fisheries. Washington Department of Fish and Wildlife Fact Sheet. July 2000. Available at URL: http://wdfw.wa.gov/factshts/hatcheries.htm, accessed July 20, 2004.

Washington Department of Fish and Wildlife. 2004a. Species of concern. Available at URL: http://wdfw.wa.gov/wlm/diversty/soc/concern.htm, accessed June 2005.

Washington Department of Fish and Wildlife, 2004b, Shellfish: Available at URL: http://wdfw.wa.gov/fish/shelfish/beachreg/1clam.htm, accessed July 19, 2004.

Washington Department of Fish and Wildlife. 2004c. Hatcheries program overview: Available at URL: http://wdfw.wa.gov/hat/overview.htm, accessed July 20, 2004.

Washington Department of Fish and Wildlife. 2004d. Hatchery Scientific Review Group Press Conference, Remarks by Jeffrey Koenings, WDFW Director, April 23, 2004: Available at URL http://wdfw.wa.gov/depinfo/director/apr2304.htm, accessed July 20, 2004.

Washington Department of Fish and Wildlife. 2004e. Hydraulic project approval: Available at URL: http://wdfw.wa.gov/hab/hpapage.htm, accessed April 17, 2005.

Washington Department of Natural Resources. 1998. Changing our water ways: Trends in Washington's Water Systems. Olympia, Washington. 133 p.

Washington Department of Natural Resources. 2000. Our changing nature: Natural Resource Trends in Washington State. Olympia, Washington. 75 p.

Washington Department of Natural Resources. 2004. The Geoduck Program: Managing a valuable natural resource for Washington citizens. Available at URL: http://www.dnr.wa.gov/htdocs/adm/comm/fs04_176.htm, accessed June 2005.

Washington Sea Grant Program. 2000. Draft Northwest Straits overview: A science gap report. Prepared for the Northwest Straits Commission, revised April 2000. Washington Sea Grant Program, Office of Marine and Environmental and Resource Programs, University of Washington, Seattle. 65 p.

Washington State University. 2004. Penn Cove water festival past and present: Washington State University's Extension Program for Island County. Fort Casey State Park, Whidbey Island, Washington. Available at URL: http://www.beachwatchers.wsu.edu/whidbey/waterfest/, accessed July 19, 2004.

West, J.E. 1997. Protection and restoration of marine life in the inland waters of Washington State. Prepared for the Puget Sound/ Georgia Basin International Task Force Washington Work Group on Protecting Marine Life. Puget Sound/Georgia Basin Environmental Report Series Number 6. 154 p. Available at URL: http://www.psat.wa.gov/Publications/west_protect_restor.pdf, accessed June 2005.

Whitfield, P.H., D. Fraser, and S. Cohen. 2003. Climate change impacts on water in Georgia Basin/Puget Sound — Special Issue. Canadian Water Resources Journal 28(4): 523-529. Available at URL: http://www.cwra.org/Publications/CWRA_-_CWR_Journals/CWRA_-_Journal_Contents/2003_Vol_28_4_/2Whitfield.pdf, accessed June 2005.

Wiles, G.J. 2004. Washington State status report for the killer whale. Washington Department of Fish and Wildlife Program. Olympia, Washington. Available at URL: http://wdfw.wa.gov/wlm/diversty/soc/status/orca/final_orca_status.pdf, accessed June 2005.

Wilson, R.C.H., R.J. Beamish, F. Atkins, and J. Bell. (eds.) 1994. Review of the marine environment and biota of Strait of Georgia, Puget Sound and Juan de Fuca Strait. Proceedings of the BC/Washington Symposium on the Marine Environment. Nanaimo, British Columbia January 13-14, 1994. Produced for the Marine Science Panel of the British Columbia/Washington Environmental Cooperation Council. Canadian Technical Report of Fisheries and Aquatic Sciences No. 1948. 390 p.

Wyllie-Echeverria, S., T. Mumford, J. Gaydos, and S. Buffum. 2003. *Zostera marina* declines in San Juan County, Washington. Westcott Bay Taskforce Mini-Workshop, July 26, 2003. Roche Harbor, San Juan Island, Washington. 18 p. Available at URL: http://mehp.vetmed.ucdavis.edu/pdfs/eelgrassrpt.pdf, accessed July 22, 2004.

8. Further Reading

Aschersleben, G., T. Bachmann, and J. Musseler (eds.). 1999. Cognitive contributions to the perception of spatial and temporal events. Advances in Psychology 129. Elsevier. Amsterdam.

Bricker, S.B., C.G. Clement, D.E. Pirhalla, S.P. Orlando, and D.R.G. Farrow. 1999, National estuarine eutrophication assessment: Effects of nutrient enrichment in the Nation's estuaries: National Ocean Service, National Oceanic and Atmospheric Administration, Special Projects Office and the National Centers for Coastal Ocean Science. Silver Spring, Maryland. 71 p.

British Columbia/Washington Marine Science Panel. 1994. The shared marine waters of British Columbia and Washington: A scientific assessment of current status and future trends in resource abundance and environmental quality in the Strait of Juan de Fuca, Strait of Georgia, and Puget Sound. Report to the British Columbia/Washington Environmental Cooperation Council.

Broadhurst, G. 1998. Impacts and threats to nearshore habitat. Chapter 2 in Puget Sound Nearshore Habitat Regulatory Perspective: A Review of Issues and Obstacles. Prepared for the Puget Sound/Georgia Basin International Task Force Work Group on Nearshore Habitat Loss. Available at URL: http://www.psat.wa.gov/shared/taskforce7.html, accessed June 2005.

Bull, P. 2002. Communication under the microscope: The theory and practice of microanalysis. Psychology Press. Routledge, London.

Chrisman, N. 1997. Exploring geographic information systems. John Wiley and Sons, New York.

Colich, F. 2003. Trace metals concentrations in stormwater runoff from the Evergreen Point Floating Bridge in the Seattle, Washington Area. *In* T.W. Droscher and D.A. Fraser (eds.). Proceedings of the 2003 Georgia Basin/Puget Sound Research Conference. Vancouver, British Columbia. March 31-April 3, 2003. Available at URL: http://www.psat.wa.gov/Publications/03_proceedings/PAPERS/POSTER/p4_coli.pdf, accessed February 2004.

Collins, B.D., and A.J. Sheikh. 2005. Historical Reconstruction, Classification, and Change Analysis of Puget Sound Tidal Marshes. Project Completion Report to: Washington Department of Natural Resources, 120 p. Available at URL: http://www.pugetsoundnearshore.org/techical_papers/historical_shoreline_dnr.pdf.

Davis, J., J.S. Labenia, D.H. Baldwin, B. French, and N.L. Scholz. 2003. Sublethal effects of the carbamate insecticide—carbaryl—on coastal cutthroat trout (abs.). *In* T.W. Droscher and D.A. Fraser (eds.). Proceedings of the 2003 Georgia Basin/Puget Sound Research Conference. Vancouver, British Columbia. March 31-April 3, 2003. Available at URL: http://www.psat.wa.gov/Publications/03_proceedings/PAPERS/POSTER/p4_davis.pdf, accessed February 2004.

Dutch, M., S. Aasen, and E.R. Long. 2003. PCB aroclor concentrations in Puget Sound sediments. *In* T.W. Droscher and D.A. Fraser (eds.). Proceedings of the 2003 Georgia Basin/Puget Sound Research Conference. Vancouver, British Columbia. March 31-April 3, 2003. 14 p. Available at URL: http://www.psat.wa.gov/Publications/03_proceedings/PAPERS/POSTER/p4_dutc1.pdf, accessed February 2004.

Dutch, M., S. Aasen, and E.R. Long. 2003. PCB congener concentration in Puget Sound sediments In T.W. Droscher and D.A. Fraser (eds.). Proceedings of the 2003 Georgia Basin/Puget Sound Research Conference. Vancouver, British Columbia. March 31-April 3, 2003. 14 p. Available at URL: http://www.psat.wa.gov/Publications/03_proceedings/PAPERS/POSTER/p4_dutc2.pdf, accessed February 2004.

Ebbert, J.C., S.S. Embrey, R.W. Black, A.J. Tesoriero, and A.L. Haggland. 2000, Water quality in the Puget Sound Basin, Washington and British Columbia, 1996-98: United States Geological Survey Circular 1216, 31 p.

Erickson, A., T. Klinger, S.C. Fradkin. 2003. A pilot study of the effects of human trampling on rocky intertidal areas in Olympic National Park, USA. *In* T.W. Droscher and D.A. Fraser (eds.). Proceedings of the 2003 Georgia Basin/Puget Sound Research Conference. Vancouver, British Columbia. March 31-April 3, 2003. 6 p. Available at URL: http://www.psat.wa.gov/Publications/03_proceedings/PAPERS/ORAL/10f_eric.pdf, accessed February 2004.

EVS Environment Consultants. 2003. Status, trends, and effects of toxic contaminants in the Puget Sound environment. Prepared for the Puget Sound Action Team, Olympia, Washington. EVS Consultants. EVS Project No. 02-1090-01, 249 p.

Gilkeson, L. 2003. Environmental trends in British Columbia, 2002 (abs.). *In* T.W. Droscher and D.A. Fraser (eds.). Proceedings of the 2003 Georgia Basin/Puget Sound Research Conference, Vancouver, British Columbia. March 31- April 3, 2003. 1 p. Available at URL: http://www.psat.wa.gov/Publications/03_proceedings/PAPERS/POSTER/p8_gilke.pdf, accessed February 2004.

Konrad, C.P. 2003. Streamflow metrics for linking landscape changes to the condition of stream ecosystems in the Puget Sound Basin (abs.). *In* T.W. Droscher and D.A. Fraser (eds.). Proceedings of the 2003 Georgia Basin/Puget Sound Research Conference, Vancouver, British Columbia. March 31-April 3, 2003. 1 p.

Leung, L.R., and W.T. Pennell. 2003. An end-to-end assessment of climate change impacts on water resources in the Western North America (abs.). *In* T.W. Droscher and D.A. Fraser (eds.). Proceedings of the 2003 Georgia Basin/Puget Sound Research Conference, Vancouver, British Columbia. March 31-April 3, 2003. 1 p.

McKechnie, L.M., and K.E. Pettigrew. 1998. Theories for the new millennium: The deployment of theory in LIS research. *In* E. Toms (ed.). Information Science at the Dawn of the Millennium. Proceedings of the 26th Annual Conference of the Canadian Association for Information Science. Ottawa, Ontario. June 3-5, 1998. p. 125-142).

McKechnie, L.M., and K.E. Pettigrew. 2002. Surveying the use of theory in library and information science research: A disciplinary perspective. Library Trends. 50(3):406-417.

McKechnie, L.M., K.E. Pettigrew, and S.L. Joyce. 2000. The origins and contextual use of theory in human information behavior research. *In* L. Hoglund (ed.). The New Review of Information Behaviour Research: Studies of Information Seeking in Context 2:47-63. Graham Taylor, London, United Kingdom.

McMurray, G.R., and R.J. Bailey (eds.). 1998. Change in Pacific Northwest Coastal Ecosystems. Pacific Northwest Coastal Ecosystems Regional Study (PNCERS). Washington, D.C. U.S. Department of Commerce (NOAA Coastal Ocean Program Decision Analysis Series No. 11).

Leckie, G.I., K.E. Pettigrew, and C. Sylvain. 1996. Modeling the Information Behavior of Professionals: Library Quarterly, v. 66, no. 2, pp 161-193.

Mote, P. 2001. There goes the rug. *In* Puget Sound Research 2001: Plenary session and Panel Discussion. Challenges Facing Puget Sound and the Georgia Basin Scientists. p. 2-9. Available at URL: http://www.psat.wa.gov/Publications/01_proceedings/keynote/plenary.pdf, accessed June 2005.

Nysewander, D.R., J.R. Evenson, B.L. Murphie, and T.A. Cyra. 2003. Trends observed for selected marine bird species during 1993-2002 winter aerial surveys, conducted by the PSAMP Bird Component (WDFW) in the Inner Marine Waters of Washington State. *In* T.W. Droscher and D.A. Fraser (eds.). Proceedings of the 2003 Georgia Basin/Puget Sound Research Conference, Vancouver, British Columbia. March 31-April 3, 2003. 11 p. Available at URL: http://www.psat.wa.gov/Publications/03_proceedings/PAPERS/POSTER/p1_nysew.pdf, accessed February 2004.

O'Neill, S.M., and J. West. 2003. PCB accumulation in marine and anadromous fishes of the Puget Sound and Strait of Georgia (abs.). *In* T.W. Droscher and D.A. Fraser (eds.). Proceedings of the 2003 Georgia Basin/Puget Sound Research Conference. Vancouver, British Columbia. March 31-April 3, 2003. 1 p. Available at URL: http://www.psat.wa.gov/Publications/03_proceedings/PAPERS/ORAL/4e_oneil.pdf, accessed February 2004.

Pettigrew, K.E., and L.M. McKechnie. 2001. The use of theory in information science research. Journal of the American Society for Information Science and Technology. 52(1):62-73.

Puget Sound Task Force. 1970. Comprehensive study of water and related land resources, Puget Sound and adjacent waters, State of Washington, appendix III, hydrology and natural environment: Pacific Northwest River Basins Commission. Vancouver, Washington. 205 p.

RE Sources. 2002. State of the North Sound and Straits. Bellingham, Washington. A Report from RE Sources and the North Sound Baykeeper. Bellingham, Washington. 38 p. Available at URL: http://www.re-sources.org/pdf/state_of_the_sound.pdf, accessed July 19, 2004.

Reed, L., K. Lynch, K. Paulsen, B. McMillan, M. Myers, G. Ylitalo, J. Labenia, T. Collier, and N. Scholz. 2003. High rates of pre-spawn mortality in Coho Salmon (*Oncorhynchus kisutch*) from urban streams in the Puget Sound Basin (abs.) *In* T.W. Droscher and D.A. Fraser (eds.). Proceedings of the 2003 Georgia Basin/Puget Sound Research Conference. Vancouver, British Columbia. March 31-April 3, 2003. 1 p. Available at URL: http://www.psat.wa.gov/Publications/03_proceedings/PAPERS/POSTER/p8_reed.pdf, accessed February 2004.

Reynolds, C.J. 2003. Hydrologic and climatic impacts of a changed climate on Georgia Basin, British Columbia (abs.). *In* T.W. Droscher and D.A. Fraser (eds.). Proceedings of the 2003 Georgia Basin/Puget Sound Research Conference. Vancouver, British Columbia. March 31-April 3, 2003. Available at URL: http://cgrg.geog.uvic.ca/abstracts/ReynoldsHydrologicThe.html, accessed February 2004.

Schaeken, W., G. De Vooght, A. Vandierendonck, and G. d'Ydewalle (eds.). 2000. Deductive reasoning and strategies. (p. 191-207). xiv, 321 p.

Sobol, M.G., and G. Klein. 1989. New graphics as computerized displays for human information processing, IEEE Transactions on Systems, Man and Cybernetics 19:893-898.

Snohomish County. Bibliography of marine resources issues, updated March 2004. Available at URL: http://www.co.snohomish.wa.us/publicwk/swm/Marine/mrcbib.htm, accessed July 19, 2004.

Sobocinski, K. L. 2003. The impact of shoreline armoring on upper beach fauna of central Puget Sound. M.S. Thesis. School of Aquatic and Fishery Sciences. University of Washington. Seattle.

Sobocinski, K.L., J.R. Cordell, C.A. Simenstad, and J. Brennan. 2003. The impact of shoreline armoring on upper beach fauna of Central Puget Sound (abs.). *In* T.W. Droscher and D.A. Fraser (eds.). Proceedings of the 2003 Georgia Basin/Puget Sound Research Conference. Vancouver, British Columbia. March 31-April 3, 2003. Available at URL: http://www.psat.wa.gov/Publications/03_proceedings/PAPERS/ORAL/10d_sobo.pdf, accessed June 2005.

Trainer, V.L., Bich-Thuy L. Eberhart, J.C. Wekell, N.G. Adam, L. Hanson, F. Cox, and J. Dowell. 2003. Increased magnitude, frequency and geographical spread of harmful algal blooms in Puget Sound (abs.). *In* T.W. Droscher and D.A. Fraser (eds.). Proceedings of the 2003 Georgia Basin/Puget Sound Research Conference. Vancouver, British Columbia. March 31-April 3, 2003. 1 p. Available at URL: http://www.psat.wa.gov/Publications/03_proceedings/PAPERS/ORAL/4f_train.pdf, accessed June 2005.

Vandierendonck, A., G. De Vooght, C. Desimpelaere, and V. Dierckx. (2000). Model construction and elaboration in spatial linear syllogisms. *In* W. Schaeken, G. De Vooght, A. Vandierendonck & G. d'Ydewalle (eds.). Deductive reasoning and strategies (p. 191-207). New York: Lawrence Erlbaum Associates.

West, J.E. 2002. Protection and restoration of marine life in Puget Sound and the Georgia Basin revisited: 1996-2002. Keynote Address, 1st Biennial Marine Ecosystem Health Program Science Symposium. September 6, 2002, Rosario Resort, Orcas Island, Washington. Program and Abstracts. Available at URL: http://mehp.vetmed.ucdavis.edu/pdfs/scisympproc02.pdf, accessed June 2005.

Windschitl, M., and B. Winn. 2000. Learning from virtual worlds. *In* B. Fishman and S. O'Connor-Divelbliss (eds.), Proceedings of the Fourth International Conference of the Learning Sciences. Erlbaum. Mahwah, New Jersey.

Appendix 1. Goals of the Puget Sound Nearshore Ecosystem Restoration Program

PNSERP partners have identified the following goals:

1. Rehabilitate ecosystem natural processes that create and maintain habitats in Puget Sound and watershed to fully support, with minimal ongoing human intervention, natural aquatic and associated terrestrial biotic communities and habitats in ways that favor native members of those communities.
2. Protect and/or restore functional habitat types in Puget Sound nearshore and watershed for ecological and public values such as supporting species and biotic communities, ecological processes, recreation, scientific research, aesthetics, and other beneficial human uses. (Define from CWA, DNR, SMA)
3. Prevent future listings and achieve recovery of at-risk native species dependent on Puget Sound as the first step toward establishing large, self-sustaining populations of these species; support similar recovery of at-risk native species in the Puget Sound and the watershed above the estuary; and minimize the need for future endangered species listings and reversing downward population trends of native species that are not listed.
4. Prevent the establishment of additional non-native species and reduce the negative ecological and economic impacts of established non-native species in Puget Sound nearshore and watershed.
5. Improve and/or maintain water- and sediment-quality conditions that fully support healthy and diverse aquatic nearshore ecosystems in Puget Sound and watershed; and eliminate, to the extent possible, toxic impacts to nearshore aquatic organisms, wildlife, and people.
6. Increase the understanding of the natural processes and functions of the Puget Sound nearshore.

Appendix 2. Executive Summary of "Application of 'Best Available Science' in Ecosystem Restoration: Lessons Learned from Large-Scale Restoration Efforts in the U.S."

By F. Brie Van Cleve, Charles Simenstad, Fred Goetz, and Tom Mumford

Product of the Puget Sound Nearshore Ecosystem Restoration Project.

Nearshore Science Team. Lessons Learned Working Group. (Version December 19, 2003).

Available at URL: http://www.cev.washington.edu/lc/PSNERP/lessons_learned.pdf, accessed June 2005.

The Puget Sound Nearshore Ecosystem Restoration Project (PSNERP) proposes to restore degraded shoreline ecosystems of Puget Sound. In the process of providing scientific direction for PSNERP, the Nearshore Science Team (NST) sought to more clearly define the role and position of scientific input into large restoration programs such as PSNERP. As part of the planning phase of this program, the NST conducted a "lessons learned" exercise to characterize the role of science in five other large-scale programs around the country. These programs including the Chesapeake Bay Program, the Comprehensive Everglades Restoration Plan, the California Bay-Delta Authority, the Glen Canyon Adaptive Management Program, and the Louisiana Coastal Areas Ecosystem Restoration Program. The NST's goal was to better understand how science is incorporated into program management and organizational structure, such that the "best available science" is realized. This document summarizes lessons learned by the NST about maximizing the best available science in conceptualizing, designing and implementing large-scale restoration.

The NST found that maintaining the independence of science from policy pressures in order to assure legitimacy and quality facilitated the incorporation of best available science into restoration actions. The NST found that the strongest assurance for scientific credibility was rigorous peer review, both internal and external to the organizational structural. "Vertical integration" was an effective tool to coordinate science with other sectors of the program. Several programs had successful strategies for educating stakeholders about science issues with publications and web sites. Although they all acknowledged the need for rigorous adaptive management, one program in particular demonstrated that adaptive management is a powerful tool that can only be effectively used if all involved understand it; this suggests that education and information dissemination are important and often neglected aspects of adaptive management. The NST found that these programs often struggled with fundamental cultural differences between science and policy and, at times, had difficulty estimating scientific resource requirements for true ecosystem management and restoration. In spite of difficulties encountered by these programs, the NST was encouraged by the numerous innovative approaches being employed to meet the challenges inherent in large-scale restoration. These observations hopefully will guide the utilization of science in PSNERP's Feasibility Study Phase and throughout the General Investigation Study. The NST intends this document to stimulate interest in improving the role of science in ecosystem restoration and provide present and future restoration practitioners with practical advice gained from predecessor programs.

Appendix 3. Research Questions for Early-Action Projects and Demonstration Projects

November 3, 2005

The following represents a list of research questions developed by the Nearshore Science Team (NST) of PSNERP. They were developed with the following process:

1. Each member of the NST was asked to provide five questions that they felt could be addressed with an **EARLY-ACTION RESTORATION PROJECT** and five questions that could be addressed with **DEMONSTRATION RESTORATION PROJECTS (**definitions provided below). Two additional categories were added: data base analyses and research approaches.
2. No effort was made to constrain members by subject or scale.
3. Questions were compiled and organized by management measure. As a result, there were some questions that did not fit any management measure and were included in the first section. Questions were organized based upon management measure and topic, generally corresponding to processes.
4. Additional questions were added that were developed during "Science Morning" discussions by the NST.
5. The list was edited to reduce the number of redundancies and improve the organization.

The following are caveats associated with this list.

1. The list of research questions is not comprehensive. It is strictly limited to what the NST considered could be answered with restoration projects.
2. The NST has not prioritized the list.
3. The NST did not focus on conservation or protection as a management measure.
4. Some questions could not be easily categorized and were left blank. Additional categories such as "comparative analyses" may be warranted.
5. There was no external review.
6. Questions vary in scope and scale and do not necessarily lend themselves to discrete studies.

Early-Action Projects (EA): Projects that are in the works that could exploited for research needs. Examples of EA projects include Capitol Lake and Seahurst Park. An EA project is one that has been designed and implemented for restoration but does not have an objective to promote science. They may have asked what should be monitored or what are research opportunities. The NST has little opportunity to modify the project design so it is more opportunistic. Some projects will not address a particular question because of how they are being implemented and in general they are not set up with control or reference sites.

Demonstration Project (DEMO): A DEMO project is one in which scientists would design the restoration action to examine some explicit hypotheses. DEMO projects would involve the participation of scientists in the design of the project. Basically, these projects are designed as science-based projects. These projects would include reference and control sites for hypothesis testing.

Data Base (DB): This means either analysis of existing data sets or existing projects. It can include a retrospective analysis and comprehensive survey. This can include monitoring of existing projects and review or existing monitoring data. SRFB project review, U.S. FWS, NOAA, Corps projects.

Research (RES): This refers to questions that are primarily of a research nature that may need to be addressed outside the restrictions of a restoration project.

Management measure	General topic or issue addressed	Question	Approach
General—Independent of a Management Measure or Comprised of Multiple Measures			
	1. Oceanographic Processes		
		a. What is the relationship between nearshore and offshore oceanographic processes?	DEMO
	2. Relationships of Biotic Communities and Shore Types		
		a. Can we link shore types to biotic communities and extrapolate over large spatial scales?	DB
	3. Pocket Estuary Related		
		a. Does the physical and biological structure of small estuaries change predictably with variation in tidal prism, freshwater input, tidal range, and sediment fluxes?	DEMO, EA
		b. How rapidly, if at all, does this shore form respond to natural or anthropogenic changes in these factors?	DEMO
		c. Develop classification of pocket estuaries and impairments and develop stratified approach to carrying out and evaluating specific restoration actions.	DB
	4. Riparian Processes		
		a. What types and extent of vegetation (types, age structure, density, continuity) are needed to provide various riparian functions? How do we quantify the various marine riparian functions?	EA
		b. What scale of revegetation is needed to restore, enhance, or replace lost functions (especially where there are constraints [e.g., urban]), and do small-scale restoration and enhancement projects work?	EA
	5. Food Web Processes		
		a. Determine change in primary productivity and organic input into Totten Inlet. Hwy 101 removal at Kennedy Creek/Totten Inlet.	EA
		b. What is the status of primary production in the nearshore. Are nutrients, light or other factors limiting?	DEMO, RES
		c. How do nearshore-offshore gradients in food webs vary and is there a pattern with various shoreline types?	DEMO, RES
		d. What is the relative contribution of algal versus vascular plant versus phytoplankton production?	DEMO
	6. Climate Change		
		a. Are climate shifts changing the food web of Puget Sound on annual or decadal scales and if so, what adjustments should be made to a strategic restoration plan to accommodate such a change?	DEMO
		b. Do we see elements of climate change in Puget Sound? If so, what are they?	DEMO
		c. How does land use and other human activities affect nutrient loading into the nearshore? Are there effects of eutrophication in the nearshore?	EA
	7. Landscape Scale Effects of Protection/Restoration		
		a. Is there a logical restoration sequence such that we can insure that the various parts (actions) “fit” together to deliver an “appropriate” ecosystem response at multiple spatial and temporal scales of analysis? How do we undertake? PHASE restoration?	EA
		b. At what scales can we detect physical, chemical and biological signals from restoration actions conducted at various scales?	EA, DEMO
		c. What are the time scales for habitat restoration actions to become fully functional and does this vary with the type of restoration action?	EA
		d. Do systems that have been the targets of multiple restoration actions show evidence of interactive or cumulative effects? For example, at least 10 restoration projects have been completed in the Duwamish River estuary over the past decade (Simenstad and others, in press). Is there any evidence that these multiple actions are beginning to “add up” to a sum greater than that of the individuals. How would we detect such a response if it were occurring?	DB
		e. Do biota, especially those identified as VEC’s, integrate the effects of multiple restoration actions across regional or other higher order scales of spatial analysis? How does this occur?	DEMO
		f. To what extent do particular life histories of specific organisms rely on the spatial configuration of habitats? This exercise, if pursued, might best begin with construction of appropriately specific Conceptual Models for relationships between biota (including especially VEC’s).	EA
		g. Can we model what climate change effects (e.g., SST, runoff, changes in wind) would be most important to nearshore communities, processes, and structures?	DEMO

Management measure	General topic or issue addressed	Question	Approach
General—Independent of a Management Measure or Comprised of Multiple Measures—Continued			
	8. Social Values and Nearshore Ecosystems		
		a. What are the relative social preferences between private and public ownership of waterfront property in Puget Sound?	EA
		b. Which ecosystem services do people value most from Puget Sound?	EA
		c. What do people perceive as the biggest threat to Puget Sound?	EA
		d. How much are people willing to pay to restore the health of Puget Sound?	EA
		e. What are the relative social preferences between protection of existing functional nearshore areas through acquisition or regulation and how do those compare with restoration?	EA
		f. Is restoration as effective as regulatory reform (strengthening regulations and enforcement to prevent further harm)?	EA
		g. What do people really need to know about the problems and solutions and are we actually providing enough information (types and quantity) to gain acceptance and affect human behavior?	EA
		h. How big a geographic area should be covered in public process notification, review, and comment of restoration proposals?	
		i. How should effects of restoration outcomes be communicated, e.g. What metrics should be used?	
		j. What will affect public acceptance or rejection of restoration projects such as dike removal?	
	9. (VECs)		
		a. Define stage-to-stage survival and growth rate estimates from freshwater to ocean entry for juvenile chinook salmon?	EA
		b. How does variability in site-scale habitat features (e.g., water depth and vegetation characteristics) and landscape-scale habitat features affect juvenile salmon and other VEC performance?	EA
		c. What are the processes that affect how juvenile salmon disperse throughout deltaic and shoreline habitats of Puget Sound?	EA
		d. There is no difference in mean residence time of juvenile salmon in higher order tidal channel systems than in lower order channel systems.	DEMO
		e. What are the most important habitats and species and why are they "the most important"? Do we know enough about the biology of specified species to "prioritize" them?	EA
		f. There is no difference in forage fish spawning on created versus restoring beaches?	DEMO
		g. Is there an interaction between hatchery and wild salmon and does it affect outcomes of restoration?	
	10. Information		
		a. Regardless of the process being examined, "in what ways can we represent the data that will be collected other scientists interested in linkages to other ecosystem processes?	
1. Restoration of Watersheds (FW)			
	1. Sediment Processes		
		a. What are the sources and ultimate fates of waterborne sediments that reach Puget Sound and how do these vary temporally?	DEMO
		b. What are the sources of sediment available during marsh evolution in any delta?	DEMO
		c. What is the fate and transport of sediment pulses from the modifying operation of existing dams, and removal of dams and determine how far away sediments have measurable influence. (Howard Hanson Dam modification; Capital Lake/Elwha River Dam Removals?)	EA
		d. Deltas. How is the pattern/distribution of landscape elements on estuarine deltas controlled by long-term changes in the distribution of fluvial sediment across the landscape? (the Louisiana Problem) Selectively remove lower stem dikes in locations specifically chosen to test hypotheses about sediment distribution or landscape characteristics.	DEMO
	2 Hydrology		
		a. How has the reconfiguration (Duwamish) and re-alignment (Snohomish, Stillaguamish, Skagit, and Nooksack) of major river channels affected nearshore processes—sediment and organic transport and deposition, inshore and offshore?	DB

Management measure	General topic or issue addressed	Question	Approach
1. Restoration of Watersheds (FW)—Continued			
	3. Nearshore Habitat Conditions—Continued		
		a. How do changes in land-use practices (either new development, or better control of runoff i.e. un-development) affect nearshore quality, local plankton communities, SAV, and via what mechanisms do changes happen?	EA
		b. What are the affects of dike removal on deltaic sediment process (channel morphology, sediment delivery)? Determine affects of dike removal on eelgrass populations associated with delta and nearby nearshore areas. Example is the Skokomish River dike removal.	
2. Beach Nourishment			
	1. Sediment Processes		
		a. What site and environmental parameters control the sediment dynamics of a nourished beach? Different types of beaches would be examined. This could include monitoring beach nourishment experiments (e.g., Lincoln Park Beach and Seahurst), perhaps as a suite of sediment placements in the same general area, with accompanying environmental monitoring (waves and water levels).	DEMO, EA
		b. How do different sediment sizes respond to wave events?	
		c. What are controls on longshore transport rates? How does this vary in Puget Sound?	
		d. How does beach orientation affect longshore and cross shore sediment transport?	
	2. Hydrology		
		a. What beach characteristics influence the extent of wave runup?	
	3. Performance of Nourishment Projects		
		a. What is the impact of different sediments sizes on longevity of the project, renourishment schedule.	
		b. Does sediment placed on the beach face move offshore?	
		c. Will a gravel beach project “acquire” sand if it is available?	
		d. What is the effect of the project on adjacent beaches?	
	4. Impacts on Biota		
		a. What is the impact of burying a beach on the benthic community?	
		b. What conditions promote re-establishment of vegetation on the berm?	
		c. Will forage fish spawn on nourished beaches?	
3. Bulkhead Removal			
	1. Nearshore Habitat Conditions (e.g., Vegetation, Beach Profile)		
		a. How does removal of a bulkhead affect beach profile and sediment structure?.	DEMO
		b. How do changes in shoreline armoring affect eelgrass and other SAV?	DB, EA
	2. Sediment Processes		
		a. What are the effects of bulkhead removal on beach sediment structure and processes both ‘upstream’ and ‘downstream’?	DEMO
		b. Does removal of bulkhead along a coastal bluff result in a change in the sediment supply for the beach? How much and when? What do we measure?	DEMO, RES
		c. What are the rates of sediment source reduction due to shoreline armoring?	RES
		d. How does presence of a bulkhead affect cross shore transport of sediment? What is the area of influence? Where are effects in relation to upper and lower beach?	DEMO, EA
		e. How does the depth of disturbance, due to wave events, vary between similar tidal elevations in front of and away from bulkheads?	EA
	3. Hydrology		
		a. How do bulkheads and their removal impact beach hydrology?	EA
		b. How is wave action affected by the presence of a bulkhead?	EA
	4. Approaches to Bulkhead Removal		
		a. At what scale does removal become meaningful/beneficial? How effective are alternative techniques and do they restore processes, structure, or functions?	DB, DEMO

Management measure	General topic or issue addressed	Question	Approach
3. Bulkhead Removal—Continued			
	4. Approaches to Bulkhead Removal—Continued		
		b. Synthesize existing information on armoring trends and amount of passive erosion occurring in Puget Sound.	DB
		c. What other areas in the world with bulkheads can serve as models for Puget Sound?	
		d. Can we separate effects of bulkhead removal from beach nourishment which often occur simultaneously? Is nourishment necessary after removal?	EA, RES
	5. Riparian Zone Processes		
		a. Determine effects of bulkhead removal (bulkheading) on riparian-zone functions both 'upstream' and 'downstream'.	DEMO
	6. VEC's/Habitat		
		a. Are there habitat attributes created by a bulkhead removal that are useful to forage fish?	
		b. What are the linkages between shoreline armoring and key biota?	
		c. What kind of shifts occur in plant and animal communities after a bulkhead is removed?	
4. Methods of Protecting Nearshore Ecosystems			
	1. Effects of BMP's and other Management Measures		
		a. How effective are buffers, setbacks, and other management measures (and what are the best recommendations for establishing such management actions)?	EA, DB
5. Restoring Tidal Hydrology to Stream and River Deltas			
A. Partial Restoration of Tidal Hydrology Tide Gates			
	1. Effects on Water Quality		
		a. Does muted tidal action (e.g., water control structures, such as SRTG) result in unnatural water quality in emergent marsh tidal channels	DEMO
B. Full Restoration- Dike Breaching or Removal			
	1. Effects on Physical Habitat Characteristics (e.g., Channel Morphology)		
		a. Will dendritic tidal channel systems evolve more naturally complex plan-form structure (in erosive sediments) without intervention than with constructed tidal channels?	DEMO
		b. Will a new estuarine delta form within 50 years if the Puyallup River is diverted?	DEMO
		c. What is the difference between dike breaching and dike removal in geomorphic structure of a restoring wetland?	DEMO
		d. Determine effects of dike removal and dike breaching on the development of channel morphology.	EA
		e. What are the differences in channel development between single breach, multiple breaches and full dike removal?	
		f. What are the effects of dike breaching or physical habitat characteristics outside the restoring marsh?	DEMO
		g. What sort of channel development will occur in the Nisqually NWR when dikes are removed (or breached)?	DEMO
		h. Should historic or remnant channels be reconnected or incorporated in marsh restoration?	
		i. Will predisking or plowing prior to dike removal affect location and speed of channel development?	DEMO
	2. Effects on Biological Habitat Conditions		
		a. Is there a difference in natural vegetation recruitment and persistence between naturally-accreting recovering emergent marshes and sediment-supplemented recovering marshes?	EA
		b. What is the difference between dike breaching and dike removal in vegetation recruitment, and fish utilization of a recovering wetland?	EA
		c. What is the effect of wood on fish utilization and fish habitat attributes (e.g., prey resources, vegetation, etc.) of recovering emergent marshes?	DEMO
		d. Does the reduced channel complexity associated with diked systems cause sedimentation of eelgrass beds?	EA
		e. How do we monitor changes in bird use and what do we compare it to?	

Management measure	General topic or issue addressed	Question	Approach
5. Restoring Tidal Hydrology to Stream and River Deltas—Continued			
	B. Full Restoration-Dike Breaching or Removal—Continued		
	3. Sediment Processes		
		a. How is the pattern/distribution of landscape elements on estuarine deltas controlled by long-term changes in the distribution of fluvial sediment across the landscape? Compare the morphology and distribution of existing and historic environments between deltas with diked and undiked portions.	
	4. Food Web Processes		
		a. There is no difference in source of organic matter supporting food webs of restoring emergent marsh wetlands than in natural emergent marsh wetlands.	DEMO
	5. Effects on Sediment Quality		
		a. What is the difference in surface sediment contamination in restoration sites in urbanized estuaries compared to non-urbanized sites?	EA

PSNERP and the Nearshore Partnership

The **Puget Sound Nearshore Ecosystem Restoration Project** (PSNERP) was formally initiated as a General Investigation (GI) Feasibility Study in September 2001 through a cost-share agreement between the U.S. Army Corps of Engineers and the State of Washington, represented by the Washington Department of Fish and Wildlife. This agreement describes our joint interests and responsibilities to complete a feasibility study to

> "*...evaluate significant ecosystem degradation in the Puget Sound Basin; to formulate, evaluate, and screen potential solutions to these problems; and to recommend a series of actions and projects that have a federal interest and are supported by a local entity willing to provide the necessary items of local cooperation.*"

The current Work Plan describing our approach to completing this study can be found at:

http://pugetsoundnearshore.org/documents/StrategicWorkPlanfinal.pdf

Since that time, PSNERP has attracted considerable attention and support from a diverse group of individuals and organizations interested and involved in improving the health of Puget Sound nearshore ecosystems and the biological, cultural, and economic resources they support. **The Puget Sound Nearshore Partnership** is the name we have chosen to describe this growing and diverse group, and the work we will collectively undertake that ultimately supports the goals of PSNERP, but is beyond the scope of the GI Study. Collaborating with the Puget Sound Action Team, the Nearshore Partnership seeks to implement portions of their Work Plan pertaining to nearshore habitat restoration issues. We understand that the mission of PSNERP remains at the core of our partnership. However, restoration projects, information transfer, scientific studies, and other activities can and should occur to advance our understanding, and ultimately, the health of the Puget Sound nearshore beyond the original focus and scope of the ongoing GI Study. As of the date of publication for this Technical Report, our partnership includes participation by the following entities:

Interagency Committee for Outdoor Recreation

King Conservation District

King County

National Wildlife Federation

NOAA Fisheries

Northwest Indian Fisheries Commission

People for Puget Sound

Pierce County

Puget Sound Action Team

Salmon Recovery Funding Board

Taylor Shellfish Company

The Nature Conservancy

U.S. Army Corps of Engineers

U.S. Environmental Protection Agency

U.S. Geological Survey

U.S. Fish and Wildlife Service

University of Washington

Washington Department of Ecology

Washington Department of Fish and Wildlife

Washington Department of Natural Resources

Washington Public Ports Association

Washington Sea Grant

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