Reconnaissance Assessment of the

STATE OF THE NEARSHORE ECOSYSTEM:

Eastern Shore of Central Puget Sound, including Vashon and Maury Islands (WRIAS 8 AND 9)

Executive Summary

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EXECUTIVE SUMMARY

INTRODUCTION

Puget Sound is the second-largest estuary in the United States, supporting over 200 species of fishes, approximately 10 species of marine mammals, and hundreds of species of aquatic invertebrates and plants. This estuary is critical to the survival of shorebirds, waterfowl, and even some upland wildlife species. Aquatic and terrestrial organisms are drawn to estuaries because of their high primary and secondary productivity, rich nutrients and food resources, and refuge provided by their relatively low-energy, shallow waters.

Central Puget Sound has become the most heavily urbanized area in the region, and the impacts of human activities have taken a toll on living natural resources and the habitats that support them. Habitat degradation, alterations, and losses have resulted from a number of activities, including:

- Dredging or filling of shallows.
- Waste and wastewater disposal.
- Nonpoint source pollution.
- Shoreline armoring and development, and associated removal of riparian vegetation.
- Changes in hydrology of tributary watersheds resulting from water diversions and construction of buildings and infrastructure.

State of the Nearshore Report

The State of the Nearshore Report (SONR) is the first attempt to provide a comprehensive summary and an assessment of the state of our current knowledge of ecological processes and conditions, natural resources, and ecosystem health in nearshore portions of Water Resource Inventory Areas (WRIAs) 8 and 9. The SONR is a preliminary assessment that compiles readily available literature, data, and information identified by a convened panel of scientists and resource managers from local and state agencies, and the University of Washington. An exhaustive literature search has not been undertaken.

The intent of the SONR is to have, in one place, a summary of the nearshore ecosystem characteristics in WRIAs 8 and 9 that will serve as a foundation for future work and decision making. The report has several specific purposes/objectives:

- Provide a basis for nearshore watershed planning.
- Provide direction for future technical work through identification of data gaps.
- Serve as a resource to researchers, planners, and managers dealing with nearshore issues in WRIAs 8 and 9.

It should be noted that this Executive Summary only highlights some of the most important findings of the report. In addition, conclusions, key findings, and data gaps are appended in their entirety to this summary. The reader is urged to read specific portions of the report and referenced materials for a more complete understanding of specific subjects. At a minimum, the reader should read the introductory sections of the main report to understand the background, approach, and purpose, in addition to how the report should, or should not be interpreted and used.

SONR and Salmon Recovery

Many stocks of wild salmonid populations in Puget Sound have declined since the middle of the twentieth century. In 1999, the Puget Sound chinook salmon and bull trout were listed as "threatened" species under the Endangered Species Act (ESA). Other populations and species, including the Puget Sound coho salmon, are under consideration for listing. These listings have prompted a series of watershed inventories and analyses to provide science-based policy direction for regional conservation and recovery planning efforts.

The SONR will provide a valuable tool for WRIAs 8 and 9 watershed planning and salmon recovery efforts. The nearshore is defined as the area between the lower photic zone (approximately –30 m mean lower low water [MLLW]) and the upland-aquatic interface (riparian zone). Anadromous salmonids have a fundamental dependence on this nearshore zone, using the high estuarine productivity for rapid growth, refuge from predation, physiological transition to life in marine salinities, and as a migratory corridor to the marine environment. Subadult and adult salmon feed extensively on forage species such as herring and surf smelt, which spawn in intertidal and nearshore areas.

The nearshore is also a focal point of natural environmental processes such as nutrient cycling and freshwater input, as well as human activities such as pollutant discharges, land-use modifications, and hydrological modifications. Human activities affect habitat types, complexity and quality, and subsequent use by salmonids. The SONR is the first report of its kind to summarize and assess what we know about salmon and other central Puget Sound nearshore species and the habitats that support them. Of equal importance is the assessment of what remains to be learned about ecosystem processes that play important roles in supporting salmon, and how salmon respond to natural and anthropogenic disturbances.

Features of the Puget Sound Region

Puget Sound is the southernmost of a series of glacially scoured channels, relatively protected by a single entrance located 135 km from the Pacific Ocean. This characteristic, coupled with substantial freshwater inputs from several major river basins, shapes the oceanographic and physical processes within the sound, which include the following:

- Waters of Puget Sound function as a partially mixed two-layer system, with relatively fresh water flowing seaward at the surface and saline oceanic water returning landward at depth, making for lower salinities compared to the rest of the coastal shelf.
- As a result of tidal energy and mixing, about half of water flow is recycled and returned to Puget Sound.
- Because of the surrounding topography, wave conditions are generally mild, with only occasional severe storms.

- Sediments in Puget Sound are accumulating, with the primary sources being river discharge, submarine erosion, and shoreline bluff erosion.
- Littoral drift cells, which supply the nearshore with the sediments they require, have a general, net direction of flow from the south to north. Significant exceptions occur in Elliott Bay, where drift is to the south along Magnolia Bluff and largely absent within the bay itself.

Nutrient Dynamics and Primary Productivity

Natural inputs of nutrients to the Central Puget Sound basin are several orders of magnitude greater than human inputs. The effects of human inputs are poorly studied, particularly in shallow nearshore waters. Some inlets and bays are poorly flushed and show signs of eutrophication. Quartermaster Harbor on Vashon Island is potentially nutrient sensitive.

Estimates of primary productivity are critical in understanding the links between phytoplankton, zooplankton, and higher trophic levels in the food chain. Primary productivity rates in Puget Sound are very high relative to other temperate estuaries, but no systematic, standardized sampling has been conducted over the years to allow an evaluation of long-term changes.

Food Web

Puget Sounds food web, which culminates in fish, birds, mammals, and humans, is based on detritus and phytoplankton production. The Sound experiences a highly productive balance of phytoplankton growth forming patchy distributions with intense blooms usually occurring in the spring and fall. Diatoms, dinoflagellates, and microflaggellates are the major types of phytoplankton in Puget Sound.

Harmful algal blooms or "red tides" are a concern in Puget Sound as the distribution and intensity of paralytic shellfish poisoning (PSP) has increased since the mid-1970s. The two primary species of concern are the dinoflagellate *Alexandrium catenella* and the diatom *Pseudo-nitschia* spp. Almost all of WRIAs 8 and 9 remain continuously closed to recreational shellfish harvest because of high fecal coliform levels and occasional PSP toxins.

Few long-term data are available to determine changes in historical levels of detritus and phytoplankton. Elevated nutrient loading from human sources may alter the normal composition of detritus and phytoplankton, but such events have not been conclusively linked to anthropogenic nutrient inputs or other activities in Puget Sound. However, studies elsewhere support this concern.

Zooplankton fill an important ecological niche as the link between primary production and fish productivity. Fish that are 50 to 200 mm in length derive a major part of their nutrition from zooplankton. Juvenile salmonids prey heavily on gammarid amphipods, harpacticoid copepods, and calanoid copepods.

The importance of zooplankton and the potential effects of uncoupling links in the food web can be observed in salmon studies conducted in the Strait of Georgia. These studies have shown a 90 percent decline in Strait of Georgia coho salmon likely due to a lack of food during their estuarine residence. It is speculated that early arriving spring runoff, possibly due to global warming or El Niño has disrupted phytoplankton blooms in the strait, which in turn, affect zooplankton blooms that the salmon feed upon.

Stressors such as development, climate change, reduced water quality, and natural cycles may be affecting zooplankton in Puget Sound, but historical and contemporary data to evaluate trends over time are lacking. Large-scale weather cycles, such as El Niño have had effects on zooplankton productivity in other waters.

Critical organisms in composite foodwebs have been constructed for Puget Sound. These include calanoid copepods and gammarid amphipods, which convert organic matter making it available in the food web. These zooplankton are also important prey for secondary consumers. Principal secondary consumers are schooling fishes such as Pacific herring, sand lance, and surf smelt, which are prey to a wide variety of larger fish species and marine birds. Other secondary consumers include greenlings, gunnels, and flatfish, which are preyed upon by larger mammals such as seals, sea lions, and orcas.

Selected Nearshore Habitats

Numerous habitat types occur within the nearshore environment, providing a host of critical functions for invertebrates, juvenile and adult fish, and foraging opportunities for birds. Available information and data on the current and historical distribution of these habitats, functions, and stressors in WRIAs 8 and 9 are summarized and assessed for the following nearshore habitats:

- Eelgrass meadows
- Kelp forests
- Flats
- Tidal marshes
- Subestuaries
- Sand spits
- Beaches and backshore
- Bluffs
- Marine riparian zones

Eelgrass Meadows – Eelgrass performs several important functions and roles in the nearshore, including:

- Primary production.
- Nutrient processing.

- Wave and current energy buffering.
- Organic matter input.
- Habitat for fish and invertebrates.
- Herring spawning substrate.
- Substrate for secondary production.
- Food for birds.

Eelgrass forms small patches to large meadows in the low intertidal and shallow subtidal zone of Puget Sound, covering about 57 percent of the shoreline of WRIA 8 and 62 percent of WRIA 9.

Eelgrass productivity can equal or exceed the productivity rates of most other aquatic plants, producing organic carbon that enters the food web. Data show that once eelgrass becomes established in an area, increases in fish and shellfish use occurs. Juvenile chum and chinook salmon use eelgrass as feeding areas. Herring spawn on eelgrass. Many other fish and invertebrate species use eelgrass meadows for refuge and feeding. Birds such as black brant geese graze directly on eelgrass, and numerous other bird species form seasonal associations with the meadows.

Several natural and human-influenced stressors to eelgrass exist, including increased turbidity, foraging, disease, clam harvesting, propeller scour, eutrophication, shoreline armoring, shading, and physical disturbances from dredging. Shoreline armoring, overwater structure shading, and eutrophication have had documented impacts to eelgrass in WRIAs 8 and 9. However, few systematic studies have been conducted to quantify losses in the study area or Puget Sound.

Historical records and data are very limited, and strong defensible conclusions regarding a net loss or gain to WRIAs 8 and 9 cannot be made.

Kelp Forests – Kelps are the largest members of brown algae in the Pacific Northwest and may form large forests that can substantially affect nearshore physical habitats and ecology. Functions typically associated with kelp include the following:

- Primary production
- Habitat for fish, especially rockfish, but also salmon
- Contribution to pelagic food webs through particulate and dissolved carbon
- Herring spawning substrate
- Wave and current energy buffering
- Substrate for secondary production
- Extraction of chemicals for commercial use

Kelps occur in small patches to large forests throughout the study area, covering 12 percent of the shoreline in WRIA 8 and 7 percent of WRIA 9, including 6.4 percent within Elliott Bay.

Most kelps are annuals that can grow very rapidly, achieving growth rates of up to 2.4 cm per day during the spring and summer, providing three-dimensional habitats in the water column of the nearshore. Many species of larval fish use kelp as settlement habitat, and adult fish feed and hide in kelp fronds. Many invertebrates such as crabs, snails, bryozoans, sponges, tunicates, anemones, and shrimp use the blades as living habitat.

Kelps need hard or rocky substrates for attachment; variations of the amount of these substrates can result in gains and losses of kelp have occurred. Limited historical analyses in Puget Sound comparing periods early in the century with more recent periods suggest increases in kelp have occurred. This may be due to erosion and subsequent beach hardening related to sea walls and other forms of shoreline armoring. Losses in kelp have also occurred, possibly from harvesting, nutrient loading from sewage, or shading from overwater structures.

Flats – Flats generally include gently sloping muddy or sandy substrates, or a mixture of pebbles and cobble within intertidal or shallow subtidal areas. Studies indicate that flats perform a variety of ecological functions, including:

- Primary production including eelgrass
- Nutrient cycling
- Habitat/support for juvenile and adult fish
- Shellfish production
- Prey production for juvenile salmon, flatfish, and shorebirds
- Detritus sink
- Predator protection for sand lance
- Wave dissipation for saltmarsh

Flats are generally located in low intertidal areas and at the mouths of streams and rivers, where sediment transported downstream is deposited. Six percent of the shoreline in WRIA 8 and 29.7 percent of the shoreline in WRIA 9 is composed of flats as defined by the ShoreZone database, which does not include lower tidal flats. Much of the flats in WRIA 9 are present in the Duwamish estuary where exposed and submerged mud- and sandflats exist below the armored upper shoreline, and in Elliott Bay beneath overwater structures.

Much of the production on flats is due to the accumulation of organic matter and dense flora of algae, primarily diatoms, that are mixed with the fine sediments. Invertebrate assemblages associated with algal communities and flats include insect larvae, amphipods, polychaetes, clams, shore crabs, tanaids, and mysids. Juvenile salmon and their invertebrate prey species are seasonally abundant on flats. Other fish that feed on flat communities include several species of flatfish, bay goby, and Pacific staghorn sculpin. Shellfish densities can be very high on flats containing gravel. Shorebirds commonly forage on flats, consuming shellfish, and other invertebrates.

Over the past century, 97 percent of the shallows and flats in the Duwamish estuary and Elliott Bay have been lost due to dredge and fill operations for urban and industrial development. Although the entire delta was filled in, much of the subsequent shoreline armoring is present in the upper intertidal zone, and gently sloping mud and sandflats exist in the lower intertidal and subtidal zones. Shoreline armoring, dredging, and filling has probably caused loss of flats in other parts of the study area, as well.

Other stressors to flats include dredging, filling, overharvest of shellfish, overabundance of organic matter, fecal and chemical contamination, shading from overwater structures, and competition from non-native species.

Tidal Marshes – Tidal marshes are very important transition zones between terrestrial and marine habitats. Marsh functions include the following:

- Primary production
- Juvenile salmon and invertebrate production support
- Adult fish and invertebrate foraging
- Salmonid osmoregulation and overwintering habitat
- Water quality improvement
- Bird foraging, nesting, and reproduction
- Wildlife habitat
- Detrital food chain production
- Wave buffering

Juvenile salmon particularly benefit from tidal marsh habitats, residing and foraging in these areas for extended periods and exhibiting rapid growth.

Historical filling, diking, armoring, and other human intrusions have eliminated all but a few small tidal marshes in the study area. Dramatic reductions occurred in the Duwamish estuary, where over 1,170 acres of tidal mash was eliminated early in the century. The largest remaining tidal marsh system in WRIAs 8 and 9 is Kellogg Island, within the Duwamish estuary. Several small marsh restoration sites are also present within the estuary.

Subestuaries (River Mouths and Deltas) — In their natural condition, the river mouth and delta are areas where the river spreads out and mixes with marine waters. River deltas develop as a result of downstream sediment transport, with the rate of delta growth related to the amount of annual freshwater and sediment discharge. Subestuaries have the following functions:

- Floodwater attenuation
- Critical transition areas for anadromous salmonids

- Water quality improvement
- Rearing for juvenile salmonids
- Eelgrass support
- Refuge for multiple species

As with tidal marshes, a wide variety of fish, birds, and other animals use subestuarine marshes for refuge, food, and reproduction.

The Lake Washington Ship Canal (WRIA 8) and the Duwamish River (WRIA 9) are the only large subestuaries in the study area. At present, no river deltas are associated with either area as a result of urban development.

In addition to the two large subestuaries, six small streams in WRIA 8 and fourteen streams in WRIA 9 discharge directly to Puget Sound. Other than reconnaissance- level fish surveys that have documented salmonid runs in many of these streams, little is known about the ecological or physical dynamics of these subestuaries. It is apparent, however, that all subestuaries have been altered as a result of urban development.

Sand Spits — Sand spits often form the borders of estuarine areas, sometimes enclosing them (partially or totally). Generally, sediments form sand spits, originating from fluvial rather than marine sources, although they may also be formed by eroding bluffs. Sand spits in Puget Sound have the following functions:

- Foraging and resting for waterfowl and shorebirds.
- Prey production for crabs, sculpin, and flatfish.
- Shellfish production.
- Primary production.

The current distribution of sand spits in WRIAs 8 and 9 is very limited; the most prominent are West Point and Alki Point within WRIA 9.

Spits are vulnerable to filling, dredging, boat wakes, changes in sedimentation rates caused by shoreline armoring, and physical disturbances caused by shoreline development, but very little specific study has been undertaken in Puget Sound.

Beaches and Backshores – Most of the shoreline of Puget Sound is composed of gravel, cobble, sand, or silt beaches. Beaches are generally distinguished from flats by their steeper grade, but generally support similar functions. Puget Sound beaches often transition to sandflats at about MLLW.

Similar to the use of flats, juvenile salmonids rely on beach environments for foraging and refuge before migrating to deeper water. Adult bull trout and cutthroat trout also forage seasonally in shallow beach habitats at high tides.

Beaches and backshore areas can be highly productive; shellfish production is commonly very high on cobble and gravel beaches where deposition includes organic matter.

Beaches are subject to the same stressors affecting flats, including overabundance of ulvoids, physical disturbances as a result of shoreline armoring, contamination, shellfish harvest, and overwater structures.

Banks and Bluffs — Banks and bluffs are typically steep areas of varying heights, located between the intertidal zone and the upland. They are a part of the riparian zone and act as a transition area between the uplands and the aquatic environment. Functions performed by banks and bluffs include the following:

- Source of sediments to beaches.
- Habitat for bluff-dwelling animals.
- Support of marine riparian vegetation and associated functions.
- Source of groundwater seepage into estuarine and marine waters.

Bluffs occupy 4.7 percent of the shoreline in WRIA 8 and 18.3 percent in WRIA 9; the largest and most prominent is Magnolia Bluff, located northwest of Elliott Bay. The health of banks and bluffs is difficult to assess. We do know that stressors include shoreline armoring, vegetative cover reduction, shoreline development, and hydrology changes. Residential development has caused erosion and stability problems along lower Magnolia Bluff over the past few years. The SFBN railroad has isolated many of the bluffs in WRIA 8 from the nearshore.

Marine Riparian Zones — Riparian zones are the vegetated interface between terrestrial and aquatic systems. Adjacent to stream environments they perform a number of vital functions that affect the quality of aquatic and terrestrial habitats. Fewer data are available regarding the functions of the riparian zone to estuarine environments, but they may include the following:

- Protection of water quality
- Bank stability
- Microclimate and shade
- Provision of wildlife habitat
- Input of nutrients
- Recruitment of large woody debris (LWD)

Marine riparian vegetation is present along only 1 percent of the shoreline in WRIA 8 and 11 percent of the shore in WRIA 9. Vegetation clearing, increased impervious surfaces and surface water runoff, pollutant discharges, shoreline armoring, and landscaping due to urbanization and shoreline development have largely removed riparian vegetation from most of the study area.

Although limited in estuarine and marine areas, studies have shown that terrestrial insects, which reside in marine riparian vegetation, compose a significant dietary component of juvenile chinook and chum salmon in subestuaries and nearshore. Other invertebrates (e.g., mysids and amphipods) important to juvenile salmonids are connected to vegetation via detritus-based food webs.

LWD recruited from marine riparian zones provides refuge for fish and wildlife. Logs that become embedded in beaches serve to trap sediments that build the backshore and reduce wave-induced erosion. Alternatives to hard armoring include the use of anchored logs and vegetation to decrease erosion in shoreline development projects.

Shading from marine riparian vegetation can enhance survival of beach-spawning surf smelt by reducing thermal stress and desiccation.

Action Recommendations for Nearshore Habitats — The assessment of selected nearshore habitats in the study area indicates that urban and shoreline development has been substantial, all but eliminating vital habitats such as tidal marshes, and greatly reducing others such as stream mouth flats and marine riparian zones. These changes have likely reduced critical functions of nearshore habitats for some aquatic organisms and possibly affected their use by species such as juvenile salmonids and other fish, invertebrates, and wildlife. The following action recommendations have been compiled in order to provide a decision-making framework to reduce further impacts to the nearshore:

- Protect existing undeveloped shoreline in WRIAs 8 and 9.
- Develop a restoration strategy for the WRIA 8 and 9 nearshore that takes a landscape perspective and helps build our knowledge of the nearshore environment. Ensure that restoration projects and studies add to the technical framework.
- Identify critical areas for protection, restoration, and enhancement in WRIAs 8 and 9, and implement programs to protect, enhance, and restore these areas. Vashon and Maury Islands have the most nondeveloped or less developed habitat available, but areas also exist in the mainland nearshore.
- Protect eelgrass beds from the adverse effects of shoreline modifications such as dredging, filling, overwater structures, armoring, and pollution.
- Protect and enhance marine riparian vegetation, considering its multiple functions when doing so.
- Improve shading for forage fish and other upper intertidal organisms with native vegetation, concentrating on areas with shoreline armoring at or above mean higher high water.
- Re-create intertidal acreage such as marshes, flats, and other habitats largely eliminated by early development. Continue the identification and restoration of suitable sites in the highly modified Duwamish estuary.

- Restore and recover estuarine intertidal flat and marsh habitat. Focus on appropriate regimes and elevations. Continue restoration efforts in the Duwamish estuary and investigate other potential subestuaries such as Miller Creek and the Edmonds Marsh.

Selected Fishes

Several groups of fish species rely on the nearshore of WRIAs 8 and 9 and are an integral component of the nearshore ecology of these areas. Many fish populations in the study area are declining and some are listed for protection or are candidates for protection under the ESA. The SONR focuses on species of concern listed by the Washington Department of Fish and Wildlife—salmonids, forage fish, groundfish, and rockfish.

Salmonids — Eight species of salmonids use the nearshore environments of WRIAs 8 and 9. Estuarine residence of juvenile salmonids is one of the critical periods that affect adult populations; a portion of this period is spent in the nearshore. Contributing to salmonid population declines are urbanization and anthropogenic activities in nearshore marine habitats. Over 70 percent of Puget Sound's coastal wetlands/estuaries have been lost to urban, industrial and agricultural development.

Chinook salmon are the most estuarine- dependent salmonid, followed by chum and pink salmon. The remaining salmonids do not rely as heavily on the nearshore as juveniles; however, sea-run cutthroat and bull trout use the nearshore extensively as subadult and adults.

Juvenile chinook are found throughout most of the nearshore of WRIAs 8 and 9 from late January through September, and may be present year-round. Studies show that this species is the most abundant salmonid in the Lake Washington Ship Canal and Duwamish estuary.

Juvenile chum salmon are found throughout most of WRIA 9, with clusters of abundance near Elliott Bay. Studies in the Duwamish estuary indicate that chum salmon are second to chinook in abundance. Juvenile chum are present in the nearshore between January and June, with peaks from March to May.

Juvenile coho and sockeye salmon are found throughout the nearshore of WRIAs 8 and 9. Steelhead trout are not often observed. These three species generally spend considerable periods rearing in fresh water—coho up to 18 months in streams, sockeye up to 2 years in a lake, and steelhead generally 2 years in streams—before outmigrating. All three species migrate through the estuary and nearshore rather rapidly at a larger size, preferring deeper waters than chinook or chum, but are often collected in beach seines over intertidal habitats.

Juvenile pink salmon have a spotty distribution in WRIAs 8 and 9, possibly because large pink runs do not use area streams. However, they have recently been found in the Duwamish River. Juvenile pink salmon generally migrate through estuaries rather quickly, but rear extensively in shallow marine waters and nearshore embayments between March and May.

Cutthroat trout and bull trout are found in WRIAs 8 and 9, although very little is known about the population or distribution of both species. Cutthroat and bull trout exhibit different anadromous lifestyles than the Pacific salmon. These species first enter marine waters during the spring after 2 to 4 years in fresh water, remaining in nearshore waters for the summer, then returning to either tidal freshwater areas to overwinter, or ascending farther upstream to spawn. The two species are multiple spawners, repeating the anadromous migrations every year.

Juvenile salmon use estuaries with a diverse range of biological and physical conditions, indicating their adaptability to a wide range of habitats.

Numerous causes have been forwarded to explain salmon population declines in the Puget Sound; those occurring in the marine environment include:

- Ocean survival.
- Loss or degradation of tidal wetlands and shallow vegetated habitats by dredge and fill operations.
- Loss of beach habitat by shoreline armoring, overwater structures, and other shoreline modifications.
- Harvest impacts.
- Contaminant inputs.

Although observational evidence exists to indicate that losses or modifications of nearshore habitats affect juvenile salmonids, few quantitative data have been collected. There is a general lack of direct data quantifying the role of estuaries and nearshore environments in the survival of juvenile salmonids. However, indirect linkages and ecosystem modeling provides indications of adverse impacts that result from shoreline modifications and development prevalent in the study area.

Forage Fish — Forage fish are a significant part of the prey base for salmon and other fishes, marine mammals, and sea birds. Five species are prevalent in the nearshore of WRIAs 8 and 9.

Pacific herring are distributed throughout WRIAs 8 and 9. Most herring stocks in Puget Sound are resident, living and feeding in nearshore and offshore schools. Most herring spawn from January through April, laying adhesive eggs on firm substrates in intertidal to shallow subtidal areas. Eelgrass is often a preferred spawning substrate, although other vegetation, oyster shells, and pilings are also used. One of the discrete Puget Sound herring stocks is present in the study area, using Quartermaster Harbor on Vashon Island to spawn. This stock is considered stable and healthy, although others in the Puget Sound are in decline.

Surf smelt are pelagic residents of nearshore estuaries and marine waters found throughout WRIAs 8 and 9. Surf smelt spawn over much of the year on mixed sand-gravel beaches within the upper intertidal zone. It is not known if discrete stocks exist (similar to herring), but surf smelt have been documented to spawn on about 195 linear miles of beach habitat within Puget Sound. Surf smelt spawning habitat surveys are incomplete, but have been documented in several locations in WRIA 8. Spawning beaches are more widespread in WRIA 9, occurring in every shore reach from north of Alki Point to Quartermaster Harbor.

Pacific sand lance are a pelagic and schooling species found throughout Puget Sound and WRIAs 8 and 9. The species is also known to burrow into unconsolidated sediments at night. Like surf smelt, sand lance spawn in the upper intertidal zone of beaches composed of sand and gravel. Sand lance are known to spawn on at least 120 miles of beach habitat in Puget Sound from November through February. Spawning beaches in WRIA 8 exist near Elliot, Picnic, and Edwards Points, and south of Meadow Point and Point Wells. In WRIA 9, spawning beaches are distributed throughout areas.

Longfin smelt and eulachon have not been documented extensively in Puget Sound or WRIAs 8 and 9. Eulachon may be rare in Puget Sound, but longfin smelt populations are believed to be present, but unstudied.

Stressors to herring populations in the study area and Puget Sound include commercial overharvest, increases in predation over the past 20 years, and shoreline modifications. Herring, surf smelt, and sand lance have specific intertidal spawning habitat requirements, making them especially vulnerable to shoreline development, especially shoreline armoring. Loss of eelgrass habitat may affect herring spawning areas. Loss of overhanging riparian vegetation along shorelines may reduce shading on surf smelt beaches, resulting in reduced survival of eggs.

Groundfish — Three species of cod, two species of flatfish and lingcod are common and important groundfish species within Puget Sound. Several of the species have critically low populations or are candidates for listing under ESA.

The cod species—Pacific cod, walleye Pollock, and Pacific hake—are at depressed or critically low populations in Puget Sound. All three species were historically observed in WRIAs 8 and 9; however, trawl surveys conducted after the mid-1970s have shown few fish.

Lingcod populations in Puget Sound are considered below average or depressed and have declined substantially since the early 1980s. The species is nonmigratory and local populations are associated with shallow waters and bottom structure. Lingcod have been documented in several areas in WRIA 8, but few data are available for WRIA 9.

English sole and rock sole are common inhabitants of Puget Sound and are found throughout WRIAs 8 and 9. Juveniles of both species and adult rock sole are commonly found in waters less than 15 m deep. Rock sole also spawn in intertidal areas; spawning beaches are found throughout WRIA 9. Both species are presently considered abundant in Puget Sound.

Rockfish — Fourteen species of rockfish have been observed in Puget Sound. Rockfish are generally associated with subtidal rocky reefs or other areas of high relief in both WRIAs 8 and 9. Copper, quillback, and brown rockfish are the most common species in Puget Sound nearshore areas, seasonally inhabiting both rocky habitats and kelp forests. Rockfish populations are considered below average in the Sound, although little stock assessment data is available for all but the most common species.

Overharvest by commercial and recreational fisheries is likely a leading cause in the decline of groundfish populations. Rockfish are susceptible to overharvest because they are long-lived and mature late. Commercial cod harvests use to occur in spawning areas. For hake, cod, and lingcod, high predation by marine mammals may also impact the recovery of populations. In addition, the decline of cod and hake populations may be influenced by warm-water conditions experienced in Puget Sound during much of the 1980s. English sole in contaminated areas of Puget Sound exhibit high rates of disease, increased parasite loads, and impaired reproduction, although population declines have not been noted.

Selected Invertebrates

Numerous invertebrates use the nearshore environment in Puget Sound, including native littleneck, butter, and manila clams; geoduck; Olympia oyster; and Dungeness crab. Invertebrates are particularly susceptible to nearshore anthropogenic activities because of their immobility and substantial reliance on nearshore intertidal and shallow subtidal habitats.

Littleneck, butter, and manila clams are considered abundant to very abundant in Puget Sound and are found on most beaches within WRIAs 8 and 9. However, present populations are poorly studied. The manila clam is non-native to the North American coast, introduced in the 1930s.

Geoduck abundance is low in WRIA 8 but several tracts exist in WRIA 9, some with high densities. Many of the geoduck tracts in the study area are polluted, preventing harvest. A comparison of present and historical abundances cannot be made because most tracts were surveyed only in the 1970s and 1980s.

Dungeness crab are found in several areas of WRIAs 8 and 9, but abundances decrease markedly south of Seattle. The natural southern boundary of significant crab populations is considered to be the southern tip of Vashon Island. There are insufficient data to compare historical and present crab abundance.

Loss of habitat, recreational overharvest, shoreline siltation, clam dredging, antifouling compounds, and pollution can have negative impacts on invertebrate populations. The degree of impact, however, cannot be determined because of a lack of quantitative data to assess population trends. Most central Puget Sound beaches are closed to shellfish harvest due to pollution.

Shoreline Conditions

Urbanization, industrial development, and shoreline development have resulted in substantial modifications to the shoreline of WRIAs 8 and 9. Available information on the current and historical distribution of shoreline modifications and their impacts on nearshore habitats within WRIAs 8 and 9 are summarized and assessed in the SONR. The assessment of modifications and impacts include:

- Shoreline armoring
- Overwater structures
- Dredging
- Filling
- Sewage discharges
- Sediment contamination
- Nonpoint pollution
- Introduction of non-native species

Shoreline Armoring — Shoreline armoring is the placement of structures in the nearshore to intercept wave energy or control the movement of sediment. WRIAs 8 and 9 are heavily armored with breakwaters, groins, bulkheads, sea walls, and revetments. About 87 percent of WRIA 8 and 75 percent of WRIA 9 shores are armored, most often with bulkheads (excluding Vashon/Maury Island and Elliott Bay).

Shoreline armoring can cause a number of physical effects to the shoreline and nearshore, including:

- Loss of beach area from placement of structures
- Impoundment of sediment behind structures, interrupting longshore transport and causing sediment starvation and beach loss
- Modification of groundwater regimes
- Lowering of beach elevations, changing intertidal beaches to subtidal areas
- Redirection and intensification of wave energy
- Alterations of substrate from fine sediment to coarse sediment and rock

These physical effects can act to affect biological processes, habitats, and species. Species assemblages often change from ones that favor fine sediments to those that favor coarse sediments and rocky substrates. For example, open sand communities supporting eelgrass can evolve over time to a community dominated by algae.

Changes in habitat structure can eliminate spawning sites for forage fish and rock sole. Riparian vegetation displaced by armoring leads to decreases in shade, cover, detrital input, and terrestrial prey upon which juvenile salmonids depend. Armoring that juts into subtidal areas forces juvenile salmonids into deeper water where they may experience increased predation. Loss of shade and sediment alterations can affect surf smelt spawning beaches. Changes in substrate can render habitat unsuitable for shellfish.

Cumulative effects from heavily armored areas such as those found in WRIAs 8 and 9 are of major concern. However, no quantitative studies on the cumulative effects on nearshore ecology have been undertaken.

Overwater Structures — Overwater structures in WRIAs 8 and 9 include floating docks, covered moorages, piers, marinas, barges, rafts, and floating breakwaters. The great majority of overwater structures are present in WRIA 9 within Elliott Bay.

Overwater structures change the levels of light, shoreline energy regimes, substrate type and stability, and water quality, which can change the abundance and diversity of nearshore species.

Light levels can be reduced below those necessary for photosynthesis and have reduced eelgrass densities and the growth of other nearshore algae. Studies have shown that piers may interfere with the nearshore migration patterns of juvenile salmonids, but it is not known if these changes result in lower survival. Boat moorage, house boats, and industrial piers have been associated with the discharge of contaminants that pollute water and sediment.

Marinas with breakwaters can create waters with low tidal exchange, causing increased temperatures, phytoplankton blooms, and depressed levels of dissolved oxygen.

Overwater structures physically change nearshore habitats, and clear effects to marine vegetation have been documented, but the actual adverse effects to fish species have not been clearly determined.

Dredging — Very few nearshore areas of WRIAs 8 and 9 are dredged, except for Elliott Bay (see Elliott Bay section) and where marinas have been installed. Disruption and loss of benthic communities is an impact of dredging, although recolonization generally occurs within 3 to 5 years. Impacts to fish and other mobile species that can avoid dredging activities and turbidity plumes may be limited; however the loss and disturbance of benthic communities can affect fish food supply.

Filling — Historically, filling of nearshore areas was conducted to create new upland areas for development. This activity frequently resulted in losses of wetlands, beaches, and other habitat, most notably in Elliott Bay (see Elliott Bay section). Outside of Elliott Bay, the greatest source of fill has been associated with shoreline armoring, railroads and roads built on beaches. As noted previously, over 70 percent of WRIA 8 and 9 shorelines have been armored.

Fill activities act primarily to physically bury existing biological communities and their habitats. Short-term exposure to plants and animals to suspended solids and reduced dissolved oxygen may also occur.

Sewage Discharges — In WRIAs 8 and 9, the primary source of untreated sewage to the nearshore are from combined water outfalls (CSOs), which discharge directly to the nearshore during periods of heavy rainfall. CSOs are present in both WRIAs 8 and 9, but only in the vicinity of the City of Seattle. Sewage discharges have been declining since the 1980s, from an annual average of 2.3 billion gal to about 1.5 billion gal.

Four types of effects can occur as a result of CSO discharges:

- Physical scouring as a result of high volumes and velocities
- Smothering of benthic communities by discharging material of high organic content
- Short-term pulses of bacteria
- Chemical contamination of sediments

Very few studies have evaluated the effects of CSOs on nearshore environments in Puget Sound, and there is a lack of baseline data for vulnerable habitats. This makes it difficult to separate effects caused by human activities from natural variation.

Sediment Contamination — Contamination in the sediments of WRIAs 8 and 9 occurs primarily in Elliott Bay and the Duwamish estuary. Outside of Elliott Bay, several organic compounds have been observed, but virtually all concentrations are below state sediment guidelines, indicating that concentrations are well below levels believed to be harmful to aquatic organisms. Additional sampling is needed to develop improved coverage and a better understanding of sediment contamination.

Nonpoint Pollution — Nonpoint pollution sources are discharges that do not have a single point of origin or are not introduced into a receiving stream from a specific outlet. Nonpoint pollution sources in WRIAs 8 and 9 include the following:

- Runoff from impervious surfaces
- Discharges from vessel traffic; five marinas and four ferry terminals are present within the WRIAs
- Discharges from residential, commercial, and industrial activities
- Leaking septic tanks

Pollutants such as nitrates, phosphates, pesticides, petroleum, and fecal coliform bacteria are washed from uplands into streams that feed into Puget Sound, or directly into marine waters. Nonpoint pollution affects nearshore ecosystems in several ways:

- Degradation of water quality can cause chronic toxicities to aquatic organisms
- Increased turbidity can affect light penetration and photosynthesis of marine plants such as eelgrass
- Increased nutrient discharges can lead to eutrophication, which can intensify algal blooms and reduce dissolved oxygen levels
- Fecal coliform discharges can contaminate shellfish beds With the exception of some areas off of Vashon and Maury Islands, all beaches in the study area are closed to harvest as a result of contamination

Non-Native Species — Surveys of non-native species found 39 species of marine algae, plants, and invertebrates that are not indigenous to Puget Sound. Eight species of non-native invertebrates have been observed in WRIAs 8 and 9. Several plant species have been observed, including Japanese eelgrass (*Zostera japonica*), cordgrass (*Spartina* spp.), and japweed (*Sargassum muticum*). Of these, cordgrass has had very negative impacts in areas where it has invaded outside of WRIAs 8 and 9 because colonies tend to be monocultures, displacing all other marine vegetation. The species also does not provide direct food or habitat for native animals.

Action Recommendations For Nearshore Habitats – The assessment of shoreline conditions and modifications in the study area indicate that much of the shore of WRIAs 8 and 9 has been modified. As noted, modifications such as shoreline armoring can cause the loss of intertidal beach habitats and shifts in biological communities. Other modifications such as overwater structures can affect the behavior of migrating salmonids, but it is not known if these changes affect survival. Nonpoint discharges of contaminants and fecal coliforms have closed shellfish beaches. The following action recommendations have been compiled in order to provide a decision-making framework to reduce further impacts to the nearshore:

Shoreline Armoring

- Reduce the amount of shoreline armoring in WRIAs 8 and 9, and prevent new installations of shoreline armoring. Restore natural physical and biological processes.
- Determine and restore natural drift-cell processes, specifically sediment budgets. Feeder areas are particularly important. Where sediment supply is unimpeded, protect it. Where it is impeded, restore or enhance it. Prevent sediment supply from being interrupted by downdrift armoring.
- Develop and implement technical guidance for alternatives to traditional shoreline armoring that maintain natural shoreline processes and functions.

Filling

- Reduce the amount of existing shoreline fill that results from shoreline development practices such as shoreline armoring, and prevent new fill. Where existing fill is removed, restore the area to low-gradient intertidal habitats such as flats and marshes.

Overwater Structures

- Protect and enhance light penetration in the nearshore, including areas under existing overwater structures.
- Eliminate use of construction materials that may release environmental contaminants.
- Eliminate obstructions to migratory corridors in the nearshore, including both inwater and overwater structures.

Water Quality

- Identify and control nonpoint pollution sources.
- Develop innovative methods of stormwater treatment, such as projects that use plantings of native vegetation to filter stormwater while improving fish and wildlife habitat.

Non-Native Species

- Monitor and prevent the introduction and spread of nonindigenous and invasive species. Identify and eliminate new sources of introductions.

Elliott Bay and the Duwamish River Estuary

The Duwamish estuary and Elliott Bay section presents a review that reveals the transformation of a natural system to a highly modified, urban estuary and bay. Because of the concentrated development in the estuary and bay, and subsequent environmental impacts, a substantial amount of scientific literature, data, and reports have been generated for this area. This section of the SONR summarizes and assesses much of this information.

Historical Development — Substantial shoreline development and modifications began on the Duwamish estuary and Elliott Bay over century ago. The largest modifications came in the way of filling large portions of the nearshore to create land. Beginning as early as 1895, tideflats and saltmarshes along the estuary and Elliott Bay waterfront were filled to create protected harbor areas. In the early 1900s, Harbor Island was created with fill material and the Duwamish estuary was channelized, replacing 9.3 miles of meandering tidal river with a 5.3-mile straightened channel. By 1986, over 1,100 acres of tidal marsh, 1,200 acres of forested wetlands, and 70,000 acres of riparian shoreline were either filled or eliminated.

Substantial changes to the Duwamish River watershed also occurred early in the century. The White, Black, and Cedar rivers, all of which originally flowed to the Duwamish basin, were diverted. Cumulatively, these changes reduced the estuary's watershed by 70 percent, eliminating several salmon runs, and changing the flow regime into the estuary and bay.

Shoreline Armoring — With the exception of the Magnolia Bluff area, nearly 100 percent of the Duwamish estuary and Elliott Bay shore has been modified with various types of armoring, including:

- Levees and dikes
- Riprap
- Bulkheads and seawalls
- Rubble

Riprap and levees predominate in the Duwamish estuary, occupying over 70 percent of the shore. However, this armoring is primarily located in the upper intertidal zone, with the lower zone dominated by exposed mud- and sandflats.

A similar level of armoring occurs along the Elliott Bay shore, primarily with riprap and vertical sea walls. Also along the bay is an unarmored area of shoreline that extends for about 3,870 linear feet along the toe of Magnolia Bluff.

Studies investigating the effects of shoreline armoring in the estuary and bay were not identified, but studies conducted in other areas indicate that juvenile salmonid densities are generally lower near riprap banks compared with natural banks.

Shoreline armoring of the bay has largely stopped shoreline and bluff erosion and eliminated sediment sources feeding the beaches and sand spits of Duwamish Head and Alki. Feeder bluffs along Magnolia Bluff remain partially or completely active, however, and continue to feed sediment to West Point and the broad sandflats south of West Point. These shallow subtidal sandflats and remnant sandy areas between Alki and Duwamish Head support productive eelgrass patches.

Overwater Structures — Docks, piers, and marginal wharves are prevalent in the study area, particularly in Elliott Bay. About 66 percent of the Elliott Bay shore and 15 percent of the lower Duwamish estuary is occupied by overwater structures. Overwater structures in the upper estuary, upstream of the turning basin, are limited to bridges.

Within the bay and estuary, the potential impact of overwater structures on the outmigration of juvenile salmonids from the Green/Duwamish basin is of considerable concern. Three studies evaluated the behavior and responses of juvenile salmonids to overwater structures in the estuary and bay. These studies found that overwater structures caused behavioral changes and interruptions in migration, but there was no evidence of increased predation or any other indications that overall survival was lowered.

Studies conducted in the bay as well as other areas repeatedly verify that changes in the underwater light environment affect salmonid behavior. However, there is a lack of quantitative data to indicate that behavioral responses to overwater structures truly decrease the survival of outmigrating juvenile salmonids.

Dredging and Filling — From the 1880s through the mid-1900s, the Duwamish estuary was straightened with extensive dredge and fill operations to form a navigation channel, and much of lower Elliott Bay was filled to create additional land. Navigation is maintained by maintenance dredging in the lower estuary about every 2 to 3 years.

Short-term impacts of dredging include temporary increases in noise levels, temporary changes in water quality, and destruction of nonmobile benthic communities. Long-term effects include habitat modification such as changes in depth, substrate, and sediment contaminant concentrations.

Sewage Discharges — About 55 CSOs and storm drains discharge treated and untreated effluents and stormwater into the Duwamish estuary and Elliott Bay. CSO discharges can affect the nearshore environments of the estuary and bay in a number of ways:

- The discharge of contaminants and sewage
- Physical scouring and sedimentation from discharges
- Physical resuspension of chemically contaminated sediments
- Discharge of untreated sewage

Although 90 percent of CSO discharges are stormwater, chemical contaminants and metals can also be discharged during storm events. Recent studies have found 7 metals and 16 organic compounds of concern in CSOs, but risk assessments found minimal risk to aquatic life and no risk to salmonids.

Resuspension of chemically contaminated sediment by scouring can result in the re-release of potentially toxic chemicals into the water column. Although no information documenting such events has been identified, the Washington State Department of Ecology has identified 25 areas in the estuary and bay that have concentrations of substances in sediment that exceed state sediment quality standards.

Risk assessment studies also found risks to localized benthic communities in the vicinity of CSOs, although sedimentation and scouring risks occurred over less than one percent of the estuary and bay.

CSOs are the primary source of untreated domestic waste waters in the estuary and bay, releasing potentially harmful microbial pathogens. Harvesting of shellfish has been prohibited in Elliott Bay and the eastern shore of Puget Sound because of the potential for bacterial discharges.

Before 1987, treated effluent from the Renton Sewage Treatment Plant flowed into the estuary, after which it was diverted to an outfall of Duwamish Head. This diversion produced marked improvement in water quality of the estuary; notably, increases in dissolved oxygen and lower ammonia and metals concentrations.

Sediment Contamination — Numerous studies have investigated sediment contamination in the estuary and bay, indicating that concentrations of polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), metals, phthalates, chlorinated benzenes, pesticides and tributyltin (TBT) are present in river and bay sediments at concentrations exceeding state sediment quality standards. Highest concentrations of sediment contaminants were found near two Superfund sites, one at Harbor Island and one at a creosote plant immediately to the west of the island. These areas are highly contaminated with metals, PAHs, and PCBs. Mercury is prevalent along the bay waterfront. Lower levels of contamination were observed in the Duwamish estuary, and about 10 percent of sediment samples exceeded state sediment guidelines.

Studies have found that concentrations of PCBs in chinook salmon in the estuary are higher than levels found in juvenile chinook salmon collected in nonurban areas. PCB bioaccumulation also has been found to be associated with impaired growth and increased mortality after disease challenge. Juvenile chinook salmon collected in the estuary also show physiological indicators of contaminant exposure. An increased incidence of reproductive impairment and liver tumors has been observed in English sole collected from the estuary and other urban estuaries.

Although studies show several impacts to fish, it is not known if, or to what extent, sediment contamination affects fish populations in the estuary.

Sediment Dynamics and Patterns — Sediment dynamics in the Duwamish estuary and Elliott Bay have changed dramatically. These changes in the estuary were spurred by the river diversions early in the century, and in the bay, by bulkheading and construction of overwater structures.

The diversions of the White, Black, and Cedar rivers, and construction of the Tacoma Water Diversion Dam and the Howard Hanson Dam have altered peak flows of the Duwamish River by 70 percent and reduced the sediment load at the mouth by at least 75 percent. The sediment load of the original basin was likely substantial; historically, three distributary channels carved in the original mud- and sandflats carried flows from the estuary to the bay.

Within Elliott Bay, sediment transport is influenced almost entirely by longshore currents or littoral drift; the length of a single longshore drift pattern is called a drift cell. Two drift cells are present along the bay shore—one cell along the shore of Magnolia Bluff that flows west to West Point, and another west-flowing cell between Alki Point and Duwamish Head. Sediments are transported around Alki Point, northward to Duwamish Head and around, terminating on the bayward side of Duwamish Head. Accumulations of sediment are observed at the terminus, as well as along the foreshore of Alki Point. Sediments from feeder bluffs at the toe of Magnolia Bluff are transported up the shore and are deposited off West Point.

Most of the Elliott Bay waterfront between Pier 91 and Duwamish Head has no appreciable net shore drift because of extensive shoreline development dominated by overwater structures. Historically it is likely that the drift around Duwamish Head extended farther south down the western shore of Elliott Bay until the beach environment transitioned into the shallows and flats of the original river delta.

Salmonid Distribution and Use — Eight species of anadromous salmonids use the Duwamish estuary, the Green River, and Elliott Bay. Chinook salmon, coho salmon, and steelhead trout have established runs in the basin; pink and sockeye salmon, sea-run cutthroat trout, and bull trout are rare.

Juvenile salmonids, depending upon the species, depend heavily on the nearshore, using these habitats for foraging, physiological transition to salt water, and refugia. All of the salmonids are opportunistic epibenthic feeders, consuming available amphipods, insects, and mysid shrimp within the estuary and bay.

Residence times in the estuary appear to be abbreviated compared with studies conducted in other areas; chinook juveniles spend about 2 weeks in the estuary and chum juveniles about 1 week. Very few juveniles of the other salmonid species were observed in the estuary.

Limited data suggest that juvenile chinook and chum salmon remain in Elliott Bay through the summer and in Puget Sound through the winter before outmigrating to the ocean. Some juvenile chinook salmon may remain in Puget Sound year-round. Very few of the other salmonid species have been observed in Elliott Bay, although juvenile pink salmon have been found at high abundances for fairly short periods. These fish likely come from other stream basins.

Adult salmonids use the nearshore as well, using areas near and in the mouth of the Duwamish River for foraging and physiological transition to fresh water before migrating to spawning areas in the Green River. In addition, adult sea-run cutthroat trout and bull trout do not migrate to open ocean areas like the salmon and steelhead, but remain in nearshore environments through the spring and early summer before ascending streams either to overwinter or spawn.

Dramatic changes to salmonid populations in the Duwamish basin can be linked to the major watershed diversions conducted early in the century. The substantial elimination of sockeye, spring chinook, and pink salmon runs in the basin are attributed to the diversions. Sockeye use the Cedar/Lake Washington drainage, and spring chinook and pink salmon use the White River.

Development of the estuary to its present characteristics has eliminated over 97 percent of former shallows, flats, and tidal marshes. This reduction has diminished the production of invertebrate food organisms and refugia, and residence times in the Duwamish estuary appear to be lower than other estuaries, but survival rates have not been adequately studied.

Other Finfish Distribution and Use – Nonanadromous fish in the Duwamish estuary are dominated by estuarine and marine species, with only a few freshwater species. Fish surveys indicate that about 30 species are commonly found, with shiner perch, starry flounder, sand lance, and pricklebacks dominating the estuarine community.

Substantially more fish have been documented in Elliott Bay compared with the estuary. Fish surveys at Alki and West Point have found about 75 species of fish, with 7 dominant species—shiner perch, English sole, rock sole, tomcod, striped seaperch, ratfish, and tube snout.

Stressors of resident fish are not well known. Studies have found a striking increase in fish associated with eelgrass compared with sand substrates, indicating that these habitats are very valuable. As reported in the Sediment Contamination section, contamination by PCBs and PAHs in English sole has been associated with reproductive impairment, liver tumors, and parasites. The extent of such impacts, and whether resident populations are being affected, is largely unknown.

CONCLUSIONS AND RECOMMENDATIONS

The objective of this study was to provide a reconnaissance-level understanding of the nearshore ecosystem on the eastern shore of central Puget Sound for the purpose of guiding nearshore watershed planning and salmon recovery actions in WRIAs 8 and 9. This summary is the first of its kind, and it provides an opportunity to review multiple and diverse sets of data. Because this was a reconnaissance-level effort, we covered most but not all of the published and unpublished literature on the region. Furthermore, funding limitations and the general lack of nearshore ecosystem data limited our ability to provide a more in-depth review and analysis. However, the section on Elliott Bay (Section 11) provides a fairly well-documented glimpse of how advanced levels of urbanization affect one region within Puget Sound's nearshore environment.

Where necessary, we also incorporated information from sources outside of the study area for the development of a more complete understanding of the nearshore environment. Most of the species, ecosystem processes, habitat types, and stressors found in the study area occur in other areas as well and, in some cases, have been better studied in other areas. Furthermore, the nearshore ecosystem is only a part of a larger landscape that requires looking beyond watershed and geopolitical boundaries for an understanding of how it functions, what influences natural functions, and how that translates into an understanding of ecosystem health.

The conclusions and recommendations sections of this report were developed to summarize and interpret the meaning of this reconnaissance-level assessment and to provide recommended actions that are likely to lead to improved ecosystem health, based on our understanding of the ecosystem and influences of anthropogenic stressors. In order for us to draw conclusions and recommendations from the report, and for interested parties to understand the context, it is important to understand the approach used in preparing the report and the guiding principles and assumptions made in the development of conclusions and recommendations. The approach used is provided in the introductory section of the report. The assumptions used to generate conclusions and recommendations include:

- The development of conclusions and recommendations uses "Best Available Science," defined as a combination of direct studies, professional expertise and experience, and the application of fundamental ecological principles (i.e., the linkages between processes, structure, and functions).
- The nearshore ecosystem is an integral part of the watershed and is influenced by both upland/upriver processes and marine processes (it is viewed as a part of the continuum across the landscape).
- Humans exhibit an increasing power/ability to modify natural ecosystem processes, structure and functions to the detriment of living resources.

- Modification (i.e., introduction of chemical contaminants, habitat alteration, resource extraction) of natural ecosystem processes and structure is likely to result in shifts in species composition, viability, and productivity.
- Improving the nearshore ecosystem is likely to be good for salmon because of their dependence on properly functioning nearshore conditions for feeding, refuge, migration and physiological transition.
- Regional and global-scale factors, such as climate variability, also influence the nearshore ecosystem.

The objectives in developing conclusions and recommendations include the following:

- Elucidate what we know about the nearshore.
- Identify particular communities, populations, or other elements of the ecosystem that require special attention.
- Identify additional information that is needed to improve our understanding of the ecosystem.
- Recommend actions that will preserve, protect, and enhance the nearshore ecosystem.
- Recommend actions that will enhance our understanding of nearshore ecosystem processes, structure, and functions.
- Provide an honest, meaningful and realistic assessment and predictions about the present and future health of the nearshore ecosystem. The assessment and predictions need to be revealing about the potential consequences of our actions and activities, or lack thereof, in light of our current understanding.

This report was written from a technical perspective to provide technical guidance. Therefore, every effort was made to avoid evaluation and interpretation of political, policy, and social considerations in both the report and in the conclusions and recommendations. However, some social values (i.e., human health and safety, commercial value) are identified but were not evaluated in this report. These considerations are the responsibility of other groups that may use this report in their planning and policy deliberations.

Conclusions

- ***The nearshore ecosystem plays a critical role in support of a wide variety of biological resources, many of which are important to the people of the region for commercial, recreational, cultural, aesthetic, and other social values.*** These resources include the physical characteristics as well as numerous species of shellfish, finfishes, birds and other wildlife. Resources such as bivalves are common on beaches and flats. A large number of fish species use nearshore habitats for feeding, refuge, migration, and reproduction. Juvenile salmon preferentially feed on prey produced in the nearshore habitats including subestuaries, flats, beaches, riparian zones, kelp, and eelgrass meadows. These habitats are far removed from salmon spawning areas, which have been the focus of salmon life history and strategies for protection of critical salmonid habitat. However, nearshore habitat clearly plays an important role in the support of these highly migratory species through both direct and indirect mechanisms. For example, the riparian zone bordering the nearshore provides a direct source of prey for salmon and shade that enhances beach conditions for spawning forage fish and other species that use upper intertidal zones.

Temporal and spatial variability in habitat structure are controlled by a number of processes in the nearshore ecosystem. Similarly, nearshore biological resources are dependent upon a set of processes that regulates the abundance, diversity, and productivity of the various habitats that the resources use. For example, substrate composition plays a critical role in the abundance and distribution of infaunal bivalve populations and forage fish spawning. If sediment structure is significantly modified, bivalves and forage fish will no longer use these areas. Physical processes, such as erosion and deposition of sediments, are forced by wave and current energies that regulate sediment composition in an area. Modification of these force factors and other conditions will necessarily result in a modification of substrate and the species that utilize a particular habitat, or substrate type.

- ***The interactive effect of human-caused changes and natural variability on processes and resources has not been studied.*** Consideration and documentation of natural versus human-induced stressors on the nearshore ecosystem are sorely needed. The underlying causes of poorly understood phenomena, such as widespread declines in herring stocks and reductions in salmon body size, may become clearer through such studies. The fact that both human and climate-related factors may play a role is only speculative at this time. In many circumstances, we lack the mechanistic understanding to judge what is natural versus what is not natural in forcing variations we see in the nearshore ecosystem.

  Although generally not proven yet, natural variations in climate and water properties may have a strong influence on nearshore processes and resources. For example, the 1982-1983 El Niño produced dramatically different plant and animal species composition in the Seahurst area. This was documented only because there was an intensive baseline study under way at the time related to the siting of a new sewage outfall in the region. This study provided evidence that the nearshore ecosystem in Puget Sound is subject to broader factors, and that these factors may not be detectable without prolonged baseline monitoring in place.

- The viability of the nearshore system processes that support these resources has been damaged and continues to be threatened by a wide variety of human-induced changes. The essential habitat-forming and many fundamental ecological processes have been severely damaged throughout much of the study area. Factors that have contributed include overwater structures, dredging, filling, shoreline armoring, shoreline vegetation removal, chemical and bacteria contamination, organic matter and nutrient loading, resource extraction (i.e., sport and commercial harvest, logging activities, mining), land-use practices (i.e., commercial and residential development, roads, bridges, transportation facilities), commercial activities (i.e., shipping, wastewater disposal), and recreational activities and support (i.e., boating, marinas). Major losses because of dredging and filling have occurred in Elliott Bay and Shilshole Bay, but losses have occurred in other areas as well as a result of development and land use practices. In many cases, multiple stressors are affecting shoreline areas. For example, Lincoln Park suffers from beach erosion caused by a seawall, but is also subjected to heavy clam harvesting and fecal contamination.

Shoreline modifications have occurred over an exceedingly high percentage of WRIAs 8 and 9 nearshore habitats, and represent one of the larger impacts on the nearshore ecology of the region. Numerous studies and reports have identified anthropogenic causes of habitat loss and degradation, species declines, and the needs for improving resource management and ecosystem health. While improvements have been made in some areas, the general condition of the nearshore environment continues on a downward trend due to a lack of attention, inadequate resources, and inadequate response to warnings and recommendations for improvement.

- ***The cumulative effects of multiple stressors, or individual stressors over various temporal and spatial scales, on the nearshore system are unstudied in a systematic way***. Despite a good foundation for conceptual approaches and an understanding of the links between shoreline structural alteration, physical processes, and biological functions, there is a surprising gap in our documentation of ecological changes (Thayer et al. 1975). Furthermore, neither historical baseline nor current monitoring data provide the basis for understanding the magnitude of this change or threshold for cumulative impacts (Canning and Shipman 1995). In order to restore nearshore systems, it is essential to better understand the interaction of multiple stressors on the ecosystem.

- ***Monitoring the performance of restored systems and baseline studies in reference areas are critical to the development of appropriate restoration strategies.*** Although not a topic of this report, restorative actions are resulting in improvements to the nearshore ecosystem. Simenstad and Cordell (2000) summarize a limited, but important data set that proves restoration can yield positive results with regard to juvenile salmon. However, in general, restoration and enhancement monitoring have been inadequate for providing guidance on appropriate techniques and long-term successes. Few restoration and enhancement projects have been designed and monitored at the appropriate temporal and spatial scales. Furthermore, few projects integrate the full suite of ecosystem functions and processes into design and monitoring. This is often the result of inadequate information, funding, and an opportunistic approach to restoration. The end result is that the success and value of restoration efforts remains in question. Monitoring programs must be rigorous, set within the proper context and scale, and coordinated between agencies and other parties, and their results must be disseminated.

- ***There are numerous data gaps in our understanding of the nearshore ecosystem that directly inhibit or weaken our ability to make informed decisions regarding management and restoration of the system. Monitoring programs are limited and have***

been inadequate for providing the level of scientific information necessary for informed resource management decisions. Resource monitoring is the responsibility of multiple entities that are often not adequately funded, or well coordinated. Gaps in our understanding are numerous and are detailed in the body of the report and summarized in the Appendix. We cannot accurately assess what might be termed a "properly functioning estuarine or nearshore system" without filling many of the data gaps. Studies to refine metrics in an integrative way are decades behind efforts in freshwater streams and rivers. Recent work initiating the use of models (i.e., Ecosystem Diagnosis and Treatment model) for assessing the role of the nearshore system in the life history of salmon has revealed substantial uncertainties in our knowledge base. There is a clear need to conduct more studies on the use of nearshore systems by juvenile salmon and improve our understanding of how the nearshore integrates with freshwater, upland, and oceanic systems.

Specific information is necessary in developing habitat management plans and restoration projects. For example, while we have some understanding of the functions, we have no direct studies on the importance of large woody debris in the nearshore system, a topic of extensive study in stream and river ecosystems in recent years. Hence, there is limited information for generating recommendations on the restoration and management of backshore areas where woody debris is found. Additionally, in the Northwest, very little empirical information has been collected on the functions of riparian vegetation in estuarine and other nearshore areas. As a result, the related roles of LWD, shading, organic and litter recruitment, prey production, sediment and water filtration, and microclimates in the survival and growth of juvenile salmonids and other nearshore-dependent species have not been well defined.

- ***There is a general lack of coordination in the collection, analysis, and dissemination of nearshore data.*** Nearshore data must be coordinated and disseminated. Although a number of research and monitoring programs are being carried out (i.e., WDFW, PSAMP, various Tribes, and the University of Washington have collected data sets for nearshore fish species), there is rarely any synthesis and may be little coordination among components of the program. Sometimes data are collected and not analyzed. In other cases where data have been collected and analyzed, information dissemination to other resource agencies is often lacking, and accessibility and retrieval may be difficult. We cannot point to an integrated ecosystem monitoring program in WRIAs 8 and 9 at this time. A conceptual model has been developed for Puget Sound (PSAMP 2000) that does include part of the nearshore system, but is lacking important elements of the upper intertidal and the terrestrial/aquatic interface (i.e., beaches, backshore, bluffs, and riparian areas). Furthermore, this model, along with other conceptual models, needs to be expanded and refined for describing the various elements and ecological relationships within the system. Such models, in conjunction with a larger management framework, are essential for developing monitoring and assessment programs. Most recently, the Nearshore PRISM working group has been developing a numerical model. This model, if developed fully, will greatly aid in our understanding and management of the nearshore system.

- ***The nearshore system of Puget Sound needs more focused attention with funded research.*** Basic information on ecology and population trends of many fish and invertebrate species is lacking, as is good historical baseline information on habitat conditions. Many scientists complain that they are pressed to answer very large and important questions about salmon recovery, but they lack the data to provide defensible responses due to a lack of context and availability of sufficient data. It is clear that until more attention is placed on the nearshore, there is a real risk that mistakes will be made in terms of management and the expenditure of funds for habitat restoration and salmon recovery.

- ***The nearshore must be addressed from an ecosystem perspective.*** The nearshore environment is influenced by a plethora of factors, both natural and anthropogenic, due to its placement in the larger landscape. Factors that effect oceanic, freshwater and terrestrial systems individually, all come together in a "great mixing bowl" to create a unique environment in the Puget Sound nearshore. Understanding all of the unique characteristics and complexities is a tremendous task that will take many years of dedicated, well-coordinated research and analysis. However, this will require a shift from our approach of single-species, or single-habitat management to an integrated ecosystem approach. For example, we need to understand that land-use practices along our shorelines have direct and indirect influences on the nearshore ecosystem (i.e., loss of vegetation, changes in sedimentation, water quality, and hydrology). These influences result in changes such as habitat structure, food supply and other elements that can reduce the viability of multiple species within the system. Other factors, such as dams and water withdrawals, geographically far removed from the nearshore, can dramatically influence sediment supply and salinity in subestuaries, which in turn changes vegetation communities, habitat structure and species composition. The nearshore is therefore not only part of an individual watershed, but is also the thread that binds together multiple watersheds. Thus, it is imperative that we not only understand the nearshore ecosystem as a unique "marine" system, but that we also look across the landscape to determine how the nearshore interacts with influences from other distinct ecosystems.

- ***Action is needed in the nearshore.*** Numerous studies and reports have previously identified the problems facing the nearshore environment (i.e., PSWQA 1988a,b; Shreffler and Thom 1993; West 1997; WADOE 1994; Broadhurst 1998; Lynn 1998; PSWQAT 1998; WADNR 2000; PSWQAT 2000), and have drawn conclusions similar to this report. Yet, while state and federal agencies, tribes, and other stakeholders have long recognized the importance of Puget Sound resources and the effects of anthropogenic impacts, the response to previous recommendations for improved protection of resources has been lacking. Protection, restoration and recovery actions have lagged while the human population and development have increased dramatically. The lack of appropriate and adequate levels of protection has led to significant declines of nearshore species and habitats. The most obvious signs of loss include the Endangered Species Act listings of Hood Canal Summer Chum salmon, Puget Sound Chinook salmon, Bull trout, a petition to list Coho salmon and 18 marine fishes, and a proposal to list the system's top predator, the orca whale.

- ***Particular attention and protective standards need to focus on communities, populations, or other elements of the ecosystem that require special attention.*** Salmon populations are only one example. While salmon have become the major driver for our recent planning and assessment work, due to regulatory (i.e., ESA) and social demands, they are certainly not the only indicator of ecosystem health and may or may not be the best indicator. They may, however, be a useful indicator due to their complex life history and utilization of the landscape. While freshwater reproduction and rearing is critical to their survival, it is also important to emphasize that most Pacific salmon are marine fishes that are dependent upon good estuarine and marine habitat conditions and prey resources. This dependency requires us to pay particular attention to other elements in the ecosystem. For example, forage fishes (i.e., surf smelt, sand lance, herring) are important prey for salmon and a multitude of other marine species, yet we have no population data for surf smelt and sand lance and do little to protect their spawning habitat. Likewise, it has been suggested that harpacticoid copepods, another primary prey item of juvenile salmonids, may be an ecologically meaningful organism for determining environmental quality in nearshore environments (Cordell and Simenstad 1988).

Other examples of nearshore ecosystem elements that play important roles and should be protected include: eelgrass and macroalgae, which provide critical habitat functions for multiple species; natural erosion of banks and bluffs, a critical habitat forming process; and crab, clam, and other invertebrate populations or communities that play important roles in the nearshore ecosystem, for which species composition and life history data are limited. These are but a few examples and, as in the rest of this report, are not intended to be exclusive of other species, populations, communities, and other elements of the ecosystem. As stated above, establishing more baseline monitoring and assessment, understanding ecosystem linkages, and understanding impacts of anthropogenic influences are critical to identifying the most important elements of the ecosystem and providing recommendations for protection. In other words, the selection of particular elements within the ecosystem, or other actions, must be made in the proper context.

Recommendations

Based on the findings and conclusions of this study, it is apparent that there are a number of general and specific actions that need to be taken to better understand and protect individual elements within the ecosystem and the nearshore ecosystem as a whole. For example, it is clear that a number of anthropogenic influences are responsible for habitat loss and species declines. Yet, we lack adequate levels of scientific investigation to fully understand and describe all of the complex ecosystem linkages to provide specific remedies for maintaining or restoring "proper functioning conditions" for all elements, at all levels within the ecosystem. Therefore, it is imperative that we identify and prioritize the most critical data gaps, habitats, species, and ecosystem processes for in-depth analysis. This will require the development of criteria and protocols for evaluating each of these elements prior to analysis. In addition, it is also imperative that we take early actions to prevent further harm and not wait as additional scientific information is generated. Early actions come in many forms and range from the development of a coordinated technical framework and conceptual models to conservation, restoration, and protection actions or standards. It is apparent that historical protection measures have been inadequate. Therefore, protection is the most important early action that can be taken, for without it, degradation will continue and future restoration, scientific investigation, and other efforts to understand and restore the ecosystem will likely not reach recovery goals. Furthermore, the cost of protection, in terms of biological and economic costs, is low relative to the cost of restoration. This is a particularly important concern because restoration methodologies are not well studied and costly restoration projects are poorly monitored for success. Monitoring and adaptive management must be integral elements of both short-term and long-term action agendas to allow for the integration of new information.

The following action recommendations are divided into specific, non-prioritized categories. Many of these actions may be, and should be, taken simultaneously to restore the nearshore ecosystem. Although this report was written for a specific geographic area, many of these recommendations apply elsewhere and will require coordination and implementation on a larger scale to restore nearshore ecosystem conditions.

Monitoring and Research

- Develop, fund, and implement a coordinated monitoring and research program for the nearshore. This will require careful resource considerations (i.e., staff and funding at appropriate levels) and participation from entities outside of King County to address issues at the appropriate temporal and spatial scales.
- Develop a technical framework for understanding how the nearshore fits into the landscape of WRIAs 8 and 9 and Puget Sound as a whole.
- Establish/support the development of a consortium of entities concerned with the nearshore environment and develop a long-term funding source for nearshore research and projects.
- Develop criteria and protocols for monitoring and assessment that may be used at various temporal and spatial scales that are widely accepted and may be used for research, protection, preservation, enhancement and restoration.

Habitat Protection, Enhancement, and Restoration

- Protect existing undeveloped shoreline areas in WRIAs 8 and 9 from development practices that would be detrimental to the nearshore ecosystem. Develop protection, acquisition, and incentive strategies for lands that would contribute to maintaining or restoring ecosystem processes and functions to the benefit of nearshore ecosystem health.
- Protect eelgrass and macroalgae beds from the adverse effects of shoreline modifications such as dredging, filling, overwater structures, armoring, and pollution.

- Protect and enhance marine riparian vegetation. In the development of standards for protection, restoration, and enhancement, consider multiple functions.
- Protect forage fish spawning areas and other upper intertidal habitats and species. Concentrate restoration and enhancement efforts on areas with shoreline armoring and other development practices that reduce ecological processes and functions that support habitat quality.
- Develop a restoration strategy for the WRIA 8 and 9 nearshore that takes an ecosystem perspective within the landscape and helps to build our knowledge of the nearshore environment. Ensure that restoration projects and studies build upon a technical framework developed for the nearshore.
- Identify critical areas for protection, restoration, and enhancement in WRIAs 8 and 9. Then protect, restore, and enhance them. Considering that the shorelines of Vashon and Maury Islands are the least developed, concentrate protection efforts on them first, but don't exclude the mainland.
- Recreate intertidal acreage such as marshes, flats, and other habitats.
- Restore and recover estuarine intertidal flat and marsh habitat. Initial considerations should focus on appropriate salinity regimes and elevations, but should also consider other ecosystem processes in developing a functional design. Places to start include the Duwamish River estuary and subestuaries such as Miller Creek.

Reduction of Shoreline Modifications

Shoreline Armoring

- Reduce the amount of existing shoreline armoring in WRIAs 8 and 9, and prevent new installations of shoreline armoring.
- Restore natural physical and biological processes lost as a result of shoreline armoring and other bank stabilization practices.
- Determine and restore natural drift cell processes, specifically sediment budgets (i.e., rates, volumes, distribution). Feeder areas are particularly important. Where sediment supply is unimpeded, protect it. Where it is impeded, restore or enhance it at the appropriate temporal and spatial scale. Prevent the loss of sediment supply from armoring and other structures (i.e., jetties, groins) within the drift cell.
- Develop and implement technical guidance for alternatives to traditional shoreline armoring that maintain natural shoreline processes and functions.

Filling

- Reduce the amount of existing shoreline fill that has resulted from shoreline development practices and shoreline armoring.
- Prevent new fill in the nearshore.
- Where existing fill is removed, restore the area to low-gradient habitats such as flats, marshes, beaches, and backshore.

Overwater Structures

- Protect and enhance light penetration in the nearshore, including areas under existing overwater structures.
- Reduce the amount of existing overwater and in-water structures.
- Eliminate the use of construction materials and construction practices that may release environmental contaminants into the aquatic environment (i.e., treated wood products such as pilings and other structural components of docks and piers).
- Remove existing sources of environmental contaminants (i.e., treated piles and old floats).
- Eliminate obstructions to migratory corridors in the nearshore, including both in-water and overwater structures.

Water Quality

- Identify and control non-point pollution sources.
- Reduce, or preferably, eliminate point-source contaminants.
- Develop innovative methods of stormwater treatment, such as projects that use plantings of native vegetation to filter stormwater and retain sediments while improving fish and wildlife habitat.

Non-native Species

- Monitor and prevent the introduction and spread of non-indigenous and invasive species. Identify and eliminate sources of introductions.

Recreational Impacts

- Eliminate habitat impacts associated with the harvest of nearshore species and other recreational uses of nearshore habitats.

As a final note, the ability to improve nearshore ecosystem health and address the recommendations contained in this report will require a number of changes in the way we as residents and stewards live in this system. Recognizing and acknowledging the influences that we have on the processes, structure and functions of this ecosystem are critical to the development of meaningful avoidance and protection standards. Providing adequate resources and a framework for the development of new information, management strategies, restoration, and preservation will require a large-scale, coordinated effort that integrates various management efforts and crosses jurisdictional boundaries. Taking an ecosystem approach to understanding and managing nearshore resources is essential. These are but a few of the necessary elements that are needed to improve the quality of the nearshore ecosystem for all that depend on it.

Despite the fact that there have been changes in regulatory and management practices, and our level of scientific knowledge has increased in recent years, the effects of urbanization have continued to take a toll on nearshore resources. It is revealing to review environmental regulations, or mitigation actions and compare them to the level of protection they have actually provided in the nearshore environment. Considering the levels of habitat loss and degradation in the nearshore, they have proven to be inadequate. These concerns are not new, as are most of the conclusions and recommendations found in this report. For example, upon review of past proceedings of Puget Sound Research Conferences (1988; 1991; 1995; 1998; 2001), these issues surface time and time again. Likewise, reports from the Puget Sound Water Quality Authority (1990), Puget Sound Water Quality Action Team (i.e., Broadhurst 1998; West 1997; Lynn 1999), Puget Sound/Georgia Basin Task Force (1994), WADNR (2000), and WDFW White Papers (i.e., Williams et al., in prep.; Nightengale and Simenstad, in prep.), identify habitat losses and causes of habitat degradation. Interestingly, the problems, findings and recommendations contained in PSWQA (1990) apply just as much today as they did then. The list of problems and findings from this report are listed below:

Problems

1. There is no systematic fish and wildlife habitat inventory for Puget Sound basin.
2. Habitat protection in Puget Sound is frequently limited by gaps in interagency coordination and program integration.
3. We lack an ecosystem approach to habitat management in the Puget Sound basin.
4. We lack state and local goals and policies for habitat protection in Puget Sound with incentives to achieve that protection.
5. The public lacks awareness, understanding, and involvement in habitat protection issues and programs.
6. Enforcement of existing habitat protection laws in Puget Sound is inconsistent.
7. We lack funding for current and new programs that protect fish and wildlife habitat in Puget Sound.

FINDINGS

1. We lack clear state and local goals and policies for habitat protection in Puget Sound.
2. A number of problems need to be jointly addressed and solved by a number of agencies, governments, tribes, organizations, and individuals currently involved in actions affecting the management and protection of fish and wildlife habitat.
3. Agencies responsible for managing fish and wildlife habitats in Puget Sound do not have sufficient authority to adequately protect these habitats.
4. The public lacks awareness and understanding of habitat protection issues and programs in the Puget Sound area.
5. We lack adequate public involvement in issues relating the protection of fish and wildlife habitat in Puget Sound.

6. The resources for staffing adequate habitat review, inventory, monitoring, enforcement, and education efforts are currently inadequate.

Hopefully, the integration of nearshore environments into watershed plans, the recent petitions to list marine species under the ESA, and the recent listings of salmonids (chinook salmon, summer chum salmon, and bull trout) under the ESA will bring additional attention, resources, and efforts to preserving, protecting, and restoring the nearshore ecosystem.

DATA GAPS AND KEY FINDINGS

Nutrient Dynamics and Other Water Properties

Data Gaps

Water property data, including nutrient data, are lacking in the study area. No long-term data of offshore or nearshore water properties exist; therefore, changing conditions and human impacts cannot be evaluated. However, an encouraging first step is the WDOE Marine Water Monitoring program that was initiated in 1992. The program has two approaches: long-term monitoring and focused monitoring. Long-term monitoring consists of visiting numerous selected stations once per month with the goal of establishing and maintaining consistent baseline environmental data. Focused monitoring entails sampling individual locations for a short period of time with increased spatial and temporal resolution relative to long-term monitoring (Newton et al. 1998). This program, however, is focused in offshore waters of Puget Sound. Collection of nearshore data is seriously lacking as well. Most data collected to date have been part of a specific research agenda and in highly localized geographic regions. The recently implemented King County MOSS water quality sampling is collecting valuable data in WRIAs 8 and 9 that will begin to fill a gap in the nearshore data.

Key Findings

Based on limited data, it appears that nurient dynamics and other water properties may be modified by anthropogenic influences, particularly during seasonal periods with higher runoff. However, seasonal, interannual, geographic and spatial data are lacking to draw definitive conclusions.

Primary Productivity Dynamics and Rates

Data Gaps

Primary productivity estimates available for benthic and water column components are lacking in any great detail with the exception of early studies done in the Duwamish River and estuary (Table 4). Production estimates are a critical component in understanding the links between phytoplankton, zooplankton, and higher trophic levels in the food chain. In addition, no systematic, standardized sampling has been conducted over the years to allow a comprehensive examination of long-term changes in productivity. Most research to date has been conducted with agency-specific goals in mind. While the collected data are very useful within a specific context, they do not address the larger questions of spatial and temporal variation or long-term distributional change.

Table 4: Data gaps for primary productivity

Gaps	WRIA 8	WRIA 9
Primary productivity estimates for both benthic and water column components	All reaches	All reaches
Time-series data to allow assessment in changes over time, including spatial, temporal, and long-term distributional changes	All reaches	All reaches

Key Findings

- The nearshore zone in Puget Sound represents an area of relatively strong benthic-water column coupling, and nutrient limitation may occur under conditions of limited vertical mixing during the spring and summer.
- Preliminary data indicates primary productivity is limited by light in winter and nutrients in summer at some areas.
- Puget Sound is a relatively productive temperate estuary.

Food Web

Phytoplankton

Data Gaps

Long-term data on phytoplankton species abundance in Puget Sound, including harmful and toxic species, are unavailable (Table 5). This data gap precludes an understanding of interannual variations in community structure, and the possible long-term effects of changes in natural and anthropogenic sources of nutrients. Although studies in the Central Basin are beginning to indicate smaller scale temporal and spatial relationships among nutrients, chlorophyll, and production, additional studies are needed to fully understand phytoplankton production. Concurrent monitoring of nutrients, insolation, salinity, water temperature, and dominant zooplankton throughout the water column is needed to clarify nutrient-phytoplankton-zooplankton relationships. All of these factors have been shown to be important in determining species composition and distribution (Takahashi and Parson 1973; Parametrix, Inc. 1984). Despite continuous closures to recreational harvesting in WRIAs 8 and 9, there has been no direct causal link established between nutrient enrichment, eutrophication, and PSP in Puget Sound (Rensel 1993).

Table 5: Data gaps for phytoplankton

Gaps	WRIA 9	WRIA 8
Long-term abundance data	All reaches	All reaches
Interannual changes in community structure	All reaches	All reaches
Long-term effects of changes in natural and anthropogenic sources of nutrients	All reaches	All reaches
Relationships among nutrients, phytoplankton, and zooplankton	All reaches	All reaches

Zooplankton and Other Heterotrophs

Data Gaps

The need for analysis of archived samples described above as well as routine sample collection of present assemblages is essential for understanding the relationship of zooplankton abundance and distribution, human activity, natural cycles, and fish populations in Puget Sound (Table 6). Specifically, useful information would include species composition at varying depths and locations around Puget Sound; seasonal distribution and relationship to human activities; links among salmon, forage fish, and zooplankton; a comparison of fish and zooplankton diets between the late 1970s and early 2000s; and baseline zooplankton data for Puget Sound so that future comparisons can be made (Frost, pers. comm.).

Table 6: Data gaps for zooplankton

	WRIA 8	WRIA 9
Distribution and abundance time-series data	All reaches	All reaches
Species composition at varying depths and locations	All reaches	All reaches
Seasonal distribution and relationship to human activities	All reaches	All reaches
Links among salmon, forage fish, and zooplankton	All reaches	All reaches
Comparison of fish and zooplankton diets in the 1970s versus the early 2000s to assess potential changes	All reaches	All reaches
Baseline zooplankton data	All reaches	All reaches

Benthic Infauna and Epifauna

Key Findings

- Planktonic, as well as benthic algal and eelgrass-dominated habitats, are highly susceptible to anthropogenic nutrient increases.
- Harmful algal blooms can be intense and result in toxic shellfish as well as other health problems affecting humans and aquatic animals. Harmful algal blooms and elevated fecal coliform levels have closed virtually all WRIA 8 and 9 nearshore habitats to recreational shellfish harvesting.

- El Niño and other anomalous climatic events affect the dynamics of planktonic and benthic habitats.
- There are a large number of introduced benthic and planktonic species that may affect the food web and functions of benthic and planktonic habitats.
- No comprehensive study has addressed food web interactions in WRIA 8 and 9 nearshore marine habitats. However, similar studies in northern Puget Sound and the Strait of Juan de Fuca offer a number of insights into Central Puget Sound processes.
- The food web of shallow nearshore habitats of the region is based upon detritus produced by marine algae, estuarine and saltmarsh vascular plants, and especially eelgrass.
- Gammarid amphipods and calanoid copepods are important primary consumers that convert organic matter to upper trophic levels. Important secondary consumers include herring, sand lance, surf smelt, and juvenile salmon.

Selected Nearshore Habitat Types

Eelgrass Meadows

Data Gaps

Gaps in our knowledge of eelgrass within WRIAs 8 and 9 include the effects of shoreline armoring and bivalve harvest (Table 10) on eelgrass meadows. We also do not know enough about the historical distribution and abundance of eelgrass to draw any meaningful conclusions. Monitoring of eelgrass beds eventually would show trends in density and abundance, and perhaps allow scientists to distinguish natural variability from adverse effects of human activities. Better data on fish use of eelgrass, and the effects of urban runoff on eelgrass, would contribute to improved management efforts.

Table 10: Data gaps for eelgrass

Gaps	WRIA 8	WRIA 9
Complete maps, including measurements of area	Northern portion of reach 1 and southern portion of reach 3	All reaches
Monitoring of eelgrass beds	All reaches	All reaches
Incidence, causes, and effects of ulvoid blooms	All reaches	All reaches except 7
Effects of nutrient loading and urban runoff on eelgrass	All reaches	All reaches
Anoxic sediment impacts	All reaches	All reaches
Clam harvesting impacts and recovery rates	All reaches	All reaches
Effects of shoreline hardening	All reaches	All reaches
Interannual variability and natural vs. human-influenced controls of variability	All reaches	All reaches
Fish (especially juvenile salmon) and invertebrate use	All reaches	All reaches

Kelp Forests

Data Gaps

The general lack of historical and recent studies of kelp in Puget Sound results in numerous gaps in our knowledge. Mapping distribution and monitoring over time, studies of kelp forest ecosystems and species interactions, and the impacts of development and changes in water chemistry would prove invaluable for enhancing our understanding and improvement of our management of kelp and kelp dependent species. The most critical data gaps in our knowledge of kelp are provided in Table 11.

Table 11: Data gaps for kelp

Gaps	WRIA 8	WRIA 9
Complete maps of kelp forest area	Reach 3	All reaches
Monitoring of kelp forests	All reaches	All reaches
Interannual variability and natural vs. human-influenced controls of variability	All reaches	All reaches
Role of kelp in the food web	All reaches	All reaches
Harvest impacts	All reaches	All reaches
Effects of shoreline hardening	All reaches	All reaches
Ecological tradeoffs of kelp forest expansion due to shoreline armoring	All reaches	All reaches
Fish (especially juvenile salmon) and invertebrate use	All reaches	All reaches
Role of nutrients, temperature, and chemical contaminants on kelp growth and health	All reaches	All reaches
Effects of anthropogenic discharges on kelp	All reaches	All reaches
Effects of *Sargassum muticum* competition in disturbed kelp forests	All reaches	All reaches

Flats

Data Gaps

Although massive filling and development of the Duwamish Estuary and Elliott Bay has occurred over the past 125 years, eliminating 97 percent of mudflat and sandflat habitats, the total impact on juvenile salmonids and other estuarine resident species is not well understood (Table 12). The following data gaps have been identified:

Table 12: Data gaps for flats

Gaps	WRIA 8	WRIA 9
Complete maps of flat area	All reaches	All reaches
Interannual variability and natural vs. human-influenced controls of variability	All reaches	All reaches
Role of flat production in the food web	All reaches	All reaches
Bivalve harvest impacts	All reaches	All reaches
Effects of shoreline hardening	All reaches	All reaches
Fish (especially juvenile salmon) and invertebrate use	All reaches	All reaches
Comparison of fish use of disturbed and undisturbed flats	All reaches	All reaches
Role of nutrients, temperature and chemical contaminants on benthic plant and animal growth and health	All reaches	All reaches

Tidal Marshes

Data Gaps

Although massive filling and development of the Duwamish Estuary and Elliott Bay have occurred over the past 125 years, the total impact on juvenile anadromous salmonids and other estuarine resident species is not well understood. Significant data gaps in marsh ecology, such as the extent of interannual variability, role of upland buffers in marsh migration, and interactions between marshes and riparian zones, also exist. The significance of marshes in groundwater recharge, the role of periodic disturbance in marsh ecology, and the importance of large woody debris as habitat structure in marshes also are not well studied. Table 13 lists the identified data gaps.

Table 13: Data gaps for tidal marshes

Gaps	WRIA 8	WRIA 9
Complete maps of marsh area	All reaches	All reaches
Interannual variability and natural vs. human-influenced controls of variability	All reaches	All reaches
Role of reduced or altered upland buffers in allowing marshes to migrate inland with sea level rise	All reaches	All reaches
Role of marsh production in the food web	All reaches	All reaches
Fish (especially juvenile salmon) and invertebrate use	All reaches	All reaches
Interactions between marshes and riparian zones	All reaches	All reaches
Role of marshes in groundwater recharge	All reaches	All reaches
Role of periodic disturbance in marsh ecology	All reaches	All reaches
Role of large woody debris as habitat in marshes	All reaches	All reaches
Carrying capacity of disturbed and undisturbed marshes	All reaches	All reaches
Role of nutrients, temperature, and chemical contaminants on benthic plant and animal growth and health	All reaches	All reaches

Subestuaries (River Mouths and Deltas)

Data Gaps

More information regarding salmon use of small streams could be gathered. As of 1990, when the last sensitive areas map was constructed, there were several small streams that had not been classified because salmonid use had not been determined. However, city of Seattle streams have recently been assessed for stream type, habitat, fish type and salmon barriers and spawning (report in preparation, Gail Arnold, SPU, pers. comm.). Data gaps for subestuaries are listed in Table 14.

Table 14: Data gaps for subestuaries

Gaps	WRIA 8	WRIA 9
Information on juvenile salmonid use of small streams	All reaches	All reaches
Extent of impervious surface development in small stream watersheds	All reaches	All reaches
Relationship between impervious surface and subestuary degradation	All reaches	All reaches
Importance of subestuaries to migrating salmonids and other fish and wildlife	All reaches	All reaches
Effects of degraded water quality and habitat loss on subestuarine carrying capacity	All reaches	All reaches

Sand Spits

Data Gaps

Little current and historical information on sand spits is available for WRIAs 8 and 9, and we do not know conclusively how natural and human-influenced forces affect them. Table 15 shows gaps in our knowledge of sand spits, including their role in the food web and as habitat for fish and invertebrates.

Table 15: Data gaps for sand spits

Gaps	WRIA 8	WRIA 9
Natural interannual variability vs. human-influenced controls of variability	All reaches	All reaches
Role of sand spit production in the food web	All reaches	All reaches
Fish ,invertebrate, and wildlife use of existing spits	All reaches	All reaches
Cumulative and site-specific effects of shoreline armoring and other development practices on spits	All reaches	All reaches
Carrying capacity of disturbed and undisturbed spits	All reaches	All reaches

Beaches and Backshore

Data Gaps

Although massive urbanization has taken place in Elliott Bay and the Duwamish Estuary, and lower levels of development have occurred on the rest of the WRIA 8 and 9 shorelines, the cumulative effects of development on beaches and backshore are not well understood. Table 17 lists some of the gaps in our knowledge of beaches and backshore.

Table 17: Data gaps for beaches and backshore

Gaps	WRIA 8	WRIA 9
Role of production in the food web	All reaches	All reaches
Bivalve harvest impacts	All reaches	All reaches
Effects of shoreline hardening and other development practices	All reaches	All reaches
Fish (especially juvenile salmon and forage fish) and invertebrate use	All reaches	All reaches
Role of woody debris in nearshore ecosystem	All reaches	All reaches
Carrying capacity of degraded and undisturbed beaches and backshore areas	All reaches	All reaches

Banks and Bluffs

Data Gaps

Within WRIAs 8 and 9, massive shoreline development and armoring activities have taken place over the last 125 years. However, the total impact this urbanization has on banks and bluffs is not well understood. Table 19 lists some of the gaps in our knowledge of bluff and bank habitats.

Table 19: Data gaps for banks and bluffs

Gaps	WRIA 8	WRIA 9
Incidence of drainage/stability problems on bluffs	All reaches	All reaches
Effects of shoreline armoring and other development on banks and bluffs	All reaches	All reaches
Portion of beach sediment budget contributed by bluffs	All reaches	All reaches
Groundwater input from bluffs and banks	All reaches	All reaches

Marine Riparian Zones

Data Gaps

Relatively little research has been conducted on marine riparian areas compared to freshwater systems. Some research has occurred in other parts of the country on the effects of marine riparian vegetation on pollution abatement, soil stability, wildlife habitat, and fish habitat. However, little research has focused on Pacific Northwest systems. Additionally, regulations regarding functional buffer widths and riparian protection are not in place compared to freshwater systems. The functions and values of marine riparian vegetation need to be better documented in the scientific literature in order to provide a better understanding of riparian functions in marine ecosystems and to create adequate policies for protection and restoration.

Table 20: Data Gaps for Marine Riparian Zones

Gaps	WRIA 8	WRIA 9
Complete maps of marine riparian vegetation, including extent (width, continuity), type, density, composition	All reaches	All reaches
Percent impervious area and type of cover (i.e., concrete, asphalt, structures)	All reaches	All reaches
Role of MRV in food web (contribution of organic carbon, insects, etc.)	All reaches	All reaches
Role of MRV in providing water quality functions, especially non-point source pollution	All reaches	All reaches
Importance of MRV in providing shade to fish & wildlife	All reaches	All reaches
Role of MRV in providing microclimates	All reaches	All reaches
Role of MRV in providing wildlife habitat	All reaches	All reaches
Role of MRV in providing fish habitat	All reaches	All reaches
Role of MRV in increasing slope stability	All reaches	All reaches
Cumulative impacts of shoreline armoring and other shoreline development and land use practices on MRV and MRV functions	All reaches	All reaches

- Key Findings
- Distribution of Habitat Types
- Nearshore marine habitats in WRIA 8 and 9 are diverse and include marine riparian vegetation, banks and bluffs, beach and backshore, tidal marshes, tidal flats, eelgrass meadows, kelp forests, and water column habitats.
- These habitats act together to create the productive Puget Sound ecosystem by providing the physical, chemical and biological processes that form habitats and drive critical functions.
- Historical maps of nearshore marine and estuarine habitats are lacking in WRIAs 8 and 9; only recently have comprehensive mapping efforts (WDNR Washington State ShoreZone Inventory) been undertaken that adequately assess the region's nearshore marine resources.
- Eelgrass productivity exceeds that of most other aquatic plants. Organic carbon produced by eelgrass is especially important in driving the nearshore marine food web of Puget Sound.
- Overwater structures, shoreline armoring, fecal contamination, climate change, dredging, filling, resource exploitation, contamination, ship wakes and propellers have all contributed to major losses of habitat area and their functions in the region
- Monitoring programs have not adequately addressed long-term changes in habitat distribution.

There is no comprehensive understanding of the effects of multiple stressors on the viability of nearshore marine habitats in the region

Selected Fishes

Salmonids

Table 23: Data gaps for salmonids

Gaps	WRIA 8	WRIA 9
Standardized habitat assessment methodologies	All reaches	All reaches
Historic data for nearshore seasonal distribution and abundance	All reaches	All reaches
Residence times and rate of migration through the nearshore	All reaches	All reaches
Annual stock assessment data for forage fish species	All reaches	All reaches
Cutthroat trout use of nearshore habitats	All reaches	All reaches
Native char (bull trout) use of nearshore habitats	All reaches	All reaches
Carrying capacity of disturbed and undisturbed nearshore habitats for salmonids	All reaches	All reaches
Relationship of prey utilization to population dynamics		
Effects of pollutants on rapidly growing juveniles	All reaches	All reaches
Magnitude and sources of natural mortality vs. mortality under stressed conditions	All reaches	All reaches
Effects of over-water structures on predation rates, migration, and habitat	All reaches	All reaches
Effects of shoreline armoring and other modifications on salmonids	All reaches	All reaches
Assessment of cumulative effects	All reaches	All reaches
Effects of loss of connectivity between nearshore habitats	All reaches	All reaches

Key Findings

There are several key findings to note from this investigation.

- Salmonids use the nearshore for key elements of their survival, including: physiological transition, migration, nursery areas, juvenile food production and feeding, adult food production, and residence and refuge.
- Some stocks of young salmon enter and pass through nearshore habitats between early March and late June, but there is substantial variability depending on the species, location, and inter-annual differences. Several stocks migrate earlier (i.e., summer chum) and many other migrate through the summer and into the fall (i.e., various chinook stocks).
- Juvenile salmonids are present in many different nearshore habitat types with a very diverse range of biological and physical conditions, indicating juvenile salmonids are adaptable to a wide range of habitats, both constructed and natural.
- Depending on species and size, many salmonids are consistent in their diet composition when in estuarine/nearshore environments, most notably chum fry but also chinook. Conversely, in some estuarine environments, such as oligohaline marshes, they appear to be relatively non-selective, especially in some developed estuaries (i.e., Duwamish and Snohomish estuaries). When salmonids convert to pelagic foraging, their diets may become more diverse, but some species (i.e., chum, coho) still show specific diet affinities for certain taxa.

- Nearshore habitats have added importance because they are spawning sites for forage fish species, and salmonids feed on all life history stages of these species.
- Chinook salmon and cutthroat trout appear to be most dependent on the nearshore environment for all stages of their marine existence. Chum and pink salmon are also highly dependent during their fry and juvenile stages. Sockeye and coho salmon appear to be less dependent than other salmonids on estuaries and the nearshore, but do utilize the nearshore environment during their outmigration.
- In addition to natural stressors, human activities such as filling estuarine wetlands and intertidal areas, armoring shorelines, fishing, and polluting nearshore waters are also significant stressors of salmonid resources in WRIAs 8 and 9.
- A number of gaps in existing data need to be filled to attain a better understanding of ecosystem change across a multitude of spatial and temporal scales.

Forage Fish

Data Gaps

Reasons for increased natural mortality in herring are unclear, especially in light of the relatively low recent abundance levels of most Puget Sound herring predators.

Smelt migrations and movements of surf smelt are unstudied, and it is unclear if adults return to natal spawning beaches or exhibit fidelity to specific spawning beaches. In fact, little basic biological information exists for all forage fish in Puget Sound. Stock assessments, dietary studies, additional spawning surveys, and information about other life history requirements are needed for all forage fish (Table 25) (Bargmann 1998).

Table 25: Data gaps for forage fish

Gaps	WRIA 8	WRIA 9
Reasons for increased mortality of Pacific herring	All reaches	All reaches
Water quality effects on nursery grounds and young-of-year	All reaches	All reaches
Complete life history requirements of forage fish species	All reaches	All reaches
Information on forage fish stocks and biomass	All reaches	All reaches
Complete spawning ground surveys	All reaches	All reaches
Quantitative data on the effects of shoreline armoring and other shoreline development on spawning grounds	All reaches	All reaches
Complete spawning ground surveys	All reaches	All reaches

Key Findings

- Forage fish found within nearshore marine habitats of WRIAs 8 and 9 include herring, surf smelt, Pacific sand lance, eulachon, and longfin smelt. Forage fish use these habitats for feeding, migration, spawning, and rearing.
- Forage fish represent a significant component of the Puget Sound food web.

- Herring natural mortality in Puget Sound has increased in recent years; Puget Sound herring stocks are a candidate species under the ESA.
- Herring return to natal spawning grounds; egg attachment sites include firm substrates such as eelgrass and macroalgae. Sand lance and surf smelt spawn on upper intertidal beach habitats with sand/gravel sediments. All of these habitats are especially vulnerable to shoreline development.
- Within WRIA 8, there are no known herring spawning areas and only a limited number of documented surf smelt and sand lance spawning beaches. Within WRIA 9, one herring stock spawns in Quartermaster Harbor (Vashon Island). Surf smelt and sand lance spawning beaches are widespread on WRIA 9 shorelines, although spawning habitat inventories are incomplete. Regular spawning surveys and stock assessment are needed throughout the study area.

Groundfish

<u>Data Gaps</u>

Stressors, critical life history stages, habitat requirements, and reasons for poor year-class recruitment are generally unknown for all groundfish species listed above. Current distribution and habitat use data are lacking for nearshore habitats (Table 27).

The early life history of juvenile rock sole is poorly documented, and time-series of abundance data for English sole are generally not available for unfished areas to assess the effects of chemical contaminants or habitat alteration.

Table 27: Data gaps for groundfish

Gaps	WRIA 8	WRIA 9
Stressors to all species	All reaches	All reaches
Life history information for pollock and rock sole	All reaches	All reaches
Use of nearshore habitats for pollock, hake, lingcod, and rock sole	All reaches	All reaches
Factors influencing year-class recruitment of pollock and lingcod	All reaches	All reaches
Reasons for hake population decline	All reaches	All reaches
Time-series abundance data to assess the effects of chemical contamination and habitat alterations on English sole in unfished areas	All reaches	All reaches

<u>Key Findings</u>

- Important groundfish (defined as foodfish that reside near or on bottom) species in WRIAs 8 and 9 include the cods (Pacific cod, walleye pollock, Pacific hake), lingcod, English sole, and rock sole. Juvenile stages of all these species rely upon shallow vegetated nearshore marine habitats for rearing.
- Puget Sound stocks of Pacific cod, walleye pollock, Pacific hake are listed as candidate species under the ESA and as critical species by WDFW. Cods once supported large commercial fisheries, which have since collapsed. Cods are short-lived with highly variable interannual recruitment success and high susceptibility to demographic overfishing.

- Lingcod are listed as candidate species under ESA, although populations are considered stable by WDFW within south Puget Sound. Large lingcod individuals are the most susceptible to overharvest. Targeting large, highly fecund individuals reduces important brood stock for future generations.
- English sole and rock sole are widespread and abundant within Puget Sound; adults use nearshore areas for feeding, refuge, and spawning. These species are susceptible to the effects of sediment contamination, fishery overharvest, and habitat loss.

Rockfish

Data Gaps

Lack of reliable abundance estimates and general life history information for many species has hampered management and conservation efforts (Buckley 1997; West 1997; Musick et al. 2000). The importance of landscape position and the availability of habitat links in siting harvest refugia need to be further clarified. Impacts of habitat fragmentation are unknown. Table 30 lists these and other data gaps for rockfish.

Table 30: Data gaps for rockfish

Gaps	WRIA 8	WRIA 9
Life history information	All reaches	All reaches
Distribution and abundance	All reaches	All reaches
Importance of landscape position and habitat connectivity in siting harvest refugia	All reaches	All reaches
Effects of habitat alteration and fragmentation	All reaches	All reaches
Effects of contaminants	All reaches	All reaches
Species specific catch information	All reaches	All reaches
Stock assessments	All reaches	All reaches

Key Findings

- Over 20 species of rockfish inhabit Puget Sound, but only 3 (copper, quillback, and brown rockfish) are commonly caught by recreational or commercial fisheries in nearshore marine habitats.
- All rockfish stocks in Puget Sound for which there are adequate data are considered vulnerable or below average by WDFW; four species copper, quillback, brown, and boccaccio rockfish were candidate species under the ESA.
- Recreational and commercial catch records show long-term declines in rockfish populations. Rockfish are susceptible to overfishing, primarily because they are long-lived and fishing selects for the largest, most fecund, individuals. Marine protected areas may be an option for protecting their home range, but recruitment is poorly understood.
- Rockfish, particularly adults, require specific habitats.
- Much recent knowledge of rockfish distribution and abundance in WRIA 8 and 9 is derived from WDFW dive, video, acoustic, and trawl surveys. Studies of artificial reefs and marine

refuges in WRIA 8 and 9 (Edmonds Underwater Park, Boeing Creek) have improved understanding of rockfish population dynamics in the region.

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Selected Invertebrates

Data Gaps

Along the mainland, there are no recent quantitative studies of invertebrates from WRIAs 8 and 9. Along the coast of Vashon Island, studies for native littlenecks have concentrated on and near Maury Island. The west coast of Vashon Island (reach 12) and much of the northeast coast (reach 9) remains unstudied. There are no data available to accurately assess population trends. Table 32 lists the abundance of three species of hardshell clams at selected King County beaches.

No data are available to accurately assess population trends of Manila clams. It is not known whether Manila clams are invasive or simply filling a previously vacant ecological niche in Puget Sound.

Except for a limited area around Edmonds, there are no recent population data for geoduck beds in WRIAs 8 and 9. There are no data for population trends that is not confounded by harvesting. Data are lacking on the effects of stressors on geoduck populations (Table 31). Although they do not occur in the study area, assessments of Olympia Oyster and abalone population structure and trends are lacking

The abundance of Dungeness crab in central Puget Sound is unknown. This is because King County is at the southern range of abundance and fishing effort is not concentrated or consistent. A mark/recapture study is planned for the winter of 2000-2001 (J. Odell, WDFW, pers. comm.). Additional information would be valuable regarding lethal and sublethal effects of organic and inorganic pollution, and impacts of shoreline alterations on various life history stages of Dungeness crab (Table 31).

Table 31: Data gaps for invertebrates

Gaps	WRIA 8	WRIA 9
Recent quantitative abundance studies for all species	Reach 3	Reaches 4 and 12, and much of reaches 7-9
Effects of changes in habitat structure due to shoreline armoring, dredging, filling, and other development practices on recruitment and survival	All reaches	All reaches
Effects of exposure to lethal and sublethal contaminants on invertebrate populations and community structure	All reaches	All reaches
Effects of changes in detrital organic matter due to loss of marine and riparian vegetation on food supply	All reaches	All reaches

Key Findings

- Shellfish populations occurring within WRIAs 8 and 9 include native littleneck clams, butter clams, Manila clams, geoduck and other clams, and Dungeness crab. All of these species are commercially and/or recreationally harvested.
- Current information on hardshell clam distribution and abundance in WRIAs 8 and 9 is derived from the King County Beach Assessment Program. Some discrepancies and inconsistencies in sampling methods and locations exist to complicate analysis of hardshell clam abundance trends.
- Lincoln Park is one of the only beach habitats that has been quantitatively sampled repeatedly between the early 1970s and late 1990s.
- Shoreline siltation, loss of habitat, and water pollution affect hardshell clam populations.
- Except for a limited area around Edmonds, the most recent geoduck surveys from the mainland sections of nearshore marine habitats of WRIA 8 and 9 were collected in the 1970s; more recent surveys were conducted (1990s) from around Vashon and Maury Islands.

Shoreline Conditions

Shoreline Armoring

Data Gaps

Although there is qualitative evidence for many of the effects of shoreline armoring on the nearshore ecosystem, there is little quantitative data linking shoreline armoring to physical and biological changes. Ecological changes within drift cells should be quantified, as well as the cumulative effects of these changes on WRIAs 8 and 9. Table 33 lists some specific data gaps that need to be filled to better understand the effects of shoreline armoring.

Table 33: Shoreline Armoring Data Gaps

Gaps	WRIA 8	WRIA 9
Quantified relationships between shoreline armoring and changes in sediment budgets	All reaches	All reaches
Quantified relationships between shoreline armoring and changes in substrate	All reaches	All reaches
Quantified relationships between shoreline armoring and loss of shallow-water habitat	All reaches	All reaches
Quantified information on cumulative effects of shoreline armoring on intertidal and subtidal benthic communities	All reaches	All reaches
Quantitative studies of the effects of shoreline armoring on juvenile salmonid feeding opportunities	All reaches	All reaches
Quantitative studies of the effects of shoreline steepening on vulnerability of juvenile salmonids to predation	All reaches	All reaches
Carrying capacity of armored versus undisturbed shorelines	All reaches	All reaches
Effective and ecologically sound alternatives to conventional shoreline armoring	All reaches	All reaches

Overwater Structures

Data Gaps

There is limited information on the distribution and abundance of overwater structures in Puget Sound. Additional information on the effects of overwater structures on plant and animal communities is needed. Table 34 lists specific data gaps for overwater structures.

Table 34: Overwater Structures Data Gaps

Gaps	WRIA 8	WRIA 9
Cumulative and site-specific effects of overwater structures on nearshore processes and biological communities	All reaches	All reaches
Effective alternatives to and mitigation measures for docks and piers	All reaches	All reaches
Assessments of risk to juvenile salmonids posed by delays in migration caused by disorientation, lack of schooling in refugia, and changes of migratory route to avoid overwater structures.	All reaches	All reaches
Quantified relationships between overwater structures and predation rates on juvenile salmonids	All reaches	All reaches

Dredging

Data Gaps

While the effects of dredging on nearshore habitats and species are known in a general sense, little quantitative data links dredging to changes in habitats and species. Data gaps are summarized in Table 35.

Table 35: Data gaps for dredging

Gaps	WRIA 8	WRIA 9
Quantitative information on the effects of dredging on benthic habitat and communities.	All reaches	All reaches
Quantitative information on the potential to entrain salmonids including bull trout		Reach 4
Quantitative information on the effects of dredging on other nearshore species.	All reaches	All reaches

Filling

Data Gaps

There are very few studies of the changes in physical and biological environments that may have occurred as a result of historical fill activities. In addition, few studies have quantified the potential beneficial effects of beach nourishment and restoration projects. Data gaps are summarized in Table 36.

Table 36: Data gaps for filling

Gaps	WRIA 8	WRIA 9
Monitoring of beach nourishment sites to determine the effects	All reaches	All reaches

of nourishment on sediment budgets and biota		
Assessment of beach nourishment as an option for restoring beach habitat and protecting upland property	All reaches	All reaches
Quantitative estimates of the amount of nearshore habitat filled for shoreline armoring and other development purposes	All reaches	All reaches, except Elliott Bay & Duwamish Estuary
Cumulative effects of loss of nearshore habitats to filling on biota, especially juvenile salmonids	All reaches	All reaches

Sewage Discharges

Data Gaps

Few studies have identified and documented in a comprehensive manner the effects of discharges on the nearshore environment. Not only are studies of the effects of discharges on these ecosystems lacking, there is also a lack of basic baseline data for these habitats in general. Without this baseline information it is difficult to identify and separate impacts caused by human activity from the natural variation inherent in the nearshore. An effort should be made to identify and categorize the baseline condition of these habitats. Site-specific studies then should be conducted to examine the condition of the habitats adjacent to different types of discharges to determine if cause and effect relationships can be drawn. Data gaps are summarized in Table 37.

Table 37: Data gaps for sewage discharges

Gaps	WRIA 8	WRIA 9
Effects of sewage discharges on the nearshore ecosystem	All reaches	All reaches
Baseline data for habitats surrounding CSOs	All reaches	All reaches

Sediment Contamination

Data Gaps

There is a lack of basic knowledge on community-level effects from the mixtures of chemicals found in the environment (Table 39). Much is known about the effects of specific chemicals on individual species from toxicity testing, however the complex mixtures found in sediment habitats make it difficult to separate the effects of one chemical from another. This is an emerging science and rudimentary tests are available; however, their cost make them prohibitive for use in monitoring studies.

Table 39: Data gaps for sediment contamination

Gaps	WRIA 8	WRIA 9
Community-level effects of mixtures of chemicals	All reaches	All reaches
Sublethal effects of single contaminants and mixtures of contaminants	All reaches	All reaches
Relationships between sublethal effects and survival of organisms, particularly salmonids	All reaches	All reaches
Characterization of sediment contamination in the subsurface	All reaches	All reaches

Non-Point Pollution

Data Gaps

The primary data gaps of non-point pollution effects on the nearshore environment are related to the location, timing, identification, and quantification of contaminants (Table 40). More investigation is needed to identify how organisms respond to contaminants. In situ monitoring using mussels and the eggs or larvae of herring and sea urchins can be used to gain insight into the sub-lethal impacts of various pollutants. Investigations related to the synergistic effects of combinations of various levels of contaminants would also be helpful in prioritizing mitigation measures and regulation enforcement.

Table 40: Data gaps for non-point pollution

Gaps	WRIA 8	WRIA 9
Location, timing, identification, and quantification of contaminants	All reaches	All reaches
Sublethal effects of single contaminants and mixtures of contaminants	All reaches	All reaches

Non-Native Species

Data Gaps

The Puget Sound Expedition was conducted over only a brief period, and much of its work is provisional. Additional taxonomic work and review is needed. There is a need to do more sampling in low salinity areas and to expand research into the waters of British Columbia. Additional information is needed on smaller organisms, such as amphipods. Relationships of these organisms to the native food chain and microhabitats need further understanding. Much work needs to be done to understand the nature of these invasions and potential solutions to impacts. See Table 43 for a list of data gaps.

Table 43: Data gaps for non-native species

Gaps	WRIA 8	WRIA 9
Repeat sampling in all seasons	All reaches	All reaches
Additional taxonomic work and review of Puget Sound Expedition samples	All reaches	All reaches
Abundance, diversity, and effects of non-native species in low salinity areas	All reaches	All reaches
Abundance, diversity, and effects of smaller non-native species, such as amphipods	All reaches	All reaches
Distribution and abundance of non-native species in the study area	All reaches	All reaches
Effects of already established non-native species	All reaches	All reaches
Effective control measures	All reaches	All reaches

Key Findings

<u>Shoreline Armoring</u>

- Within WRIAs 8 and 9, between 75% and 87% of the shoreline has been armored or otherwise modified from historic conditions.
- Armoring modifies shoreline processes, affecting habitat structure and biological community composition.
- Shoreline armoring activities likely represent one of the most dramatic sources of nearshore marine habitat modification in Puget Sound.
- The linkages between shoreline armoring and biological impacts have not been adequately quantified to determine the types and levels of impact to nearshore biota.

Elliott Bay and The Duwamish River Estuary

Shoreline Conditions

<u>Data Gaps</u>

Despite the level of shoreline armoring in the Duwamish Estuary, Elliott Bay, and other urban embayments adjacent to anadromous streams, the effects of armoring on nearshore ecosystems have not been studied extensively. Table 46 shows the identified data gaps.

Table 46: Data gaps for shoreline armoring

Data Gaps – Shoreline Armoring
▪ There have been no definitive studies investigating the effects of armoring on juvenile salmon feeding opportunities. A few studies have investigated changes in the epibenthic community on armored habitats vs. natural habitats. Armored habitats have been found to provide suitable habitat for some forms of epibenthos that are known prey of juvenile salmonids; however, the ecological significance of different epibenthic communities to salmonids has not been studied.
▪ There have been no quantitative studies investigating the effects of shoreline armoring and associated shoreline steepening on the vulnerability of juvenile salmonids to predation. Existing data are qualitative, observational, or anecdotal (Heiser and Finn Jr. 1970; Pentec 1991).
▪ Long-term multi-estuary studies investigating residence time, survival, and growth in disturbed and undisturbed estuaries are needed to determine how highly modified environments affect salmonid populations.

Overwater Structures

Data Gaps

Studies conducted directly in Elliott Bay as well as other areas repeatedly verify that changes in the underwater light environment affect salmonid behavior and physiology. Table 47 shows the identified data gaps.

Table 47: Data gaps for overwater structures

Data Gaps – Overwater Structures
▪ Quantitative data are needed to determine the effects of overwater structures on migrating salmonids.
▪ Quantitative data are needed to determine the effects of overwater structures on predator-prey interactions, shifts in species composition, and physical dynamics of nearshore habitat.
▪ Quantitative and experimental data are needed to assess the risk to juvenile salmonids posed by:
▪ Delays in migration caused by disorientation
▪ Loss of schooling in refugia because fish schools disperse under low light conditions
▪ Changes of migratory route into deeper waters without refugia to avoid the light change
▪ Increases in losses to predators attracted to overwater structures.

Dredging

Data Gaps

Records of ACOE dredging in the Duwamish begin in 1928. No records of earlier dredging activities in the Duwamish were found.

Little is known about the cumulative effects of dredging on the nearshore ecosystem. Additional studies are needed to determine the short-term and long-term impacts to multiple species and ecosystem functions at dredging and disposal sites.

Filling

Data Gaps

The extensive filling of the Lower Duwamish River and Elliott Bay has undoubtedly had a dramatic impact on ecosystem processes, structure, and functions. Yet, there have been few studies that have attempted to quantify lost functions and the resultant impacts on aquatic resources.

Sewage Discharges

Data Gaps

Although numerous sediment and water quality investigations have been conducted in the Duwamish Estuary, some data gaps remain. Table 48 shows the identified data gaps.

Table 48: Data gaps for sewage discharges

Data Gaps – Sewage Discharges
▪ There is a lack of water and sediment monitoring data for nearshore habitats—most studies are conducted in deeper water, farther offshore. ▪ The CSO Water Quality Assessment conducted by Parametrix and King County DNR uses a water quality assessment model that could be further refined and validated by implementing a sampling program to verify the model's prediction of sediment transport and chemical concentrations. ▪ Additional studies are needed to determine the contaminant levels and impacts of acute stormwater discharges in the Duwamish and other industrialized drainages

Sediment Contamination

Data Gaps

Numerous sediment investigations have been conducted in the Duwamish Estuary and Elliott Bay; the areal distribution of surficial sediment contamination in the nearshore study area is relatively well known. Table 49 shows several data gaps that have been identified.

Table 49: Data gaps for sediment contamination

Data Gaps – Sediment Contamination
▪ Sediment contamination farther out into Elliott Bay is not as well characterized as in the nearshore. Although juvenile salmonids are less likely to contact these deeper sediments, studies have shown physiological impacts to flatfish associated with highly contaminated areas. ▪ The rate and role of natural attenuation is not well understood in the estuary and bay. Given recent reductions in contaminant inputs, it is not clear whether, or to what degree, natural burial and attenuation is reducing contaminant concentrations over time. ▪ Sediment contamination in the subsurface is not as well characterized as in surface sediments. Understanding the degree of subsurface contamination and the potential for it to become biologically unavailable is important when evaluating dredging and natural attenuation remedial options. ▪ The relationship between observed sublethal biological effects and the survival of fish, such as juvenile salmon and demersal resident marine fish, is largely unknown. Biochemical effects and physiological effects have been associated with contaminated areas, but whether this reduces growth or survival or affects behavior is not clear. As evidence, despite the documented levels of contamination along the Duwamish Estuary, hatchery chinook salmon released to the Green River by the Washington Department of Fish and Wildlife (WDFW) have a high fry-to-adult survival rate compared to other hatchery stocks released to cleaner areas of Puget Sound.

Key Findings

Shoreline Armoring

- Nearly 100 percent of the shoreline of the Duwamish Estuary is modified by riprap, steep mud banks, levees, or bulkheads.
- Seawalls with riprap toes, in conjunction with overwater structures, are present along much of the Elliott Bay waterfront. Seawalls are also present along about half of the sandy beach habitats along Alki Beach.
- The most substantial unarmored area in the study area is about 3,870 linear ft situated along Magnolia Bluff adjacent to Discovery Park.
- Very few studies have evaluated the effects of armoring on fish and other aquatic resources in the study area.

Elliott Bay

Data Gaps

Although several studies have examined the effects of changes in sediment dynamics on Elliott Bay and the Duwamish, numerous data gaps remain. Table 50 lists these data gaps.

Table 50: Data gaps for sediment dynamics

Data Gaps – Sediment Dynamics
▪ A comparison of the volume of silt, clays, and sands that currently are transported through the Howard Hansen Dam to sediment loading of these materials prior to the dam's inception would be useful. ▪ More definitive studies that address sediment transport from Elliott Bay to the Turning Basin in the Duwamish River are needed. ▪ Studies that address the impact of dredging activities on sediment transport from Elliott Bay to the Duwamish River are lacking. ▪ Calculation of sediment budget to determine if Duwamish River estuary habitats are stable or threatened by the loss of sediment supply.

Key Findings

Duwamish River

Dramatic alterations to flooding, stream flow, channel form, and sediment supply have significantly altered the sediment dynamics of the Duwamish River in ways that will continue to have long-term effects on its evolution. Large floods were primarily responsible for transporting and depositing large woody debris and sediments that regularly changed the configurations of the main active channel, side channels, and sloughs as well as providing abundant habitat for a variety of fish and wildlife. Today, the largest floods are a fraction of historical volumes and are allowed to occur only during the wettest time of the year (December through February). In conclusion:

- The sum total of these activities have resulted in a highly controlled river that has effectively eliminated the Duwamish River's ability to form and maintain channel complexity, such as lateral migration of the main channel, side channel and slough formation, and delta formation.
- Howard Hansen Dam has undoubtedly affected flooding in the Duwamish River, however its impact to sediment loading (silts, clays, sands) is largely unknown.
- There remains a question of how much contaminant transport occurs in the Duwamish River resulting from the tidal pumping of sediments landward. The assumption presented by ACOE (1997 p.36) implicates dredging practices for allowing the tide to migrate farther upstream than it had prior to channelization and dredging. This assumption may have some validity considering the potential combined effects of deepening the channel, reducing the watershed area by 70 percent, and reducing the freshwater discharge by 70 percent (ACOE 1997). Reducing the mean annual flow may have compromised the stream's ability to resist upstream migration of the high tides for greater time periods. Dredging the channel lowers the elevation of the channel bottom, which also makes it more accessible to a wider range of tides.
- The materials that compose the streambed may contain a greater concentration of sediments from Elliott Bay over a larger stretch of the Duwamish River if: (1) GeoSea Consulting's (1994) assertion is correct in that tidal activity dominates sediment deposition in the

Duwamish Waterway; and (2) tidal activity is occurring farther upstream than it had previously.

- More conclusive studies are required in order to show: (1) if sediment transport occurs from Elliott Bay to the Duwamish River; (2) if and to what extent dredging operations increase sediment transport from Elliott Bay to the Duwamish River; and (3) the spatial distribution of marine sediment deposition and riverine deposition.

Elliott Bay

- Two drift cells are present along the shore of Elliott Bay—one cell along the shore of Magnolia Bluff and another segment of a drift cell between Alki Point and Duwamish Head.
- Net shore drift along the southwest shore of Magnolia Bluff is dominated by westerly drift converging with shore drift from the northwest side of the bluff, forming a cuspate spit at West Point. The origin of the southwest Magnolia drift cell is immediately west of the Elliott Bay Marina.
- Net shore drift between Alki Point and Duwamish Head is also dominated by a westerly drift that begins well south of Elliott Bay near Burien. Sediments reaching the south shore of Alki Point are transported west and north around the point.
- Most of the Elliott Bay waterfront between Pier 91 and Duwamish Head has no appreciable net shore drift because of shoreline development. Water depth and the obstruction of piers precludes any significant longshore transport. At present, the only source of sediment for shore drift is erosion of undefended fill material.

Salmonid Distribution and Use

Data Gaps

Numerous studies have been conducted on salmonid use in the Duwamish Estuary, Elliott Bay, and other areas of Puget Sound. Much is understood regarding the general migratory behavior, timing, distribution, and feeding habits of juvenile salmonids, but key questions remain, particularly with regard to restoration issues and optimal habitats and the quantitative effects of degraded habitats. The following data gaps are summarized in Table 54:

Table 54 Data gaps for salmonids

▪ Data Gaps – Salmonids
▪ Most estuarine and nearshore habitat studies have been conducted in developed areas; relatively little information has been collected in less- or non-degraded habitats. The responses of juvenile salmonids in developed areas may not be representative of natural estuaries. There is a need to study and document juvenile salmonid behavior in undisturbed areas to establish a baseline.
▪ There is a lack of quantitative sampling data for juvenile salmonids' use of nearshore and open beach habitats around Elliott Bay.
▪ Juvenile salmonids grow rapidly, but there are no data on possible food limitations in the Duwamish Estuary and Elliott Bay, nor comparison data from undisturbed estuaries and bays (i.e., on the growth potential of these fish in the absence of the high degree of habitat disturbance evident in the area).
▪ More data are needed regarding predation on juvenile salmonids in the estuary and the effects of highly modified habitats on survival. The interactions between overwater structures and shoreline hardening and salmonid predation rates are not known. Habitat modifications that increase predation, or which offer a greater degree of protection and refuge, have not been well studied. A better understanding of physical separation that may or may not exist between juvenile salmonids and their predators is needed.
▪ The role of shoreline armoring and other upland development practices, such as modifying riparian zones, on juvenile salmonids is poorly understood.
▪ Additional information is needed on the presence and habitat utilization of native char.
▪ There is also a need for the long-term collection of quantitative data on residence time and condition indices, and the same from relatively undisturbed estuaries. These data, collected annually, would provide the necessary baselines to better evaluate future development projects for their impacts on juvenile salmon habitats, and would guide the selection and construction of restoration sites in the estuary.
▪ The long-term effects of bioaccumulation and toxicological pathways through the food chain have not been assessed.
▪ Estuarine carrying capacity for the Duwamish and Elliott Bay need to be addressed. There is a lack of quantified information on habitat carrying capacity for juvenile salmonids.

Key Findings

- Eight species of anadromous salmonids use the Duwamish Estuary, Green River, and Elliott Bay. Chinook and coho salmon and steelhead are common, while pink and sockeye salmon, sea-run cutthroat trout, and bull trout are much less common.. Small runs of chum salmon also occur, with larger runs in recent years.
- Juvenile chinook and chum salmon are highly dependent on estuarine habitats, as evidenced by studies of residence time, diets, and behavior. During their downstream migration, these species enter the estuary during the late winter/early spring and most individuals appear to spend 1 to 2 weeks in the estuary before entering Elliott Bay. They are, however, likely to be present in the estuary during at least eight months of the year. Less is known about

residence times in the bay, but most have left the bay by the end of summer. The other salmonids are less abundant and do not appear as estuarine dependent as chinook or chum salmon.

- All of the juvenile salmonids in the estuary have been found to feed on gammarid amphipods, dipteran insects, and harpacticoid copepods.
- Adult chinook and coho salmon runs in the Green River appear stable, with larger runs over the past 15 years compared to earlier years. Chum salmon runs have historically been small in the Green River, but over the past 3 years larger runs exceeding 10,000 fish have been observed. In contrast, winter steelhead runs have shown a steady decline over the past 30 years. Appreciable pink and sockeye salmon runs do not occur in the Green River.
- Sea-run cutthroat trout are present in the Green River, but little is known about the species.
- Bull trout have been reported in the river, but are not believed to spawn in the basin.
- Historically, it is believed that spring and fall chinook, coho, sockeye, pink, and chum salmon; winter run steelhead, sea-run cutthroat, Dolly Varden char, and bull trout used the basin.
- Changes in species composition and abundance can be linked to the development of the estuary. The substantial elimination of sockeye and spring chinook salmon runs are likely linked to the diversion of the Black and White Rivers early in the century. The substantial elimination of pink salmon may be due to diversions or channel armoring in the lower river.
- There is a general lack of sufficient ecological data to quantify the role of estuaries in the development and survival of juvenile salmonids. Many distributional studies have been conducted, but the links between habitat use, growth and survival, and armoring, industrial development, and other alterations to habitat and ecosystem processes and functions are limited in terms of ecosystem modeling and scientific monitoring.

Other Fin-Fish Distribution and Use

Data Gaps

Although the Duwamish Estuary and Elliott Bay have been fairly well studied, the focus has been on salmonid use as juveniles, and adult salmonid stock assessment. Gear types most effective at sampling non-salmonids (i.e., bottom and mid-water trawls, purse seines) have not been used in recent studies. Several data gaps regarding other fin fish species are apparent and identified in Table 57:

Table 57: Data gaps for other fin-fish species

Data Gaps – Other Fin-fish Species
▪ Stock assessments of demersal fish species are needed. Very little is known regarding the populations and movements of demersal species, particularly those candidates for ESA listing. Interactions of fish populations with oceanographic conditions, such as long-term temperature regimes and interactions with predators, are not clear. ▪ Existing data sets for demersal fish species have been collected by WDFW and the University of Washington, but have not been fully analyzed or published. The Muckleshoot Indian Tribe has not analyzed extensive beach seining data from 1995. ▪ Stock assessment of important forage fishes such as surf smelt and sand lance are lacking. Beach spawning habitats in the study area are not fully known and it is unclear whether discrete spawning populations exist or use specific beach habitats. ▪ An assessment of toxicological pathways through the food chain is needed.

<u>Key Findings</u>

- Non-anadromous fish species documented within the Duwamish Estuary are dominated by estuarine and marine species, with only a few freshwater species. Thirty-three species were observed in a recent survey dominated by shiner perch, staghorn sculpin, starry flounder, sand lance, and prickleback.
- In contrast, the fish assemblage in Elliott Bay is much larger; fish surveys have documented about 80 species. Dominant species include English and rock sole, Pacific tomcod, shiner and striped seaperch, tubesnout, and ratfish.
- The highest abundance and species richness occurs during the summer and fall with the lowest during the late winter and early spring.
- Studies have found striking increases in abundance and species richness in fish assemblages associated with eelgrass compared to sand substrates.

Shellfish Distribution

<u>Data Gaps</u>

Shellfish populations in Elliott Bay are presently not harvested because of high fecal coliform counts and industrial effluent inputs. However, the ability of shellfish to improve water quality by removing pollutants from the water column is unknown. The effects of this bioaccumulation on shellfish and other species are also unknown.

<u>Key Findings</u>

Limited data suggests that over 400 acres of suitable geoduck habitat may exist in Elliott Bay, which could support over 700,000 clams.