PART II: FACTORS OF DECLINE/CONDITIONS

# 4. Summary of Estuary and Nearshore Conditions

# 4. SUMMARY OF ESTUARY AND NEARSHORE CONDITIONS

## INTRODUCTION

The nearshore environment in the WRIA 9 watershed is extremely complex, productive, and provides important habitat structure and functions for the support of salmonids and other fish and wildlife. While historical urbanization and development practices have altered or destroyed much of this habitat, efforts are underway to develop planning and management strategies to reduce ongoing losses and recover habitat processes and ecosystem functions that are vital to the survival of our nearshore natural living resources. Achieving these goals requires an understanding of these processes, functions, and species life history requirements. Unfortunately, while numerous documents describe salmon life history, habitat requirements, and strategies for assessment, recovery, and management, few even mention estuarine and marine ecosystems and life history requirements, even though anadromous salmonids depend heavily upon the nearshore for early survival and spend most of their lives in the marine environment. This lack of scientific knowledge leaves us few alternatives but to develop a conceptual approach to understanding the nearshore ecosystem and how salmonids depend upon and interact with the system.

A conceptual model builds upon existing knowledge of the physical, chemical, and biological processes that form and maintain habitat. In addition, it may use principles of conservation biology and landscape ecology and account for effects of human-induced activities. Conceptual models show how various processes interact to form nearshore habitat and ecological functions important to salmonids. In the absence of adequate levels of quantifiable data, we can use such a model to help us understand how natural processes interact and how alterations or modifications in these processes may affect multiple or individual species. For example, erosion of coastal bluffs that were built from glacial deposits, and the transport of these sediments along the shoreline, are processes that form and maintain our beaches. Rivers and streams also supply sediments to our beaches. Sediment type and distribution determines species composition and use in certain areas. If sediment sources are cut off, or distribution is interrupted, it could change the plant and animal species composition within an area. Indirectly, these changes could affect salmonids if those species happen to be important for refuge or prey items for salmonids. There are numerous examples of how alterations in ecosystem processes, individually and cumulatively, change habitat characteristics and may affect salmonids directly or indirectly. Yet, we know little about many of these individual processes and even less about the ecosystem as a whole.

This chapter begins with a conceptual model of salmonid use of the nearshore, and discusses what is known about salmonid use of the nearshore and the factors that may adversely affect salmonid habitat. Key findings and data gaps are listed at the end of each section. Much of the information in this chapter is drawn from the draft *Reconnaissance-level Assessment of the State of the Nearshore* report (SONR) (Williams, et al. In Prep.). The draft SONR gathers together existing information about selected nearshore and estuarine habitats and species, providing a summary of what is known about the nearshore ecosystem in WRIAs 8 and 9. Because the SONR is still in draft form, all information in this chapter is considered **preliminary and subject to change**. The final report will refine and expand upon the information offered below, and list recommendations for addressing data gaps and habitat limiting factors in the nearshore environment. Readers are strongly encouraged to refer to the final document, which is scheduled for publication in January 2001.

## GEOGRAPHIC SCOPE

This chapter covers the marine and estuarine nearshore environments of WRIA 9, including Vashon and Maury Islands (Figure NS-1). This area encompasses approximately 83 miles of shoreline, of which 49 are on Vashon and Maury Islands. The northern boundary of the WRIA 9 nearshore is West Point, and the southern boundary is just north of Dumas Bay in the City of Federal Way. The Washington Department of Ecology places Vashon and Maury Islands within WRIA 15. However, discussions are underway with Kitsap County, Lead Entity for WRIA 15, on an agreement to include Vashon and Maury Islands in WRIA 9 for planning purposes. Therefore, nearshore and estuarine environments of Vashon and Maury Islands are included in this chapter. While the geographic scope of this chapter is WRIAs 8 and 9, it is important to note that salmonids from other WRIAs utilize the WRIA 9 nearshore as they migrate.

## DEFINITION OF THE NEARSHORE

The nearshore environment is strongly linked to both upland habitats and deeper waters, and is the interface between marine and terrestrial environments. For the purposes of this report, the seaward boundary of the nearshore is the outer limit of the photic zone [approximately -30 meters Mean Lower Low Water (MLLW)] (Figure NS-2), or the depth beyond which there is insufficient sunlight penetration for active photosynthesis. The nearshore environment extends landward to include coastal landforms such as bluffs, the backshore, sand spits and coastal wetlands, as well as the riparian zone on or adjacent to any of these areas. In addition, the nearshore environment includes sub-estuaries such as the tidally influenced portions of river and stream mouths (Figure NS-3). Examples of sub-estuaries in WRIA 9 include the mouths of direct drainages to Puget Sound such as the Duwamish River and Miller and Des Moines Creeks.

# SALMONID USE OF THE NEARSHORE ENVIRONMENT

Salmonids, particularly chinook, chum, and the anadromous form of cutthroat trout, depend upon the nearshore environment both as juveniles and as adults. The nearshore environment is also vital to numerous aspects of the food web upon which all anadromous salmonids depend. This section presents a conceptual model of salmonid use of the nearshore environment and then discusses salmonid use in detail.

## CONCEPTUAL MODEL

The nearshore environment is complex and can be highly productive. It is constructed and maintained by a wide variety of processes. Figure NS-4 is a conceptual model illustrating how these processes interact to form nearshore habitat structures, which provide essential ecological functions to salmonids. The figure also shows the locations where human activities affect this ecosystem.

The geoclimatic setting provides many of the building blocks for the ecosystem. For example, the geologic history of Puget Sound left massive deposits of sediments. The bathymetry and topography of Puget Sound create the basis for shallow, deep, and steep habitats. A wide variety of physical, chemical, and biological processes work with these building blocks to create habitat structure. Erosion and sediment transport processes carry sediments to beaches, spits, and other coastal landforms. Tides bring nutrients, and expose certain areas and inundate others. Fresh water flows into Puget Sound via rivers, streams, and seeps, all of which create complex patterns of salinity.

These ecological processes create a diversity of habitat types that provides essential ecological functions. Where and when these processes operate without interruption, they create connected habitats. The quantity and quality of habitat also are linked to these processes; where they operate naturally, they generate high quality habitat. These processes also contribute to the foodweb through nutrient cycling, tidal flux, introduction of organic litter and insects, and maintenance of highly productive habitats such as eelgrass. The cumulative result of these processes working in concert is a complex landscape composed of a variety of habitat types and functions.

This system is extremely important to salmonids, particularly juveniles. Cederholm et al. (2000) found that one of the most important concepts in understanding how juvenile salmonids use nearshore habitat is that they do not necessarily use individual habitats. Instead, they utilize a "landscape mosaic" of habitats due to changes in tides, freshwater runoff, and life history requirements. Many factors, such as predator/prey distributions, tides, river flows, and genetic structure, affect how juveniles move through the nearshore. However, the distribution and connectivity of critical landscape features such as brackish rearing and tidal freshwater areas may be just as important in providing opportunities for juveniles to use preferred habitats (Cederholm et al. 2000).

However, in many instances human activities have disrupted the processes that create and maintain this landscape mosaic, as well as the habitats themselves. Shoreline development, particularly bank hardening, blocks the natural erosion processes that create beaches and shallow-water habitats. Diversion of rivers, such as the Cedar and White from the Green, reduces freshwater flows and freshets important for maintaining salinity gradients and complex flood plains. Dredging and channelization of rivers, such as the Green/Duwamish, eliminates estuary complexes and flood plains. Filling of lowlands creates new land for development, but destroys marshes, flats, swamps, and other shallow habitats. Although many of these changes were made historically, habitat loss and disruption of processes continues in the nearshore. As a result, the landscape mosaic upon which salmonids depend has been and continues to be altered, degraded, and in some areas, destroyed.

The remainder of this chapter provides more detail about salmonid use of the nearshore environment, and the factors that adversely affect the nearshore landscape, likely limiting salmonid production.

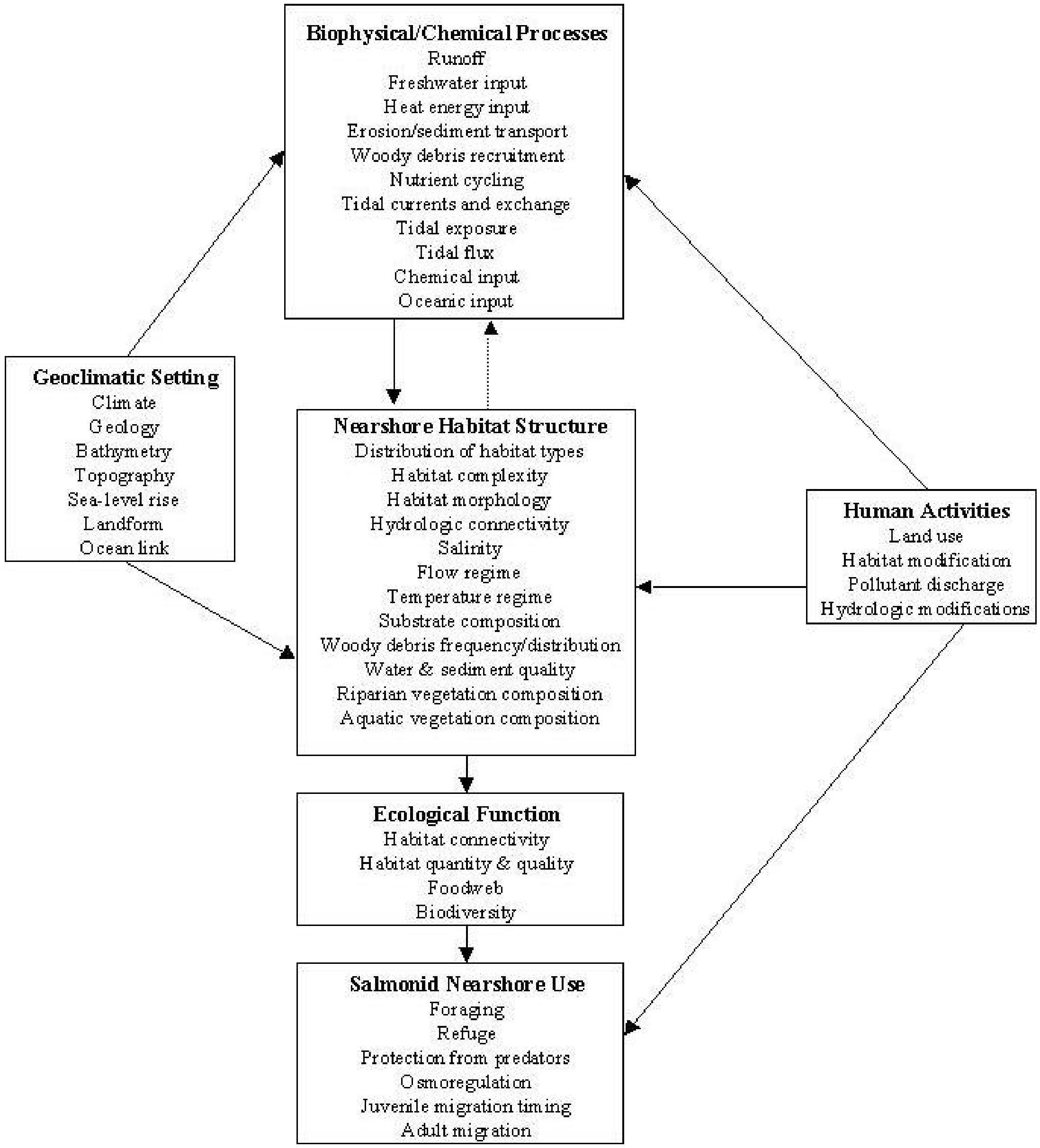


**Figure NS-4: Conceptual model of salmonid use of the nearshore environment (after Martin, 1999)**

## SALMONID USE OF THE NEARSHORE ENVIRONMENT

The landscape mosaic of nearshore habitats provides a number of critical functions for salmonids (Williams and Thom, 2000; Simenstad, 1999; Aitkin, 1998):

- Migratory corridors for both adults and juveniles
- Refuge for both adults and juveniles
- Nursery habitat for juveniles
- Food production and feeding areas for adults and juveniles
- Residence/staging areas for adults
- Physiological transition for adults and juveniles

The following discussion provides an overview of these functions and individual species' use of the nearshore.

### NEARSHORE SUPPORT OF JUVENILE SALMONIDS

Studies of juvenile salmonid use of estuaries indicate that early estuarine survival can be a key determinant of adult returns (Simenstad 1999). During this life stage, juvenile salmonids rely on the nearshore for feeding, refuge, and the salinity gradients necessary for the physiological transition from fresh to salt water (Williams and Thom, 2000). Juvenile salmonids depend upon a detritus-based food web for their prey resources. However, the composition of this detritus varies from place to place in the nearshore. Some estuaries depend upon eelgrass more than others, whereas some receive most detritus from rivers, and still others depend more upon phyto-plankton and benthic algae (Wissmar and Simenstad, 1998). Studies to determine the relative inputs of detritus have not been conducted in WRIA 9.

Juvenile salmonids depend upon shallow-water habitats, especially in the early stages as they make the physiologically difficult transition from fresh to salt water, avoid predators, and grow rapidly. In particular, tidal marshes and channels, eelgrass beds, and shallow sand and mud flats provide protection from predators and places to rest and forage. As smolts grow larger and begin to move into deeper waters, they rely more heavily on planktonic prey, but some, especially chinook, continue to eat insects that drift out from shore (Simenstad 1999). Juvenile salmonids rely on high quality and diverse habitats as they migrate to the ocean.

### NEARSHORE SUPPORT OF ADULT SALMONIDS

Adult salmonids use the nearshore as a place to feed and rest. Returning spawners may remain in the nearshore environment for up to 21 days before entering freshwater streams and rivers. Throughout the adult phase, several types of forage fish, including surf smelt, sand lance and Pacific herring, are primary prey items for some species of salmonids (Williams and Thom, 2000). These forage fish rely on nearshore habitats for meeting a variety of life history requirements, including spawning, refuge, and feeding. Adult salmonids also use nearshore environments to complete their physiological transition from salt to fresh water.

## INDIVIDUAL SPECIES' USE OF THE NEARSHORE

Eight species of anadromous salmonids are present in nearshore areas of WRIA 9: chinook, coho, chum, pink, and sockeye salmon, and steelhead, anadromous coastal cutthroat, and native char. Of all salmonid species, juvenile chinook and chum are the most dependent on the nearshore environment (Williams and Thom, 2000; Aitkin, 1998). Juvenile chinook have been documented as staying up to 189 days in sub-estuarine environments such as marshes and river mouths, but there are no published data that define total residence times in coastal nearshore areas. Most juvenile chinook spend only about two weeks in the heavily industrialized Duwamish estuary (Williams et al., In Prep.). Although the peak juvenile out-migration occurs in spring (March-June), juveniles commonly arrive earlier and may be present in the nearshore environment throughout the year if conditions are favorable. For example, recent beach seining studies found juvenile chinook in WRIA 9 nearshore areas through August (pers. comm., B. Mavros) and into November (pers. comm., T. Nelson). Juvenile chum salmon are also highly dependent on nearshore areas for feeding, refuge, and growth for extended periods (Williams and Thom, 2000).

Juvenile pink salmon feed and take refuge in nearshore environments, peaking from March-June, although they may arrive earlier and stay later. Pink salmon juveniles typically move quickly through sub-estuaries and seem to prefer bays and shallow areas, but may be found in estuarine tidal channels for brief periods. Because coho smolts are much larger than other juveniles by the time they reach the nearshore, scientists believe that they prefer deeper habitats than do other anadromous salmonid species. However, they do utilize shallow-water habitats such as eelgrass and flats in the coastal nearshore and tidal channels in sub-estuaries, as seining studies have shown. Several studies also have shown that juvenile coho utilize sub-estuaries, sometimes in high densities (Johnson, 1999). Juvenile sockeye appear to have the shortest residence time in the nearshore of all salmon species, but take refuge and forage in productive habitats there. Coastal cutthroat trout juveniles, subadults, and adults use a variety of nearshore habitats, but congregate near gravel beaches with upland vegetation and shallow nearshore habitats with large woody debris for feeding and migration. Also, since cutthroat rarely spend the winter in marine waters, they utilize tidal freshwater areas of sub-estuaries until conditions are favorable for upstream migration. Steelhead trout prefer deeper waters and seem to spend very little time in the nearshore. Unfortunately, little is known about native char use of the nearshore environment (Williams and Thom, 2000). However, it is assumed that native char (e.g., bull trout) use the nearshore for feeding and migration. Recent seining efforts have captured native char in the Duwamish River (pers. comm., B. Taylor).

## KEY FINDINGS

- Salmonids, especially juveniles, utilize a landscape mosaic, rather than individual habitats *per se* in the nearshore. Eight species of anadromous salmonids utilize nearshore habitats in WRIA 9.
- Salmonids produced in other geographic areas also utilize nearshore habitats in WRIA 9.
- A wide variety of physical, chemical, and biological processes create and maintain the diversity and connectivity of nearshore habitats.
- Human activities can interrupt these processes, and alter, degrade, or destroy habitats.

- Early salmonid survival and growth can be an important determinant of adult returns.
- The nearshore environment provides migratory corridors, nursery areas, feeding and prey production areas, refuge, and habitat for the physiological transition from fresh to salt water environments for juveniles of all species of salmonids.
- The nearshore provides migratory corridors, staging and feeding areas, and habitat for the physiological transition from salt to fresh water environments for adult salmonids.
- All anadromous salmonids utilize and depend upon the nearshore. Of the salmonid species, chinook and chum salmon rely most heavily upon the nearshore environment.

### DATA GAPS

- Little detailed information is available on the importance of nearshore habitats to the growth and survival of fish. Actual juvenile salmonid use of eelgrass, kelp, flats, tidal marshes, subestuaries, beaches and backshore areas are data gaps.
- There is a general lack of data quantifying the role of nearshore habitats in the development and survival of juvenile salmonids.
- The relative contributions of different sources of detritus to the food web in WRIA 9 are not known.
- There is limited data on the residence time or migration rates and spatial patterns of juvenile salmonids in the nearshore, or on how these times and patterns influence survival.

## NEARSHORE AND ESTUARINE HABITAT LIMITING FACTORS

As discussed in the previous section, salmonids rely upon a complex landscape of habitats in the nearshore environment, but human activities have disrupted this landscape. This section provides more information about these activities and details about their effects in WRIA 9. For the purposes of this report, we have grouped these activities into five categories: (1) loss of habitat in the migratory corridor, (2) degradation of water and sediment quality, (3) alteration of processes, (4) loss of riparian functions, and (5) introduction of non-native species. Each of these is discussed below.

### LOSS OF HABITAT IN THE MIGRATORY CORRIDOR

Over the past 150 years, substantial amounts of habitats have been altered and/or destroyed in WRIA 9. By far the most striking example of nearshore habitat loss in WRIA 9 occurred in the Duwamish River Estuary and Elliott Bay, beginning as early as 1895. In order to create new land for development and deeper channels for navigation, 97 percent of shallow areas, flats, and marshes in the Duwamish were eliminated by 1986 (Figure NS-5). All (100 percent) of the tidal swamps bordering the Duwamish were filled by 1940 (Williams et al., In Prep.).

Although these habitat losses may be considered historic, habitat loss continues to occur. Lynn (1998) describes several mechanisms for nearshore habitat loss, including the following:

- Shoreline armoring eliminates riparian habitat, leads to beach erosion, interrupts sediment transport, disrupts organisms dependent on those sediments, and displaces and destroys high intertidal habitat. Vertical bulkheads in lower intertidal zones may slow the migration of juvenile salmonids in migratory corridors (Heiser and Fin, 1970).

- Filling displaces aquatic vegetation, eliminates shallow-water habitats such as marshes and flats, and can cover spawning habitat.
- Dredging kills nearshore organisms during dredging, destroys shallow-water habitats by deepening them, releases toxins into the water column if sediments are contaminated, and removes vegetation that traps sediments.
- In-water structures cast shade, which can kill organisms and seems to prevent juvenile chinook from passing under the structures, interrupting their migration (Williams et al., In Prep.).

Shoreline armoring (i.e., bank hardening) is the placing of structures such as bulkheads, seawalls, and riprap along the shoreline in order to protect upland property from erosion. According to the ShoreZone database recently compiled by the Washington Department of Natural Resources (WDNR), shoreline armoring covers 75% of the shorelines in WRIA 9, and from 50-90% of shorelines in the Duwamish River and Elliott Bay (Williams et al., In Prep.). Therefore, it is reasonable to infer that shoreline armoring has caused a significant amount of nearshore habitat loss and degradation in WRIA 9.

Although the filling of all tidal swamps, and almost all marshes and flats, in the Duwamish River and Elliott Bay are the most dramatic examples of filling in WRIA 9, smaller-scale filling activities continue. Nearshore habitats often are filled to support residential development, especially the installation of shoreline armoring.

Most dredging in WRIA 9 has occurred in the Duwamish River, Elliott Bay, and marinas. Extensive dredging in the Duwamish straightened and widened the channel, eliminated the distributary channels, and created the East and West Waterways. These projects contributed to the near-total loss of flats and marshes in the Duwamish Estuary (Williams et al., In Prep.). Dredging also occurs in marinas and slips in order to maintain navigational safety. In WRIA 9, overwater structures are most prevalent in Elliott Bay and the Duwamish, but residential docks and piers occur along the shorelines of Puget Sound as well (Williams et al., In Prep.).

The combination of these massive, historic habitat losses and the cumulative impacts of smaller, on-going losses has resulted in major changes in the landscape mosaic upon which salmonids depend. However, little is known about the effects of these changes on salmonid use of WRIA 9. Few studies have examined salmonid behavior in developed estuaries versus natural ones, there is no data on possible prey resource limitations in the Duwamish and Elliott Bay, and the effects of shoreline armoring and other development practices on salmonids are poorly understood.

## DEGRADATION OF WATER AND SEDIMENT QUALITY

Numerous human activities can lead to degradation of water and sediment quality in the nearshore. Storm water runoff, improperly functioning septic systems, point source discharges, oil spills, agricultural practices, and clearing and grading practices all contribute contaminants to nearshore waters and sediments (Lynn, 1998). Adverse effects of degraded water and sediment quality include smothering of marine plants through excess sedimentation or algal blooms caused by nutrient enrichment (Lynn 1998), and bioaccumulation in fish, shellfish, and mammals (Williams et al., In Prep.).

Water and sediment quality in Elliott Bay and the Duwamish have been degraded severely. Studies have shown that several organic compounds (such as PCBs and PAHs) and metals (such as mercury, cadmium, and zinc) are present in the sediments of some areas of Elliott Bay and the Duwamish at levels that exceed state standards. The most highly contaminated areas are within the East and West Waterways of the Duwamish and west of Harbor Island, and are Superfund sites.

Although there is much less information about water and sediment quality in the nearshore environment of WRIA 9 outside of Elliott Bay and the Duwamish River, the data that exist indicate that water and sediment quality are acceptable. Subtidal water samples indicate that water quality is generally good (http://dnr.metrokc.gov/wlr/waterres/marine/index95.htm) outside of Elliott Bay and the Duwamish. King County monitors sediment quality at Alki Point and Seahurst Park, and has found that the levels of various contaminants in the sediments are well below those thought to be harmful to benthic organisms (Williams et al., In Prep.).

Adverse effects of degraded water and sediment quality include smothering of marine plants through excess sedimentation or algal blooms caused by nutrient enrichment (Lynn 1998), and death of organisms through poisoning or smothering. These processes damage the landscape mosaic upon which salmonids depend, and can decrease their prey resources. Degraded water and sediment quality also can affect juvenile salmonids directly. Several studies have noted that these chemicals bioaccumulate in fish, shellfish, and mammals collected in the Duwamish River estuary, and have found indications of genetic damage in juvenile salmonids (Williams et al., In Prep.). However, not enough is known about the sublethal effects of these contaminants on salmonids or other species.

## ALTERATION OF PROCESSES

As the Conceptual Model (Fig. NS-4) shows, many processes create and maintain habitat in Puget Sound, and are fundamental to the maintenance of the habitat mosiac upon which salmonids depend. Human activities have altered or interrupted many of these, but perhaps the most significant changes in WRIA 9 have been interruption of sediment transport and alteration of freshwater input.

### INTERRUPTION OF SEDIMENT TRANSPORT

In Puget Sound, nearshore sediments come primarily from slumping of banks and bluffs, while the remainder comes from rivers and streams. The transport of sediments from the landslides and streams is critical to the maintenance of beaches, spits, flats, eelgrass beds, and other nearshore habitats. Waves and currents provide the bulk of this transport, which is organized into units called drift cells. Drift cells are zones along the coast that act as closed or nearly closed systems with respect to transport of sediments (Johannessen, 1992), and generally begin with an area in which sediment is deposited or eroded, such as bluffs (often called feeder bluffs). Waves and currents then carry this sediment to an area of deposition, such as a beach, headland, or spit. Although daily and seasonal changes in tides and currents can change the direction of drift, over the long term each drift cell has a direction of net sediment transport (Johannessen, 1992). Figure NS-6 shows the drift cells in WRIA 9.

In WRIA 9, shoreline armoring and other shoreline development have interrupted the natural movement of sediment. Shoreline armoring traps sediment behind and beneath it, preventing waves and currents from picking it up. Armoring also reflects wave energy more strongly than a natural beach does, causing waves and currents to scour beaches and flats in front of seawalls and other structures, further upsetting the natural balance of sediments. Because shoreline armoring prevents nourishment of beaches while erosion continues to occur, beaches in front of shoreline armoring structures may narrow or disappear entirely (Williams and Thom, 2000).

Other shoreline development can alter sediment transport processes as well. Roads, homes, marinas, and other structures built along the shoreline can deprive the nearshore of sediments. Where structures jut into the water, they can inhibit, and in some instances block, the movement of sediment past them.

The ShoreZone mapping program conducted by the Washington Department of Natural Resources indicates that approximately 75% of the 83 miles of WRIA 9 shoreline is armored. Surveys conducted for the Port of Seattle indicate that nearly 100 percent of the shorelines of the Duwamish River Estuary is modified by dikes, levees, or revetments. From river mile (RM) 12 to the Turning Basin, 56 percent of the shoreline had visible riprap armoring and 3 percent had vertical bulkheads in some portion of the intertidal zone. From the Turning Basin to the mouth of the Duwamish, 65.8 percent of the shoreline is riprapped and 5.3 percent has near-vertical bulkheads. Nearly 90 percent of Elliott Bay is riprapped or armored with rubble, and 16.2 percent has vertical bulkheads or seawalls. Along much of the shoreline, bulkheads or seawalls occur in the upper intertidal zone with riprap or rubble in the lower zone (Williams et al., In Prep.). It is reasonable to infer these extensive modifications of the WRIA 9 shoreline alter natural sediment transport processes.

Sediment transport processes are critical to the formation and maintenance of many nearshore habitats that make up the landscape mosaic. In turn, many nearshore plant and animal species rely on particular sediment sizes for spawning, attachment, burrowing, or root development. For example, forage fish, especially surf smelt and sand lance, require certain sediment grain sizes for their spawning grounds (Williams et al., In Prep.). Forage fish are a key prey item for some species of adult salmonids, particularly chinook and coho. Figure NS-7 shows the known distribution of forage fish spawning beaches in WRIA 9, based upon data from the Washington Department of Fish and Wildlife[1]. Significant changes in sediment size caused by the interruption of sediment transport processes could deprive these important fish of their spawning habitat (Williams and Thom, 2000). Increased erosion also can deprive juvenile salmonids of the shallow habitats they require for protection from predators (Williams and Thom, 2000).

Although shoreline armoring and other development have interrupted sediment transport processes around the Sound, few quantitative studies of the effects of shoreline development on

[1] These data are likely incomplete because surveys have not been conducted on all beaches, or in multiple years. The figure also does not show surveyed beaches where forage fish spawn was not recovered.

sediment transport have been done. In turn, few quantitative studies of the effects of interrupted sediment transport on biological communities exist.

### ALTERATION OF FRESHWATER INPUT

Freshwater is very important to nearshore habitats. In particular, in estuaries such as the Duwamish, freshwater is necessary to create the gradations in salinity that influence habitats and species. Floods create complex habitats in natural flood plains. Streams and seeps support riparian vegetation.

In WRIA 9, significant alteration of freshwater input has occurred in the Duwamish River estuary. Historically, the Cedar, Black, Green, and White Rivers flowed into the Duwamish River, producing a mean annual flow of between 2500 and 9000 cfs (Williams et al., In Prep.). The White River was diverted in 1911, followed by the Black and Cedar Rivers in 1916, reducing the drainage area of the Duwamish Basin by 70 percent. Two dams on the Green River, a water diversion dam and the Howard Hansen Dam, further restrict flows and flooding in the system. By 1996, the mean annual flow of the Duwamish was about 1700 cfs, a reduction of between 32 and 81 percent (Williams et al., In Prep.)[2].

These alterations have affected the Duwamish Estuary in a number of ways. The severe reduction in drainage area and management of floods has eliminated the large floods that historically created side channels and sloughs, deposited large woody debris, formed deltas, and reworked sediment deposits. The diversion of the White River removed the historic primary source of sediments for the Duwamish. Reductions in the freshwater input, coupled with dredging of the Duwamish Waterway, allows salt water to penetrate further up the estuary than it did historically (Williams et al., In Prep.). These changes have altered dramatically the landscape upon which salmonids in the Green River depend. However, little is known about how these changes affect salmonid behavior or survival.

## LOSS OF RIPARIAN FUNCTIONS

Riparian areas are the transition zones between aquatic habitats and upland areas, such as banks and bluffs. Although much is known about the importance of riparian areas in freshwater systems, relatively little research has been conducted on the functions and values of riparian vegetation in marine systems. Brennan and Culverwell (In Preparation) hypothesize that marine riparian areas provide functions similar to freshwater riparian areas and may provide additional functions unique to marine systems. Marine riparian areas may provide numerous functions including wildlife habitat, erosion control, pollution abatement, sediment retention, shade, organic matter, large woody debris, and salmonid prey items (insects) to the nearshore environment. In particular, data exists to show that salmonids benefit directly or indirectly from many of these riparian functions. For example, juvenile salmonids continue to feed on terrestrial insects even when moving to deeper marine waters (Simenstad 1999), and some species of adult salmonids prey upon surf smelt, which spawn in the upper intertidal zone (Williams et al., In Prep.). Surf smelt eggs, deposited during the summer months, experience higher survival on

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[2] For more information about hydrologic modifications in the Green/Duwamish section, see Chapter 2.3, Hydromodification.

shaded beaches than on non-shaded beaches in north Puget Sound, suggesting that the shade provided by riparian vegetation is important to the survival of the species (Penttila, 2000).

However, shoreline armoring and other shoreline development have reduced severely the amount of marine riparian vegetation in WRIA 9. When bulkheads or seawalls are constructed, riparian vegetation is removed. Owners of shoreline residences cut down trees and other native vegetation to improve their views, or make room for structures, roads, and landscaping. The ShoreZone mapping program conducted by the Washington Department of Natural Resources (WDNR) estimated that marine riparian vegetation exists along only 11 percent of the WRIA 9 shoreline. Because WDNR defined marine riparian vegetation as only trees overhanging the intertidal zone, this number likely underestimates the actual amount of marine riparian vegetation in WRIA 9 (Williams et al., In Prep.). However, it is safe to infer that the majority of WRIA 9 shorelines do not have marine riparian corridors that provide effective ecological functions.

## NON-NATIVE SPECIES

Non-native species are those species that have been introduced to Puget Sound through a variety of means, including discharges of ballast water from ships, packing materials for seafood shipped from overseas, and intentional or unintentional establishment by the mariculture industry. Non-native species may compete with and/or displace native species, inflicting severe damage on the food web and the nearshore ecosystem.

Very little data exists about non-native species in WRIA 9. The 1998 Puget Sound Expedition identified 39 non-native species in the shallow waters of Puget Sound as a whole (Cohen et al., 1998), but did not indicate which species were found in specific geographic areas. The chapter on non-native species elsewhere in this report contains a comprehensive list of these species.

Non-native species of concern include *Spartina spp.*, salt marsh grasses native to the east coast of the United States that drive out native marsh plants; and *Sargassum muticum*, a seaweed that can smother intertidal species. However, little data exists about these or other organisms' effects on the landscape mosaic upon which salmonids depend, or on salmonids themselves.

## KEY FINDINGS

- Massive amounts of habitats critical for juvenile salmonid support in the migratory corridor have been lost. For example, 97 percent of the marshes and flats, and 100 percent of tidal swamps, have been removed from the Duwamish River.
- Shoreline armoring, dredging, filling, and overwater structures have contributed much of this loss of habitat in the migratory corridor.
- Commercial, industrial, and residential development has contributed toxic chemicals and organic compounds to the water and sediments of the nearshore environment in WRIA 9, primarily in Elliott Bay and the Duwamish River.
- Among many others, sediment transport and freshwater input processes are critical for maintenance of important nearshore habitats.
- In WRIA 9, shoreline armoring and development have interrupted sediment processes. Approximately 75 percent of the WRIA 9 shoreline is armored.

- Significant alterations of freshwater input have occurred in WRIA 9, particularly in the Duwamish River basin. These alterations have reduced habitat complexity and sediment loading in the Duwamish.
- Significant amounts of marine riparian vegetation have been lost from WRIA 9 shorelines. The WDNR ShoreZone program estimates that only 11 percent of WRIA 9 shorelines have trees overhanging the intertidal zone.
- Non-native species may be detrimental to salmonid survival in the nearshore in WRIA 9, but more data is necessary to identify specific effects of particular species.

## DATA GAPS

- Little is known of the cumulative effects of loss of habitat in the migratory corridor on juvenile salmonids.
- The details of juvenile salmonid use of nearshore habitats are not well understood.
- Complete maps of nearshore habitats do not exist in all areas.
- The carrying capacity of natural and altered nearshore habitat for salmonid support is not fully understood. Similarly, the amount of carrying capacity in the nearshore necessary to support self-sustaining runs of salmonids is not known.
- Sublethal effects of sediment and water contaminants on salmonids and other nearshore organisms are fully understood.
- Very little is known about the cumulative effects of interrupting natural sediment transport processes in the nearshore.
- Although shoreline armoring is very widespread in the nearshore environment, few studies address the effects of armoring on nearshore biota over the long term. Similarly, little is known definitively about the cumulative effects of shoreline armoring on the nearshore environment. More specifically, very few studies have investigated the effects of shoreline armoring on juvenile salmonid feeding, vulnerability to predation, and overall survival.
- Surveys of forage fish spawning areas are incomplete, and stock assessments are absent.
- The effects of the major hydromodification of the Duwamish River on salmonids are not known.
- Very little data on the functions and values of marine riparian vegetation exists.
- Non-native species may be detrimental to salmonid species' survival in WRIA 9, but more data is necessary to identify specific effects of particular species.
- Assessment methods for evaluating habitat quality and for directing mitigation, restoration, preservation, and enhancement efforts are lacking.

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