10. SHORELINE CONDITIONS

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SHORELINE ARMORING

Although the term shoreline armoring is often used in reference to bulkheads and seawalls, it is used more broadly here to describe a number of different structures. Shoreline armoring is, in a general sense, the placement of structures in the nearshore in an attempt to intercept wave energy and/or control the movement of sediment. Because these structures typically are constructed of rock, concrete, wood, or metal, the practice is sometimes referred to as shoreline hardening.

Property owners armor their shorelines for a variety of reasons, including the following:

- To create areas of calm water, such as for a marina
- To stabilize entrances to harbors, rivers, and inlets
- To trap sand in an effort to control beach width
- To protect upland property from wave-induced erosion
- To retain or stabilize unstable banks and bluffs
- To create shoreline real estate by retaining fill
- To establish moorage for vessels
- To enhance property values
- To protect foundations of structures

However, shoreline armoring often fails to accomplish these goals, and can have serious unintended adverse effects upon nearshore habitats and species. Even so, shoreline armoring is widespread in Puget Sound: the recent increase in the population of Puget Sound has resulted in the armoring of more than 29 percent of the shoreline, with an additional 1.7 miles of shoreline armored each year (Canning and Shipman 1995). More than half of the shoreline of the Main Basin of Puget Sound, and 79 percent of the eastern shoreline of the central basin, have been modified as a result of shoreline armoring (Puget Sound Water Quality Action Team 2000).

Types and Distribution

There are six main types of shoreline armoring structures:

- *Breakwaters* are self-supporting structures intended to deflect or absorb waves, creating areas of calm water (Mulvihill et al. 1980; ACOE 1984). Most breakwaters are placed in high-energy environments, are generally parallel to the shore, and are commonly built up from the seafloor with rough stone, pre-cast concrete, sheet piles, or pilings.
- *Jetties* are built perpendicular to shore, often starting landward of the high water mark and extending into the subtidal (Mulvihill et al. 1980). Jetties are constructed in an effort to stabilize entrances to harbors, bays, and rivers (ACOE 1981).
- *Groins* are similar to jetties, but serve a slightly different purpose. Property owners install groins to trap sediments, usually to increase the width of a beach (ACOE 1981).

- *Bulkheads* are vertical or near-vertical structures built parallel to the shoreline (ACOE 1981), usually of concrete or rock. Property owners construct bulkheads in an effort to protect upland property from wave-induced erosion, to stabilize banks and bluffs, to retain fill, and to create moorage for vessels (ACOE 1981).
- *Seawalls* are more massive bulkheads and generally are built in areas of moderate to high wave energy (ACOE 1981).
- *Revetments* are built either to protect foundations of structures such as bulkheads and piers or as a form of bulkhead, and most often are constructed of large rocks called riprap.

Marine shorelines of WRIAs 8 and 9 are heavily armored. The ShoreZone database shows that 87 percent of the WRIA 8 shoreline and 64 percent of the WRIA 9 shoreline is armored (WDNR, 1999). In WRIA 9, 75% of the mainland shoreline, 84% of the Elliott Bay shoreline, and 50% of the Vashon/Maury Island shoreline are armored. In WRIA 8, almost the entire shoreline from Shilshole Bay north is armored as a result of the Burlington Northern railroad tracks being built on the shoreline. Bulkheads and seawalls are the most common shore protection technique used in Puget Sound.

In WRIAs 8 and 9, breakwaters form the outer boundaries of marinas. Edmonds, Shilshole Bay, Elliott Bay, and Des Moines Marinas all have breakwaters. There are no jetties in WRIAs 8 and 9. Although groins can no longer be built in Washington State, there are a few in WRIAs 8 and 9. Those identified include one in Edmonds (Brackett's Landing Park), several along the shoreline of the Magnolia neighborhood in Seattle, in Seahurst Park in Burien, and some in Des Moines and Federal Way.

Physical Effects of Armoring on the Nearshore

Washington Department of Ecology's Coastal Erosion Management Studies (MacDonald et al. 1994) present an excellent description of the impacts of armoring on physical processes of the nearshore environment. Much of this section is drawn from their work.

The most prominent effects of shoreline armoring on nearshore physical processes are as follows (after Macdonald et al., 1994):

- Loss of beach area from placement of structures
- Impoundment of sediment behind structures
- Modifications of groundwater regimes
- Lowering of beach elevations
- Redirection and intensification of wave energy
- Alterations of substrate
- Loss or riparian vegetation and associated functions

Each of these impacts is described below.

Shoreline armoring structures often are built at or below the high water mark, on or across the beach itself, and/or out into the intertidal and subtidal zones. One obvious effect of such construction is that these beach, intertidal, and subtidal habitats are permanently lost.

Furthermore, the processes and functions that feed into, or are provided by these altered areas are interrupted.

Shoreline armoring structures, especially bulkheads, seawalls, revetments, groins, and jetties, trap sediments. Bulkheads, seawalls, and revetments often prevent sediments from moving from banks and bluffs to the beach, where longshore currents can entrain them. Groins and jetties, if built properly, interrupt longshore transport, causing sediment to accumulate on their updrift sides and be redirected offshore. As a result, shoreline armoring interrupts sediment delivery and transport in drift cells, thereby starving downdrift beaches of necessary sediments (see Drift Cells, Section 3).

If shoreline-armoring structures are impermeable, they can cause alteration of local groundwater regimes. An impermeable structure such as a bulkhead can cause the water table behind it to rise, thereby increasing pore pressure in the beach material and rendering it more susceptible to wave erosion (Macdonald et al., 1994). Changes in groundwater regimes also can exacerbate landslides.

Longshore transport of sediment is a natural and healthy process in Puget Sound (see Drift Cells, Section 3). However, if waves and currents remove sediments from beaches that are sediment starved, the beach will retreat landward and erode. If a seawall is built on a retreating beach, the beach in front of the seawall will continue to erode and steepen. In turn, the water in front of the seawall will deepen, gradually changing the environment from beach to intertidal or subtidal.

If shoreline-armoring structures are placed below the ordinary high water mark, they will interact with waves more frequently. Vertical structures such as bulkheads reflect waves back into the surf zone, where their energy adds to that of incoming waves to increase the rate of the erosion in front of the structure (Tait and Griggs, 1991). As a result, the beach in front of the structure narrows, and ultimately can disappear. If the structure has an end wall that anchors it to the uplands, the end wall will reflect wave energy onto the adjacent beach, causing it to erode as well. This increased erosion often encourages adjacent property owners to construct shoreline-armoring devices, creating a domino effect (Macdonald et al., 1994).

The installation of shoreline armoring does not halt the processes of erosion; as described above, armoring can intensify erosion. Waves continue to entrain sediments in front of such structures, particularly fine sediments such as silt, clay, fine sands and gravel. As a result, finer sediments are removed from areas in front of bulkheads and seawalls, leaving behind coarser sediments such as gravel and cobble. Over time this process results in a change in overall substrate character from fine to coarse sediments. Many of the beaches in Puget Sound are composed of only a thin veneer of finer sediments, underlain by a coarse material, or hardpan. Thus, the erosion of a sand/gravel beach can result in a complete loss of natural beach characteristics and associated fauna.

Many of these effects can take years or even decades to become apparent, so studying and documenting them is very difficult and rarely attempted. In addition, because many of these effects occur at locations downdrift of armored areas establishing cause and effect relationships is challenging.

Biological Effects of Armoring on the Nearshore

The physical effects of shoreline armoring discussed above lead to shifts in habitat structure and species assemblages, changes in ecological processes, and direct and indirect impacts on nearshore species and communities. Thom and Shreffler (1994) provide an excellent overview of these effects; unless otherwise cited, the information in this section is drawn from their work.

Shoreline armoring causes sediment starvation, and intensifies wave energy so that fine sediments are winnowed away, leaving behind coarse sediments and eventually bedrock, or hardpan. These changes amount to a shift in habitat structure. As a result, the species assemblages also change, from ones that favor finer sediments to those that favor coarse sediments and rocky substrates. For example, such a shift in the most common beach habitat type in Puget Sound, a mix of sand and gravel would change from an assemblage of small crustacea, bivalves, and eelgrass to rocky/hardpan communities composed of barnacles, seaweed, and other associated flora and fauna. In addition, the structures bury the organisms and habitat under the footprint of the structure, potentially reducing prey production and organic reduction for higher trophic levels.

Shoreline armoring also affects ecological processes. Because armoring can increase erosion rates on beaches, it removes areas for organic matter to accumulate. The composition of such matter also changes if armoring displaces vegetation. This organic matter provides habitat for insects and amphipods, and provides nutrients as it is converted through reduction and decomposition. Shoreline armoring can alter nutrient dynamics further if it interrupts the flow of streams to a beach or changes the groundwater regime. Freshwater carries nutrients and inorganic compounds to beaches and the intertidal zone. Shoreline armoring can affect the migration of animals, including fish. Groins and jetties that jut into the subtidal zone force juvenile salmonids and other fish into deeper waters where they may experience increased predation. Armoring also alters shade on beaches, as discussed under Marine Riparian Zones. Loss of shade on surf smelt spawning sites reduces egg survival (Penttila, 2001).

Shoreline armoring has a number of direct and indirect effects on finfish and wildlife Loss of riparian cover leads to decreases in the shade, cover, detrital input, and terrestrial prey upon which juvenile salmonids depend. Loss of wetland vegetation such as tidal marshes eliminates critical refuge, forage, and osmoregulation areas. Alterations in marine riparian vegetation lead to loss of habitat complexity, refuge, and nutrient sources. Shifts in intertidal and subtidal communities reduce nutrients and food sources for juvenile and adult fishes, such as salmonids, birds and other wildlife. Loss of shallow-water habitat and changes in intertidal communities degrade migratory corridors.

Changes in habitat structure eliminate spawning sites for forage fish and rock sole. For example, surf smelt require high intertidal sites with particular sediment sizes for spawning. They are therefore particularly vulnerable to direct loss of habitat from the construction of shoreline armoring as well as changes in substrate caused by armoring.

Aquatic vegetation, shellfish and other invertebrates also are affected by shoreline armoring. When shoreline armoring increases erosion at one point, those sediments are deposited downdrift, or offshore, and can smother aquatic vegetation and benthic infauna, changing community composition. For example, changes in substrate can render habitat unsuitable for clam recruitment, or for the establishment of eelgrass. Habitat functions supported by eelgrass or other substrate types, such as foraging, spawning and refuge are, in turn, lost.

Cumulative Effects of Shoreline Armoring on the Nearshore

Site-specific effects of individual bulkheads include burial, beach erosion, transference of wave energies, which can result in erosion of adjacent lands, reduction of sediment input, reduced riparian functions and other associated system processes and functions. While these individual, site-specific effects may not have a dramatic impact on the overall system, the cumulative impacts within the site and throughout the system (or subsystem such as a drift cell) are likely to be much more severe. Because shorelines in WRIAs 8 and 9 are heavily armored, these cumulative effects are a major concern.

Unfortunately, there currently are no quantitative studies of the cumulative effects of shoreline armoring on the ecology of the nearshore ecosystem in Puget Sound (Thom et al., 1994). Studies elsewhere have quantified some of the physical effects (i.e., Tait and Griggs 1991). The principles of landscape ecology and conservation biology should be incorporated into any future assessment.

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

Types and Distribution

Overwater structures in marine waters include floating docks, covered moorages, houseboats, boathouses, houses, piers, pilings, marinas, barges, rafts, booms, mooring buoys, and floating breakwaters (Nightingale and Simenstad 2001).

There is limited information on the distribution and abundance of overwater structures in Puget Sound. Floating docks, covered moorages, and mooring buoys are common around Puget Sound. There are 54 docks and piers in WRIA 8, and 3 marinas, according to the ShoreZone database (WDNR 1999). The same database records 81 docks and piers along the mainland shoreline of WRIA 9, 73 docks and piers in Elliott Bay, and 37 docks and piers around Vashon/Maury Islands, for a total of 191 docks and piers in WRIA 9. There are 12 marinas in WRIA 9: one on the mainland shoreline, one in Elliott Bay, and 10 on Vashon/Maury Islands (WDNR, 1999).

According to the Shoreline Management Act, houseboats are not allowed anywhere in the state except limited locations in Lake Union and Portage Bay. Boathouses and overwater houses are typically associated with floating docks. Piers often serve as a connection between floating docks and the upland. Pilings are widely scattered around Puget Sound, some associated with docks and others relics of long abandoned shoreline activities. Barges, rafts, and booms are typically associated with overwater industrial activities and often are relocated to various worksites.

Effects upon Nearshore Ecosystem

Overwater structures are typically located in the nearshore. They change the levels of light, shoreline energy regimes, substrate type and stability, and water quality (Nightingale and Simenstad 2001). These changes result in altered abundance and diversity of species in nearshore marine ecosystems. Light levels may be reduced to levels below those necessary for photosynthesis, fish feeding, predator avoidance, schooling, and migration. Overwater structures can alter wave energy and sediment dynamics, affecting substrate size, type and stability, plant propagation, fish foraging, spawning and migration, and shellfish settlement and rearing. Overwater structures can affect the seabed, disturbing or destroying benthic organisms and vegetative growth. Construction materials can leach contaminants into the environment and boats, boathouses, houseboats, and marinas are sources of water pollution.

Docks, piers, and pilings can interfere with the light for plant growth and propagation (Simenstad et al. 1998). The area of shade created by overwater structures is related to the structure size, height, height above the water, orientation to the sun, and the construction materials (Olson et al. 1996, 1997). Covered moorages, houseboats, boathouses, and houses can cover relatively large areas of the water surface, constantly shading the area below the structure. Fixed floating docks completely block the light to the surface, creating constant shade for an unchanging area while those anchored by chains move and allow for light penetration to areas as they are uncovered (Penttila and Doty 1990). Marinas are groupings of individual piers, often behind a breakwater, where large areas of light reduction can occur. Barges, rafts, booms, and floating breakwaters block light and can affect plant reproduction within one week (Penttila and Doty 1990).

Studies of marinas found fish near the shoreline and perimeter of the marina, but not in dark areas under the docks and moored boats (Nightingale and Simenstad 2001). Avian predation on fish in marinas did not appear to be related to the floating docks and moored vessels. Studies have found fewer juvenile fish under piers than in surrounding open waters and reveal that piers supported by piles interfere with the migration of fish (Able et al. 1998; Nightingale and Simenstad 2001). The construction of piers increases turbidity and the sound of pile driving can influence fish behavior. Floating breakwaters allow for improved fish passage over conventional solid breakwaters, but their impacts on fish behavior are not fully understood (Nightingale and Simenstad 2001). When barges, rafts, vessels, and booms ground into the nearshore bottom, this can kill benthic and intertidal organisms and plants and disrupt the substrate habitat.

On the eastern shore of WRIAs 8 and 9 marinas are typically located behind a breakwater, and changes in wave energy and sediment transport occur with their presence. Elsewhere, marinas may be located in embayments with low wave energy where a breakwater is unnecessary, or limited to a floating breakwater. The chains that anchor mooring buoys can scour the substrate and destroy vegetation and benthic organisms. Marinas create waters with low tidal exchange and, if phytoplankton blooms occur, low DO concentrations can result in fish kills.

In addition to the effects of overwater structures, additional impacts may occur as a result of vessels temporarily or permanently moored to those structures. Covered moorages, houseboats, and boathouses are associated with cleaning, pesticide, herbicide, paint, petroleum and maintenance products that can enter the water. Boats add additional shading, and props can scour the bottom affecting benthic organisms and plants. Boat discharges introduce contaminants and nutrients, changing the habitat that plant and animal species require (Nightingale and Simenstad 2001). The water quality of marinas is affected by boat engine exhaust, fuel spills, sewage discharge, and contaminated stormwater runoff coming from parking lots close to the marina.

Construction and maintenance practices associated with overwater structures also result in adverse effects to aquatic habitats and species. Dredging, filling and pile driving can result in short-term and long-term disturbance, or modification of physical and biological processes. For example, dredging and construction materials (i.e., creosote treated piles) used in marine construction result in contaminant releases. Pile driving, dredging, and other practices create noise that may result in avoidance behavior by some species. Dredging and the placement of inwater structures alters sediment distribution and composition, hydrology, and biological community composition as a result of habitat alterations that occur with each construction or maintenance event. A more extensive discussion of these individual effects may be found in other sections of this report.

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

Dredging is conducted to create and maintain slips and channels for berthing and navigation. Dredging and disposal are regulated through state and federal permit systems. Dredged material containing low levels of contaminants may be disposed at designated open water disposal sites under the Puget Sound Dredged Disposal Analysis (PSDDA) program. Dredged material that cannot be placed at an open water disposal site is required to be treated or disposed at a confined facility. Confined disposal sites are generally located in upland (i.e., landfill) or nearshore areas.

Current and Historical Dredging Sites

Very few nearshore areas of WRIAs 8 and 9 outside of Elliott Bay (see section 11) are dredged. Maintenance dredging is conducted at the City of Des Moines Marina (reach 8). There may also be maintenance dredging at Shilshole Bay Marina located in Seattle, just north of the entrance to the ship canal.

The Des Moines Marina was constructed in 1970. Dredging was first required in 1983 because of shoaling in the entrance channel (Hartman 1993). The only other dredging was in 1994 when 5,200 yd^3 of sediment was removed from the entrance channel to the marina and near the south breakwater (PSDDA 1996). Sediments from both dredging projects were disposed at the PSDDA open-water disposal site in Commencement Bay (Hartman 1993).

It is likely that dredging is also required to maintain safe navigation at Shilshole Marina (reach 3). However, there is no record of recent dredging at this marina under the PSDDA program. The marina could have been dredged before 1988 or outside of PSDDA requirements if sediments were disposed at an upland location.

Effects on the Nearshore Ecosystem

Disruption and loss of benthic communities in the dredged area is an unavoidable impact of dredging, although recolonization generally occurs within three to five years. Benthic habitat characteristics such as elevation and grain size may be changed by dredging and result in a different biological community than that originally present. Dredging impacts on fish and mobile species that can avoid the dredging activity and turbidity plume are likely to be limited.

However, the turbidity plume may contain chemical contaminants that are resuspended and may make their way into the food web. In addition, the siltation of nonmobile species can result in a loss (i.e., mortality) and disturbance of benthic communities can affect community composition and fish food supply. Possible impacts on fishes are reduced by dredging during periods when they are not likely to be present in nearshore areas.

One potential environmental impact of dredging in nearshore areas is a temporary increase in turbidity due to sediment resuspension. While mechanical dredging generally maintains most of the dredged material in the bucket in a cohesive clump, some sediment loss and resuspension into the water column occurs. Since marinas are protected from strong currents and have reduced water circulation, the majority of suspended sediment generated in the Des Moines Marina dredging projects, for example, likely remained in the immediate vicinities of the marina. While this reduced sediment dispersion into Puget Sound, it may also have lengthened the period that turbidity impacts within marinas.

Sediments at the Des Moines Marina in both 1983 and 1994 were sampled and analyzed and showed very low levels of the contaminants in question. For both projects, the dredged material was approved for disposal at a designated PSDDA open-water disposal site. Since chemical concentrations in the sediments were low, loss of contaminants during dredging was not a major concern at this marina.

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

Historically, outright filling of nearshore areas was conducted to create new upland areas for development and frequently resulted in loss of wetlands, beaches, riparian zones, and other habitat. Another major historical and current source of nearshore fill is shoreline armoring, which buries nearshore habitat and sometimes retains additional fill. Beach nourishment also is a type of fill, but usually is done to restore lost nearshore habitat. Modern filling projects usually are conducted to create or restore habitat, or to cap contaminated sediments.

Current and Historical Filling Sites

The most striking example of filling in WRIAs 8 and 9 is the evolution of Elliott Bay and the Duwamish Waterway. These changes are discussed in Section 11.

Outside of Elliott Bay, the greatest source of nearshore fill has been shoreline armoring. As discussed above, WRIA 9 is 75 percent armored, and WRIA 8 is 87 percent armored. Therefore, filling has occurred along the majority of WRIA 8 and 9 shorelines.

Other types of filling projects are habitat restoration and beach nourishment projects. Beach nourishment is the intentional placement of sediments in order to recreate or widen a beach. Beach nourishment restores and protects the natural beach and represents an increasingly popular "soft" alternative to traditional shoreline armoring techniques such as bulkheads and seawalls. Beach nourishment has been a key component of park enhancement in several locations within WRIAs 8 and 9, including West Point in Discovery Park (reach 3-4), Meadow Point at Golden Gardens (reach 2-3), Seacrest Park on West Seattle's Elliott Bay shoreline (reach 4), and Lincoln Park in West Seattle (reach 6). Probably the best-documented example of beach nourishment in the study area is at Lincoln Park in West Seattle (reach 6). The purpose of this project was to protect a failing seawall, restore eroded beach, and to reduce or prevent future beach erosion.

Effects upon Nearshore Ecosystem

The potential environmental impacts of nearshore filling include the following:

Changes in the Physical Environment

- Elevation
- Currents and circulation
- Profile or morphology (slope, angle)
- Substrate type and size

Because filling involves placement of additional materials in the nearshore environment, bathymetry and topography are altered at the site. For example, in the case of shoreline armoring, the topography of the beach changes abruptly at a bulkhead and more gradually at a revetment. These changes in bathymetry also can alter currents and circulation at the site.

Filling changes beach profile or habitat morphology. Addition of beach nourishment material widens the beach and often makes its slope gentler. Filling of habitats such as marshes eliminates the complex morphology of channels and intervening lands. If fill materials are different from the original substrate at the site, substrate types and/or sizes will change.

Changes in the Biological Community

- Displacement of and changes to existing biological communities.
- Alterations in intertidal or shallow subtidal habitat.
- Short-term exposure of plants and animals to suspended solids and reduced dissolved oxygen.

Fill materials bury existing organisms. If the changes in bathymetry or topography are significant enough, these organisms may not be able to recolonize the site and will be displaced. If the fill changes the substrate type or size, alterations in intertidal and shallow subtidal habitats ensue. As a result, the plant and animal communities on the site may shift. During emplacement of fill, plants and animals experience increased turbidity and reduced dissolved oxygen.

Beach Nourishment and Restoration Projects

It is important to note that some types of fill may have beneficial effects upon the nearshore environment. Beach nourishment projects usually are undertaken to protect upland property, and if done properly, consist of sediments similar to those that naturally would be at the site. As a result, beach nourishment projects can restore beach habitats, and as sediments erode away from the project, can provide downdrift beaches and habitats with much-needed sediments. Although nourishment projects change beach elevation and profile, and alter sediments, if done properly they restore the beach and sediments to their natural condition. Beach nourishment projects do have the same negative effects as other fill projects: they bury existing organisms, and subject plants and animals to short-term construction impacts. However, it is likely that their beneficial effects outweigh their negative impacts.

Similarly, many nearshore habitat restoration or sediment remediation projects involve some placement of fill. Because the purpose of these projects is to restore lost habitats such as marshes or to enhance existing ones, in time their beneficial effects could outweigh the negative impacts of fill.

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 of nourishment on sediment budgets and biota	All reaches	All reaches
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

In WRIAs 8 and 9, the primary source of untreated sewage discharges to the nearshore are from CSOs. CSOs are discharges of untreated sewage and stormwater that flow directly into the nearshore, lakes, or streams during periods of heavy rainfall (King County Department of Natural Resources and Brown & Caldwell, Inc., 2000). These systems consist of one sewer that carries both sewage and stormwater away from development, and were built before the 1950s, when separated sewers for stormwater and sewage became mandatory. Subsequently, Metro (now King County) built pipelines to capture and transport the combined sewage to new treatment plants. CSOs remain as relief valves for when heavy rainfalls overwhelm the capacity of the sewage system. Sewage is then discharged into the nearshore in order to protect the sewer infrastructure and prevent sewage from backing up into homes, streets, and wastewater plants (King County Department of Natural Resources and Brown & Caldwell, Inc., 2000).

Within WRIAs 8 and 9, sixteen marine CSOs are found within the City of Seattle-King County operates seven of the sixteen CSO locations within the City of Seattle. The City operates the remaining nine. However, the City's pipes drain smaller basins than the County pipes do, so overflows from the City systems tend to be smaller in volume and shorter in duration than overflows from the County system.

Since the early 1980s, King County has undertaken a program to reduce the frequency and volume of CSOs. Between 1981 and 1983, King County's combined sewers discharged almost 2.3 billion gallons of combined sewage each year. As a result of several CSO control projects, King County has reduced the annual volume of CSOs to about 1.5 billion gallons (King County Department of Natural Resources and Brown & Caldwell, Inc., 2000). The ultimate goal of the program is to reduce CSOs to an average of one untreated discharge event per site per year. The City of Seattle has also done a significant amount of CSO reduction work.

Types and Distribution

West Point and North (WRIA 8)

There are six discharge points to Puget Sound north of the West Point Treatment Plant outfall (Table 41). King County operates two of the discharges and the City of Seattle operates the remaining four. The largest of these is the Carkeek Park CSO Treatment Plant (reach 2). Discharges from this CSO Treatment Plant were modeled in 1999 and the results indicated that on average, there could be discharged as much as 51 million gallons/year (MGY) of treated effluent into the Sound during nine separate discharge events. If the trends modeled in 1999 continue it is projected that by 2005 the average volume could increase to 53 MGY in nine discharge events (King County Department of Natural Resources and Brown & Caldwell, Inc., 2000). The 1999/2000 year was actually a low rainfall year and the measured volume from the plant was actually 8 MGY during six events. The County considers this controlled. The North Beach CSO is located to the south of Carkeek Park. In the 1999 modeling exercise results indicated that there could be an average of 6 MGY discharged during 17 events. This trend was expected to continue into 2005 (King County Department of Natural Resources and Brown & Caldwell, Inc., 2000). In actuality there was 1.5 MGY discharged during 12 events.

The four City of Seattle CSOs are pumping stations. These are monitored for CSO discharge frequencies, but not volumes. Seattle considers these CSO discharges controlled. Seattle is now in the process of determining CSO discharge volumes from pumping stations by upgrading monitoring systems.

Alki Point and South (WRIA 9)

There are ten CSOs south of Alki Point. Five are operated by King County and five by the City of Seattle. Results of models run in 1999 indicated that the Alki Point CSO Treatment Plant could discharge an average of 52 MGY of treated effluent during four events over a one-year period. This volume and rate of discharge was modeled to continue through 2005 (King County Department of Natural Resources and Brown & Caldwell, Inc., 2000). The actual number of events in 1999 was 2 with a volume of 4 MGY. The County considers this controlled. The Barton St CSO was modeled to discharge with the greatest frequency at eight times a year with a combined volume of 8 MGY (King County Department of Natural Resources and Brown & Caldwell, Inc., 2000), however in 1999 there were no discharge events. There were no known CSO discharges in 1999 from the City of Seattle outfalls. The outfall at SW Brace Point has been monitored since April 2000. One small overflow was recorded.

Effects upon Nearshore Ecosystem

There have been very few studies that have dealt specifically with the effects of CSOs on the nearshore environment. An extensive study by King County on the effects of CSOs on the Duwamish River and Elliott Bay, examined the physical and chemical stressors both in the nearshore and offshore but did not include the outer beaches (KC WTD 1999). Most programs conducted in the study area were further offshore and related to effluent discharges (Word et al. 1981, Cominski et al. 1984, KC DNR 1999) or to baseline studies and the potential for siting a discharge in the deep subtidal (Thom et al. 1978, Word and Ebbesmeyer 1984). The one exception was the benthic infauna and sediment chemical study of the Duwamish Diagonal CSO in the Duwamish River (SEA 1998 and KC DNR 1999). This study is discussed elsewhere in this report.

There are five types of effects that occur as a result of CSO discharge events. The severity of the effect depends on the volume and duration of the event. These five types of effects are scouring, smothering of benthic communities, short-term pulses of bacteria, chemical contamination of water column, and chemical contamination of sediments. Scouring occurs as a result of the high volumes and velocities of discharges. If the CSO has a high organic content, this material may settle out and smother organisms in the lower portion of the nearshore immediately adjacent to the scoured area. CSOs also carry human pathogens, including protozoa, bacteria, viruses, and possibly tapeworms and round worms (Parametrix, Inc., and King County Department of Natural Resources, 1999). Elevated levels of these pathogens persist in the nearshore environment for short periods following CSOs. Chemical impacts will be discussed in general terms under Sediment Contamination.

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

Types and Distribution

West Point and North (WRIA 8) and Alki Point and South (WRIA 9)

King County routinely monitors sediment quality at a variety of locations in the area north of West Point (reach 3) and south of Alki Point. Table 18 presents the results of analyses for metals and organic compounds at four intertidal stations in 1997. The organic compounds reported here represent four of the primary classes of chemicals of concern. These include bis (2-ethylhexyl) phthalate (phthalates), high molecular weight polycyclic aromatic hydrocarbons (HPAH), low molecular weight polycyclic aromatic hydrocarbons (LPAH), and total polychlorinated biphenyls (PCB aroclors). The results are presented for each compound in mg/kg dry weight for metals and ug/kg dry weight for the organic compounds (Table 38). Data in the table represent a general snapshot of chemical conditions in the nearshore area outside of Elliott Bay. A comparison of the data to the Washington State Sediment Management Standards, Sediment Quality Standard (SQS) value for each metal and to the Washington State Lowest Apparent Effects Threshold (LAET) value indicates that concentrations are well below levels believed to be harmful to benthic ecosystems and in fact most were at or below the method detection limit.

Table 38: Data for four intertidal stations showing concentrations of selected metals and four classes of organic compounds

		North of West Point (WRIA 8)		South of Alki Point (WRIA 9)	
		Station			
Parameter	**WA SQS (1) LAET (2)**	**Richmond Beach JSWX01**	**Carkeek Park KSHZ03**	**Alki Point LSKR01**	**Seahurst Park MTEC01**
Percent Fines	NA	1	4.6	1.2	1.4
TOC (mg/kg)	NA	234	693	500	245
Arsenic	57(1)	3U	3.2U	3U	2.7U
Cadmium	5.1(1)	0.2U	0.2U	0.2U	0.2U
Copper	390(1)	11.4	6.7	5.8	7.4
Lead	450(1)	9.8	3.7	5.1	2.9
Silver	6.1(1)	0.2U	0.3U	0.2U	0.2U
Zinc	410(1)	30.9	26.1	20.3	25.4
Phthalates	1300(2)	16.7U	19.9U	19.8U	17.2U
LPAH	5200(2)	44.9U	53.4U	53.2U	46.1U
HPAH	12000(2)	44.9U	53.4U	53.2U	46.1
T PCBs	130(2)	14U	16U	16U	14U

(1) Washington State Sediment Management Standards Chapter 173-204 WAC
(2) Washington State Sediment lowest apparent effects threshold (LAET)

Effects upon Nearshore Ecosystem

Impacts to the nearshore community as a result of chemical contamination arise from two causes. These include organic enrichment and physiological effects of the chemicals themselves. Organic enrichment is caused by the presence of excess amounts of organic carbon, which acts as a food source for invertebrate communities. If a benthic community is inundated with a large amount of organic carbon at least two events could occur. The first is that the benthic community could be directly smothered by the excess organic carbon. The portion of the community that is not smothered will undergo the second of two events—organic enrichment. It could also result in DO depletion in near bottom waters. The effects of organic enrichment have been studied for 50 years and much is known about how enrichment affects benthic communities. If the nearshore habitat consists of sand there will be a shift in community structure from a suspension or surface detrital feeding community to one dominated by surface or subsurface deposit feeding organisms. Sensitive species (amphipods, echinoderms) will decrease in abundance while tolerant species capable of exploiting the high organic carbon availability will increase. If the nearshore habitat consists of fine silts and clays, the community may still undergo a change. There would be an increase in abundance of tolerant species that may lead to the habitat being dominated only by those species that thrive in habitats with a high organic carbon content.

Changes in nearshore communities caused by chemical contamination are more difficult to document. These effects can be masked by the presence of organic carbon, which can have a stimulatory effect on the nearshore community. Catastrophic input of chemicals into the nearshore environment will have an immediate, acute impact on the community resulting in the immediate loss of all but the most tolerant individuals. Little is known about the chronic input of low levels of chemicals to this habitat. Evidence suggests that sensitive species will decrease in richness and abundance (as described above) while there may be no change in the condition tolerant species (Word et al. 1981). However, this inference was based on an examination of the deep subtidal benthic community in the erosional environment off the West Point outfall, rather than a true nearshore community.

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

Definition and Types

The U.S. Environmental Protection Agency (EPA) defines non-point pollution as pollution that does not have a single point of origin or one that is not introduced into a receiving stream from a specific outlet (EPA 2000). Residential and commercial development creates non-point pollutants that are generally carried off the land by stormwater. When land that would naturally soak up rain and natural runoff is cleared of vegetation and then covered with an impervious surface, more surface water is generated during storms. Impervious surfaces in developed areas include roofs, sidewalks, driveways, parking lots, and even lawns. Pollutants, such as nitrates, phosphates, pesticides, petroleum, sediments from cleared soil, and fecal coliform bacteria from onsite sewage systems, are washed from the land into streams and eventually into marine waters.

Residential non-point pollution sources are associated with everyday activities such as operating motor vehicles, washing equipment and structures, fertilizing home gardens, and controlling pests. Leaking septic tanks also allow contaminants to enter groundwater that can eventually enter nearshore waters. Examples of commercial non-point pollution sources include industrial waterfront facility roofs, storage yards, and parking lots; agriculture activities; strip malls; and gas stations. Non-point pollution also results from vessel use on the surface waters of WRIAs 8 and 9. Exhausts and spills associated with these activities enter the water directly. WRIA 8 has one ferry terminal (Edmonds) and three large marinas, and WRIA 9 has two ferry terminals (Seattle and Fauntleroy), one large marina, and several smaller marinas. In addition, two ferry terminals and two small marinas are located on Vashon and Maury Islands.

Effects upon Nearshore Ecosystems

Non-point pollution affects nearshore ecosystems in several ways. Pollutants contained in untreated runoff enter nearshore marine waters and degrade water quality. Clearing nearshore land may cause turbid nearshore waters. Leaking septic tanks and other non-point sewage sources contaminate shellfish beds. Exhaust, maintenance waste, and spills associated with boating activities pollute waters directly.

Some of the contaminants in surface water runoff increase levels of organic nutrients in receiving water bodies. This may lead to local eutrophication, which can intensify algal blooms, increase turbidity, and reduce DO levels, especially in estuaries. Increased growth of macroalgae species such as *Ulva* may degrade nearshore habitat by limiting eelgrass *(Zostera* spp.) distribution through competition. Eelgrass beds are ideal habitat for many nearshore species including juvenile salmonids and spawning forage fish.

Residential and commercial development may directly disturb or alter the nearshore if vegetation is cleared, reducing the filtration of non-point source pollution by riparian vegetation. Clearing vegetation along the shoreline may destabilize bluffs and, through the process of erosion, increase sediment loads into the nearshore system. In the past, pier construction for a single-family house was not tightly regulated, but cumulative effects of pier construction by many homeowners along the shoreline may harm the nearshore system through contaminant releases from construction materials and boat operations.

Almost 40 percent of Washington’s shellfish beds have been closed as a result of environmental contamination. Failing septic systems, animal waste, stormwater runoff, and discharge from boats are the primary non-point pollution sources (WDOE 1998).

Commercial marinas affect nearshore habitat by increasing boat traffic and decreasing water quality. Boaters affect water quality in several ways. Small amounts of leaking oil can contaminate many gallons of water, and paint scrapings and many boat solvents are toxic to nearshore fish and wildlife (Puget Sound Water Quality Action Team 2000). Untreated sewage that is pumped overboard introduces bacteria and viruses to the nearshore and may contaminate shellfish. Altogether, these additional forms of non-point pollution can have large negative impacts on the nearshore ecosystem.

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

Definition

Plants and animals that are introduced into habitats in which they do not naturally occur are called non-native species. They are also known as non-indigenous, exotic, introduced, or invasive species. Non-native species have been introduced to the Puget Sound through shipping (attached to ship hulls and through discharge of ballast water), aquaculture, commercial fisheries of various kinds, and other human activities. Introductions of non-native species have been known to profoundly affect ecosystems. By competing with native species for food and habitat as well as preying on them, non-native species can reduce or eliminate populations of native species.

Distribution and List

The Puget Sound Expedition Rapid Assessment survey for non-native marine organisms, based on techniques developed in San Francisco Bay, was conducted September 8 through 16, 1998. This study found 39 non-native species in the samples collected. Of these, 11 were new records for Puget Sound and five were known but had no information previously published about them. Five species were found in Elliott Bay (the bryozoan species *Bowerbankia gracilis*, *Schizoporella unicornus*, and a *Bugula* sp., and the urochordates *Botryllus schlosseri* and *B. violaceus)*. Seven species were found at Des Moines, including the two urochordates and two of the bryozoan species found at Elliott Bay. The bryozoans *Bugula stolonifera* and *Cryptosula pallanciana*, and the urochordate *Ciona savignyi* were also found at the Des Moines sampling area.

Table 41 provides a list of 39 non-native species collected by the 1998 Puget Sound Expedition. It includes information about species' native range, first record on the Pacific Coast and in Puget Sound, and possible means of introduction.

Table 41: Origins, First Records, and Mechanisms of Introduction of 39 Non-Native Species Collected by the 1998 Puget Sound Expedition

General Taxon	Native Range	First Pacific Coast Record	First Puget Sound Record	Possible Mechanism of Introduction
Seaweed				
Sargassum muticum	Japan	1944	* 1948	OJ
Grass				
Spartina anglica	England	1961-1962	1961-62	MR
Eelgrass				
Zostera japonica	W Pacific	1957	* 1974	OJ
Foraminifera				
Trochammina hadai	Japan	* 1971	* 1971	BW, SF, OJ
Cnidaria - hydroid				
Cordylophora caspia	Black Sea and Caspian Sea	ca. 1920	ca. 1920	BW, SF
Cnidaria - anemone				
Diadumene lineata	probably Asia	1906	< 1939	OA, SF
Annelida				
Hobsonia florida	NW Atlantic	1940	1940	?
Annelida				
Pseudopolydora paucibranchiata	* Japan	* 1950	* 1993	* BW, SF
Mollusca - snail				
Batillaria attramentaria	Japan	1924	1924	OJ
Mollusca - snail				
Crepidula fornicata	NW Atlantic	1905	1905	OA
Mollusca - snail				
Myosotella myosotis	Europe?	1871	1927	OA (SB, SF)
Mollusca - bivalve				
Crassostrea gigas	Japan	1875	1875	OJ
Mollusca - bivalve				
Mya arenaria	NW Atlantic	1874	1888-1889	OA
Mollusca - bivalve				
Nuttallia obscurata	Japan, Korea (China?)	* 1991	* 1993	BW
Mollusca - bivalve				
RudiVenerupis (Ruditapes) philippinarum (Tapes japonica, Venerupis philippinarum)	NW Pacific	1924	1924	OJ
Copepoda				
Choniostomatid copepod	?	?	1998	?
Cumacea				
Nippoleucon hinumensis	Japan	1979	* mid-1990s	BW

General Taxon	Native Range	First Pacific Coast Record	First Puget Sound Record	Possible Mechanism of Introduction
Isopoda				
Limnoria tripunctata	?	1871 or 1875	* 1962	SF
Amphipoda				
Ampithoe valida	NW Atlantic	1941	* 1966	BW, OA, SF
Amphipoda				
Caprella mutica	* Sea of Japan	1973-1977	1998	BW, OJ
Amphipoda				
Corophium acherusicum	* N Atlantic	1905	1974-1975	OA, SF
Amphipoda				
Corophium insidiosum	N Atlantic	1915	* 1949	OA, SF
Amphipoda				
Eochelidium sp.	Japan or Korea ?	* 1993?	1997	BW
Amphipoda				
Grandidierella japonica	Japan	1966	* 1977	BW, OJ, SF
Amphipoda				
Jassa marmorata	NW Atlantic	1941	* 1990?	BW, SF
Amphipoda				
Melita nitida	NW Atlantic	1938	* 1998	BW, OA, SB, SF
Amphipoda				
Parapleustes derzhavini	* W Pacific	1904	1998	SF
Entoprocta				
Barentsia benedeni ?	Europe	1929	1998	OJ, SF
Ectoprocta (Bryozoa)				
Bowerbanki gracilis	NW Atlantic?	<1923	<1953	OA, SF
Ectoprocta (Bryozoa)				
Bugula sp. 1	?	?	1993	?
Ectoprocta (Bryozoa)				
Bugula sp. 2	?	?	1998	?
Ectoprocta (Bryozoa)				
Bugula stolonifera	NW Atlantic	<1978	1998	SF
Ectoprocta (Bryozoa)				
Cryptosula pallasiana	N Atlantic	1943-1944	1998	OA, SF
Ectoprocta (Bryozoa)				
Schizoporella unicornis	NW Pacific	1927	1927	OJ, SF
Urochordata (Tunicata)				
Botrylloides violaceus	Japan	1973	1977	OJ, SF
Urochordata (Tunicata)				
Botryllus schlosseri	NE Atlantic	1944-1947	* 1970s	OA, SF
Urochordata (Tunicata)				

General Taxon	Native Range	First Pacific Coast Record	First Puget Sound Record	Possible Mechanism of Introduction
Ciona savignyi	* Japan	1985	1998	BW, SF
Urochordata (Tunicata)				
Molgula manhattensis	NW Atlantic	1949	1998	BW, OA, SF
Urochordata (Tunicata)				
Styela clava	China to Sea of Okhotsk	1932-1933	1998	BW, OJ, SF

Source: Cohen et al. 1998
* = Correction to information in Cohen et. al. 1998, the Puget Sound Expedition Report.
< = First records consisting of written accounts that do not state the date of planting, collection, or observation.
( ) = Parentheses indicate less likely mechanisms.
OA = with shipments of Atlantic oysters
OJ = with shipments of Japanese oysters
SF = in ship fouling or boring
SB = in solid ballast
BW = in ship ballast water or seawater system
MR = planted for marsh restoration or erosion control

Table 42 lists non-native species known to be established in Puget Sound, but that were not collected by the 1998 Puget Sound Expedition. This list is incomplete and is not intended to be an all-inclusive list.

Table 42: Origins, First Records, and Mechanisms of Additional Non-Native Species in Puget Sound

General Taxon	Native Range	First Pacific Coast Record	First Puget Sound Record	Possible Mechanism of Introduction
Grass				
Spartina alterniflora	NW Atlantic	1910	1910	MR, SB
Grass				
Spartina patens	NW Atlantic	< 1930	?	MR
Cnidaria - hydroid				
Bougainvillia muscus (= B. ramosa)	N Atlantic	1975	1981	SF
Cnidaria - hydroid				
Cladonema radiatum	NW Atlantic and Mediterranean	1988	1988	SF, BW
Platyhelminthes				
Pseudostylochus ostreophagus	Japan	1954	1954	OJ
Annelida				
Neanthes succinea (cosmopolitan)	?	1896	1998	OA, SF
Annelida				
Streblospio benedicti	N Atlantic	1932	1998	OA, BW, SF
Mollusca - snail				
Cecina manchurica	Japan, China	1961	1961	OJ
Mollusca - snail				
Ceratostoma inornatum	Japan	1924	1924	OJ
Mollusca - snail				
Crepidula plana	W Atlantic	1901	1930s	OA
Mollusca - snail				
Urosalpinx cinerea	NW Atlantic	1890	1929	OA
Mollusca - bivalve				
Musculista senhousia	Japan, China	1924	1924	OJ
Mollusca - bivalve				
Mytilus galloprovincialis	NE Atlantic Mediterranean	1940s	1980s	SF
Copepoda				
Mytilicola orientalis (= m ostreae)	W Pacific	1938	1946?	OJ
Copepoda				
Pseudodiaptomus inopinus	Asian N Pacific	1990	1991	BW

Source: Cohen et al. 1998

< = First records consisting of written accounts that do not state the date of planting, collection, or observation.

OA = with shipments of Atlantic oysters

OJ = with shipments of Japanese oysters

SF = in ship fouling or boring

SB = in solid ballast

BW = in ship ballast water or seawater system

MR = planted for marsh restoration or erosion control

Selected Species

Zostera japonica

Life history – Known as Japanese eelgrass, *Zostera japonica* reproduces like many other seagrasses. Flowering and pollination occur underwater. Seeds are produced, often in great quantities. The growth of an eelgrass meadow occurs by vegetative spread with the extension of the rhizome and the germination and growth of seedlings. A seagrass must have four properties to exist in the sea. It must be adapted for life in a saline medium, be able to grow when completely submerged, have an anchoring system to withstand wave action and tidal currents, and have a capacity for hydrophilus pollination.

Effects on nearshore ecosystem – While Japanese eelgrass colonizes previously unvegetated mud flats, improving grazing opportunities for waterfowl, it also competes to a degree with native eelgrass (*Zostera marina*) and changes the structure and diversity of the invertebrate community within the sand or mud. *Z. japonica* is found in WRIAs 8 and 9.

Spartina spp.

Life history – Commonly known as cordgrass, *Spartina* is an invasive grass that is well established in many areas of Puget Sound. Three species of *Spartina* have been introduced to Western Washington. *Spartina* grows tenaciously in the intertidal area of mud, sand, or mixed sand/pebble marine beaches. It reproduces both with seeds and massive runners, which makes it a difficult plant to control.

Effects on nearshore ecosystem – *Spartina* grows in dense colonies that trap sediments and raise the elevation of tideflats, thereby reducing and/or changing the invertebrate population and eliminating the availability of the area for feeding by shorebirds and fish. *Spartina* chokes out native vegetation, does not provide food or habitat for many native animals, and can even increase flooding. It occurs at a few locations along the shorelines of WRIAs 8 and 9.

Copepods

Life history – Copepods are tiny shrimp-like creatures that live throughout the ocean and on the ocean floor, as well as in association with other animals. Because they are so small, free-living copepods can feed only on small food items such as bacteria, diatoms, or other unicellular forms. Eggs produced by the female copepod are carried in clusters in one or a pair of egg sacs attached to the base of the abdomen. Males often have a modified first antenna that is used in copulation. Copepods live relatively long lives for their size (weeks-months). They can be grazers of phytoplankton when small, carnivorous when large, and a few are parasites. Eleven molts take place between 12 different life stages: 6 naupliar, 5 copepodite, and a single reproductive adult stage. In general, for each copepodite stage, another body segment is added.

Effects on nearshore ecosystem – Copepods are key organisms in the food chain. If non-native copepods out-compete or prey on native species, it may weaken other species that depend on native copepods for food. For example, juvenile fishes depend on copepods during critical stages of their life histories.

Sargassum

Life history – Commonly known as Japweed, *Sargassum muticum* is a brown algae that originates in Asia. It is tolerant of wide temperature and salinity ranges. This species has both male and female parts in the same individual and is self-fertile. Fertile branches of adult algae produce gametes. When the ova are released, they are not broadcast into the surrounding water like most algal gametes, but remain attached to the receptacle. After fertilization, the zygotes continue to grow on the parent for several days before dropping to the ocean floor. The enveloping mucilage protects them from environmental stress. Their large size also allows them to settle rapidly, and the well-developed rhizoids adhere quickly to the substrate. This results in young plants settling near the parent (within 3 meters), where conditions are likely to be favorable (Monterey Bay Aquarium Research Institute 1999). A holdfast can also regenerate fronds. Fertile branches lead to long range dispersal. *Sargassum muticum* is a bushy plant that can shade out competitors.

Effects on nearshore ecosystem – For five decades *Sargassum* species have been known for their invasive colonization that competes with native perennial brown algae. Faunal communities on *S. muticum* were compared with those on *Laminaria saccharina*, a native alga displaced by *S. muticum* (Osborn 1999). *S. muticum* is able to support a more abundant and species-rich community than the native alga *L. saccharina* because of its high degree of morphological complexity. Only two species never occurred on *S. muticum* that were common on *L. saccharina,* whereas 15 species were common on *S. muticum* but never found on *L. saccharina*. Abundance of fauna increased as *S. muticum* biomass increased over time. The particulate load on *S. muticum* was heavy and consisted primarily of diatoms. Epibiont diversity and abundance increase in areas invaded by *S. muticum* because of the increased habitat, productivity, and complexity that *S. muticum* provides. Furthermore, it should be noted that *Sargassum* is commonly used by herring as spawning substrate throughout the Puget Sound basin (D. Penttila, WDFW, pers. comm.). For these reasons, eliminating *S. muticum* is not recommended based on the impact *S. muticum* has on epifauna and its potential for providing herring spawning substrate. However, *S. muticum* may negatively affect water movement, light penetration, sediment accumulation, and anoxia at night. Further research is needed before management decisions can be made regarding *S. muticum*, which occurs in WRIAs 8 and 9.

Other Species

Other significant non-native species include the oyster drill (*Ceratostoma inornatum*), varnish or dark mahogany clam (*Nuttalia obscurata*), and the European green crab (*Carcinus maenas*).

Effects on nearshore ecosystem – The oyster drill preys upon young oysters, significantly decreasing oyster survival and profits from oyster beds. The varnish clam was introduced into the Strait of Georgia around the early 1990s and is now widespread there; however, its impact on native bivalve species remains unassessed. The green crab, reported in Willapa Bay in 1998, is a voracious predator that feeds on many types of organisms, particularly bivalve molluscs (clams, oysters, and mussels), polychaetes, and small crustaceans. If it becomes established, it may have a significant impact on the state's clam and oyster culture industries, as well as the commercially important Dungeness crab fishery.

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

Shoreline Armoring

- 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.

Overwater Structures

- One of the most dramatic recognized impacts of overwater structures is shading, which alters primary production levels and animal behavior.
- Overwater structures appear to interfere with fish migratory behavior and alter other physical, chemical and biological processes in nearshore environments.

Dredging

- The few nearshore areas that are regularly dredged include Elliott Bay, the Duwamish Waterway, Des Moines Marina, and Shilshole Marina.

- Dredging displaces benthic communities and changes nearshore bathymetry.

Filling

- Filling has occurred extensively in Elliott Bay and the lower Duwamish River; elsewhere in WRIAs 8 and 9, filling occurs primarily as a function of shoreline armoring or beach nourishment activities.
- Filling eliminates or alters nearshore habitats.

Sewage Discharges

- Off the shorelines of WRIA 8 and 9 combined there are 16 combined sewer overflow (CSO) discharge points (excluding Elliott Bay and the Duwamish). In addition, primary-treated effluent is released in discrete discharge events at Carkeek and Alki.
- Very few studies have dealt specifically with the effects of CSOs on the nearshore environment and little baseline data exists to document effects.

Sediment Contamination

- Outside of Elliott Bay, most marine sediments have low contamination levels as determined by WA State standards, although little sampling has been done in the shallow nearshore environments.
- Little is known of the effect that mixtures of chemical contaminants (synergistic effects) have on benthic communities.
- Most shoreline development outside of Elliott Bay and Shilshole Bay (approximately 90%) is residential in nature and contributes to sediment contamination.

Non-Point Pollution

- Non-point pollution results from everyday residential, commercial, and industrial activities.
- The effects of non-point pollution on the nearshore include contamination of water and sediments, nutrient loading and resultant algal blooms, and increases in erosion and turbidity.

Non-Native Species

- Far fewer non-native species were found in Puget Sound than have been found in San Francisco Bay. However, several non-native species of concern, including *Spartina spp.* and *S. muticum*, are found in WRIAs 8 and 9.
- Expansions of existing non-native species and future introductions could have significant effects upon the Puget Sound ecosystem.