7. SELECTED NEARSHORE HABITAT TYPES

7. SELECTED NEARSHORE HABITAT TYPES

Numerous habitat types occur within the nearshore environment, including eelgrass meadows, kelp forests, flats, tidal marshes, subestuaries, sand spits, beaches and backshore, banks and bluffs, and marine riparian vegetation. These habitats provide a myriad of critical functions. For example, eelgrass meadows, kelp forests, flats, tidal marshes, sand spits and riparian zones provide primary production. All habitat types support invertebrates and juvenile and adult fishes (including juvenile salmonids), and provide foraging and refuge opportunities for birds and other wildlife.

Several known factors cause these habitats stress, including physical disturbances from shoreline armoring, marina construction, and bivalve harvesting; shading from overwater structures; contamination by chemicals; and competition from non-native species. Unfortunately, numerous data gaps in our understanding of these habitats exist, making it difficult to fully assess them. Information about the historical distribution/abundance of these habitats is lacking, and there are no comprehensive maps. What role these habitats play in the food web is also not well understood, as are the effects of shoreline armoring and bivalve harvesting.

This section provides more detail about the functions of, stressors to, and data gaps about these nearshore environments. It also discusses the current and historical distributions of these habitats in WRIAs 8 and 9, where known.

Eelgrass Meadows

Functions within Ecosystem

Eelgrass (*Zostera marina* L.) is one of about five species of seagrass that occurs in the Pacific Northwest. It forms small patches to large meadows in the low intertidal and shallow subtidal zone in Puget Sound. Phillips (1984) lists the following functions for eelgrass:

- Primary production
- Nutrient processing
- Wave and current energy buffering
- Organic matter input
- Habitat for fish and invertebrates
- Food for birds

There is a growing understanding of the importance of eelgrass in the nearshore ecosystem. Studies of primary production in Puget Sound indicate that eelgrass productivity can equal or exceed the productivity rates of most other aquatic plants. Rates reported for eelgrass productivity in the Pacific Northwest range from 200-806 g C m^{-2} yr^{-1} (Thom 1984; Kentula and McIntire 1986; Thom 1990).

Organic carbon produced by eelgrass can enter the food web through the microbial decomposition and processing of both particulate and dissolved eelgrass materials. This organic matter is incorporated in the diet of fish and other marine animals including juvenile salmon (Simenstad et al. 1988). Large mats of eelgrass produced from very dense beds accumulate high on beaches, where it is broken down by bacteria and by macroinvertebrates important in the diet of fish and birds. The ability of eelgrass to alter sediment composition and dynamics has not been studied in Puget Sound, but it is believed that the meadows do affect sediment deposition. It has been found that eelgrass increases the organic matter in sediments in Puget Sound. Eelgrass mediates nutrient fluxes into and out of the sediment (Thom et al. 1994).

Limited data show that once eelgrass is established in an area, there is an increase in fish and shellfish using the area (Thom et al. 1999). In Drayton Harbor, there is a clear indication that juvenile chum and chinook salmon use eelgrass for feeding and rearing during spring. Herring are known to lay eggs on eelgrass. Other fish that use eelgrass habitat for refuge or feeding areas are the bay pipefish, crescent gunnel, kelp perch, lingcod, penpoint gunnel, shiner perch, snake prickleback, striped seaperch, and tube-snout (Simenstad et al. 1991). Birds associated with eelgrass habitat feed on the plants, invertebrates, and fish found among the eelgrass. They include the black brant, bufflehead, Canada goose, common snipe, glaucus-winged gull, great blue heron, greater yellowlegs, and spotted and least sandpipers. Dungeness crab, Pacific harbor seals, and river otters are also associated with eelgrass (Simenstad et al. 1991). Among the few direct grazers on eelgrass are the black brant goose and isopods (*Idotea resecata*) (Thom et al. 1995). A rich epiphytic flora and associated small invertebrate fauna form seasonally on eelgrass leaves. Eelgrass beds provide a multitude of functions including habitat structure, refuge, prey resources, and reproduction.

Processes that Maintain Eelgrass Meadows

Based on a variety of investigations over the past ten years, we have learned a great deal about the factors that control the presence and growth of eelgrass. Eelgrass commonly occurs in shallow soft-bottom tideflats, along channels, and in the shallow subtidal fringe. Factors that affect its distribution and growth along with the ranges that are optimal for eelgrass are shown in Table 9.

Table 9: Factors controlling eelgrass growth

Factor	Optimal Conditions
Light	3 M PAR d^{-1}; spring and summer
Temperature	7-13 ^{o}C
Salinity	10-13$^{o}/_{oo}$
Substrata	Fine sand to mud
Nutrient	Soil nutrients present moderate to low water column
Water Motion	Up to 3-m s^{-1} tidal 80-cm s^{-1} burst. Some motion is good

Source: Thom et al. 1988; unpublished data; Phillips 1984.

Location of Eelgrass

Eelgrass occurs from about +1 m to -5 m MLLW in the central Puget Sound area (Bulthuis 1994; Thom et al. 1998). .The primary factor controlling distribution at the upper boundary is desiccation stress, and at the lower boundary is light penetration (Thom et al. 1998).

Competition for light and nutrients with macroalgae species can also affect eelgrass distribution.

Our current understanding of the distribution of eelgrass is limited because comprehensive surveys have not been performed within WRIAs 8 and 9. The primary sources of distribution data are from surveys that included observations made during low tides and covered primarily intertidal and very shallow subtidal meadows and patches. These data include the Coastal Zone Atlas (WDOE 1979), which is more than 20 years old, and very recent estimates provided by the Washington State Department of Natural Resources (1999). Other site-specific studies supply some detail within the East Passage (Thom et al. 1976; Thom et al. 1984; Thom and Hallum 1990). The most comprehensive maps of eelgrass, which include subtidal meadows, have been developed for the region between Picnic Point and Shilshole Bay (Woodruff et al. 2000).

WRIA 8 Eelgrass Distribution

According to the Washington Department of Natural Resources (WDNR) ShoreZone database and studies conducted by Woodruff et al. (2000) for King County, eelgrass covers approximately 25,548 m (57 percent) of the shoreline in WRIA 8 (Figures 14 and 15). In reach 1, eelgrass ranges from dense to patchy, but is generally continuous. Between Picnic Point and Point Edwards at the northern end of WRIA 8, only patchy eelgrass has been recorded. However, surveys are needed to evaluate the condition of subtidal eelgrass. In reach 2, eelgrass is also dense to moderate and almost continuous. Eelgrass is generally continuous in reach 3 except for the break at Shilshole Marina.

WRIA 9 Eelgrass Distribution

The ShoreZone database (WDNR) indicates that eelgrass covers approximately 114,150 m (66 percent) of the shoreline in WRIA 9 (Figure 15). Eelgrass occurs in patches near West Point and between Alki Point and Duwamish Head in reach 4 (Figure 15). Eelgrass is patchy in reaches 5 and 6. In reaches 7 and 8, eelgrass is continuous except near very steep points (i.e., Brace Point). There are short stretches in reaches 7 and 8 where continuous eelgrass meadows are visible during low tides. Reaches 9, 10, and 12 around Vashon Island have patchy and continuous eelgrass meadows visible during low tides. Approximately 82 percent of the Vashon/Maury Island shoreline is covered by eelgrass (WDNR, 1999). Eelgrass is present in Quartermaster Harbor (reach 11) (Echeverria, pers. comm.).

The ShoreZone database also indicates that eelgrass meadows are found along 7000 m of the Elliott Bay nearshore, representing about 26.7 percent of the shoreline (Figure 15). The distribution of eelgrass is entirely outside of the highly developed Seattle waterfront with concentrations around West Point, along Magnolia Bluff adjacent to Discovery Park, and between Duwamish Head and Alki Point (Washington Department of Ecology [WDOE] 1979). The Duwamish/Alki beds occupy about 1.25 mi of shoreline (Thom and Hallum 1990). Little or no eelgrass is present within the Duwamish Estuary.

Eelgrass Density

Eelgrass density is highly variable but can reach in excess of 800 shoots m^{-2} in central Puget Sound (Thom et al. 1998). There are few published reports on density within WRIAs 8 and 9. Mean densities that have been reported from specific studies range from about 50-400 shoots m^{-2} (Thom 1988; Thom and Hallum 1989; Thom 1990; Thom and Albright 1990).

Thom and Hallum (1990) categorized the eelgrass beds between Alki Point and Duwamish Head as moderately dense to dense. During a field survey conducted at low tides in May 2000, Pentec observed eelgrass to be sparse and patchy, but widely distributed between West Point and the southern end of Discovery Park.

Phillips (1972) found that eelgrass beds near Alki Point occupied substrates of fine sand with mud between –1.1 and –12.3 ft MLLW. The beach in this area was gently sloping with relatively turbid water compared to other eelgrass beds in Puget Sound. The densest eelgrass growth was observed at –1.1 ft MLLW at about 50 to 75 ft from the MLLW mark. Sparse but luxuriant growth was observed at –1.5 MLLW at about 140 to 160 ft from the MLLW mark. Beyond this point, growth was very sparse to –12.3 ft where the eelgrass bed ended.

Stressors

Stressors to eelgrass are those things that negatively affect the factors that control eelgrass growth or directly affect eelgrass itself. There are two broad categories of stressors: natural stressors, and human-influenced stressors. This section discusses each in turn.

Natural Stressors

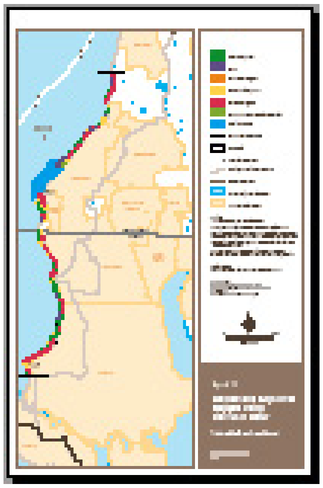
Natural stressors to eelgrass include the following:

- Increased turbidity
- Foraging
- Black rot disease
- Rhizome exposure
- Hydrogen sulfide in soils

Increases in turbidity caused by suspended sediments or phytoplankton blooms reduce water clarity. A persistent reduction in water clarity would result in less light, and could cause eelgrass, especially those plants at the lower (deeper) edge of the distribution, to die. Some organisms, including invertebrates and black brant geese, forage upon eelgrass.

Black rot disease was responsible for killing almost all eelgrass on the eastern United States in the 1930s (many East Coast eelgrass populations have since recovered and are now considered healthy). Black rot disease has been recorded and confirmed for Puget Sound, but systematic surveys for the disease are not available for WRIAs 8 and 9 (Bulthuis 1994).

Figure 14   Eelgrass and Kelp Areas Mapped Using Side-Scan Sonar



Click here to view figure

Figure 14 back

Figure 15   Eelgrass and Kelp Shoreline Lengths

Click here to view figure

Figure 15 Eelgrass and Kelp Shoreline Lengths

Waves and currents can expose eelgrass rhizomes. Extended exposure, especially during low tides, can result in damage to the plants because of drying of the roots and rhizome. There is no documentation of excessive exposed rhizomes in WRIAs 8 or 9.

Hydrogen sulfide (H_2S) develops in highly organic sediments. Eelgrass is susceptible to high H_2S levels and will die if H_2S is a persistent feature of the sediment conditions (Goodman et al. 1995). Although areas with elevated H_2S have been noted at the Seahurst bight (WRIA 9, reach 7) and Fauntleroy Cove (WRIA 9, reach 6), there are no documented cases of loss of eelgrass due to high hydrogen sulfide levels.

Human-Influenced Stressors

Stressors to eelgrass caused or exacerbated by human activities include the following:

- Clam harvesting
- Propeller scour and wash
- Eutrophication
- Physical disturbances from shoreline armoring
- Shading from overwater structures
- Physical disturbances from dredging and filling

In the study region, clam harvesting has been observed to disturb the benthic community, at least temporarily. However, no systematic quantification of this effect has been attempted. Physical disturbance by excessive propeller wash can gouge sections of eelgrass meadows. These gouges are commonly observed in heavily used beaches, especially where geoduck harvesting is popular. However, no cases of this problem are documented in WRIAs 8 and 9.

Eutrophication has been shown to result in the growth of massive amount of epiphytes on eelgrass leaves, which can result in the death of the eelgrass host. There is little information on epiphyte loads in the region. It appears from the work conducted at Seahurst Park that epiphytes were not overly abundant there (Thom and Albright 1990).

Eutrophication in Puget Sound is believed to influence the buildup of massive ulvoid mats that grow in the intertidal and shallow subtidal zones. Ulvoids detach during windy periods, and pile up in thick mats over eelgrass, which can smother and kill the eelgrass (Thom et al. 1998). Although likely to be a problem in some areas, the only documented occurrence of eelgrass impacts from ulvoid mats was reported at Fauntleroy Cove (WRIA 9, reach 7).

Shoreline armoring impedes sediment supply to nearshore habitats, and this sediment starvation can lead to changes in nearshore substrates. Typically, sediment changes from sand or mud to coarse sand, gravel, and finally hardpan. If sediment becomes too coarse, eelgrass may be driven out. Also, construction of shoreline armoring devices can cover or destroy eelgrass meadows (Williams and Thom, in prep.). Overwater structures can deprive eelgrass of the light they need to thrive (Simenstad et al., 1998; Nightingale and Simenstad). Dredging operations can excavate eelgrass meadows or cause detrimental increases in turbidity, and filling can smother eelgrass meadows permanently.

Historical Distribution

Comprehensive historical records of eelgrass distribution are lacking in WRIAs 8 and 9. Eelgrass information comes from site-specific studies, which are incomplete in terms of providing a historical picture of distribution.

In an attempt to document changes in eelgrass, Thom and Hallum (1990) compiled all known records of eelgrass. The oldest records came from marks on U.S. Coast and Geodetic Survey navigation charts that were developed for several bays in Puget Sound, including Padilla Bay. These charts date back in some cases to the period of 1850-1890. No records on these charts showed eelgrass in any portion of WRIAs 8 and 9. Other site-specific records on eelgrass include dive work done by Ron Phillips in 1962 at about 100 locations throughout Puget Sound and Hood Canal.

Even though comprehensive historical records are limited, Thom and Hallum (1990) reported an anecdotal observation indicating that the Duwamish Head eelgrass meadow has been declining in size since the 1960s. Intertidal eelgrass also may have declined at the southern end of reach 1 (WRIA 8). The historical data in Thom and Hallum show eelgrass in this area, whereas the WDNR maps show no eelgrass. WDNR records best document eelgrass from very shallow water to intertidal areas. Subtidal eelgrass appears to remain in this area, however. Eelgrass may have increased, although it remains patchy, in reach 3 near West Point. Patchy intertidal eelgrass may also have increased in reaches 4, 5, 6 and 9 in WRIA 9 based on a comparison of the records of Thom and Hallum (1990) and WDNR maps.

Reasons for Change

We surmise that eelgrass occurred in most shallow water areas in the region, and that disturbances such as overwater structures, bulkheads, marinas, groins, and dredging and filling have resulted in loss of eelgrass in the region. Areas where intertidal eelgrass may have declined (i.e., reach 1, Lincoln Park) are in regions of extensive shoreline armoring. Areas where eelgrass has increased may be related to increased fine substrata (i.e., from fill at Lincoln Park). However, the mapping records were conducted at different scales and with various methods, and it is difficult to draw strongly defensible conclusions.

Data Gaps

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

Table 10: Data gaps for eelgrass

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

KELP FORESTS

Kelp Functions within the Ecosystem

Bull kelp, *Nereocystis luetkeana* (Mertens) P. & R., is the largest brown algae found in the Pacific Northwest. It forms small patches to large forests in the shallow subtidal zone in Puget Sound. Other large brown algal species common in the study region include *Costaria costata* (Turner) Saunders, *Laminaria saccharina* (L.) Lamouroux, and *Sargassum muticum* (Yendo) Fensholt. These latter species are often found associated with bull kelp forests. *S. muticum* is a non-native species that was introduced by the Japanese (Pacific) oyster mariculture industry to the Northwest in the 1930s (Anderson 1998) (see Non-Native Species).

There is no comprehensive evaluation of the functions of kelp in Puget Sound, but the following list highlights functions typically associated with kelp:

- Primary production
- Habitat for fish, especially rockfish, but also salmon
- Contributor to pelagic food webs through particulate and dissolved carbon
- Herring spawning substrate
- Wave and current buffering (Duggins 1980) (Harrold et al. 1988) (Jackson and Winant 1983)
- Substrate for secondary production
- Extraction of chemicals for commercial use (Whyte and Englar 1980)

A kelp forest provides a three-dimensional habitat. This is important for many fish whose larvae use the kelp as settlement habitat. Adult fish feed on and hide in the kelp fronds. Many invertebrates such as crabs, snails, bryozoans, sponges, tunicates, anemones, and shrimp use the blades as living habitat (Foster and Schiel 1985).

Primary production has been estimated as growth rates in only a few areas in the Pacific Northwest. Production rates for bull kelp at West Point (WRIA 8, reach 3) and Lincoln Park (WRIA 9, reaches 5 and 6) were reported to be 0.6-4.2 cm d^{-1} (Thom 1978). Bull kelp can grow at rates up to approximately 2.4 cm d^{-1} during the spring and early summer (Duncan 1973). Growth rates of other kelp species are slower than bull kelp (Thom 1978).

Processes that Maintain Kelp

Kelp grows attached to bedrock or pebble to larger sized gravel in the very low intertidal and shallow subtidal zone. Growth is dependent on light and temperature (Rigg 1917; Vadas 1972; Druehl and Hsiao 1977). Limited experimental evidence indicates that *N. luetkeana* photosynthesis is limited by carbon during summer (Thom 1996). Because of this, all of the kelps exhibit a dynamic seasonal cycle with a period of maximum growth rate in spring and early summer. Winter is a period of low biomass. The stipe and fronds of bull kelp die completely in winter, and exists as a microscopic phase until spring. None of the kelps are resistant to drying. Hence, plants that colonize the intertidal zone early in spring are generally lost to desiccation later in spring. Because it forms a dense canopy, bull kelp can exhibit major control over the abundance of the other kelp and algal species (Thom 1978).

Kelp forests are subject to herbivory. Sea urchins graze on kelp, generally feeding on drift material, but sometimes removing entire plants by grazing through their holdfasts (Foster and Schiel 1985). Gastropods graze on the plant tissue, but do not remove entire kelp plants.

Variations in the amount of rocky substrata can result in gains and losses of kelp. Expansion and contraction of the kelp forest at Lincoln Park can be explained by changes in sediment deposition resulting from construction of the seawall in the mid-1930s (Thom and Hallum 1990). Landslides can affect early spring development of kelp through excess siltation (Shaffer and Parks 1994).

Location of Kelp

Kelp occurs in small to large meadows throughout WRIAs 8 and 9. Maps are available for *N. luetkeana* and *L. saccharina*.

WRIA 8 Kelp Distribution

According to the ShoreZone database (WDNR), kelp was recorded at more than 5,433 m (12 percent) of shoreline in WRIA 8. Bull kelp occurs in small patches in reach 1, but has not been reported from the northern half of reach 1 (Figure 14). Bull kelp is limited to a small area at the north end of reach 2. Kelp occurs along the breakwater of Shilshole Marina and on the north side of West Point in reach 3. *L. saccharina* distribution is highly discontinuous. Locations where this species has been mapped occur in reach 2.

WRIA 9 Kelp Distribution

Both *N. luetkeana* and *L. saccharina* are discontinuous throughout WRIA 9 (Figure 15). According to the ShoreZone database (WDNR), kelp was recorded at more than 11,771 m (7 percent) of shoreline in WRIA 9. Kelp borders about 7 percent of the mainland shoreline, and about 6.5 percent of Vashon Island. In this area, *L. saccharina* appears to border more shoreline than *N. luetkeana*, especially on Vashon Island. *N. luetkeana* has been noted at several other locations not shown on the figures. For example, kelp forms consistently on the south side of Point Williams (reach 6). Hence, the areas that have actually been mapped are probably conservative representations of the true distribution of kelp in this region.

The ShoreZone database (WDNR) indicates that kelp forests are found along 1,700 m of the Elliott Bay nearshore representing about 6.4 percent of the shoreline. The Coastal Zone Atlas (WDOE 1979) shows just one forest rounding Duwamish Head. Thom and Hallum (1990) reported 450 linear ft of kelp between Pier 91 and Alki Point. A recent field survey (May 2000) conducted by Pentec Environmental found patches of kelp beds, composed primarily of *Nereocystis luetkeana,* west and north of Pier 91 along lower Magnolia Bluff. Thom et al. (1984) estimated that the Magnolia Bluff kelp patches covered a total of 32.4 acres. Thom (1978) investigated a kelp bed of *N. luetkeana* off West Point. This study found a rich and abundant understory composed of several algal species including *Ulva* spp., *Iridaea cordata, Gigartina papillata*, and *Antihamnionella glandulifera*.

In the Duwamish Estuary and Elliott Bay, patches of bull kelp have been observed in the East Waterway near the northeastern and southeastern portions of Harbor Island and along the Seattle waterfront (G. Blomberg, pers. comm.; B. Bookheim, WADNR, pers. comm.).

Kelp Density

The stipe density of bull kelp has been reported from West Point (WRIA 8, reach 3) and Lincoln Park (WRIA 9, reach 6) to range between 0.9-3.8 stipes m^{-2} (Thom 1978). These fall within the range reported elsewhere in the Pacific Northwest (Rigg 1917; Foreman 1984).

Stressors

There are no investigations on the overall health or indicators of health for kelp in Puget Sound. Some potential health indicators are:

- Degree of tissue bleaching
- Epiphyte loads
- Changes in distribution and density
- Physical disturbances from shoreline armoring, marina construction, and harvesting
- Shading from overwater structures

Spilled oil can cause bleaching of kelp tissue, which results in death of the plant (Antrim et al. 1995). Epiphytes normally occupy kelp plants (Markham 1969; Thom 1978). Where abrasion has damaged the epidermal tissue, infection by epiphytes appears to be more pronounced (Thom 1978). Heavy epiphyte loads have been noted at West Point and Lincoln Park. Although not tested, this type of damage may affect the growth and survival of the plant.

Physical disturbances from kelp harvesting may have occurred at a kelp bed near Alki Point in the late 1980s. Harvesting before kelp developed sori reduced the size of kelp beds at Alki Beach and reduced recruitment (Thom and Hallum 1990).

Beach nourishment also can disturb kelp. At Lincoln Park, the addition of finer sediments altered the substrate from hardpan to coarse sand and gravel, covering the hard bottom sites used for bull kelp attachment (Williams and Thom, in prep.).

Nutrient loading can adversely affect kelp growth. For example, Thom (1978) found that brown algal cover was negatively related to increasing sewage volume at Seattle beaches. Shading from overwater structures in Elliott Bay has also been observed (Thom, personal observations) as a potential stressor.

Historical Distribution of Kelp

It is likely that kelp distribution has changed in the study area based on maps produced by the Department of Agriculture in 1911-1912 and maps produced for the Coastal Zone Atlas in the mid-1970s (Thom and Hallum 1990). In reach 1 in WRIA 8 and all reaches in WRIA 9, kelp was previously reported to occur along a greater length of shoreline than it has recently been reported (Figures 14 and 15). Historical records indicate that kelp “ringed” Vashon Island (Thom and Hallum 1990). It is not known whether this meant that kelp was more or less evenly distributed around the island or that kelp was frequent around most of the island. Hence, historical records may overestimate kelp distribution.

Thom and Hallum (1990) also reported a change from 0 to 450 linear ft of kelp forest in Elliott Bay according to surveys conducted in 1911, 1912, and 1978, but did not know whether the earlier surveys evaluated the same areas of Elliott Bay as the later one did. The 1978 study did find that the main Puget Sound basin and South Sound recorded large increases in kelp forests compared to 1911 and 1912.

Reasons for Change

There are three documented cases of changes in kelp distribution. The first was recorded at Lincoln Park in West Seattle (WRIA 9, reach 6), where kelp covered about 180-215 m of shoreline in 1911-1914. By 1974, kelp covered at least 600 m of shoreline (Thom and Hallum 1990). The change is attributed to coarsening of subtidal substrata because of erosion related to a seawall that was installed on the beach in the 1930s. A rocky substratum is required for kelp attachment. After the beach was nourished with coarse sand in the late 1980s, kelp distribution decreased (U.S. Army Corps of Engineers [ACOE], Seattle District, unpublished data). Changes in kelp distribution may be a good indicator of the coarsening of shallow subtidal substrata in Puget Sound.

The second record involves loss of kelp at Alki Beach by the late 1980s (Thom and Hallum 1990). Data indicate that harvesting of kelp before it developed reproductive sori resulted in reduced recruitment. The non-native brown alga, *S. muticum*, eventually colonized space formerly occupied by bull kelp.

Finally, experimental manipulations and growth rate studies at West Point and Lincoln Park indicate that kelp growth may be enhanced at West Point. Because nutrients from sewage effluent were suspected of reaching the beach, it was hypothesized that the altered kelp bed structure and growth was driven partially by greater nutrients there (Thom 1978).

WDNR monitoring of kelp forests along the Strait of Juan de Fuca indicates that kelp forest abundance and distribution changes annually to some degree. Year to year variation of 30 percent is common (B. Bookheim, WADNR, pers. comm.). Annual variability, driven by natural factors (i.e., climate), probably occurs in Puget Sound as well.

Data Gaps

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

Table 11: Data gaps for kelp

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

FLATS

Functions within Ecosystem

Flats can be variously defined, but generally include gently sloping sandy or muddy intertidal or shallow subtidal areas. Mudflats consist of unconsolidated sediment with particles that are smaller than stones and are predominantly silt (0.0625 to 0.00391 mm) and clay (0.00391 to 0.00024 mm) (Simenstad et al. 1991). The substrate is usually high in organic content with anaerobic conditions existing below the surface. Sandflats have unconsolidated sediment with particles that are smaller than stones and are predominantly sand (2.0 to 0.074 mm) (Simenstad et al. 1991). The substrata on flats can also be composed of a mixture of pebbles and cobble. There is no comprehensive assessment of the functions of flats in the Pacific Northwest.

Studies conducted in Puget Sound and other Washington estuaries have proven the following list of functions for flats:

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

There is commonly a dense flora of microalgae, primarily diatoms, which inhabit the fine sediments of flats. Chlorophyll a concentration, an indicator of the density of microalgae, is reported to range from 140-380 mg m^{-2} on flats in Puget Sound (Thom 1989). Published rates of primary production measured for flats range from 22-59 g C m^{-2} $year^{-1}$ (Thom 1984; Thom 1989). Inorganic nutrient flux rates can be substantial on flats, especially muddy flats (Thom et al. 1994). Flats with more organic matter and higher densities of benthic infaunal invertebrates tend to have higher respiration rates and associated nutrient flux rates. Nutrient flux from flats may be an important source of nutrients to primary producers in the general vicinity of the flats, although this has not been conclusively shown.

Juvenile salmon prey species have been shown to be seasonally abundant on flats and their distribution is linked to the benthic microalgal abundance (Thom et al. 1989). Prey abundance at Seahurst Park ranged from 90,000-230,000 individuals m^{-2} in 1982-1983.

Undisturbed channels and sloughs within tidal flats contain numerous invertebrates and fish and are used by shorebirds, herons, raccoons, otter, mink, and other organisms as important foraging areas. Precise invertebrate assemblages probably vary with salinity and substratum type, but common animals include chironomid (insect) larvae, amphipods, polychaetes, clams, shorecrabs, tanaids, and mysids (Dethier 1990).

Fish species that feed on invertebrates from flats include chum salmon, bay goby, Pacific staghorn sculpin, English sole, sand sole, speckled sanddab, and starry flounder (Simenstad et al. 1991).

Especially in flats containing some gravel, bivalve densities can be great (Armstrong et al. 1976; Thom et al. 1994). Gravel is purposely added to flats to enhance clam production for commercial and recreational harvesting.

Shorebirds are commonly observed feeding on flats in the Pacific Northwest. Studies in Grays Harbor (Herman and Bulger 1981) and Padilla Bay indicate that the birds are consuming invertebrates produced on the flats. American Widgeon preferentially eats the non-native seagrass Zostera japonica, which grows in the upper portions of tideflats in many areas of Puget Sound. Other birds that feed on flats include the bufflehead, common goldeneye, horned grebe, common snipe, dunlin, great blue heron, and the least and western sandpipers (Simenstad et al. 1991).

Processes that Maintain Flats

Sediment required to maintain flats is primarily supplied by rivers, streams, and eroding bluffs. Nearshore currents and waves, along with river flow dynamics, act in concert to distribute and rework sediments on flats. While sediment composition as well as sediment dynamics exert primary control over the biological community that develops on flats, seasonal abundance of algae and invertebrate prey species also appears to be driven by variations in light and temperature (Thom et al. 1989). In addition, detritus sources help maintain levels of organic matter that are an important component of flats and support biotic communities that utilize flats.

Location of Flats

Flats are generally located at the mouths of streams and rivers where sediment transported downstream is deposited. They are also located in embayments, below the swash/backwash zone and other areas of low wave and current energies where longshore currents and waves deposit sediment. According to the ShoreZone database (WDNR), tidal flats cover 2,862 m (6 percent) of shorelines in WRIA 8, and about 4800 m (2 percent) of WRIA 9 shorelines. All of these flats are around Vashon and Maury Islands. There are tidal flats in WRIA 9, however, that were not reported as such during the WDNR program. The ShoreZone definition of flats is unidirectional, horizontal, or gently sloping surfaces of less than 5°. This definition, or the resolution of mapping methods, does not capture all flats in the study area.

Significant areas of intertidal shallows and flats exist throughout the lower Duwamish River. Although nearly the entire lower river channel is confined by levees, riprap, and bulkheads, much of this armoring is present at the top of the intertidal zone, and natural, gently sloping mud and sandflats are present in the lower zone.

From River Mile (RM) 11.0 to RM 5.3 in the upper Duwamish Estuary, exposed mudflats and submerged shallow shoals (near or below MLLW) occupy approximately 5,340 linear ft of shore (1.0 mi) representing about 8.9 percent of the shoreline. Almost all of these habitats are present between the Turning Basin (RM 5.3) and RM 6.0 (Pentec Field Survey 1999). From the Turning Basin to the river mouth, a substantial amount of exposed sandflats and mudflats are present. Approximately 45,400 linear ft or 8.6 mi of shoreline is composed of flats representing 55.9 percent of both banks (Port of Seattle, unpublished data). Intertidal mudflats are present at and just below the Turning Basin (RM 5.3) within Slips 4 and 6 and on Kellogg Island (Tanner 1991). However, most of these flats have dikes or shoreline armoring on one side and navigational channels on the other, resulting in constrained or homogenous habitat in some areas. Fewer flats and shallows occupy areas of Elliott Bay. From Duwamish Head to Terminal 91 exposed mud and sand substrates occupy approximately 11,750 linear ft (2.2 mi) representing 16.9 percent of the bay shore (Port of Seattle, unpublished data). Most of this is beneath existing overwater structures.

Sediment Characteristics of Flats

Flats generally include gently sloping sandy or muddy beaches, but can also include a mixture of pebbles and cobble. Limited sediment grain size data from flats in WRIAs 8 and 9 show that flats are primarily composed of fine sand (69-77 percent), with lesser amounts of coarse sand and silt (Thom et al. 1984).

As stated above, habitats composed of gently sloping banks and very fine-grained sediments occupy areas near the Turning Basin between RM 5 and 6, and around Kellogg Island (Tanner 1991). Cordell and Morrison (1996) found that the sediments in both of these areas were composed of more than 40 percent fines. This study also found several intertidal benches composed primarily of sand (0.125 to 0.5 mm grains) with less than 10 percent fines. These areas were located at Terminal 105 near the mouth of the river, at the General Administration Building at about RM 3, and near the West Seattle Bridge.

Stressors

There are no comprehensive studies on the health of flats in WRIAs 8 and 9. Health indicators include, but are not limited to the following:

- Unnatural erosion or deposition of sediment
- Harvesting of shellfish and other marine life
- Overabundance of organic matter loading including ulvoid mats
- Fecal and chemical contamination
- Physical disturbances from shoreline armoring, marina construction, and upland development practices
- Shading from overwater structures
- Competition from non-native species
- Loss of emergent and riparian vegetation

All of these indicators are suspected of occurring throughout WRIAs 8 and 9, based on site-specific studies (Matches et al. 1984; Thom et al. 1984; Thom et al. 1988).

In the Duwamish, the floodplain has been separated from the river channel by shoreline armoring, limiting the recruitment of fine-grained sediments to areas upstream of the estuary. Sediment contamination by several metals and organic compounds has also been observed at concentrations exceeding state sediment management standards. This contamination is particularly prevalent in flat habitats near the Turning Basin (RM 5.3).

Historical Distribution

Over the past century, 97 percent of the shallows and flats in the Duwamish Estuary and Elliott Bay have been lost (Blomberg et al. 1988). The largest area of intertidal flats eliminated over the past century is the former river delta at the mouth of the Duwamish River. This area, as well as the adjacent sides of the bay, represented approximately 1,450 acres of intertidal flats and subtidal shoals that were filled between 1895 and 1940 (Bortleson et al. 1980; Blomberg et al. 1988). Substantial flats and shallows likely were also lost when the meandering lower river was straightened to form the navigation channel.

There are no maps of the distribution of flats other than what can be deduced from Coast and Geodetic Survey nautical charts developed in the mid-to-late 1800s. These charts are available for larger deltaic flats such as the Duwamish River delta, but are not for nearshore areas and smaller stream deltas. The linked bathymetry-topography maps developed by the University of Washington's Puget Sound Regional Synthesis Model (PRISM) are based on records from the mid-1950s and later. Based on these maps, flats occur in most embayments (i.e., reach 2, reach 7, and reach 11).

Reasons for Change

Between 1895 and 1986, industrial and urban development created nearly 2,500 acres of new land from the former Duwamish River delta and estuary (Bortleson et al. 1980; Blomberg et al. 1988). Navigational requirements for the shipping industry and flood control spurred the channelization, armoring, and diking of the Duwamish Estuary. Dredging and filling have resulted in loss of all flats in the Duwamish River delta (Thom and Hallum 1990). Shoreline armoring, dredging, and filling have caused loss of flats in other parts of WRIAs 8 and 9 as well.

Data Gaps

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

Table 12: Data gaps for flats

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

TIDAL MARSHES

Functions within Ecosystem

Tidal marshes include salt and freshwater marsh habitats that experience tidal inundation. General marsh functions include those commonly listed for wetlands, which include: fish and wildlife support; groundwater recharge; nutrient cycling; flood attenuation; and water quality improvement. Functions demonstrated for tidal marshes in the Pacific Northwest are as follows:

- Primary production
- Juvenile fish and invertebrate production support

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

Primary production rates for regional tidal marshes range from 529-1,108 gC m^{-2} yr^{-1} (Thom 1981). Juvenile salmon have been shown to reside in tidal marshes in the Puyallup River estuary and Grays Harbor. Salmon forage on prey resources produced in, and imported to, the marsh system (Shreffler et al. 1992). Significant growth of juvenile salmon residing in these systems has also been reported. Prey resource production has been documented in small, restored tidal marshes in the Duwamish Estuary (Simenstad and Cordell 2000).

In a diel study of fluxes of dissolved and suspended matter between the Gog-le-hi-te marsh and the Puyallup River, it was shown that the marsh exported organic matter and imported some invertebrates (Simenstad and Thom 1996). The water entering the marsh was warmed and salinity increased in the system. Dissolved oxygen was also increased in the system. It should be noted, however, that the Gog-le-hi-te system is a restoring tidal marsh, likely to be short of reaching equivalency, and does not necessarily represent other tidal marsh systems in other parts of Puget Sound.

As an example of tidal marsh habitat utilization, the Gog-le-hi-te system was shown to be used by 118 bird species within the first five years of its existence (Simenstad and Thom 1996). Grazing of marsh vegetation by waterfowl was noted, as was foraging of fish by great blue heron and kingfishers. In general, shorebirds procure invertebrate prey and raptors feed on small mammals, amphibians, and reptiles. In addition, passerines such as red-winged blackbirds and marsh wrens nest in tidal marshes (Simenstad et al. 1991).

Processes that Maintain Tidal Marshes

Marshes accrete sediment and organic matter and thereby build land both upward and outward. They are maintained primarily by adequate hydrology as well as sediment supply. Marshes generally occur in more protected areas where waves and currents do not erode the marsh. Salinity effects saltmarsh plant species composition and the lower limits of distribution. In addition, surface (river and stream channel) and groundwater (seepage) discharge influence salinity, thereby influencing plant species composition and distribution. Alterations in hydrology, sediment supply, sea level, or marsh plant production can affect the maintenance of the marsh.

Location of Tidal Marshes

The current distribution of marshes in WRIAs 8 and 9 is extremely limited due at least in part to historical filling, diking, armoring, and other human intrusions. The ShoreZone database (WDNR) shows only a small marsh system in reach 9 on Vashon Island. Maps developed during the National Wetland Inventory program in the 1980s also show the small tidal wetland on Vashon Island and surrounding wetlands in reaches 2, 7, 9, 10, 11, and 12. We were unable to verify that these systems were actually tidal wetlands. A small tidal saltmarsh located in Edmonds between the area immediately east of the railroad tracks and south of the Edmonds ferry terminal is connected to Puget Sound.

WRIA 8

The ShoreZone database (WDNR) does not show any tidal marsh system in WRIA 8.

WRIA 9

Tanner (1991) mapped tidal marshes as part of a search for potential restoration sites in the Duwamish Estuary. This study found that the largest remaining tidal marsh in the entire system is located at Kellogg Island between RM 1.0 and RM 2.0 in the lower estuary. Northern portions of Kellogg Island are intertidal, and include an interior high marsh, flooded only by higher spring tides, and a regularly flooded low marsh. High marsh plants include *Carex lyngbyei, Distichlis spicata, Juncus balticus*, and the non-native *Phragmites* sp. The Washington State Department of Transportation created a pocket of brackish marsh connected to the Duwamish by culverts between RM 3.0 and RM 2.5. Tanner (1991) also found very small areas of fringing emergent vegetation, usually dominated by *Scirpus americanus* and *C. lyngbyei*, scattered throughout the estuary, but considered these areas too small to map. Cordell et al. (1998) observed natural and transplanted small emergent wetland patches dominated by *C. lyngbyei* and *Scirpus* spp. These areas were located just above and below the Turning Basin, near Slip 6 and Terminal 105.

Stressors

There have been no reports on health indicators of tidal marshes in the region. Some potential health indicators are as follows:

- Disturbed community structure
- Disturbed plant growth
- Presence of non-native species
- Buffer encroachment
- Runoff scour
- Elevated soil contaminant concentrations
- Presence of man-made debris
- Physical disturbances from shoreline armoring, marina construction, and harvesting
- Chemical contamination

These systems are vulnerable to physical disturbances by human actions (i.e., filling, dredging, hydrologic constriction, boat wakes) as well as chemical contamination. Debris, such as plastics and other man-made materials, can accumulate in tidal marshes, which can bury and smother marsh plants (Thom et al. 2000).

The Kellogg Island tidal marsh appears to be stable, but Tanner (1991) reported that the erosion of dredged material is slowly raising the elevation of the area and threatening the high marsh community. Both the Kellogg Island and Route 509 marshes have also had incursions of the disturbance-tolerant non-native species *Phragmites* sp. (T. Dean, pers. comm.). Cordell et al.

(1998) found that some of the small emergent wetland patches were frequently disturbed by wave action, large pieces of industrial and woody debris, and boat wakes. The study also observed that grazing by geese might be limiting emergent growth in some areas.

Historical Distribution

Approximately 1,170 acres of tidal marsh habitat was originally present in the Duwamish Estuary before development began. Most of this area fringed the meandering river channel and was filled to accommodate the straightened navigation channel and flood-control measures (Blomberg et al. 1988). Most of the 1,170 acres of tidal marsh occupied areas between +8 ft to +11 ft MLLW (Blomberg et al. 1988). These areas were likely vegetated by *S. maritimus* and *S. americanus*, *C. lyngbyei*, and *Triglochin maritimum* (Tanner 1991). Vegetation found higher in the marsh probably included tufted hairgrass (*Deschampsia caepitosa*), saltgrass (*Distichlis spicata*), pickleweed (*Salicornia virginica*), Baltic rush (*Juncus balticus*), silverweed (*Potentilla pacifica*), and red fescue (*Festuca rubra*) (Dethier 1990).

Tidal marshes in the Puyallup River-Commencement Bay area develop over the elevation range of 3-5 m MLLW (Thom et al. 2000). It is reasonable to infer that marshes in WRIAs 8 and 9 would have formed at similar elevations.

Reasons for Change

Between 1895 and 1986, industrial and urban development created nearly 2,500 acres of new land from the former Duwamish River delta and estuary (Bortleson et al. 1980), eliminating 97 percent of tidal marshes in the Duwamish Estuary and Elliott Bay. Navigational requirements for the shipping industry and flood control spurred the channelization, armoring, and diking of the Duwamish Estuary. Overwater structures have shaded out marsh plants, and the effects of other development activities, such as changes in hydrologic inputs, likely have deprived marshes of the sediments and salinity regimes they require.

Data Gaps

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

Table 13: Data gaps for tidal marshes

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

SUBESTUARIES (RIVER MOUTHS AND DELTAS)

Subestuaries are those areas of river and stream mouths that experience tidal inundation, including their deltas and any associated marshes. Fresh and saltwater mix here, providing a range of salinities. These are the areas where rivers broaden, attenuating localized flooding. Like marshes, subestuaries provide juvenile salmonid rearing and feeding areas, can support eelgrass beds if salinities are high enough, and provide refuge, feeding, and production areas to a wide variety of birds, fish, mammals, invertebrates, and reptiles.

The following discussion includes a general overview of all stream and river subestuaries in the study area, with a limited discussion of the Duwamish River mouth and delta. Additional information on the Duwamish system is found in Section 11 of this report.

Functions within Ecosystem

In their natural condition, the river mouth and delta are areas where the river spreads out, attenuating floodwaters. The following list highlights functions typically associated with subestuaries:

- Floodwater attenuation
- Critical transition areas for anadromous salmonids
- Water quality improvement
- Rearing areas for juvenile salmonids and other estuarine dependent species of fish and wildlife
- Supports eelgrass
- Refuge for multiple species

Often subestuaries are associated with wetlands, which further slow peak flows. Vegetated wetlands (emergent marshes and forested flood plains) that persist along margins of river deltas can trap sediments and uptake nutrients, or other contaminants, which might otherwise be delivered by the river to the nearshore environment.

Subestuaries, particularly saltmarshes, are important rearing areas for juvenile salmonids, providing refuge and food before they leave for open waters. Provided salinities are not too low, these areas can also support eelgrass, an important habitat for many species. Additionally, freshwater outlets are used by birds for bathing and drinking, particularly in the late summer months when freshwater is more limited (Norman 1998).

Like tidal marshes, a wide variety of birds, fish, mammals, amphibians, reptiles, and invertebrates use subestuarine marshes for refuge, food, and reproduction.

Processes that Maintain Subestuaries and Deltas

River deltas develop as a result of downstream sediment transport, with the rate of delta growth related to the amount of annual freshwater discharge (Downing 1983). In protected bays, freshwater and saltwater are stratified in the water column at the river mouth, providing a means for sediment to settle out of the river plume. This process forms the mud shoals and tidal flats that exist at the heads of protected bays. The small streams that are located along the shoreline of Puget Sound may form small deltas if the mouths are located in areas protected from waves and tidal currents. Over time wetland accretion occurs on the deltas as marsh vegetation slows the water and settles out fine sediments.

Location of Subestuaries

WRIA 8 Subestuary Distribution

The only large outlet in WRIA 8 is the Lake Washington Ship Canal, which empties into Shilshole Bay. There is no floodplain or river delta associated with this outlet, which was historically a small bay and was developed into a ship canal for navigation. The canal is extremely important for anadromous fish migration because it is the only way into and out of the Lake Washington/Cedar/Sammamish System. Aside from this large subestuary, there are six small streams (classification information not available) in WRIA 8, located approximately every 10 km along the shoreline, with three in reach 1 and three in reach 2 (Figure 1). Some of these have deltas.

WRIA 9 Subestuary Distribution

The Duwamish River is the only large class 1 stream in WRIA 9 that empties directly into the nearshore. There are 14 class 2 streams, 13 with salmonids and one with salmonid use undetermined. Four of these are located on Vashon Island. One is in reach 7, and six are in reach 8, with two emptying into Poverty Bay, including the one with undetermined salmonid use. Three of these streams empty into Dumas Bay, which is in WRIA 10 (Figure 1) (King County 1990).

Stressors

Many of the streams in the study area are in urbanized areas and have been altered by development, resulting in fish habitat loss, water pollution, erosion and sedimentation, landslides, and flooding (King County 1990). Many of the small wetlands that were once associated with the small streams are degraded or gone as a result of filling and other development practices. The primary cause of small stream degradation in the region is impervious surface development within the watershed. Vegetation removal and covering of land surface by human infrastructure leads to a decrease in the amount of precipitation that soaks into the soil, and a subsequent increase in the amount of water delivered directly to the stream. These changes, in turn, cause a greater frequency and higher peaks for flood events, upsetting the processes that naturally sustain stream channels, greater inputs of sediment and contaminants to the stream system, and ultimately, the nearshore environment.

Historical Distribution

The general locations of most of the small streams are probably the same as they were historically. However, channelization and upland development have likely changed their natural flows, floodplain, and riparian characteristics. Unfortunately, the lack of historical monitoring results in an inability to accurately assess historical conditions of small streams. The most obvious and greatest changes have occurred in larger systems, such as when the White River and Cedar River were diverted out of the Green/Duwamish, reducing the basin by more than two-thirds. This had a corresponding effect on the river mouth and delta. In WRIA 8, the greatest change was to the Sammamish River, with the construction of the Lake Washington Ship Canal. The Sammamish once had a fairly large river delta and associated wetland system.

The distribution and dynamics of the original Duwamish River mouth and delta were shaped by substantially different hydrology patterns before development occurred in the region. Before 1906, the large unregulated freshwater outflow of the original Duwamish River included the Green, Black, Cedar, and White River basins. The combined area of the river systems was approximately 1,640 mi^2 versus its present drainage of 500 mi^2 (Blomberg et al. 1988; ACOE 1997). Historically, the discharge of freshwater through the estuary was estimated to range between approximately 2,500 cfs and 9,000 cfs. Present mean discharges range from under 500 cfs to about 4,000 cfs. Because of the glacially fed White River, the lower estuary would have been subject to high sediment and turbidity levels, likely causing a dynamic delta and multiple shifting distributary channels (Blomberg et al. 1988).

Bortleson et al. (1988) identified three original distributary channels through the delta. One distributary channel flowed around the west side of Kellogg Island to intertidal flats near present-day Harbor Island and west of this area. The second and third channels discharged to areas east of present-day Harbor Island to intertidal flats now occupied by downtown Seattle and the waterfront. From north to south, a broad intertidal area extended from the bay beyond marshlands near the river mouth to the northern edge of the present-day Harbor Island. From east to west, the intertidal area of the river mouth extended from Beacon Hill in Seattle to the hills of West Seattle.

Reasons for Change

Development activities, particularly diversions of rivers and dredging and filling activities, have significantly altered subestuaries in WRIAs 8 and 9. As reported above, the Duwamish Estuary has been straightened, and shoreline armoring has eliminated channel migration. All of the original delta has been eliminated by filling, and the flow of the river has been greatly reduced with the diversion of the Black, White, and Cedar river basins.

Data Gaps

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

Table 14: Data gaps for subestuaries

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

SAND SPITS

Functions within Ecosystem

Sand spits may enclose (partially or totally) intertidal estuarine areas. Substrata are typically sand, silty sand, or gravelly sand. Functions of sand spits in the Pacific Northwest include:

- Foraging areas for waterfowl and shorebirds
- Prey production for shellfish, marine fishes, and macroinvertebrates
- Infauna production (i.e., bivalves, burrowing worms)
- Primary production
- Spawning habitat for forage fishes

In general, pickleweed *(Salicornia virginica)* dominates the upper zones of these estuarine, intertidal marsh areas, forming dense mats. Other halophytes such as *Distichlis spicata* and *Atriplex patula* may be present (Dethier 1990).

Processes that Maintain Sand Spits

In the Pacific Northwest, sediment particles contributing to sand spit formation originate primarily from fluvial, rather than marine, sources (Simenstad et al. 1991). However, in the Puget Sound region, sediments deposited on sand spits may also originate from eroding bluffs. Waves and currents transport this material along the shoreline until it settles out near an embayment, forming a spit. Changes in river sediment load, ocean currents, and wave action can affect the maintenance of sand spits.

Location of Sand Spits

The current distribution of sand spits in WRIAs 8 and 9 is extremely limited. The ShoreZone database (WDNR) does not include spits. However, documentation of shore-drift patterns indicates that several small spits do exist in reaches 3, 8, 11, and 12 (WDOE 1991).

- Reach 3: Two spits are documented. The most obvious is the large symmetrical spit at West Point. The West Point spit is classified as a triangular cuspate foreland, formed by material eroding from feeder bluffs (Magnolia Bluff) and carried by local longshore transport and nearshore currents (MacDonald et al. 1994). The convergence of two drift cells occurs at the West Point spit (Schwartz et al. 1991). The second is a drift-aligned sand and gravel intertidal spit oriented toward the southwest and located northeast of West Point.
- Reach 4: In contrast, Alki Point is a tombolo spit that formed during geological upheavals over a thousand years ago (H. Shipman, pers. comm.).
- Reach 8: East of the rounded headland immediately southwest of Dumas Bay, shore drift is responsible for an intertidal spit.
- Reach 11: A number of small spits are found in Quartermaster Harbor between Vashon and Maury Islands. They include a spit near the Dockton headland, an intertidal sand and gravel spit north of Dockton Point, three spits along the northeastern shore of Burton Peninsula (a muddy sand spit and two lobate intertidal spits), and the symmetrical sand, granule, and pebble cuspate spit on the eastern shore of Burton Peninsula.
- Reach 12: Several spits are documented along Colvos Passage. The first is a sand, granule, and pebble spit to the north of Fern Cove. Another mixed sand and gravel spit is located at south side of the Cove. A third spit is located at Peter Point, and a fourth spit, predominantly sand with some granule and pebble, is located at the headland south of Peter Point.

Stressors

These systems are vulnerable to filling, dredging, boat wakes, and changes in sedimentation rates such as those caused by shoreline armoring. They also are vulnerable to physical disturbances caused by shoreline development.

Because of potential for fecal coliform and pathogen contamination, the beaches (including sand spits) of WRIAs 8 and 9 are closed to commercial shellfish harvesting (Puget Sound Water Quality Action Team 2000). Chemical contamination is likely in WRIAs 8 and 9, but few studies have focused on sand spits.

There have been no reports of health indicators specific to sand spits in the region. However, general health indicators that have been reported, or can be assumed to effect areas that contain sand spits include the following:

- Unnatural erosion or deposition of sediment
- Fecal and chemical contamination
- Alteration of natural habitats
- Overharvesting of shellfish

Historical Distribution

Very little information is available on the historical distribution of sand spits in WRIAs 8 and 9. However, sand spits enclosing saltmarsh subestuaries were once present at Elliot Point and at Edwards Point at the north and south ends of reach 1, respectively. Prior to the development of the Elliott Bay Marina in 1992, a zone of drift divergence on the southeast shore of Magnolia Bluff created an intertidal sand and gravel spit near Pier 91. The marina eliminated the net shore drift that created this spit. No information on the Alki Point spit was identified.

Studies have found that the West Point spit appears stable, despite shoreline armoring along Magnolia Bluff. In comparing distance and area measurements from aerial photographs between 1936 and 1977 with original surveys conducted in 1883, it was determined that the spit changed less than 40 ft. The construction of a sludge lagoon along the spit in 1962 interrupted littoral drift and caused rapid modification to the shoreline both up and downdrift. However, the sludge lagoon was removed in 1980 and replaced by a gravel beach. After the first year of construction, about 14 percent of the beach material moved around the point to the north side of West Point. About 60,000 square yards of beach grass were planted in the sand fill to aid stabilization of the backshore. Since 1981, the beach has remained relatively intact (Macdonald et al. 1994).

Reasons for Change

Shoreline armoring, shoreline development, dredging, and filling are likely the major causes for loss of sand spits and associated habitat. Construction of the Elliott Bay Marina eliminated the spit near Pier 91.

Data Gaps

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

Table 15: Data gaps for sand spits

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

BEACHES AND BACKSHORE

Functions within Ecosystem

Beaches include boulder, cobble, gravel, sand, and silt areas that comprise most of the shoreline of Puget Sound. They are generally steeper than tideflats described above. Backshore areas are immediately landward of beaches and are zones inundated only by storm-driven tides. A typical profile of an undisturbed shoreline in Central Puget Sound would have an upper backshore or storm berm area that collects logs and algae and other debris during storms. The intertidal portion of the beach, between OHW and about MLW, is typically relatively steep and comprised of a mixture of cobbles and gravel in a sand matrix. At about MLW the beach slope typically breaks to a relatively flat low-tide sand terrace.

Functions supported by beaches are numerous, and are generally similar to those described above for tideflats. However, the level of each function differs from tideflats. Ecological functions of beaches that have been documented in the region include:

- Primary production
- Nutrient cycling
- Refuge for multiple species
- Prey production for juvenile salmon and other marine fishes
- Fish habitat, including forage fish spawning
- Infaunal and epifaunal production

Organisms in these habitats are diverse, with both epifauna and infauna. Beaches are used as feeding areas by cutthroat trout, juvenile salmon, pisciverous birds such as cormorants, grebes, loons, mergansers, and great blue herons, bivalve-eating birds such as scoters and goldeneye (Dethier 1990), and shorebirds that probe into the substrate, or sweep the shallow water with their bills for invertebrate prey.

Backshore areas have not been studied well for their ecological functions. However, we do know that woody debris accumulates in this zone through transport at extreme high tides. It is generally believed that this woody debris can help stabilize the shoreline, trap sediments and organic matter, and provide microhabitats for invertebrates and birds. Backshore areas also support a unique assemblage of vegetation tolerant of wind, salt spray, and shifting substrate.

Processes that Maintain Beaches and Backshore

Like tideflats, beaches and backshores are maintained by the dynamics of erosion and deposition of sediment. Large woody debris and vegetation contribute to the formation and maintenance of beaches and backshore areas.

Location of Beaches and Backshore

Beaches and backshore areas occur within all reaches of WRIAs 8 and 9. A beach is an accumulation of unconsolidated material formed by waves and wave-induced currents in the zone that extends landward from the lower low water line for large (spring) tides, to a place where there is a marked change in material or physiographic form, usually the effective limit of storm waves. Backshore areas are those where water reaches only during extreme high tides that occur during major storms. Based on the ShoreZone database (WNDR), the total shoreline length that contains beaches is presented in Table 16.

WRIA 8

The ShoreZone database (WNDR) shows 36,959 m of beaches within WRIA 8.

WRIA 9

The ShoreZone database (WNDR) shows 124,843 m of beaches within WRIA 9. The mainland shoreline has 45,386 m of beaches, and Vashon/Maury Islands have 6800 m of beaches. About 11,455 m of beach environment is present between West Point and Alki Point, representing 43.3 percent of the bay shoreline. The majority of beach habitats are present northwest of Pier 91 and southwest of Duwamish Head, outside of the waterfront area. The predominant substrates are sand and sand mixed with pebbles.

Table 16: Shoreline lengths where various beach types were recorded in the ShoreZone database

Type	WRIA 8 Length (m)	Percent of Total WRIA 8 Shoreline	WRIA 9 Length (m)	Percent of Total WRIA 9 Shoreline
Beach – Total	36,959	82.8	124,843	72.0
Boulders	464	1.0	0	0
Diamicton*	0	0	5,151	3.0
Pebbles	0	0	201	0.1
Sand	13,439	30.1	61,884	35.9
Sand/pebbles	5,684	12.7	46,615	27.1
Sand/boulder	1,955	4.4	831	0.5
Cobble/pebbles	698	1.6	637	0.4
Sand/fines	0	0	5,967	3.5
Sand/pebbles/cobble	10,019	22.5	3,959	2.3
Sand/pebbles/boulder	1,977	4.4	0	0
Cobbles/pebble/boulder	498	1.1	0	0
Sand/cobble/boulder	0	0	1,185	0.7
Cobble/pebble/boulder/sand	2,225	5.0	1,983	1.2

* Diamicton is a non-sorted to poorly sorted mixture of sand and larger rounded and angular particles in a matrix of silt and clay.

Two taxa of seaweed, *Ulva* spp. and *Fucus gardneri*, dominate beaches in the region, but several other algal species may be locally common. *F. gardneri* (rockweed) is always found attached to more stable rocks ranging from small cobbles to boulders or to artificial substrata such as pilings or riprap. *Ulva* (sea lettuce) typically attaches to pebble or larger substrata, but may also be found in viable free-floating patches deposited along beaches. The distribution of rockweed provides a good indication of the general distribution of intertidal pebble-to-boulder substrata. The widespread distribution of rockweed and sea lettuce is illustrated in Figure 16.

Stressors

Beaches are subject to the same stressors affecting flats (see Table 12). These include overabundance of ulvoids, physical disturbances as a result of shoreline armoring, contamination by organic matter and fecal coliform, *Spartina* conversion to monoculture marshes, and overwater structures and marinas. Shellfish harvesting can also be particularly damaging to these systems.

Some indicators of the health of beaches include the following:

- Fecal contamination
- Chemical contamination
- Alteration of natural habitats
- Alteration of resource use of natural habitats

- Alteration of sediment supply
- Presence of non-native species

Shoreline armoring is particularly harmful to recruitment of new beach materials. This is evident along the entire beach from Alki Point to Duwamish Head where seawalls are present for approximately 13,000 linear ft from Pier 91 to Magnolia Bluff. Only 5,580 linear ft from Magnolia Bluff to West Point are free of shoreline armoring (Pentec Field Survey 2000b). Shoreline armoring likely reduces recruitment of new beach materials throughout WRIAs 8 and 9.

Because of the potential for fecal coliform and pathogen contamination, the beaches of WRIAs 8 and 9 are closed to commercial shellfish harvesting (Puget Sound Water Quality Action Team 2000). Chemical contamination is likely, but few studies have focused on beaches.

Historical Distribution

No comprehensive historical maps are available for assessing historical distribution. However, prior to filling and urbanization of Elliott Bay, beach habitat likely was more extensive than it is today, particularly in the waterfront area. In areas where development has occurred, such as at Shilshole Marina and Elliott Bay, it has likely resulted in loss of beaches and beach functions.

Reasons for Change from Historical Distribution

Shoreline armoring, overwater structures, dredging, filling, and resource harvesting are likely the major causes for loss of beach habitat.

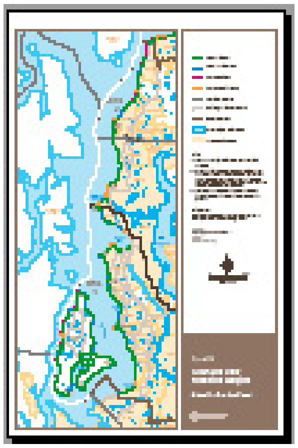
Data Gaps

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

Table 17: Data gaps for beaches and backshore

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

Figure 16 *Fucus* and *Ulva* Shoreline Lengths



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BANKS AND BLUFFS

Functions within Ecosystem

Banks and bluffs are typically steep areas of varying heights, located between the intertidal zone and the upland. They are a part of the riparian zone and act as an important transition area in this aquatic/terrestrial interface. The ShoreZone database (WDNR) identifies cliffs as those areas with a slope of more than 20 percent grade. Banks and bluffs can be composed of sediments of varying grain sizes as well as rocks and boulders. Functions performed by banks and bluffs include the following:

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

Processes that Maintain Banks and Bluffs

These habitats are formed and maintained by the dynamics of numerous factors including soils, wind, erosion, hydrology, and vegetative cover.

Location of Banks and Bluffs

Based on the ShoreZone database (WDNR), the distribution of cliffs of various types are shown in Table 18. As the table shows, bluffs in WRIA 8 are primarily high and steep, as are more than half of the bluffs in WRIA 9.

Table 18: Shoreline lengths where various cliff types were recorded in the ShoreZone database

Type	WRIA 8 Length (m)	Percent of Total WRIA 8 Shoreline	WRIA 9 Length (m)	Percent of Total WRIA 9 Shoreline
Cliff –Total	2,115	4.7	44,957	14.4
Inclined/low (20-35°; <5m)	0	0	10,183	5.9
Inclined/moderate (20-35°; 5-10m)	472	1.1	5,379	3.1
Inclined/high (20-35°; >10m)	0	0	1,700	1.0
Steep/low (>35°; <5m)	0	0	1,554	0.9
Steep/moderate (>35°; 5-10m)	0	0	6,025	3.5
Steep/high (>35°; >35m)	1,643	3.7	20,115	11.7

Stressors

The “health” of banks and bluffs is difficult to assess. We do know that stressors include shoreline armoring, vegetative cover reduction, shoreline development, overwater structures, dredging, filling, sediment extraction, and hydrology changes.

Residential development has caused some erosion and stability problems in a variety of places, including along the lower bluff southeast of Discovery Park. In general a change in the erosion rate of these areas would affect not only the protection of the upland area, but also the sediment composition and elevation of beaches and other intertidal and shallow subtidal habitats. Hence, where bank erosion rates have been increased or where erosion has been interrupted by artificial means (i.e., a seawall), the health of the adjacent habitats that are dependent on sediment from the bluffs is affected. Additional information on these types of problems can be found in the Shoreline Conditions section of this report.

Historical Distribution

The historical distribution of banks and bluffs has not been mapped. Obvious, but unquantified, changes have occurred in Elliott Bay, Shilshole Bay, Seahurst Park, and other areas where shoreline development has been extensive.

Reasons for Change

The major obvious changes are likely due to shoreline armoring and coastal development that directly affects bluffs and their maintenance processes. For example, the bluffs behind Elliott Bay were removed and/or lowered to form downtown Seattle.

Data Gaps

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

Table 19: Data gaps for banks and bluffs

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

MARINE RIPARIAN ZONES

Functions within the Ecosystem

Riparian zones are those areas on or by land bordering a stream, lake, tidewater, or other body of water (Hall 1987) that constitute the interface between terrestrial and aquatic ecosystems (Swanson et al. 1982). They perform a number of vital functions that affect the quality of aquatic and terrestrial habitats as determined by their physical, chemical and biological characteristics. Riparian-aquatic interactions are now recognized by scientists as so important that riparian buffers have been established as a central element of forest practice rules and watershed restoration efforts (Spence et al. 1996). Riparian vegetation composition, density and continuity are some of the most important characteristics of riparian systems. In general, healthy riparian systems have the following characteristics (Brennan and Culverwell, in prep.):

- long linear shapes
- high edge to area ratios
- microclimates distinct from those of adjacent uplands
- standing water present all or most of the year, or a capacity to retain water
- periodic flooding which results in greater natural diversity
- composition of native vegetation differing somewhat from upland systems

Most of what we know about riparian functions and values comes from investigations of freshwater systems, which have been the subject of extensive research. Although marine riparian zones have not been subject to the same level of scientific investigation, increasing evidence suggests that riparian zones serve similar functions regardless of the salinity of the water bodies they border (Desbonnet et al. 1994) and are likely to provide additional functions unique to nearshore systems (Brennan and Culverwell, in prep.). Riparian functions that are known or likely to contribute to nearshore ecosystem health include protection of water quality, and bank stability; provision of wildlife habitat, microclimate, and shade; and input of nutrients and large woody debris (figure 17). Each of these functions is briefly reviewed below.

Water Quality

The use and effectiveness of vegetated buffers for pollution abatement and the protection of aquatic ecosystems has been well documented (i.e., Phillips 1989; Groffman et al. 1990; U.S. EPA 1993; Desbonnet et al., 1994; Lorance et al., 1997; Bernd-Cohen and Gordon 1998; Rein 1999; and, Wenger 1999). Vegetation binds soils, retains and absorbs contaminants, and reduces overland flow volume and velocity. The effectiveness of riparian buffers for pollution and sediment control depends on a number of factors, including (Brennan and Culverwell, in prep.):

- soils
- geomorphology
- hydrology
- biological processes (i.e., microbial activity)
- vegetation type
- slope height and angle

- annual rainfall
- level of pollution loading
- types of pollutants
- surrounding land uses
- buffer width

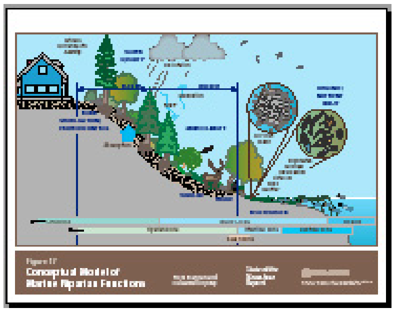
The degradation of urban waterways is directly linked to urbanization and has been exacerbated by the lack of adequate runoff storage, treatment, and filtration mechanisms (Brennan and Culverwell, in prep.). The major pollutants found in urban runoff include sediment, nutrients, road salts, heavy metals, petroleum hydrocarbons, herbicides, pesticides, pathogenic bacteria and viruses (U.S. EPA 1993). The loss of vegetation and resultant increase of contaminants in the system are the result of human activities, such as clearing, grading, compaction of soils, landscaping practices, and the installation of impervious surfaces such as roads, buildings, sidewalks, and parking lots. Pesticide, herbicide, and fertilizer application also contributes to nutrient and contaminant loading. Vegetation removal and the introduction of sediments, nutrients and other contaminants into the aquatic environment can result in eutrophication and reduce plant and insect food sources for fish and wildlife species (Knutson and Naef 1997). In addition to these indirect effects, contaminants can have direct effects on aquatic organisms including increased mortality in adults, juveniles and embryos, reduced reproductive success, birth defects, anorexia and loss of body weight, retarded growth, and changes in species or community composition.

Many of the contaminants introduced into the nearshore are passed through the food chain and are found in higher trophic levels. For example, Calambokidis (1995) and others have found excessively high levels of PCBs in harbor seals and orca whales in Puget Sound. Water quality is also a human health and safety issue. Most of the beaches in King County have been closed to shellfish harvest, and some to finfish harvest, as a result of high contaminant levels found in sediments, aquatic organisms, and the water column. Although this action is a good precautionary measure for human health and safety, much remains to be learned about direct and indirect cause and effect relationships between urbanization and the health of individual species and the ecosystem.

Wildlife Habitat

Healthy riparian areas along marine shorelines support abundant and diverse assemblages of wildlife. For example, Brennan and Culverwell (in prep.) identified 205 wildlife species (5 amphibians, 4 reptiles, 153 birds, and 43 mammals) in a review of wildlife species known or expected to have a direct association with riparian habitat along the marine shorelines in Central Puget Sound. This represents approximately 70 percent of the 292 wildlife species known to inhabit all of King County. Wildlife species diversity and abundance is greatly influenced by the composition and continuity of vegetation and the proximity of riparian areas to Puget Sound, which offers a moderate climate, greater habitat complexity and increased opportunities for feeding, foraging, cover and migration.

Figure 17 Conceptual Model of Marine Riparian Functions



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Wildlife habitat requirements in freshwater riparian zones are complex and have received a significant amount of review and analysis. However, few studies have focused on wildlife habitat requirements in marine riparian areas and we must depend upon wildlife studies and studies of riparian support functions elsewhere to begin to understand the potential of marine riparian areas. For example, Brown (1985) reports that 359 of 414 (87%) species of wildlife in western Washington and western Oregon use riparian areas and wetlands during some season or part of their life cycle (Cedarholm et al., 2000). In a review of riparian buffers needed to support wildlife in Washington State, Knutson and Naef (1997) determined that the average width reported to retain riparian functions for wildlife habitat was 287 feet (88 meters). In their review of the literature on wildlife habitat protection, Desbonnet et al. (1994) offer recommendations of 198-330 feet (60-100 meters) for general wildlife habitat, 304 feet (92 meters) for protection of significant wildlife habitat, and 1980 feet (600 meters) for the protection of critical species. It is suspected that buffer requirements for freshwater systems may be significantly less than for some marine and estuarine riparian systems because of the influences of wind, salt spray, desiccation, and general microclimate effects on vegetation and associated wildlife (Klaus Richter, pers. comm.).

Aside from direct habitat loss, one of the greatest impacts of urbanization on wildlife comes from habitat fragmentation (Stenberg et al. 1997; Knutson and Naef 1997). The isolation of remnant habitat parcels makes utilization and recolonization difficult or impossible (Knutson and Naef 1997). This is of particular concern for species with low mobility such as amphibians (K. Richter, KCDNR 1995; Knutson and Naef 1997). Because many wildlife species depend upon wide, continuous corridors, vegetative cover, climate, food, and separation from the disturbance of urbanization, the loss and fragmentation that results from urbanization greatly limits wildlife species distribution, diversity and abundance. Developing a better understanding of wildlife species' life history requirements and their utilization of marine riparian zones, and the effects of habitat loss, alteration, and fragmentation will require additional directed studies in these areas.

Microclimate

Riparian plant and animal communities are greatly influenced by their proximity to marine waters. Physical influences on these communities include temperature and moisture regulation, tidal inundation, wind exposure, and salt spray. Marine littoral communities are, in turn, influenced by riparian condition, with overhanging vegetation and organic litter, moisture, and soils playing important roles in species distribution and abundance. In both environments, many organisms, such as amphibians and upper intertidal invertebrates, depend upon cool, moist conditions for survival. Many of the habitat-forming processes and much of the habitat structure is due to the presence of vegetation. Riparian vegetation provides shade and organic matter, retains soils and moisture, and reduces the effects of wind and salt spray.

The removal of riparian vegetation increases the exposure of the land and water to the sun, wind, and precipitation. The resultant effects are increased temperatures, decreased moisture and humidity, increased runoff and elevated water temperatures entering marine systems, desiccation or erosion of soils, and increased stress for organisms dependent upon cool, moist conditions. As marine shorelines have become developed, many of these habitat features have been replaced with concrete, rock, asphalt, and other impermeable structures that displace habitats and species. It is assumed that the effects of alteration or elimination of microclimates in marine riparian areas as a result of urbanization are similar to the impacts that have been demonstrated in freshwater riparian areas. Further investigation is needed to quantify the relationship between marine riparian vegetation, microclimates and the impacts of urbanization.

Shade

In freshwater streams, riparian vegetation moderates the amount of solar radiation that reaches the stream channel and runoff entering the stream, thereby dampening seasonal and diel fluctuations in stream temperature (Beschta et al. 1987). In estuarine areas that receive tidal exchange and flushing of larger volumes of water, the effect of shading on water temperature would likely be substantially less than in small stream environments. However, shade may be important for regulating water temperatures in tidal channels and for direct drainages (i.e., streams, springs, and seeps) to marine waters. Furthermore, shade has long been recognized as an important factor in reducing desiccation from solar radiation in marine intertidal organisms (Calvin and Ricketts 1968; Connell 1972). In a literature review of the causes of spatial and temporal patterns in intertidal organisms, Foster et al. (1986) found that the most commonly reported factor responsible for setting the upper limits of intertidal animals is desiccation.

In Puget Sound, there are few studies that show the direct linkage between shade and nearshore species composition, or dependence. However, Penttila (1978) suggests that shade can increase the success of surf smelt spawning by reducing the mortality attributed to thermal stress and desiccation. A recent study comparing shaded and unshaded summer spawning sites found that shaded sites had significantly lower egg mortality (Penttila, 2001). Surf smelt are obligate beach spawners and are also an important source of prey in the nearshore ecosystem. Ongoing studies by the University of Washington may provide additional data that reveals the contribution of riparian vegetation in thermal regulation and species composition in supralittoral zones. However, additional information is needed to fully understand the importance of shading in the nearshore.

Nutrient Input

Riparian areas act as both sources of organic matter and sinks for trapping and regulating the flow of nutrients. Although the amount of input and level of importance to the marine system have not been quantified, riparian vegetation has the potential of producing significant amounts of organic matter. The organic matter that falls to the forest floor and becomes a part of the soil, or enters the aquatic environment, directly or indirectly, contributes to the detrital food web. Organic detritus is the principal energy source for food webs in estuarine and shallow marine benthic portions of the ecosystem; the principal source of this detrital carbon is debris from macrophytes in the system (Gonor et al. 1988). Nutrients, such as nitrogen, are also fixed by roots of some plants and metered out to the aquatic system through runoff, leaf and stem litter, or large woody debris.

Riparian vegetation also makes indirect contributions of nutrients to the nearshore system in the form of prey resources. The organic debris produced by riparian vegetation often collects on beaches and combines with marine-derived plant material to form beach wrack. The structure and decomposition of beach wrack attracts a diverse array of terrestrial insects and marine invertebrates. Many riparian plants attract insects that become prey for terrestrial and aquatic consumers. For example, a number of studies have identified terrestrial insects as a significant dietary component of juvenile chinook and chum salmon diets in subestuaries and other nearshore waters throughout Puget Sound (Fresh et al. 1979; Fresh et al. 1981; Pearce et al. 1982; Levings et al. 1991; Shreffler et al. 1992; Levings et al. 1995; Miller and Simenstad 1997; Cordell et al. 1999a,b; Cordell unpublished data). In addition, other invertebrates, such as mysids and amphipods, are connected to vegetation via detritus-based food webs and serve as important prey for salmonids and other fishes, birds, and invertebrates in the nearshore.

Current nearshore food web analysis by the University of Washington has identified important habitats and food web connections for chinook salmon in Puget Sound, including (Cordell et al. unpublished data):

- Intertidal and shallow subtidal areas that produce amphipods and other epibenthic crustaceans. As has been established for juvenile chum salmon, these probably include intertidal flats as well as vegetation and areas of high detritus buildup.
- Nearshore vegetated terrestrial habitats that are the source of terrestrial insects in the diets.
- Feeding on planktonic grazers such as euphausiids, shrimp, and crab larvae, planktonic amphipods, and copepods.
- Feeding on other secondary pelagic consumers such as herring and other fishes.

Due to the limited sampling and dietary analysis of juvenile salmonids and other species in the nearshore environment, additional studies are needed to quantify and understand the contribution of riparian vegetation to nearshore food webs and the impacts of vegetation loss along marine shorelines. However, it is clear that as vegetation is eliminated, the food supply and the thus the carrying capacity of the nearshore ecosystem is reduced (Brennan and Culverwell, in prep.).

Bank Stabilization

Vegetation is well recognized as an effective tool in reducing erosion and increasing slope stability by intercepting and extracting moisture through the canopy and roots, mechanical reinforcement of soils and restraint by the roots and stems, and adding structure to beaches that traps sediments and protects the toe of slope (see Myers 1993; Menashe 1993; Macdonald and Witek 1994; Gray and Sotir 1996; Brennan and Culverwell, in prep.). Vegetation, once established, provides a self-perpetuating and increasingly effective permanent erosion control (Kittredge 1948; Menashe 1993). Soils, slope height and angle, drainage, and other factors are also very important in determining susceptibility to erosion. However, for all shorelines, and particularly those in areas with steep and eroding bluffs, native vegetation is usually the best (and most cost effective) tool for keeping the bluff intact and for minimizing erosion (Broadhurst 1998).

The loss or removal of shoreline vegetation can result in increased rates of erosion and higher frequency of slope failure. This cause-and-effect relationship can be demonstrated convincingly as a result of many field and laboratory studies reported in the technical literature (Gray and Sotir 1996). Land use practices such as commercial, industrial, and residential development, along with infrastructure such as roads, bridges, and railroads, have all had a dramatic effect on the volume, type, density, and extent of riparian vegetation that remains along the shoreline. Removal for development, landscaping, and view corridors has greatly decreased the amount of vegetation available to perform slope stabilization functions. These activities also result in increased impervious surfaces. Combined, these alterations have resulted in increased erosion and, often, the subsequent installation of armoring, or bank stabilization structures, which typically results in additional vegetation removal. While many recommendations and efforts have been made to utilize vegetation management and alternatives to structural solutions for controlling shoreline erosion (see Macdonald and Witek 1994; Zelo et al. 2000), current regulations do not make use of these alternatives mandatory.

Large Woody Debris (LWD)

One of the primary roles of riparian vegetation relative to aquatic ecosystems is the contribution of habitat structure in the form of LWD. The mechanisms for delivery of LWD into the nearshore include natural and human-induced erosion of banks and bluffs, erosion of wooded riverbanks and delivery through the estuary, and drift logs delivered by the tides. The role of LWD in freshwater lotic systems has been well documented and has led to increasing efforts to utilize LWD for bank stabilization and habitat restoration (i.e., Johnson and Stypula 1993; WDFW 1998). Coarse woody debris is also an important part of estuarine and oceanic habitats (Gonor et al. 1988) and plays important roles for both fish and wildlife (Brennan and Culverwell, in prep.). Cedarholm et al. (2000) recognized the importance of LWD in increasing habitat complexity and heterogeneity, serving particularly important benefits to salmonids in estuarine marshes and nearshore environments. Weitkamp (1982) observed juvenile salmon feeding on biota attached to boom logs near Pier 90 in Elliott Bay. In Tillamook Bay, Oregon, large stumps were placed on the mud flats at the mouth of the Tillamook River with the intent of increasing fish habitat (Tillamook Bay National Estuary Project 2000).

Vegetation and woody debris provide nutrients to the aquatic environment and refuge for fishes and wildlife, and function as hydraulic buffers to flood and storm surges, or wave energies. Structurally, LWD provides potential roosting, nesting, refuge, and foraging opportunities for wildlife; foraging, refuge, and spawning substrate for fishes; and foraging, refuge, spawning, and attachment substrate for aquatic invertebrates and plants in the nearshore environment (Brennan and Culverwell, in prep.). Logs that become imbedded in beaches serve to trap sediments that help to build the berm and backshore. The logs provide moisture and nutrients for the establishment of vegetation, which further stabilizes beaches. Once established, these features can be effective at reducing wave-induced erosion. In an effort to avoid the impacts of conventional shoreline armoring (bulkheads), a number of projects have selected alternatives that include the use of anchored logs and vegetation to decrease erosion (Zelo et al. 2000).

Location of Marine Riparian Vegetation

Marine riparian vegetation, defined as trees overhanging the intertidal zone, was found along 1,335 ft. of shoreline in WRIA 8 and 22,408 ft. in WRIA 9 (Washington Department of Natural Resources 1999). This represents 1 percent and 11 percent of the shoreline, respectively. However, the width, species composition, continuity, density, and age structure of riparian vegetation have not been determined. These factors are important for determining riparian functions and values and for developing management and recovery options. Regardless, it is apparent that little riparian vegetation remains due to urbanization and shoreline development practices in WRIAs 8 and 9.

Stressors

Stressors can be broken down into natural and anthropogenic causes. Natural stressors include earthquakes, slides, disease, parasitism, wave action during storms, and wind. Anthropogenic stressors include vegetation clearing, increased impervious surfaces and surface water runoff, air and water pollution, herbicides, and intentional changes in vegetation (i.e., landscaping). Vegetation removal and the introduction of exotic species change community structure, increase the chance of competitive interactions, change soil chemistry and microclimate, and increase solar and wind exposure.

Historical Distribution

Macdonald and Witek (1994) provide a brief historical description of vegetation type and distribution :

> Historically, western Washington included the most densely forested region in the United States. Temperate coniferous forests predominated and the size and longevity of the dominant species was unrivaled elsewhere in the world (Franklin and Dyrness 1988). Explorers and early pioneers describe old-growth forest coming right down to the shore – an occurrence now limited to scattered inaccessible sites along the outer ocean coast of the Olympic Peninsula (Egan 1990; Dunagan 1991; Kruckeberg 1991).

Historical photographs and other historical accounts of northwest estuaries (i.e., Sedell and Duval 1985; Maser et al. 1988; Dunagan 1991) suggest that the above description is representative of the study area.

More recent changes may be represented by a study conducted by American Forests, a Washington D.C.-based non-profit organization. They analyzed satellite imagery of 3.9 million acres of land on the east side of Puget Sound to determine how forest cover in the basin changed from 1972 to 1996. The analysis showed that dense vegetation and tree canopy coverage declined by 37 percent. The decline in coastal areas is likely to have occurred earlier and in greater amounts due to high development pressures and land use practices in these areas.

Reasons for Change

Vegetation clearing occurs with most development projects, including those at the water's edge. Most Puget Sound shorelines were logged off around the turn of the century (Macdonald and Witek 1994). Timber on the shorelines was some of the first cut due to the ease of access and transport (Dunagan 1991) and for land development (Brennan and Culverwell, in prep.). Over time, vegetation has been removed for timber, housing and other land development, roads, railroads, port development and other commercial and industrial development, view corridors, shoreline armoring, landscaping, beach access, and other land use practices. While much research, attention, and protection have been given to freshwater riparian areas, very little attention has focused on the potential importance of marine riparian areas. Some local governments provide limited guidelines for the removal of vegetation in their shoreline master programs, but most regulators admit it is extremely difficult to enforce (Broadhurst 1998) and regulations and enforcement have been woefully inadequate to protect this critical element of the nearshore ecosystem (Brennan and Culverwell, in prep.).

Data Gaps

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

Table 20: Data Gaps for Marine Riparian Zones

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

Key Findings for Selected Habitats

- Distribution of Habitat Types
- Nearshore marine habitats in WRIA 8 and 9 are diverse and include marine riparian vegetation, banks and bluffs, beach and backshore, tidal marshes, tidal flats, eelgrass meadows, kelp forests, and water column habitats.
- These habitats act together to create the productive Puget Sound ecosystem by providing the physical, chemical and biological processes that form habitats and drive critical functions.
- Historical maps of nearshore marine and estuarine habitats are lacking in WRIAs 8 and 9; only recently have comprehensive mapping efforts (WDNR Washington State ShoreZone

Inventory) been undertaken that adequately assess the region's nearshore marine resources.

- Eelgrass productivity exceeds that of most other aquatic plants. Organic carbon produced by eelgrass is especially important in driving the nearshore marine food web of Puget Sound.
- Overwater structures, shoreline armoring, fecal contamination, climate change, dredging, filling, resource exploitation, contamination, ship wakes and propellers have all contributed to major losses of habitat area and their functions in the region
- Monitoring programs have not adequately addressed long-term changes in habitat distribution.
- There is no comprehensive understanding of the effects of multiple stressors on the viability of nearshore marine habitats in the region.

Eelgrass

- Eelgrass meadows are highly productive habitats that support primary production, process nutrients, provide wave and current energy buffering, supply organic matter, and provide invaluable fish and wildlife habitat.
- Eelgrass meadows are found along approximately 57 percent of the WRIA 8 shoreline and 62 percent of the WRIA 9 shoreline (excluding Elliott Bay and the Duwamish).
- Eelgrass meadows are found along 4.4 mi of the Elliott Bay nearshore along Magnolia Bluff and between Alki Point and Duwamish Head, representing about 27 percent of the shoreline.
- Eelgrass between Alki and Duwamish Head is reported as moderately dense to dense, while eelgrass along Magnolia Bluff is reported as sparse and patchy.
- No eelgrass is present in the Duwamish Estuary or along the Elliott Bay Waterfront.
- Stressors to eelgrass include natural factors such as disease and overgrazing, as well as human influences such as shoreline armoring, overwater structures, dredging, and filling.
- Anecdotal observations suggest that the Alki meadow has been declining since the 1960s.

Kelp Forests

- Kelp supports primary production, provides fish and wildlife habitat, contributes organic and particulate carbon to the food web, provides wave and current buffering, and is a substrate for secondary production.
- Kelp is found along 12 percent of the WRIA 8 shoreline, and 7 percent of the WRIA 9 shoreline (excluding Elliott Bay and the Duwamish).
- Kelp (primarily *Nereocystis luetkeana*) is found along 1.1 mi of the Elliott Bay nearshore between Alki Point and Duwamish Head and along lower Magnolia Bluff. Patches have also been observed in the East Waterway near the mouth of the Duwamish River.
- Kelp forests in the study area may have been reduced since the 1980s due to harvest practices. However, there is evidence of increased abundance and distribution in the whole of Puget Sound compared to early in the century. Other stressors include nutrient loading and shading from overwater structures.

- Apparent increases in kelp may be the result of shoreline armoring and subsequent hardening of shallow subtidal substrates, which favors kelp attachment, recruitment, and growth.

Flats

- Flats are invaluable habitats that support primary production, process nutrients, provide habitat for fish and wildlife, produce prey for fishes and shorebirds, and buffer wave and current energy.
- The ShoreZone database indicates that flats are found along 6 percent of WRIA 8 shorelines, but does not indicate any in WRIA 9. However, flats are present along the WRIA 9 shoreline.
- Stressors to flats include filling, dredging, overwater structures, and overharvest of flat species.
- Ninety-seven percent of the historical shallows and flats in the Duwamish Estuary and Elliott Bay have been lost over the past century because of industrial and urban development. About 1,450 acres of intertidal flats and subtidal shoals were filled between 1895 and 1940.
- Despite these losses, nearly 12 linear miles of mudflats, submerged shallow shoals, or gently sloping exposed mud/sand habitats are present in the study area, most of which are in the Duwamish Estuary between the Turning Basin and river mouth. However, much of this flat habitat is constrained by shoreline armoring on one side and dredged channels on the other.
- Most of Elliott Bay and the Duwamish is armored. Much of the armoring is present at the top of the intertidal zone, and gently sloping mud and sand habitats are present in the lower zone.
- The health of flats is not clear. In the Duwamish, the floodplain is separated from the river, thus limiting the recruitment of fine-grained sediments. Also, sediment contamination is prevalent.

Tidal Marshes

- Marshes support primary production, provide nursery areas for fish and invertebrates, produce prey resources for adult fish and invertebrates, support other wildlife, protect water quality, buffer waves, and shelter salmonids as they osmoregulate and overwinter.
- The distribution of marshes in WRIAs 8 and 9 is extremely limited due to historical diking, filling, armoring, and other human intrusions.
- Ninety-seven percent of the historical tidal flats in the Duwamish Estuary and Elliott Bay have been lost over the past century because of industrial and urban development and the creation of a navigation channel.
- The largest remaining tidal marsh in the Duwamish is Kellogg Island, which includes interior high marsh, flooded low marsh, and intertidal flats. The non-native, invasive species *Phragmites* spp. has also been observed in the marsh.

- Historically, about 1,170 acres of tidal marsh habitat occupied areas of the Duwamish Estuary before development began. Most of the area fringed the meandering river channel and was filled to accommodate the straightened navigation channel.
- Very small patches of fringing emergent vegetation, usually dominated by *Scirpus* spp. and *Carex* spp., have been observed in the Duwamish Estuary. Some of these areas may be in jeopardy because of disturbances from boat wakes, large pieces of industrial and woody debris, and grazing by geese.

Subestuaries (River Mouths and Deltas)

- Subestuaries attenuate floodwaters, provide transition areas for salmonids, improve water quality, provide rearing areas for juvenile fishes, support eelgrass, and provide refuge for fish and wildlife.
- Most subestuaries in WRIAs 8 and 9 are at the mouths of small streams. There are 6 in WRIA 8 and 14 in WRIA 9.
- The major stressor to subestuaries is development, which results in filling, dredging, increases in impervious surfaces, water pollution, and erosion and sedimentation.
- The existing river mouth of the Duwamish Estuary and the upper 12 miles of river are constrained almost entirely by riprap and bulkheads. The entire original river delta was filled by 1940.
- Historically, the river mouth and delta were shaped by different hydrology patterns than today. Before 1906, the Duwamish Estuary received outflow from the Green, Black, Cedar, and White Rivers, draining over three times the present area. The glacially fed White River added substantial sediment flows. Historically, three distributary channels flowed through the delta.

Sand Spits

- Sand spits provide foraging areas for wildlife, produce bivalves, and support primary production.
- In WRIA 8, there is a spit at West Point. In WRIA 9, there are spits at Alki Point, Quartermaster Harbor, and along Colvos Passage.
- Sand spits are vulnerable to filling, dredging, boat wakes, and changes in sedimentation rates such as those caused by shoreline armoring and development.
- West Point and Alki Point are two prominent sand spits present in the study area. West Point formed by the convergence of two drift cells, while Alki Point formed as a result of geologic upheavals.
- Before development of the Elliott Bay Marina, a zone of drift divergence on the southeast shore of Magnolia Bluff created an intertidal sand and gravel spit near Pier 91. The marina eliminated the net shore drift that created this spit.

Beaches and Backshore

- Beaches and backshore areas support primary production, cycle nutrients, provide refuge for multiple species, produce prey for fishes, and support bivalves.
- There are almost 37,000 meters of beaches in WRIA 8, and over 45,000 meters of beaches in WRIA 9.
- Major threats to beaches include shoreline armoring, overwater structures, shellfish harvesting, and contamination with organic matter and bacteria.
- The majority of beach habitats in Elliott Bay/Duwamish are present northwest of Pier 91 and southwest of Duwamish Head, outside of the waterfront area.
- Shoreline armoring is particularly harmful to recruitment of new beach materials. This is occurring along the entire beach from Alki Point to Duwamish Head, and likely occurs throughout WRIAs 8 and 9. Seawalls are present for approximately 13,000 linear ft from Pier 91 to Magnolia Bluff. Only 5,580 linear ft from Magnolia Bluff to West Point are free of shoreline armoring.

Banks and Bluffs

- Bluffs provide sediments to beaches, habitat for wildlife, marine riparian vegetation, and groundwater seepage.
- Bluffs in WRIA 8 are primarily high and steep, as are more than half of the bluffs in WRIA 9. In WRIA 8, almost 5 percent of the shoreline is banks and bluffs. In WRIA 9, bluffs line approximately 18 percent of the shoreline.
- Stressors include shoreline armoring, reduction of vegetative cover, shoreline development, overwater structures, dredging, filling, sediment extraction, and hydrology changes.

Marine Riparian Vegetation

- Very few data have been collected on the functions of riparian vegetation in estuarine and nearshore areas. However, marine riparian vegetation likely protects water quality, bank stability, microclimate, and shade; and provides wildlife habitat, nutrients and large woody debris.
- Excluding Vashon Island and Elliott Bay/Duwamish, marine riparian vegetation is found along 11 percent of the WRIA 9 shoreline. There is marine riparian vegetation along 1 percent of the shoreline in WRIA 8.
- Stressors to marine riparian vegetation include earthquakes, landslides, storm waves, wind, clearing for development and landscaping, and shoreline armoring.
- Stands of riparian vegetation are present in the upper Duwamish Estuary (8.5 mi along both banks between RM 5.3 to RM 12), Kellogg Island, the adjacent shore (0.8 mi), and along Magnolia Bluff (3 mi). In remaining areas, riparian vegetation is sparse, replaced by industrial development, armoring, and overwater structures.
- Along Magnolia Bluff, much of the riparian zone likely provides high quality riparian function. Most of the vegetation is adult deciduous trees that extend uninterrupted for

more than 300 ft up the bluff. Landslides and instability along southern portions of the bluff have been observed in areas developed for residential use.

- Along the upper Duwamish Estuary, the riparian zone is often less than 100 ft wide and may not provide high quality riparian function.
- Historically, more than 1,200 acres of forested wetlands occupied areas along the Duwamish Estuary. About 12 mi (64,000 linear ft) of riparian forest occupied areas between Pier 90 and Duwamish Head.