BAINBRIDGE ISLAND NEARSHORE ASSESSMENT

SUMMARY OF BEST AVAILABLE SCIENCE

October 2003

Battelle

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PREFACE

The Bainbridge Island Nearshore Assessment was funded by the Salmon Recovery Funding Board (SRFB) as part of its mission to support habitat protection and restoration projects. This project was initiated, in part, as a result of the recent listing of Puget Sound chinook salmon as "threatened" under the Endangered Species Act and other proposed listings for Puget Sound marine species. The factors contributing to the decline of these species are complex and include, among other factors, the loss and modification of habitat caused by human activities across the region. Some of the early research suggests that the ecological functions and processes which form the habitat that support those species need to be maintained and protected in order to sustain natural populations. While Bainbridge Island does not naturally support freshwater use by chinook salmon, the City does include approximately 48.5 miles of saltwater shoreline which plays a critical role in the life-cycle of Puget Sound chinook and other species of concern. The overarching goal of this project and the City's Salmon Recovery and Conservation Strategy is to collect and employ critical information to ensure that Bainbridge Island provides and maintains a healthy and functional ecosystem that contributes to sustainable salmonid populations within the region.

The goals of the Nearshore Assessment are to 1) conduct a baseline characterization of the Bainbridge Island nearshore environment and assess its ecological health and function, 2) identify restoration and preservation opportunities and develop a strategy for ranking and prioritizing opportunities, and 3) develop a management framework based on the functions and processes of nearshore ecology. The findings of the project will be used by the City and the Bainbridge Island community to propose, pursue, and make informed decisions about nearshore preservation and restoration opportunities. The knowledge gathered regarding management of nearshore resources will also be integrated into the City's regulations that govern the development and use of the nearshore.

Management of the Bainbridge Island Nearshore Assessment was provided by the City of Bainbridge Island (COBI) with technical review and support provided by technical representatives of the Salmon Recovery Funding Board and the City's Environmental Technical Advisory Committee.

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City of Bainbridge Island
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FUNDING

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Battelle Marine Sciences Laboratory (MSL) prepared and organized the content of this report for the City of Bainbridge Island. Battelle did an exceptional job pulling this document together under the time and budget constraints. The City is responsible for reviewing, compiling, and publishing the report. The City's Environmental Technical Advisory Committee provided peer review as well as general technical advice. A whole-hearted thank-you to the ETAC for all their volunteer time and effort. Thanks also goes to Cinde Donoghue, Tim Gates, and Hugh Shipman from the Washington State Department of Ecology for their helpful advice throughout the project. The technical representatives of the Salmon Recovery Funding Board (SRFB) provided early peer review of the scope-of-work for the project. Applied Environmental Services, Inc. and Anchor Environmental LLC prepared preliminary drafts of this report for the City.

Because of the nature of this document, there has been an extensive use of figures and tables from existing publications, especially the <u>State of the Nearshore Ecosystem</u> prepared for King County and the recent White Papers prepared for the Washington State Departments of Ecology (WDOE), Fish and Wildlife (WDFW), and Transportation (WSDOT). King County produced many of the graphics used in this report. Additionally, many of the photographs used throughout the document were taken by the Washington State Department of Ecology and Applied Environmental Services, Inc.

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Cover Photos:

Left photo from the City of Bainbridge Island web page (2001); right-top photo: WA Department of Ecology (2000); and right-bottom photo: Applied Environmental Services, Inc. (2001).

LIMITATIONS

As with any report, there are limitations (inherent or otherwise) that must be acknowledged. This report is limited to the subjects covered, materials reviewed, and data available. The authors and reviewers have made a sincere attempt to provide accurate and thorough information using the most current and complete information available and their own best professional judgement. Since this document is a summary of the best available science, the reader is encouraged to become familiar with the original documents cited. Any questions regarding the content of this report should be referred to the original authors and the City of Bainbridge Island staff responsible for its production.

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I. INTRODUCTION

Bainbridge Island is located within the central Puget Sound Basin, east of the Kitsap Peninsula and west of the City of Seattle and in the year 2000 had a population of 20,308 (US Census). The Island is approximately five miles wide and ten miles long, encompassing approximately 17,778 acres, or 28 square miles, and is one of the largest Islands in Puget Sound. The Island is characterized by an irregular coastline of approximately 53 miles, with numerous bays and inlets and a significant diversity of other coastal land forms (i.e. spits, bluffs, dunes, lagoons, cuspate forelands, tombolos, tide flats, stream and tidal deltas, islands, and rocky outcrops).

A. BEST AVAILABLE SCIENCE

This summary of the best available science (BAS) is the foundation of the Nearshore Assessment. The goal of this document is to summarize the existing nearshore scientific literature as it relates to the environment of Bainbridge Island. Topics include nearshore species, habitats, functions, and processes, as well as how human activities might affect nearshore systems. Because this project will provide a management basis for City regulations, this document meets the legal requirement established under the Growth Management Act (WAC 365-195-900 through 365-195-925) to use BAS when revising comprehensive plans and development regulations. The requirement includes definitive standards as to what constitutes BAS and who qualifies as an expert. The material presented here, as well as the consultants and technical advisors working on this project, meet these standards.

It should be noted that best available science is just that, best available, and includes only the scientific knowledge and resource information available at this time. By its nature, this summary document is not independently exhaustive. It was intended that this document rely and build upon other recent and more extensive BAS projects, in addition to available local scientific information, to focus on the environment and human activities specific to Bainbridge Island. It should also be noted that the Nearshore Assessment is expected to produce more detailed and updated information than is presented in this BAS document. Forthcoming documents from the Nearshore Assessment project will be based upon the information presented here, but will also depart from this document with new knowledge, data, and professional analysis.

B. ORGANIZATION OF THE REPORT

This report is organized to assist the reader in understanding the nearshore ecosystem and the associated effects of human modifications. Chapter II provides a brief overview of nearshore ecological concepts, defines key terms, and provides a conceptual model that establishes a framework for understanding the impacts of human shoreline alterations to nearshore ecosystems. Subsequent chapters are organized on the basis of this conceptual model. Chapter III discusses nearshore physical characteristics and dynamics, Chapter IV discusses nearshore habitats, and Chapter V discusses nearshore biological resources. Chapter VI discusses the effects of nearshore modifications, while Chapter VII provides summary conclusions and recommendations. Because this document is intended to be a summary, the reader is encouraged to refer to the bibliographic references for additional information (Chapter VIII). This document, although written for a broad audience, includes many technical terms and concepts. The reader is encouraged to refer to the extensive glossary (Chapter IX) and list of acronyms and abbreviations (Appendix C). .

II. NEARSHORE ECOLOGY OVERVIEW

The habitats of the nearshore environment are a fundamental component in the diverse landscape mosaic of the Puget Sound ecoregion. Following is an overview of some key concepts related to defining the nearshore, its individual habitats, and the functions that they provide to Puget Sound.

A. DEFINING THE NEARSHORE

The nearshore environment is generally defined as the area encompassing the transition from subtidal marine habitats to associated upland systems. Williams and Thom (2001) define this in practical terms as the zone where direct functional interactions occur between upland and marine habitats. In Puget Sound specifically, this area typically includes habitats from the marine riparian zone to the lower limit of the photic zone (generally to a maximum of 30 m below mean lower low water [MLLW]). Within this range occur the strongest interactions between the marine environment and coastal processes. For example, upland vegetation (marine riparian habitat) contributes to beach and bank stability, provides shade for the upper intertidal zone, and contributes organic matter (leaf litter, woody debris) to the nearshore marine ecosystem (Williams and Thom 2001; Williams et al. 2001) (Figure II-1).

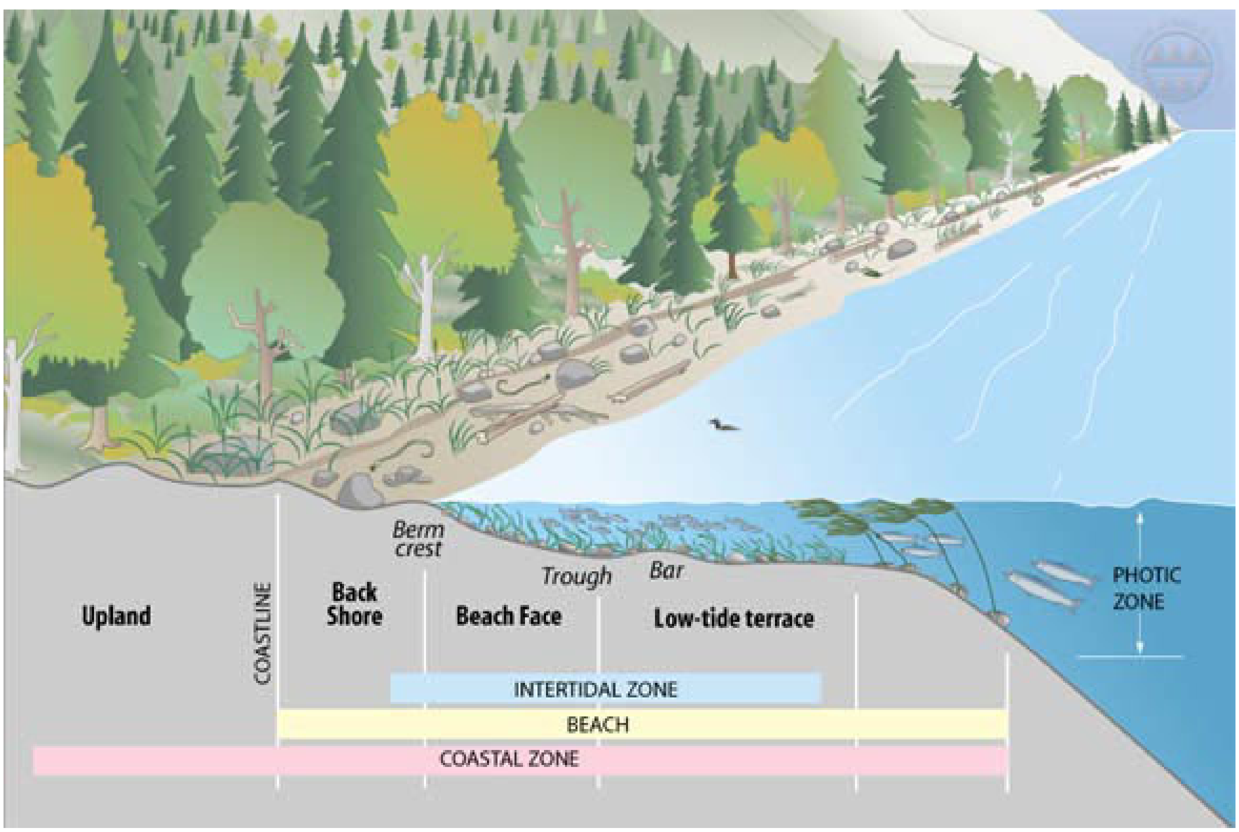

Figure II-1. Nearshore section illustrating typical tidal zonation (Source: King County Dept of Natural Resources)

B. HABITAT CLASSIFICATION

Within the nearshore, natural marine and estuarine communities generally occur along predictable gradients. These gradients correspond to local physical attributes (specifically, elevation and depth, substrate, wave energy, and salinity), and these known habitats and corresponding physical environment relationships have been used to create standardized classification systems intended for habitat inventory and mapping work in Washington State (Dethier 1990). Summary examples of these classification systems can be found in Appendix B of this document.

The nearshore vertical zones for Puget Sound marine and estuarine systems can be generally divided into the following classifications (following Dethier 1990) (Figure II-2):

- Backshore/Supralittoral – habitats that are outside the typical range of tidal influence and may be wet only occasionally from spray or irregular flooding; above mean higher high water (MHHW) of spring tides
- Intertidal/Eulittoral – habitats between MHHW and MLLW (extreme lower low water of spring tides [ELLW] in Dethier 1990); regularly inundated by the fluctuation of tides
- Shallow Subtidal – habitats that are rarely uncovered by low tide, 15 m or less below MLLW
- Deep Subtidal – habitats that are never uncovered by low tide, deeper than 15 m below MLLW.

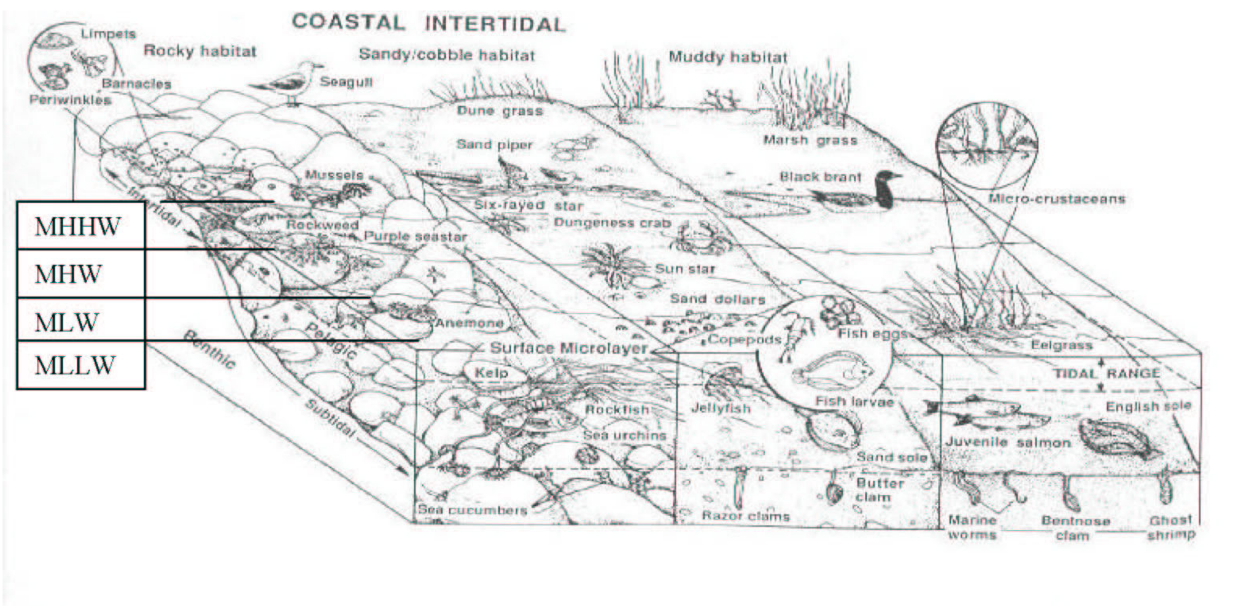

Figure II-2. Generalized distribution of major intertidal habitat types along an elevation (depth) gradient (from Nightingale and Simenstad 2001a., adapted from Krukeburg 1990, artist Sandra Noel).

Within these vertical classification zones, other physical, geological, and chemical factors (specifically, wave energy, substrate, and salinity) interact to constrain the distributions and interactions of marine plants and animals (Dethier 1990). A natural community can be defined as a distinct and recurring assemblage of plants and animals naturally associated with each other and with a particular physical environment. Thus, habitats are distinguished by their physical constraints and biotic communities. Habitat types found in Puget Sound include eelgrass meadows, kelp forests, banks, flats, marshes, sand spits, subestuaries, and marine riparian areas. The structure and typical species composition of habitat types relevant to Bainbridge Island are described in detail in Chapter IV of this document.

C. Defining Function

Ecological functions are natural attributes of a given habitat that "serve" the resources that rely upon that habitat. Ecological functions are defined by the structure (i.e., size, shape, substrate, and species composition) of the habitat, and the species interactions that occur therein. For example, bull kelp, found in the shallow subtidal zone of Puget Sound, provides a variety of functions to the nearshore ecosystem that are derived from its complex forest-like structure. These functions include refuge and feeding habitat for fishes (especially rockfish), spawning habitat for herring, and buffering of wave and current energy (Williams and Thom 2001). As ecosystems grow increasingly complex, functions that are provided by one habitat may also be beneficial to other habitats, resulting in a broad network of interactions. From a landscape perspective, the presence of a variety of nearshore habitats contributes a wider range of potential ecological functions (e.g., biodiversity maintenance) to the ecosystem as a whole.

To help evaluate the ecological functions of individual habitats for fish and wildlife within Puget Sound, standardized protocols have been developed that describe recommended techniques for quantitatively measuring habitat attributes that characterize these potential functions (Simenstad et al. 1991). Expert- and literature-derived guidance was used during this process to develop habitat-specific lists of representative fish and wildlife species, and their primary functional mechanisms (i.e., reproduction, feeding, refuge, and physiological adaptation). Specific examples of typical nearshore species and aspects of habitat functional dependence are discussed in Chapter V of this document.

It should be noted that within the Puget Sound ecoregion, the nearshore zone provides a number of necessary functional benefits to salmon, a key species that indicates local watershed health and provides cultural and economic resources to communities region-wide. Some of these functions include prey production (i.e., food for juvenile and adult salmon), migratory corridors, refuge for juveniles from predators, and juvenile rearing. In addition, salmon transport marine-derived nutrients back into freshwater streams and forests as they spawn and become prey for wildlife (see Cederholm et al. 2000), thus linking the functions of the nearshore ecosystem to the health of the entire watershed. The specific functional benefits of the nearshore to salmon are further explored in Chapter V.

D. Nearshore Ecologic Models

As the classification systems have demonstrated, nearshore habitats are defined by a variety of complex interactions between physical, geological, chemical, and biological components. The effects of human-caused changes in physical conditions can cause a change in the structure of habitats, which will ultimately affect the habitat's function. From this general reasoning, we can derive simple relationships (models) that may help us predict or understand natural and human-caused effects on nearshore ecosystem functions. These models, based on existing knowledge and best professional judgment, are especially useful when there is a pervasive lack of empirical data.

The physical components of an ecosystem are referred to as its "controlling factors" because of the strong dependence of biological entities upon them. For example, the local combination of controlling factors (such as slope, depth, tidal cycle, and wave energy) will define the type of plant species that can exist in that area. Biological communities, which are often spatially constrained by these local controlling factors, serve to further define the structure and functions (e.g., refuge, nutrient cycling) of the nearshore ecosystem (Williams and Thom 2001; Williams et al. 2001) (Table II-1). Once established, biological components may, in turn, influence controlling factors; so biological alterations can impact the ecosystem from a foundational level (for example, temperature regulation and nutrient input from overhanging vegetation).

Table II-1. List of Controlling Factors and Associated Habitat Structural and Functional Attributes (from Williams and Thom 2001).

Controlling Factors	**Habitat Structure**	**Habitat Processes**	**Ecological Functions**
Depth Substrata Slope Light Wave Energy Hydrology Temperature Salinity Nutrients Water Quality	Density Biomass Individual Lengths Diversity Patch Size Patch Shape Landscape Position	Production Sediment Flux Nutrient Flux Carbon Flux Landscape Connectivity	Disturbance Regulation Prey Production Reproduction Refuge Carbon Sequestration Maintenance of Biodiversity Movement/Migration

A conceptual model approach can be used to illustrate the interactions that occur in the nearshore ecosystem as influenced by controlling factors and associated habitat structure and function (for example, the effect of wave energy and light on plant biomass, and resulting links to primary production). Empirical data are often lacking on the impacts of specific activities to a given habitat's structural and functional attributes. Conceptual models are useful because they allow us to use existing information to identify the linkages between (and among) the controlling factors and biological components of an ecosystem. When changes occur at the controlling factors level, the associated biological and ecological responses can then be inferred and tested. In its most basic form, impact assessment can be approached through the response chain illustrated in Figure II-3 (from Williams and Thom 2001).

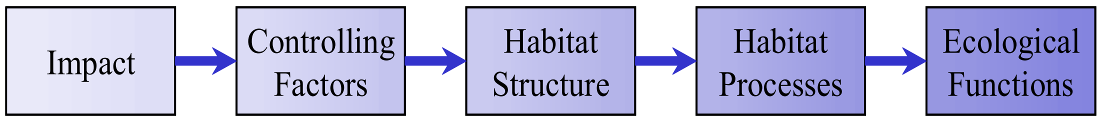

Figure II-3. Conceptual model linking shoreline impacts to ecological functions (from Williams and Thom 2001).

This approach provides the necessary framework for assessing complex systems - where data gaps often exist - and will be used throughout this document. The following chapters focus on surveying three key areas within this framework for the Bainbridge Island nearshore environment: physical characteristics and dynamics (Chapter III), habitats (Chapter IV), and biological resources (Chapter V). Based on an understanding of these factors, the potential impacts of nearshore modifications by humans can then be assessed in greater detail (Chapter VI).

III. NEARSHORE PHYSICAL PROCESSES

A. GENERAL DESCRIPTION

Bainbridge Island is essentially an eroding coastal system in which sediment along its shoreline is derived from the island itself. The sediment found in beaches, mud flats, and tidal marshes is the result of upland erosion. The several small streams that flow into the headwaters of the bays on Bainbridge Island contribute fine material that may eventually make its way to the open coast, but by far the largest volume of coastal and beach sediment is derived from the recession of the bluffs, which are comprised mainly of glacial deposits.

Once the unconsolidated sedimentary material reaches the beach, it is redistributed and sorted by waves and currents, and is formed into gravel or sand beaches, cuspate forelands, and spits. Under normal wave and tide conditions, the forces of water and gravity sort the beach into zones, leaving a pavement of coarse gravel material high on the beach and winnowing the fine sands and mud, which are deposited in a low-tide terrace. Finer material (silt and clay-sized particles) that remains in suspension is removed from the shoreline by the tidal currents and is deposited in sedimentary basins, usually in deep water, though some may be retained on tidal flats. During storm conditions, even relatively coarse material may be removed from the beach and be permanently deposited out of the reach of waves. Storms, which typically occur from late fall into spring, may produce water levels that are higher than normal, as well as large waves that remove material from the toe of the bluff. The rain may also saturate the soil and further weaken bluffs, which slide down slope and add sediment to the beach. Though bluffs may remain stable for a number of years, when they do slide, the effect may be significant and catastrophic. The mudslide that occured on January 19, 1997, at Rolling Bay destroyed several homes and took the lives of an entire family. The type and extent of bluff erosion depends on a number of geologic factors and environmental conditions, and not all slides are as extensive as that of January 1997 (Macdonald and Witek 1994). Because beach material on the Island shoreline is primarily derived from erosion, the permanent stabilization of a bluff through the use of structures or other methods deprives the beach of its natural source of replenishment.

A great deal of engineering knowledge about general coastal processes has been developed. The Army Corps of Engineers (USACE), Coastal and Hydraulics Laboratory (CHL) publishes engineering guidance and calculation tools for wave prediction, sediment transport, beach protection methods, structure design, and coastal construction. The Coastal Engineering Manual (CEM) is replacing the Shore Protection Manual, which for many years was an international standard for coastal engineering technology. As chapters are developed and reviewed, they are placed on the (CHL) web site (http://www.wes.army.mil/). The guidance in the CEM is the latest available, has been reviewed by international experts, and is respected as a worldwide authority. The guidance has been developed based on theory, tested in laboratory experiments, and confirmed by field measurements. In spite of this rigor, few of the conditions examined correspond with those encountered in Puget Sound (e.g., large tidal range with strong currents, coarse gravel beaches). Specific applications of the CEM technologies must consider the conditions under which they were developed, and adjustments using engineering judgement must often be made for the site of interest.

The presentation below will consider the Bainbridge Island coastal system from landward to seaward, proceeding from the supply of sediments to the beach, to the oceanographic and hydrodynamic processes, and finally to the transport of the beach material itself. A summary of the key findings and conclusions for general applications is given at the end of the chapter.

1. FEEDER BLUFFS

The geology of Bainbridge Island is the product of a series of glacial advances and retreats, and its morphology is a result of sculpting, sea level rise, and erosion since the retreat of the last major ice sheet approximately 13,000 years ago. The primary surface material on the island consists largely of the Vashon-Lodgemont Till, a poorly sorted, very compact, non-stratified mixture of gravel, sand, silt and clay with occasional boulders, and Vashon advance outwash sand and gravel and lacustrine silts and clays. The beach sediment reflects this predominantly glacial origin.

The erosion of the bluff may be initiated from the upland side by hydrologic and hydrogeological processes that lubricate and weaken the soil, or from the water side by waves and fluctuating high water levels that undercut the bluff and cause collapse. In either case, water and gravity work together as the major forces of bluff erosion. Once the sediment is on the beach, wave action may work against gravity to temporarily move the sediment up the beach face, but gravity always prevails. Eventually the sediment is transported into deep water where it is unavailable to the coastal system.

Few large rivers deposit beach sediment into Puget Sound (Downing 1983). Only relatively small streams provide fine-grained sediment to Bainbridge Island shores, and most is retained in the heads of embayments or in tidal marshes. Beaches in Puget Sound are typically supplied with sediment by bluff erosion. The contribution of the predominantly glacial bluffs results in beach materials that range in size from cobbles to silts/clays (see Figure III-1 for the general process). Grain-size descriptors often used to classify sediment are summarized in Table III-1. The Wentworth (1922) system is shown mainly for historical purposes, because it is most frequently associated with the grain-size distribution scale. The system proposed by Dethier (1990) can be used for habitat classification and for general beach characterization. The system of Komar (1998a) is best for detailed studies of grain-size distribution, for instance, in designing a beach nourishment project.

Until recently, engineering guidance for beach nourishment projects depended on a comparison of the grain-size distribution of the native beach material relative to the borrow material. An overfill factor, R_A, and a renourishment factor, R_J, were calculated based on the mis-match between the native and borrow grain-size distributions. More recent guidance treats sediment characteristics using a single grain-size parameter, the median grain diameter, D_{50}, which is why a relatively narrow gradation such as Komar's is required. Additional guidance is based on equilibrium beach profile concepts, an assessment of storm-induced erosion, and an assessment of wave-driven longshore transport losses (Dean 2002; National Research Council 1995; U.S. Army Corps of Engineers 2001a).

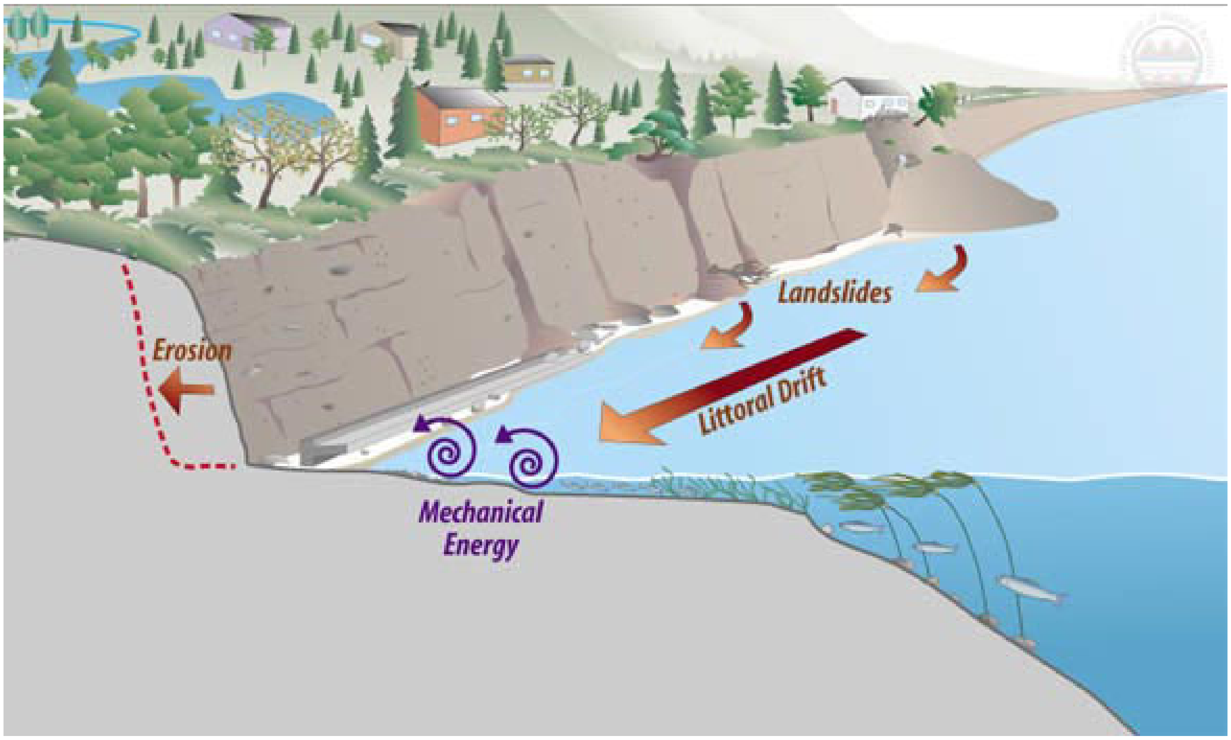

Figure III-1. Bluff erosion and littoral transport alongshore. (Source: King County Dept of Natural Resources).

Table III-1. Grain-Size Classifications

Grain Diameter, mm	Size Description		
	Wentworth (1922)	**Dethier (1990)**	**Komar (1998)**
> 256	Boulder	Boulder	Boulder
64 to 256	Cobble	Cobble	Cobble
4 to 64	Pebble	Gravel	Pebble
2 to 4	Granule	Sand	Granule
1 to 2	Coarse sand		Very coarse sand
0.5 to 1			Coarse sand
0.25 to 0.5	Medium sand		Medium sand
0.125 to 0.25	Fine sand		Fine sand
0.0625 to 0.125			Very fine sand
0.0039 to 0.626	Silt	Mud	Silt
< 0.0039	Clay		

a. Groundwater and Surface-Water Drainage

The coastal bluffs of Bainbridge Island are typical of those in other areas of Puget Sound in their predominantly glacial origin. Several sources are available that describe the processes contributing to bluff erosion and steps that property owners can take to reduce landslide activity (Macdonald and Witek 1994; Zelo and Shipman 2000). Coastal bluffs are normally stable at slopes of 30 to 40 degrees. Many of the Bainbridge Island coastal bluffs, however, are steeper than 40 degrees and are susceptible to downslope movement. Heavy rains that saturate and weaken soils provide lubrication between layers and contribute to slope failure. The process is exacerbated by removal of vegetation and by the increased runoff that usually accompany development. When slopes are nearly vertical, waves also can undercut the toe of the bluff or remove sediment, which also contributes to the erosion process. These factors are illustrated in Figure III-2.

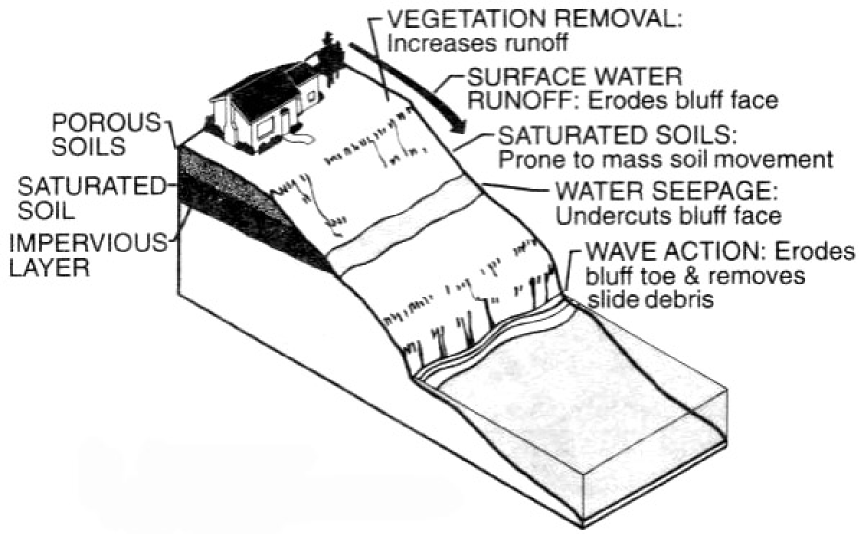

Figure III-2: Factors related to erosion of the nearshore upland (Source: Manashe 1993).

b. Development, Vegetation, and Bluff Stabilization

More than 82% of the Bainbridge Island shoreline is classified as developed (P. Best, COBI unpublished data; *personal communication*, 2002). With the exception of Eagle Harbor, single-family residential is the primary land use in nearshore uplands. Development of an area typically involves land clearing, excavating and backfilling of soils, the compacting of soils, installation of septic drain fields, and the building of roads. All of these activities can have a profound influence on the stability of the nearshore uplands and bluffs. They can affect the groundwater and surface water flows (as discussed in the previous section) and may cause erosion of the nearshore uplands (Manashe 1993). Figure III-3 illustrates these factors with additional details provided by Manashe.

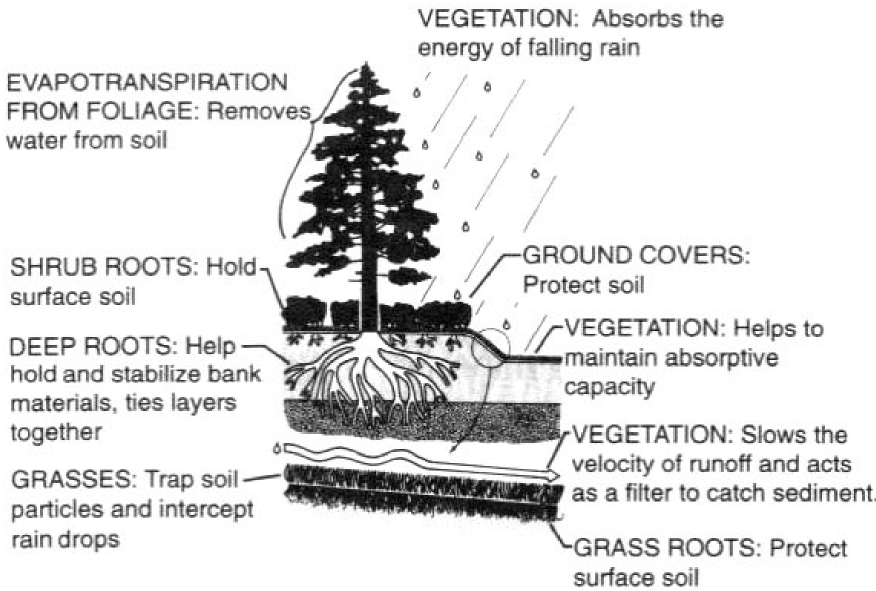

Figure III-3. Effects of vegetation in minimizing erosion (Source: Manashe 1993).

c. Mapped Eroding Bluff and Feeder Bluff Locations

The Coastal Zone Atlas (Washington State Department of Ecology 1980) shows locations of feeder bluffs and erosion scars from past slope failures. The term "eroding bluff" is a more general category than a "feeder bluff." The primary difference between an eroding bluff and feeder bluff is the type of sediment delivered to the beach, although specific criteria for Puget Sound feeder bluffs have not been developed (H. Shipman, WDOE, *personal communication*, 2002). Eroding bluffs contribute sediment to the beach irrespective of its size or gradation (e.g., the full range of fine materials, sands, silts, and clays to coarse materials, such as gravel, with no distinction between proportions of each). Feeder bluffs, on the other hand, are typically comprised of highly erodable coarser sediment, and as a result, contribute higher proportions of coarser materials, particularly sand and gravel.

The Geologic Stability Map in Appendix A illustrates known locations of unstable bluffs and landslide activity. Areas of eroding bluff activity were identified by Anchor Environmental and Applied Environmental Services during the fall of 2001 along the shorelines south of Agate Pass, at Battle Point, north of Fletcher Bay, near Blakely Harbor, near Yeomalt Point and Ferncliff, around Skiff Point northward nearly to Faye Bainbridge State Park, and west of Port Madison Bay near Agate Point. More investigation is needed to discern which eroding bluffs are contributing coarse sediment (gravels) in proportions substantial enough to be considered "feeder bluffs" versus eroding bluffs. A combination of historical aerial photography and on-site investigation is needed to make these distinctions.

2. Sediment Supply and Availability

The focus of the guidance provided by Manashe (1993) is to assist coastal property owners in stabilizing the coastal bluff. Slope failure is a natural process that supplies sand and gravel to the Island's beaches. Artificial stabilization (i.e., bulkheads, retaining walls) of the bluff deprives or slows this contribution and can exacerbate beach erosion. Sediment around Bainbridge Island is derived from predominantly glacial deposits that comprise the bluffs and nearshore upland areas. River deposits are not a significant source of material for Puget Sound beaches (Downing 1983; Shipman and Canning 1993). Stream discharge into several of the inlets on Bainbridge Island may contribute a small amount of additional beach material. These areas include Manzanita Bay, Fletcher Bay, Pleasant Beach, Blakely Harbor, Eagle Harbor, Point Monroe Lagoon, and Murden Cove.

Both substrate type and sediment abundance information for Bainbridge Island are available from the Washington State ShoreZone Inventory (Washington State Department of Natural Resources 2001). The substrate type is illustrated on the Substrate Type Map in Appendix A. The map illustrates that the dominant nearshore substrate types are gravel and sand (mixed coarse). Also shown are sand and muds and fines in the embayments of Port Madison Bay, Eagle Harbor, Blakely Harbor and Fletcher Bay. Rocks, gravels, and sand are shown around Restoration Point.

Sediment abundance (see Sediment Abundance Map in Appendix A) is a qualitative estimate of sediment abundance within the shore-unit as quantified by ShoreZone (Washington State Department of Natural Resources 2001). 'Abundant' indicates areas with accretional landforms and highly mobile sediment; 'Moderate' means some mobile sediment but not likely to rapidly move; and 'Scarce' signifies areas of bare rock or rock with cobble/boulder veneer. Most of Bainbridge Island is in the 'Moderate' rating of sediment abundance. Tips of points, such as Battle Point and Yeomalt Point are noted to contain sediment in abundance (Figures III-4a and III-4b). Restoration Point, an area of hardened mudstone at the southeast tip of the Island, has little sediment abundance (Figure III-5).

B. Coastal Processes

As illustrated in Figure II-1, the zones in which coastal processes are active include the marine riparian zone, the backshore, the beach face (or normal breaker zone), and the low-tide terrace. Failure of the bluff face may from time to time change the landward position in this definition. Because waves in Puget Sound are generally small, the point at which waves would not affect sediment movement would occur well seaward of the lower limit of the photic zone. Natural forces and human influence constantly mold the coastal environment.

The beach component of the nearshore environment is defined as the profile of the shore in which sediment is moved by wave forces. This area includes the backshore to the limit of high water, the beach face, the low-tide terrace, and an offshore zone (Figure III-6). Though the bluff may contribute to the beach from time to time, it is not part of the beach in this definition. The offshore zone is the seaward portion of the beach profile to a depth below which waves no longer affect the bottom sediment. The beach width is measured perpendicular to the shoreline, from the deepest depth where the most extreme waves cease to cause sediment movement to the landward limit of wave run-up (Komar 1998a).

Figure III-4a. Spit, marsh, & lagoon at Battle Point. (© WA Dept of Ecology 2001).

Figure III-4b. Cuspate foreland at Yeomalt Point. (© WA Dept of Ecology 2001).

Figure III-5. Rock outcrop at Restoration Point (© WA Dept of Ecology 2001).

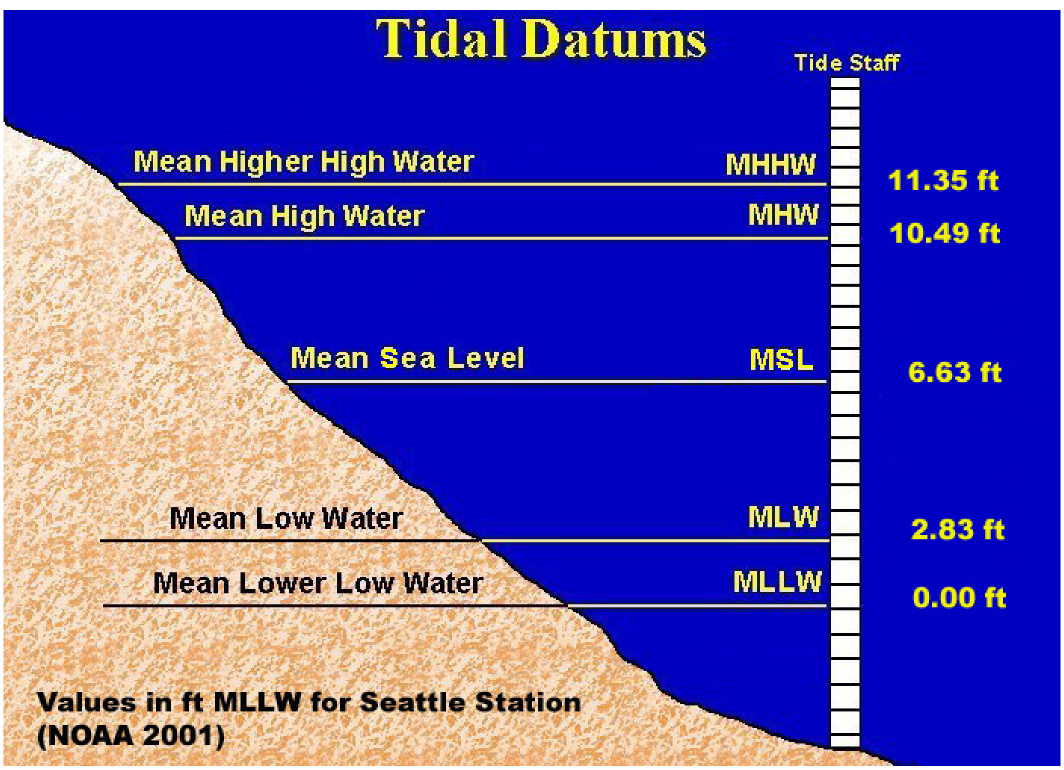

Figure III-6. Tidal datums for the Seattle Station (Source: NOAA 2001)

The Bainbridge Island beaches are generally characterized as having steeply sloping, gravel and cobble beach faces, narrow to no backshore widths, and extensive low-tide terraces. This type of beach seldom possesses a true surf zone as may be found on ocean beaches; instead, the waves break close to shore and develop directly into an intense swash that runs up and then back down the beach face (Komar 1998a). The breaking waves are effective in mobilizing the fine sediment, which is transported in suspension to be deposited on the low-tide terrace or in deeper water. The coarse sand and gravel that remains behind as a lag deposit forms an effective veneer that protects the high-tide beach and is moved by only the largest waves. There are some protected inlets, bay areas, and cuspate forelands where the beach slope is more gradual, with a beach face composed of gravel and sand.

This section addresses the nearshore physical processes that occur in Puget Sound, focusing primarily on those important to Bainbridge Island. Tides and the changing sea level are presented first, followed by effects of waves and currents. Finally, we address sediment transport and deposition processes.

1. TIDES

a. Tidal Elevation

The tides surrounding Bainbridge Island are characterized as mixed semi-diurnal. There are generally two high- and two low-water stands each lunar day (i.e., about 25 hours) (Figure III-7). Other factors that may affect water level are storm surges, seasonal effects of water temperatures, and El Niño events. Tides occur on a predictable basis, whereas storm surge and El Niño, though they may increase water level by several feet, are much less certain. Effects due to water temperature change (e.g., thermal expansion) are generally small but have been documented, for instance, in studies in California (Namias and Huang 1972).

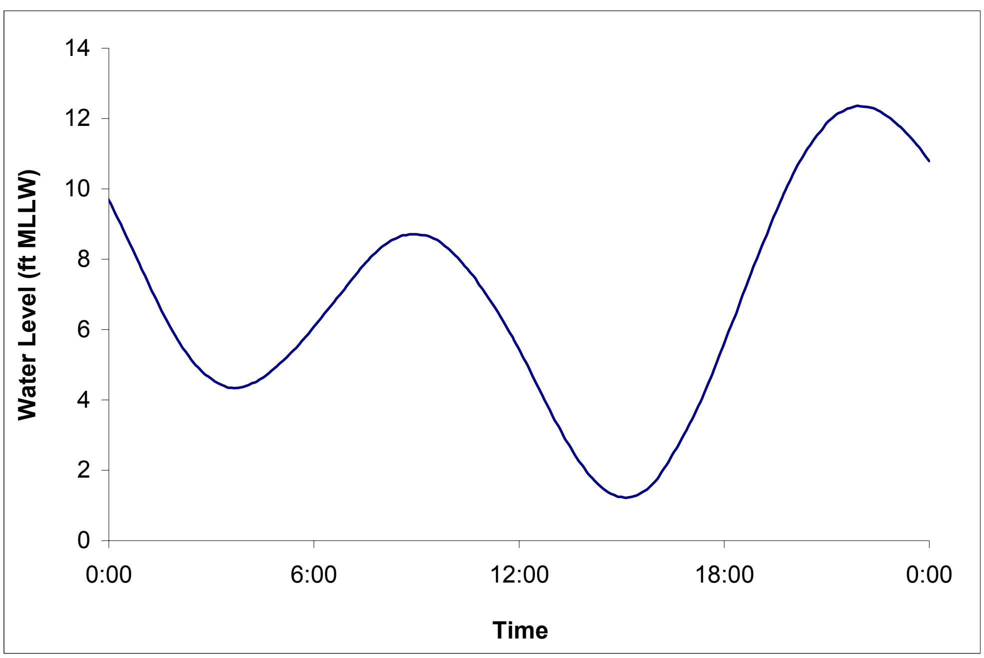

Figure III-7: Example tide signature for the Seattle Tide Gauge (Source: NOAA 2001).

The mean tidal range (water elevation difference between MHHW and MLLW) around Bainbridge Island is about 11.5 feet. The highest estimated tides may exceed this level by about 3.5 feet. These extreme high tides typically occur during the winter when storms with strong on-shore winds, rain run-off, and highest waves are also most likely. The phase and elevation of tides have been tabulated and are available through commercial tide prediction programs and through web sites maintained by the National Oceanic and Atmospheric Administration (NOAA) and others. The prediction of water-level change resulting from rainfall, wind, and wave conditions is less certain, because it depends on weather conditions.

b. Long-Term Sea-Level Changes

Water levels also change over longer periods of time due to seasonal processes, El Niño events, geologic processes, and global warming. For example, the Puget Lowland is subsiding as a result of tectonic movements. The vertical adjustment of the Earth's crust is related to redistribution of crustal material following removal of the glaciers. Because of the uneven distribution of the load and differences in crustal material, this subsidence occurs unevenly, tilting the land under Puget Sound and causing more rapid sea-level rise in the south Sound than in the north. Combining "best estimate" rates of global sea-level rise developed by the Intergovernmental Panel on Climate Change (IPCC) (Warrick et al. 1996), along with regional differences in sea level caused by global variations in seawater temperature, atmospheric pressure, and ocean currents (Hengeveld 2000), and local subsidence, leads to a total sea-level rise of about 40 cm (1.3 ft) at Seattle by the year 2060 (Canning 2001). A major rupture along the Seattle Fault zone, which crosses Bainbridge Island just south of Eagle Harbor, could significantly change these estimates. The relative vertical displacement of the fault depends on the energy of the earthquake but could be more than 2 m (6.6 ft), with the south side of the fault rising relative to the north (Koshimura and Mofjeld 2001; Nelson et al. 2002).

Though sea-level rise has been cited as a factor that is inducing the slow erosion of the Puget Sound shoreline (Canning and Shipman 1995a), its specific impact is probably masked by sea-level changes that occur on seasonal and other frequencies.

An El Niño event occurs every 3 to 7 years, the latest observed in 1997 to 1998. During these periods, shifts in wind and pressure patterns in the central and western equatorial Pacific Ocean cause warmer than normal water to pile up against the North and South American continents in the eastern Pacific. This phenomenon results in a general sea-level rise of a foot or more above normal, and it may remain elevated for the duration of the El Niño event, typically several months. During the 1982 to 1983 El Niño, a water-level rise of 35 cm (nearly 14 inches) was documented along the Oregon coast (Komar 1998b), and during the 1997 to 1998 event, the monthly mean-water level at Toke Point in Willapa Bay was up to 40 cm (1.3 ft) above monthly mean sea level (Canning 2001).

Normally, sea level changes by about a foot during the year as a result of variations in global atmospheric pressure and sea-surface temperature. Elevation changes of this amount have been documented at Neah Bay, with the highest elevation occurring in winter and coinciding with highest astronomical tides and the most severe storms (Komar 1998b). No detailed studies have been conducted of sea-level changes in Puget Sound during El Niño events or to document the annual variation, though changes of the same order as observed at Neah Bay could be anticipated.

The details of the effects of global change remain controversial. The IPCC concludes that increases in global temperatures over the next century could accelerate the historical rate of global mean sea-level rise from 1 to 2.5 mm/yr (the rate presently observed in the Puget Sound region) to about 5 mm/yr, with an uncertainty of 2 to 9 mm/yr (Neumann et al. 2000). The general warming of the atmosphere may also lead to changes in global circulation patterns and consequent alterations in rainfall as well as storm intensity and frequency. "Best estimates" of local sea-level rise on Bainbridge Island, which combines global-change estimates with subsidence, are given above. The estimates for Seattle should be used for the Island.

c. Tidal Currents

Tidal-current velocities around the Island are variable both temporally and spatially and can be quite strong, particularly in Rich Passage and Agate Passage, where velocities may reach 5.3 knots and 7.0 knots, respectively. Maximum velocities depend on tidal range and vary by season, with the strongest currents occurring in December when the greatest tidal ranges are observed. Tidal currents at selected locations around Bainbridge Island are also available in tabulated form through NOAA and may be obtained from a variety of commercially available computer programs.

2. Wave Characteristics

Waves are characterized by length, period, and height, and are the physical representation of energy moving through water. The short-period waves generated by local winds and vessel wakes are superimposed on the water elevation that varies with tide, season, and longer-term influences. In addition to winds and vessels, waves may be generated by geologic sources (i.e., large-scale bluff collapse, seismic forces). Though the magnitude of the latter can be theoretically calculated based on energy considerations, the occurrence is not yet predictable and is beyond the scope of this study. The wave energy is translated across the water and is ultimately expended on the shoreline, working to erode, transport, and deposit beach sediment (U.S. Army Corps of Engineers 2002; Terich 1987). Compared with other locations in the U.S., Puget Sound is considered to be a moderate wave-energy environment, even in the most exposed locations (Macdonald and Witek 1994).

a. Wind Waves

Wind waves are short-period waves that are created by winds blowing over a distance of open water, or fetch. The wave conditions in Puget Sound are normally quite mild (less than 3 ft wave height), but waves of considerable height (greater than 6 ft) have been reported during storms. Wind blowing over the water surface imparts energy to the water, which is expressed in surface current and in the development of surface waves. The main factors that affect the generation of such waves are fetch – the distance over which the wind works on the water; duration – the length of time the wind blows over the water; and wind speed. In open water, with known fetch and time, and for a given wind speed, wave height and period can be calculated. The basic definitions applied to surface waves are shown in Figure III-8.

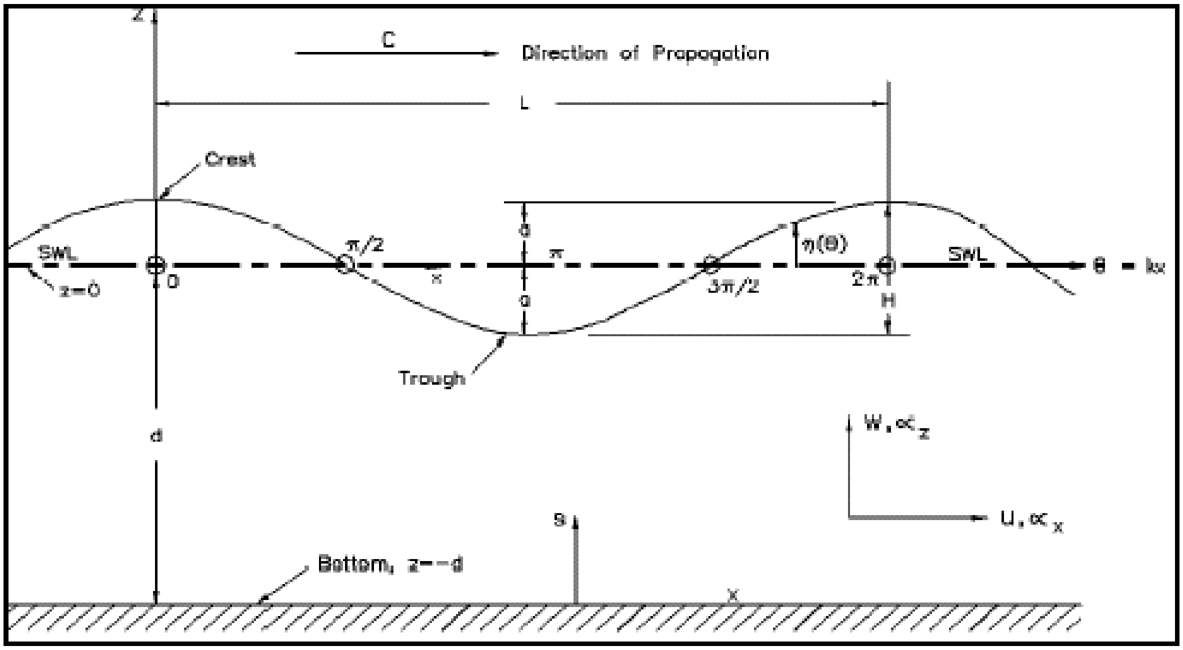

Figure III-8. Surface wave definitions. ***L*** *is wave length,* ***H*** *is wave height, and* ***d*** *is the still-water depth. Wave steepness is defined as H/L. Other definitions and relationships can be found in USACE (2002).*

Natural events, such as storms, wave heights, and wind velocity and duration, are categorized by their statistically determined return interval. The "100-year storm," for instance, is defined as the storm that has a 1/100 (1%) chance of occurring in a given year, and the 50-year storm has a 1/50 (2%) chance of occurrence in a year. Because the events are governed by independent random processes, it is possible to have more than one, 100-year event in a given year or in successive years. The specialized field of extreme value statistics (or extremal analysis) is used to arrive at these return-interval estimates. By assuming that the distribution of storm intensity follows certain statistical rules, one can arrive at return estimates by extrapolating from shorter measurement records. It is typical that the 100-year wave height can be estimated by extrapolation from a 20-year record of extreme wave data. Coastal structures are usually designed to withstand conditions with given return intervals. The design condition is selected based on analysis of the risk of encountering and surviving the extreme event during the life of the structure. The intended length of service, cost of replacement, and consequences of failure are all factors that should be considered when selecting the return interval to be used for design.

Knowledge of the wave conditions at a coastal site is necessary to predict sediment transport rates, design methods to protect or restore the beach, or design infrastructure, such as marinas and port facilities. Design wave criteria are usually based on years of wave data that allow calculation of a given return-interval condition. Coastal structures may be designed to resist the 50- or 100-year wave condition. The annual sediment transport rate along a stretch of beach may be determined by applying an appropriate numerical model for an entire year of wave action. The wave data necessary to complete these engineering or management activities may be obtained from direct measurement of the waves or, as is more often the case, by calculation of wave conditions based on measured wind, fetch, and duration. A large proportion of the annual transport may occur during a single storm. Because storm frequency, duration, and strength, as well as more moderate weather conditions vary from year to year, it is necessary to consider long-time series data to decide what constitutes "normal conditions."

Winds have been measured in many more locations and for longer periods of time than have waves, so the known relationship between wind speed, duration, and fetch are used to "hindcast" waves. Many methods of wave prediction are available in the oceanographic literature, from simple empirical equations (U.S. Army Corps of Engineers 1984) to elaborate numerical models (Meteorological Service of Canda 2000). Under relatively uniform and steady wind conditions in the open ocean, waves can be determined with fairly high accuracy. Calculation of waves in Puget Sound and around land masses such as Bainbridge Island requires special consideration of factors such as over-water wind speed, air-sea temperature differences, and steering by land forms. In addition, as waves enter shallow water or encounter currents, they change height and direction (U.S. Army Corps of Engineers 2002). Because sediment transport is highly dependent on the angle the wave makes with the shoreline, these shoaling effects should be considered. Such wave transformations are treated in more detail below.

There are no permanent meteorological stations on Bainbridge Island. The West Point Lighthouse on the north side of Elliot Bay may be used to obtain regional wind information. Both wind speed and direction data from 1984 to present are available from this station. These data should be carefully evaluated for application to specific sites around Bainbridge Island, because local features may substantially change wind conditions and their related waves and currents. Washington State Ferries (WSF) has also begun collecting wind data aboard a limited number of ferries transiting Puget Sound routes, including those between Bainbridge Island and Seattle. Depending on location and numbers of observations, some of these data may be useful for wave estimates.

The ShoreZone Inventory (Washington State Department of Natural Resources 2001) classifies the shorelines of Bainbridge Island by Wave Exposure Class (see Appendix A Wave Exposure Map). The fetch distance limits the maximum wave heights around the Island. This means that under even very strong winds blowing for a long time, the wave height will reach only a limited maximum because the maximum height is ultimately governed by the distance over which the wind blows and not by the wind speed or duration (U.S. Army Corps of Engineers 2002). The ShoreZone Inventory has assigned three exposure classes to the waters around Bainbridge Island based on fetch distance and the potential wave heights that may be generated: 'semi-protected' with a fetch distance of 6 to 30 miles (10 to 50 km); 'protected' with a fetch of between 0.6 to 6 miles (1 to 10 km); and 'very protected' with less than 0.6 miles (1 km) of fetch. Based on the USACE (2002), these distances correspond to the following significant wave heights: 0.6 mi fetch – 0.8 ft wave height; 6 mi fetch – 2.6 ft wave height; 30 mi fetch – 6.0 ft wave height. The "significant wave height" is a statistical way of representing the sea state and corresponds to the average of the highest 1/3 of the waves present. The maximum single wave may be nearly twice as high as the significant height (Goda 1985). The east side of Bainbridge Island and Restoration Point is predominantly semi-protected. The west side of Bainbridge Island and around Eagle

Harbor are predominantly protected. Finally, the bays and inner harbors of Bainbridge Island (such as the Point Monroe Lagoon, Port Madison Bay, Manzanita Bay, Fletcher Bay, inner Blakely Harbor, inner Eagle Harbor, and inner Murden Cove) are very protected.

The Coastal Zone Atlas provides estimates of deep-water wave heights (Washington State Department of Ecology 1980). Generally, deep-water wave heights around all of the shoreline areas of Bainbridge Island are estimated to range from 0.5 to 2 feet, with the exception of Restoration Point on the southeast tip of Bainbridge Island, where deep-water wave heights are estimated to be 2 to 4 feet, based on the long fetch toward the south. Again, these estimates are based on the significant wave height.

The eastern shore of Bainbridge Island is exposed to both southerly and northerly winds (and waves) from Puget Sound. The southern and western shorelines face smaller bodies of water, and the potential for large storm waves is somewhat limited because of the reduced fetch. The maximum fetch in Puget Sound can reach 35 miles. Around Bainbridge Island, the typical fetch distance is between 4.7 and 7.9 miles (7.6 and 12.7 km) (Schwartz et al. 1989). Around Bainbridge Island, waves come from mostly the southwest, and the wave height can range from 2 to 5 feet high (Canning and Shipman 1995a). The maximum significant wave height occurs during winter storms and can reach heights of 5 to 6 feet (Washington State Department of Ecology 1979a; Washington State Department of Ecology 1980). These estimates vary somewhat based on the assumptions of the authors but are generally consistent. They should not be used for engineering purposes, because interaction with the local sea bottom changes wave characteristics through the process of shoaling, refraction, or diffraction.

Few actual measurements of waves have been made in Puget Sound. Wave buoy data were collected at a location two miles southwest of West Point from September 1993 to December 1994 (Shepsis et al. 1995). Based on this record, the significant wave height was reported to be 3.3 ft (wave period of 5.1 sec). Additionally, Shepsis et al. (1995) reports that wave heights from 1.0 to 1.3 ft were observed 40% of the time, wave heights from 1.3 to 2.25 ft were observed 25% of the time, wave heights from 2.25 to 3.2 ft were observed 15% of the time, and waves greater than 3.2 ft were observed 10% of the time; the remaining times were reported calm (Williams et al. 2001).

b. Vessel-Generated Waves

Vessels operating in Puget Sound generate wake waves that have characteristics that depend on the size, speed, hull shape, draft of the vessel, and water depth in which the vessel is operating. The waves generated by an individual vessel are of short duration relative to the amount of storm-generated (or wind-generated) waves; however, depending on the number of vessels and their characteristics, the wake waves may cause a beach to establish a new equilibrium. This new equilibrium may result in changes to the beach slope or size and gradation of beach material.

Recent studies have shown that the passenger-only fast ferries operating through Rich Passage at full operational speeds (i.e., 34 knots) can produce nearshore wave heights of 2.1 feet (and wave periods of about 8.4 sec), and other vessels may produce waves up to 2.2 feet (and wave periods of about 4.5 sec) (Anchor Environmental 2000). Both of these measurements were made with wave gauges deployed at about –4 ft MLLW for 1- to 2-months duration.

c. Tsunamis

The extension of the surface expression of the Seattle Fault passes through Bainbridge Island just south of Blakely Harbor. The east-west linear feature can be seen on the Topographic and Bathymetric Relief Map (Appendix A) and is named the Toe Jam Hill Fault. The U.S. Geological Survey (USGS) predicts that a zone surrounding this fault line will be a zone of probable ground rupture in the event of a major earthquake (Nelson et al. 2002). The expected ground motion would be uplifted on the south side of the fault and subsidence north of the fault. Amount of motion depends on the magnitude of the earthquake (Nelson et al. 2002). The NOAA Pacific Marine Environmental Laboratory (PMEL) has developed numerical models of probable water-level change and tsunami inundation associated with the potential displacement (Koshimura and Mofjeld 2001). Earthquakes and the consequent tsunami are considered inevitable in the long run, but the timing is presently beyond the ability of prediction. Coastal ecosystems would be impacted by the ground motion, attendant slope failure, and tsunami.

d. Wave Transformation

As waves move toward shore, the bottom eventually affects them. This occurs at a water depth that is about half of the wave's length (i.e., the distance between two wave crests, Figure III-8). Wind waves in Puget Sound seldom exceed lengths of 80 feet, so would feel bottom at a maximum of about 40 feet. The encounter with the bottom slows the wave travel and reduces the wavelength. Since the wave period does not change, the wave becomes steeper and eventually breaks. The characteristics of the breaker; e.g., plunging, surging, or spilling, depends on bottom slope and, for the same offshore wave condition, the breaker type can vary with tidal elevation. For waves that approach the shore with their crests at an angle to the local depth contour, the part of the wave in shallow water travels more slowly than that part in deeper water and the wave crest will bend toward the shore. This process, known as refraction, tends to align the wave crest with the shoreline and decrease the angle the breakers make with the beach. Though the process of refraction can be performed graphically, in all but the simplest cases, numerical models are used to predict the transformation of waves from deep to shallow water. Figure III-9 shows the path that wave rays, drawn perpendicular to the wave crest, would follow as waves approach a hypothetical shoreline. The wave energy expended at the shoreline depends on the breaker height squared, so accurate prediction is important to estimate sediment transport.

When waves break, part of their energy is lost in turbulence, while the other part is transferred to beach sediment. After breaking, water surges up the beach, exerting strong forces on sediment. A return flow along the bottom, the undertow, balances this shoreward movement of water. Areas on the shore where wave rays converge receive more wave energy and will have higher breaker heights than areas where waves diverge. As a result of this convergence and divergence, wave energy is concentrated at the headlands and diminished in bays.

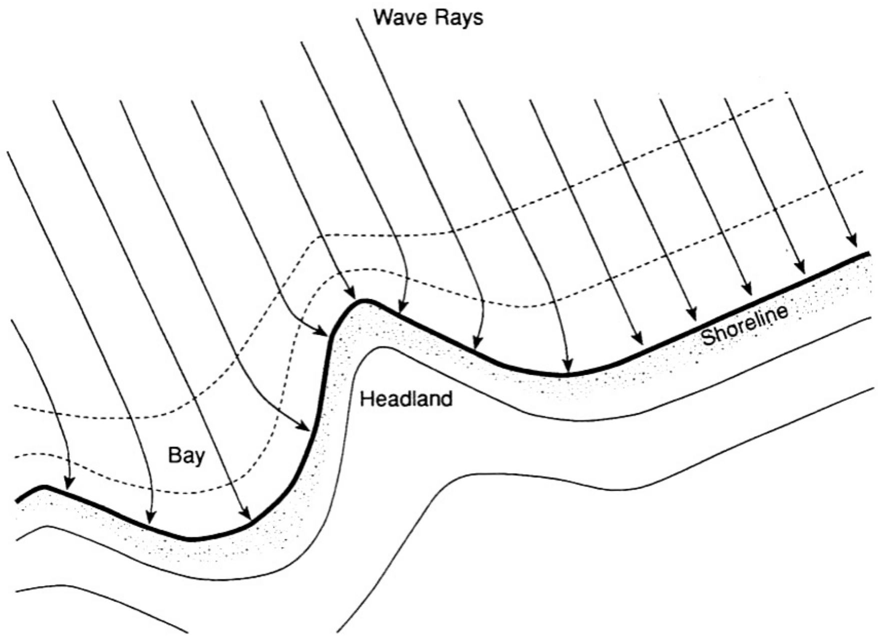

Figure III-9. Wave Refraction (Source: Macdonald et al. 1994).

The above explanation relates to refraction caused by interaction with the bottom. Refraction also takes place when waves encounter currents that slow one part of the wave more than another. Tidal currents may, therefore, influence the wave direction. This aspect of wave propagation has not been applied to studies around Bainbridge Island.

Another type of wave transformation is called diffraction. Diffraction occurs when a barrier, such as a small island, a breakwater, or a jetty, interrupts a train of waves. The energy is transferred along a wave crest, and this creates waves in the sheltered area. The combined effects of both diffraction and refraction are important in modifying wave energy and direction. These are taken into account in recent numerical calculation methods (Kirby et al. 2002).

These processes are important because they change the breaking wave height and the angle that the waves make relative to the shoreline and, therefore, affect the direction and rate of wave-generated sediment transport.

e. Wave-Generated Currents

The currents in the Bainbridge Island nearshore are generated by tide, local wave breaking, and wind. The tides are the most persistent and predictable source of current, but the wind waves are also important, because breaking waves suspend sediment, which is then transported by even minor current flow. Tidal currents tend to act along the length of a shoreline and vary in magnitude with distance from the deepest part of a passage to the shore. Waves also generate longshore currents. Waves that break at an angle to the shoreline impart momentum in the direction of wave breaking and generate a current in the surf zone. Even when waves approach with their crests parallel to the shore, they transport water, which builds up against the shoreline. The excess may then move longshore until it finds an outlet where it can move offshore in the form of a rip current. On the open sandy coast, rip currents are often observed at the breaks in sand bars. Rip currents can also be observed adjacent to natural features or structures, such as boat ramps or groins that extend perpendicular to the shoreline. Rip currents are narrow coastal jets that transport water and suspended sediment away from the beach. Undertow is a less rapid though sometimes persistent seaward current along the bottom that transports water to the offshore. Figure III-10 is a schematic that shows several types of currents that originate from breaking waves (see also Komar 1998a).

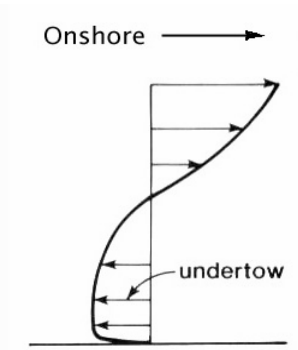

Figure 8(a). Undertow (from Fredsoe and Deigaard 1992).

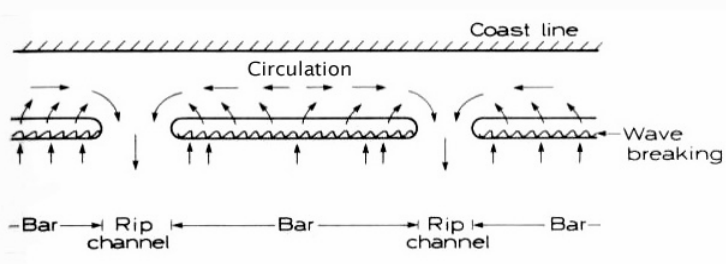

Figure 8(b). Rip Current (from Nielsen 1992).

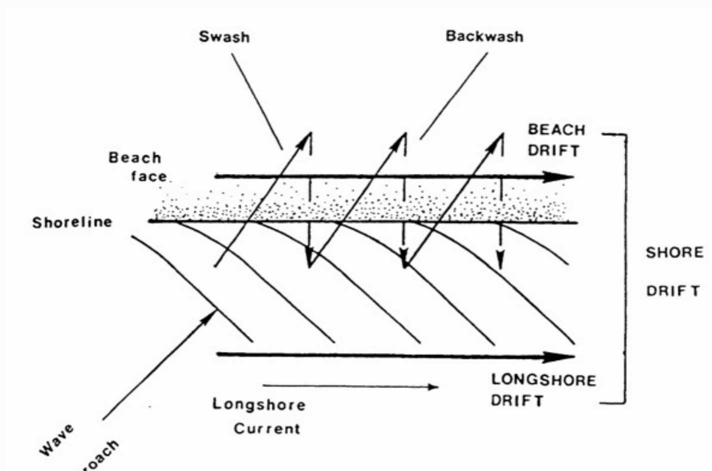

Figure 8(c). Longshore Current (from Macdonald et al. 1994).

Figure III-10. Current Systems

C. Sediment Transport Processes

The combined actions of waves and currents, as well as gravity, transport beach sediment in the longshore and cross-shore directions. The physical processes that contribute to sediment transport caused by waves are known in concept, but the details are difficult to determine because of the statistical nature of the problem. Waves arrive in a spectrum of heights and periods, and the sediment is composed of a complex distribution of sizes and densities. Most sediment transport estimation techniques relate wave power (longshore wave-energy flux) to the immersed weight of the sediment. A great deal of national attention has been given to determining transport rates, and the U.S. Army Corps of Engineers maintains a laboratory and scientific staff that is continually improving the technology. Computer prediction methods are available from the Corps as well as from the private sector for predicting transport on beaches. However, these may not be directly applicable to the beaches on Bainbridge Island for a number of reasons:

- Sediment transport formulations are based on laboratory experiments or field observations of sand-sized material of single grain size or a small range of grain sizes. Most field studies have been conducted on open-ocean beaches. The predictions do not apply to poorly sorted sands, gravels, and cobble material common to Puget Sound beaches (Komar 1998a, p.399).
- The prediction methods assume constant sediment characteristics in the cross-shore direction. This is not the case on Puget Sound beaches, where low-tide terraces are composed of fine material and the high-tide beach is composed of a wide range of grain sizes from coarse sand and gravel.
- Sediment transport predictions depend critically on knowing the direction of the predominant wave energy along the beach, as well as the height of the breaking wave. These factors are influenced by the local bathymetry, which is seldom sufficiently known and is, itself, influenced by the sediment motion.
- The rate of longshore transport is a complex function of wave energy, angle of wave attack, beach slope, current magnitude, sediment size (and size distribution), material density, and availability of beach materials. Not all of these factors are well known in most situations.

For the above reasons, predictions of beach sediment transport rates should be viewed with caution. The net direction of transport can often be reliably determined from other factors; the general processes are described below.

1. Drift Cells

The shoreline of Puget Sound has been characterized in a series of reports beginning in the 1970s by Schwartz et al. (1991) as consisting of a number of drift cells. These cells are compartmentalized zones along the shoreline that act as discrete systems with respect to transport of beach sediment. A drift cell consists of segments of shoreline that include the source of sediment, the area where they accumulate or deposit (a sink), and the connecting path or driftway between the two (Downing 1983). The concept was developed from observations on California beaches, where it was noted that beach sands could be traced from a source (river) along shore (transport) and eventually to a sink (submarine canyon), where the sand was removed from transport in the coastal system. It is a particularly useful concept on open coastlines where cells can be more easily identified than in Puget Sound. Drift cells around Bainbridge Island have been identified (Schwartz et al. 1991; Terich 1987) and are illustrated on the Drift Cells Map in Appendix A.

The drift cells and direction of net drift were inferred from observation of geomorphic and small-scale features along the shoreline. Though the general directional trends are often obvious from observation of large-scale features such as spits and cuspate forelands, the details of the drift direction are sometimes in error and should be used with caution. In other cases, the drift cells do not represent closed systems, because sediment may bypass spits and embayments in deeper water and enter an adjacent drift cell. The selection of the cells does not consider processes that may take place in the active transport zone in deeper water, nor does it consider long-term transport trends.

The maps prepared by Schwartz indicate direction of inferred net transport. Estimates of potential transport rate are available in the Washington Coastal Zone Atlas (1980). These estimates are based on seasonal observations of wind direction and estimates of the resulting wave transport calculated from empirical formulas available in the early editions (1977) of the Shore Protection Manual (U.S. Army Corps of Engineers 1984). These should be considered as very rough indicators of potential transport and should not be used for most engineering purposes.

Spits and tidal flats are the most common types of shoreline features encountered around Bainbridge Island. Several spits are obvious around Bainbridge Island; e.g., Point Monroe (Figure III-11), Battle Point, Fletcher Bay, and Wing Point.

Tidal flats and flood tidal deltas were also observed in Murden Cove, Rolling Bay, and the inner harbors and bays of Manzanita Bay, Port Madison Bay, Fletcher Bay (Figure III-12), Blakely Harbor, and Eagle Harbor. A low-tide tombolo formation was observed behind Treasure Island in Port Madison Bay, and cuspate forelands were observed near Rolling Bay and Skiff Point, and near Yeomalt Point and Wing Point. Taggart (1984) inventoried and detailed the different drift cells in Kitsap County. He pointed out that artificial modifications of the shoreline could affect net shore drift by forming an artificial drift-cell terminus, a region of no apparent net shore drift, or could result in erosion.

Figure III-11. Spit, lagoon, and tidal flat at Point Monroe (© WA Dept. of Ecology, 1992).

2. Cross-Shore Transport

Breaking waves also move onshore and offshore. Fine sediment suspended in the water column is transported in the offshore-directed currents. Larger sediment particles that are mobilized by the combined shear stress of the wave and current are moved down-slope under the influence of gravity. High waves and storm-generated waves, which occur mostly in the winter, tend to move sediment offshore where it can/may be permanently removed from the coastal system. Figure III-13 shows the general sediment transport components.

Figure III-12. Spit, tidal delta, lagoon, and tide flat at Fletcher Bay (Source: Space Imaging, 2001).

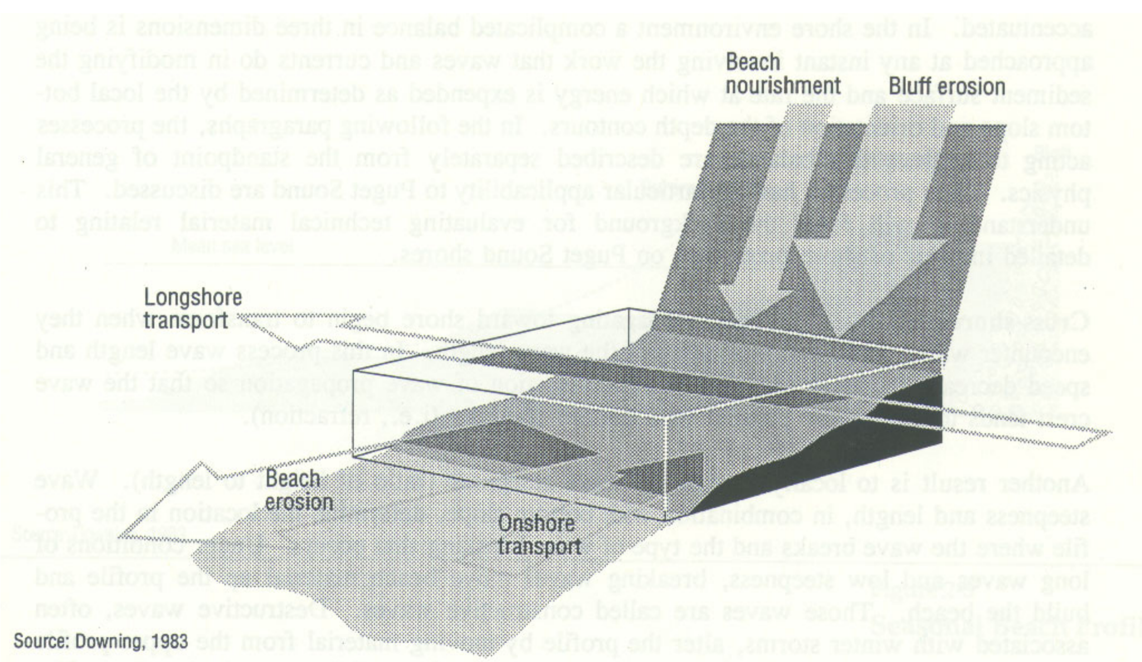

Figure III-13: Sediment loss and supply on a coastal shoreline.

3. Seasonal Variations

During most of the year, the wind-generated waves around Bainbridge Island are quite small and only the fine-grained materials are moved up and down the beaches. During winter storms, however, which tend to arrive from the southwest, sediment transport can be considerable. Strong storm waves originating from the south transport sediment to the north. Most of the sediment transport that occurs in Puget Sound can be attributed to storm events and potentially to vessel transit. If either of these events coincides with a high tide, waves can attack the shoreline at higher elevations, potentially causing increased sediment movement.

Whereas winter storms around Bainbridge Island carry sediment loads alongshore, mostly from south to north and offshore, the summer season experiences northerly winds that induce a north-to-south movement of sediment. During this season, waves exert little energy on the beaches. Smaller waves can return some of the finer sands from offshore back up onto the beaches (Downing 1983). The importance of the seasonal variation in sediment movement varies from location to location. The Coastal Zone Atlas (Washington State Department of Ecology 1979b) details the direction and importance of the littoral transport rates for the winter season and for the summer season. The estimates are based on potential sediment transport rates and on an older version of the Shore Protection Manual. There are no known systematic studies of the rates and directions of annual sediment transport for Bainbridge Island.

D. Key Findings and Conclusions

The general coastal processes that occur around Bainbridge Island have been summarized above. The general characteristics of the factors that influence or contribute to coastal processes have been defined around the Island, but site-specific detail is lacking. The following is a listing of the key findings, observations, data gaps, and resources.

- Bainbridge Island is an eroding system in which the bluffs contribute sediment to the beach, where waves and currents redistribute it along the shoreline. No other sources other than the island supplies material to the beaches. In the long run, storms remove more beach material than is returned to the beach during mild wave conditions. Modifications (such as bulkheads or other bank armoring to “stabilize” the slope) that limit the supply of sand and gravel to the beach will have long-term consequences elsewhere, as will construction measures that modify the natural transport of sand along the shoreline. Detailed mapping of the Bainbridge Island nearshore uplands indicating areas susceptible to erosion (due to groundwater flow, surface water flow, or development) has not been conducted. As individual development projects are considered, site-specific investigations should be required to evaluate the conditions of the local soils and surface water runoff and drainage.
- The directions and rates of sediment transport along the Island’s beaches are the result of calculated wave conditions, which are based on winds measured at a site considerably distant from the Island. Though the results of these studies are useful as large-scale indicators of processes, they may be misleading for particular sites. Site-specific investigations should be considered to reevaluate waves, currents, and sediment transport conditions based on recent developments in coastal engineering technology. The

long-term consequences of the decision or action may also have to take into account such issues as earthquake risk, tsunami inundation and sea-level changes.

- Considerable resources and technologies exist to predict sediment transport caused by waves on Island beaches. The technologies were developed for other locations and should be applied to Bainbridge Island with caution. The differences in conditions between the Island and those for which the technologies were developed should be acknowledged and quantified where possible.

IV. NEARSHORE HABITATS OF BAINBRIDGE ISLAND

This chapter describes the types of nearshore habitats found in Puget Sound, the species that are characteristic of these habitats, habitat functions, and known or suspected factors that stress or otherwise disrupt the habitats. The nearshore zone of Bainbridge Island contains the majority of nearshore habitat types recognized in Washington State.

A. NEARSHORE HABITAT CLASSIFICATION SYSTEMS

Nearshore habitats have been classified in a number of ways. One of the most widely used schemes is *A Marine and Estuarine Habitat Classification System for Washington State* (Dethier 1990) developed for the Washington State Department of Natural Resources. This scheme defines classes of habitats by their depth, substratum type, energy level (i.e., wave, currents), as well as some "modifiers" such as salinity range. The Dethier scheme expands the breakdown of habitat types, which provides more regional relevance to the national wetland habitat classification system developed by Cowardin et al. (1979).

A list of the various major habitat classes in the Dethier scheme is provided in Appendix B. Some of the major habitat types that occur within the nearshore environment include eelgrass meadows, kelp forests, seaweed beds, flats, tidal marshes, subestuaries, sand spits, and beaches and backshore. Although not part of Dethier's classification scheme, the nearshore also includes banks, bluffs, and marine riparian vegetation. Because physical processes, such as wave energy and currents, determine where these habitats will develop, the Dethier scheme classifies habitats or groups of habitats by physical conditions. For example, the class "Estuarine intertidal mixed-fines; partly enclosed" describes a set of conditions in backwater areas of estuaries (i.e., salinity commonly less than 30 parts per thousand [ppt]) or on deltas away from large distributory channels. Within this class, vascular marsh plant communities and eelgrass predominate. Another example of a class is "Marine intertidal rock; semi-protected and protected". The most common habitat type in this class is seaweed beds. This habitat class occurs where salinity is generally above 30 ppt, oceanic swell or extensive wind fetch is minimal, and rocks predominate because of steepness of the shore or currents. With the Dethier scheme, habitat types can be predicted for areas where physical conditions are known. This classification scheme can assist in determining both what types of habitats existed historically in areas that have been severely altered, predicting habitats in areas where only physical conditions are known, and determining what types of physical and chemical conditions need to be established in order to restore habitats.

Simenstad et al. (1991) developed protocols for monitoring nearshore habitats in Puget Sound for the U.S. Environmental Protection Agency (EPA) in a report titled, *Estuarine Habitat Assessment Protocol*. As in Dethier (1990), the Habitat Protocols report included a list of habitat types and the species most commonly associated with the habitat types. In addition, the report contains known linkages between habitats and species. Juvenile salmon, for example, are found in eelgrass meadows, because they are known to feed and find refuge in eelgrass. Hence, the Habitat Protocols report contains valuable information on the functions of the common nearshore habitats. The report also is useful in predicting what functions would be altered or changed if a habitat is altered or destroyed. In addition, the functions benefitting from restoration or protection of a habitat can be predicted.

B. Habitat Structure, Diagnostic Species, Functions, and Stressors

This section describes the common nearshore habitat types in central Puget Sound, along with the functions of these habitats and factors affecting habitat distribution and functions. We generally use the habitat names as described in Simenstad et al. (1991), but refer where appropriate to the Dethier class. We draw heavily from a recent report on the nearshore system along the eastern shoreline of central Puget Sound developed by Williams et al. (2001). The report, *Reconnaissance Assessment of the State of the Nearshore Ecosystem: Eastern Shore of Central Puget Sound, Including Vashon and Maury Islands (WRIAs 8 and 9)*, summarizes what is known about the distribution, functions, and status of nearshore habitats in the region.

Habitats common in this region include eelgrass meadows, kelp forests, flats, tidal marshes, subestuaries, sand spits, beaches and backshore, banks and bluffs, and marine riparian vegetation. The structure of a habitat refers to the number, composition, size, and spatial distribution of species comprising the habitat. For example, a kelp bed is dominated by bull kelp (*Nereocystis luetkeana*) but has subdominant species of seaweed, as well as benthic animals such as polychaete worms, anemones, and sea stars. In addition, the "architectural" structure afforded by the kelp forest canopy attracts many structurally oriented fish species, such as rockfish. The food chain for animals resident in the forest is largely based on the organic matter produced through photosynthesis by kelp and other algae, including phytoplankton, associated with the forest. Because the kelp forest slows currents, some portion of the food produced remains within the kelp forest. However, currents transport some of the organic matter, algae, and animals produced in the kelp forest to other habitats. This transport may be critical to the maintenance of animal and algal populations in the matrix of habitats comprising the "landscape" of the nearshore ecosystem. The understanding of the importance of this transfer of energy and organisms among habitats is just beginning to be evaluated.

A generalized distribution of the major or common aquatic habitat types is illustrated in Figure II-2. Four major factors determine the types of habitats present at a site: salinity, depth, substrata type, and water motion (i.e., energy from waves and currents). Species are distributed by their tolerance to salinity, drying and submergence, attachment or burial requirements (e.g., do they need to attach to stable rocks or burrow in the mud), and their ability to withstand water motion. Light controls the depth that plants and algae can grow in water. Distribution and dynamics of bluffs, banks and marine riparian vegetation are dependent on substrata type and water motion. In addition, the vegetation in the riparian zone is dependent on light and water level in the soil. Sunlight decreases rapidly with increasing depth, especially in turbid water. The upper elevation limit is determined by their ability to withstand desiccation or drying during low tides. Tide marsh plants are adapted for long periods of emergence and periodic inundation of seawater at high tides and freshwater during rainy periods or flood events. There is often intense competition among species occupying stable rock surfaces. In these habitats, competition may play a major role in determining the structure of the community.

1. Eelgrass Meadows

Figure IV-1. Eelgrass meadow.

Eelgrass (*Zostera marina*) is a marine seagrass (i.e., a rooted plant that produces flowers) that forms meadows, literally pastures of flowing grass, that range from patchy to contiguous and extensive (Figure IV-1) (Table IV-1). Eelgrass meadows are formed within the lower intertidal to shallow subtidal zones, from about +1 m to -5 m relative MLLW in the central Puget Sound area (Bulthuis 1994; Thom et al. 1998). Eelgrass shoot density is highly variable and range from 50 to 800 shoots per square meter in central Puget Sound (Thom et al. 1998). According to recent data, eelgrass covers 10,500 ha (26,000 acres) in Puget Sound (Puget Sound Water Quality Action Team 2002). An invading species of seagrass (*Zostera japonica*) occurs in Puget Sound also. This species is smaller in size but can reach very high densities on the order of 5 times greater than eelgrass. Although *Z. japonica* can grow intermixed with eelgrass, it generally forms meadows at somewhat higher elevations in the intertidal zone than does eelgrass.

Through photosynthesis, eelgrass is a major contributor to the detritus used in both nearshore and deep-water food webs. Annual reported eelgrass production rates range from 200 to 806 g of carbon per square meter per year within Puget Sound (Williams et al. 2001). Detritivores (animals that feed upon dead plant and animal material), such as harpacticoid copepods, gammarid amphipods, and isopods, incorporate carbon energy directly from detritus formed by eelgrass dieback, and fish utilize carbon energy from the detritus indirectly by consuming these benthic organisms (Simenstad et al. 1979; Nightingale and Simenstad 2001b). New evidence reveals that mats of detached eelgrass (and probably *Z. japonica*) are common at depths as great as 100 m in Puget Sound (Woodruff et al. 2000). Through this process, very large amounts of organic matter reach the deeper parts of Puget Sound where the material can be used by animals far from areas where eelgrass was produced.

Eelgrass grows to a height in excess of 2 m in some areas, and shoots can be as dense as 500 per square meter. This dense and lush canopy provides a three-dimensional surface for the attachment of many species and an effective hiding place for small fish. By its position in the intertidal-shallow subtidal zone, it forms refuge habitat for a wide variety of nearshore fish and invertebrate species. Many of these fish species show a strong affinity for eelgrass because it offers shelter from predators and abundant food resources. Among these species are bay pipefish, crescent gunnel, kelp perch, lingcod, penpoint gunnel, shiner perch, snake prickleback, striped seaperch, and tubesnout (Simenstad et al. 1991).

Juvenile chum and chinook salmon are often found feeding and residing in eelgrass meadows and their edges. Juvenile salmon feed on small crustacea found associated with the leaves of eelgrass and at the base of the eelgrass plants. Many of the prey items include harpacticoid copepods, which occur in high abundances in the epiphytes (small algae that attaches to the leaves of the seagrass) that attach to the oldest portions of the eelgrass leaves. These prey taxa are most abundant during the spring when the juvenile salmon migrate along the nearshore region. Pacific herring (*Clupea harengus pallasi*) populations depend on eelgrass meadows where they often deposit eggs and rear as juveniles. Herring, in turn, are important in the diet of many larger animals including, salmon, seals, and sea birds.

Dungeness crab (*Cancer magister*) are also commonly associated with the protective cover of eelgrass habitats. Other common invertebrates include bivalves, such as the cockle (*Clinocardium nuttallii*). A number of unique species of invertebrates are found almost exclusively in eelgrass meadows, such as the brooding sea anemone (*Epiactis prolifera*), the chink shell (*Lacuna variegata*), the sea slug (*Phyllaplysia taylorii),* and the bubble shell (*Haminoea virecens*). The large nudibranch gastropod (sea slug) *Melibe leonine* is often found in eelgrass meadows, and is considered one of the foremost curiosities in Puget Sound. Several other bird species are often found feeding in eelgrass meadows including great blue heron, greater yellowlegs, least sandpiper, and spotted sandpiper. Eelgrass is the preferred food of black brant geese. The non-native seagrass *Z. japonica* has also been found in the stomachs of American widgeon (Baldwin and Lovvorn 1994).

Table IV-1. Eelgrass Meadow Habitat

Diagnostic species:
Eelgrass (*Zostera marina*)
Common Associates:
Sea lettuce (*Ulva* spp)
Black brant (*Branta bernicula*)
Bay pipefish (*Syngnathus leoptorhynchus*)
Tube-snout (*Aulorhyncghus flavidus*)
Dungeness crab (*Cancer magister*)
Distribution:
Low intertidal and upper subtidal zone, along protected and semi-protected shorelines with unconsolidated substrata
Functions:
Primary production
Nutrient processing
Wave and current energy buffering
Organic matter input
Habitat for fish, invertebrates, and epiphytes
Food for birds
Factors controlling growth:
Light
Temperature
Salinity
Depth/inundation
Substrata
Nutrients
Water motion
Stressors:
Turbidity
Overwater structures
Shoreline armoring
Dredging
Boat wakes
Eutrophication
Shellfish harvesting

Eelgrass grows in saline waters but can withstand periodic flushes with freshwater, as long as they do not last too long (the actual duration of time is not well studied). Eelgrass can occur on river and stream deltas away from very high salinity waters. Eelgrass can grow in a wide variety of substrata types ranging from fine sands to gravel but grows best in medium-fine sand with some organic matter. The organic matter is a source of nutrients to the plants through its roots. Nutrients in the water column can also be taken up by the leaves of the plants. Desiccation (drying) stress limits the upper boundary of eelgrass meadows, and the lower boundary is limited by light penetration in the water (Thom et al. 1998). Competition for light and nutrients with macroalgae species can also affect eelgrass distribution. Eelgrass is harmed by any activity that reduces light or disturbs the sediment where it grows. Hence, docks, boat wakes, and modification of shorelines all have resulted in loss of eelgrass. Heavy shellfish harvesting can also impact eelgrass (Boese 2002). High inorganic nutrient levels can fuel seaweed or ulvoid blooms that have resulted in smothering of eelgrass. The WDNR ShoreZone Inventory (Washington State Department of Natural Resources 2001) shows continuous or patchy green algae (*Ulva* ssp.) along a majority of Bainbridge Island shoreline. The few areas that did not contain ulvoids include an area northwest of Yeomalt Point, and portions of Fletcher Bay and Hidden Cove (Algae Occurence Map, Appendix A). Although there is concern that the invading non-native smooth cordgrass, *Spartina alterniflora,* may eventually take over areas now occupied by eelgrass, that has not occurred as yet (Simenstad and Thom 1995).

Eelgrass occupies an estimated 18.7 miles of Bainbridge Island shoreline (Washington State Department of Natural Resources 2001). Eelgrass is dominant along the northwestern, northern and eastern shorelines, and notably absent along the western shoreline south of Battle Point to Point White (Eelgrass and Kelp Occurrence Map, Appendix A). In two separate studies conducted by Battelle Marine Sciences Laboratory during the summers of 2000 (Woodruff et al. 2000) and 2001 (Borde et al. 2001), several small beds of eelgrass were documented along the southern shoreline of Bainbridge Island. These studies also confirmed the lack of eelgrass along the western shoreline just north of Point White. The reasons eelgrass was lacking in this area are not evident. The WDNR ShoreZone Inventory utilized helicopter flyovers to conduct surveys (i.e., quick visual survey of large areas of intertidal shoreline), whereas the Battelle MSL surveys focused on the specific areas near Rich Passage and utilized aerial photography and diver transects to examine subtidal beds. Each survey result indicated eelgrass in the same general locations, with slight differences in the actual distribution, probably because the MSL surveys were heavily ground-truthed. The ShoreZone surveys are meant to provide information on the general broad-scale distribution and may not be highly accurate at finer scales. However, additional eelgrass data should become available in the future through the WDNR Submerged Vegetation Monitoring Project. Approximately 60 sites throughout Puget Sound have been selected for long-term monitoring. One site, Battle Point, is located on Bainbridge Island. The project was initiated in 2001 and is designed to assess changes in eelgrass abundance and distribution, an indicator of estuarine health.

2. KELP FORESTS

Kelp beds in Puget Sound are formed by bull kelp, which is the largest member of brown algae found in the Pacific Northwest (Figures IV-2 and IV-3) (Table IV-2). Because bull kelp requires attachment to the bottom, it only develops into dense forests where rocky substrata is available. Bull kelp is an annual plant, reaching its greatest length and density during summer. The stipe density of bull kelp has been reported to range between 0.9 to 3.8 stipes per square meter (Thom 1978).

Several other species of large seaweeds occur in the understory of the canopy formed by bull kelp. These species may persist throughout the year, even when bull kelp is not present. Kelp can increase in length on the order of 5 cm per day during the summer. Based on estimates of biomass at the start and end of the growing season, kelp can produce approximately 10 kg (wet weight) of biomass per square meter in 3 months in Puget Sound (Thom 1978). This estimate equates to approximately 500 g of carbon per square meter.

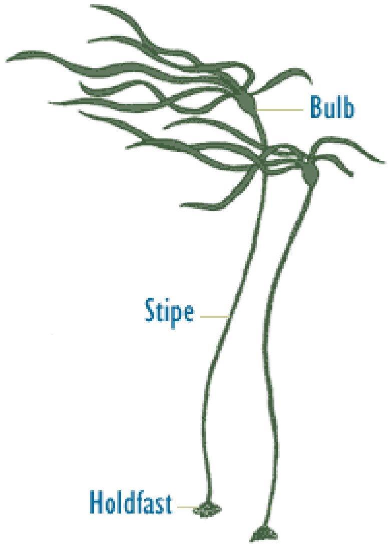

Figure IV-2. Bull kelp morphology (Source: WA Dept. of Ecology).

Figure IV-3. Bull kelp forest.

Table IV-2. Kelp Forest Habitat

Diagnostic species:
Bull kelp (*Nereocystis luetkeana*)
Common Associates:
Brown seaweed (*Costaria costata*)
Brown seaweed (*Laminaria saccharina*)
Brown seaweed (*Sargassum muticum*)
Rockfish (*Sebastes spp.*)
Distribution:
Low intertidal and upper subtidal zone, along shorelines with cobble and boulder substrata
Functions:
Primary production
Nutrient processing
Wave and current energy buffering
Organic matter input
Habitat for fish and invertebrates
Factors Controlling Growth:
Light
Temperature
Salinity
Substrata
Nutrients
Water motion
Stressors:
Turbidity
Overwater structures
Shoreline armoring
Boat wakes
Eutrophication
Harvesting for food

Sargassam muticum is a non-native brown seaweed species associated with kelp forests. It was introduced by the oyster mariculture industry to the Northwest in the 1930s (Anderson 1998). *Sargassum* can occupy space on rocks normally used by bull kelp if bull kelp is damaged or lost for some reason (Thom and Hallum 1990).

Kelp was mapped early in the 20th century, because it was considered an important source of potash. The WDNR ShoreZone Inventory (Washington State Department of Natural Resources 2001) indicates that 11% of the Puget Sound shoreline is bordered by floating kelp (Puget Sound Water Quality Action Team 2002). Subsequent mapping has shown that kelp is either similar to historic levels or has increased in area since that time. The partial explanation may be that armoring of shorelines has increased erosion and exposed more rocky substrata. Kelp forests form refuge habitat for a number of fish species, especially rockfish. Juvenile and subadult salmon have also been noted in kelp forests. Because kelp attains a size in excess of 15 m between late winter and midsummer, it is considered one of the fastest growing organisms in the world. Adequate light, temperature, and nutrients are required for this growth. Kelp is effective at reducing wave energies and thereby reducing the erosion of beaches. Herring are known to spawn on kelp blades. Sea urchins can graze extensively on kelp in some areas. Massive floating mats of kelp and other species begin to deposit on beaches in the fall and winter, where amphipods and other "shredders" break up the material, which makes the plant material available to other animals. Many rockfish species are commonly found associated with kelp forests. Besides providing a three-dimensional structure that affords some protection from predators, food abundance is high. The structure of the forest alters currents and may help concentrate planktonic food used by these fish and invertebrates in the forest.

Factors affecting water clarity or light can adversely impact kelp. Competition with other understory species can affect kelp abundance. In particular, once *Sargassum* becomes established it may be hard for bull kelp to recolonize an area (Thom 1978). Kelp in shallow waters has been subject to increasing harvest pressure, which may be reducing its distribution near highly populated areas (Thom and Hallum 1990). Oil was effective in bleaching and killing plants during the *Tenyo Maru* oil spill in 1991 (Antrim et al. 1995).

According to the WDNR Shorezone Inventory, several kelp beds have been observed at Wing Point on the eastern shore of Bainbridge Island and Point White along the southwestern shore (Eelgrass and Kelp Occurrence Map, Appendix A).

3. Flats

Flats generally include gently sloping sandy or muddy intertidal or shallow subtidal areas (Figure IV-4) (Table IV-3). Because of the quiescent conditions and the input of organic matter, mudflats are usually high in organic content, and anaerobic conditions may exist below the surface. Sandflats, which are comprised of larger sized particles, are often more aerobic. Flats serve a wide variety of functions.

The main primary producers on flats are diatoms that inhabit the upper few mm of fine sediment of flats. Chlorophyll *a* concentration, used to estimate diatom biomass, ranges from 140 to 380 mg per square meter on flats in Puget Sound (Thom 1989). Primary production measured for flats range from 22 to 59 g of carbon per square meter per year (Thom 1984; Thom 1989), and daily and seasonal inorganic nutrient flux rates can be substantial, especially on muddy flats (Thom et al. 1994a). Nutrients released from sediments on flats may fuel algae growth on the flats and in the water column.

Sediment-dwelling invertebrates, such as polychaete worms, amphipods, and small bivalves, can be very abundant on flats. On two beaches dominated by sand and mudflats, Armstrong et al. (1976) recorded 203 (Richmond Beach) and 178 (Carkeek Park) species of invertebrates. Invertebrates residing in the sand and mud can reach densities on the order of 6000 per square meter (Thom et al. 1984). Eight or more species can be found per small core sample (5.5-cm diameter). These animals feed on organic matter on the surface and in the sediment, and hence are dependent not only on production on the flats themselves, but also on deposition of detritus produced in other areas.

Figure IV-4. Tide flats in Murden Cove (© WA Dept. of Ecology 1992).

Table IV-3. Flats Habitat

Diagnostic species:
Sediment-associated diatom flora
Sediment-dwelling invertebrates
Common Associates:
Various seaweed species as drift
Dunlin *(Calidris alpina)*
Sandpipers (e.g., *Caladris mauri*)
Bay goby (*Lepidogobias lepidus*)
English sole (*Parophrys vetulus*)
Starry flounder (*Platichthys stellatus*)
Distribution:
Intertidal, in protected and semi-protected bays, often near sources of sediment such as streams and rivers
Functions:
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 salt marsh for fish and invertebrates
Factors controlling functions:
Light
Temperature
Salinity
Upland hydrology
Substrata
Nutrients
Water motion
Stressors:
Unnatural erosion or deposition of sediment
Overharvesting of shellfish
Overabundance of organic matter loading including ulvoid mats
Alteration of dendritic tidal channels
Fecal and chemical contamination
Physical disturbances from shoreline armoring, marina construction, and harvesting.
Shading from overwater structures
Competition from non-native species

The prey (e.g., harpacticoid copepods, amphipods) of juvenile salmon can reach high densities (18,000 per square meter) on flats, and heavy consumption by salmonids can drive these prey abundances very low (Thom et al. 1989). Studies indicate that the flats are heavily used for feeding by juvenile salmonids especially very early in spring, after which the salmon shift to feeding lower in the intertidal and shallow subtidal zone (Thom et al. 1989). Much of the prey production on the flats is believed to be driven by benthic diatom production that occurs early in spring. Because light drives benthic diatom growth, the flats increase their production in early spring when light increases with the onset of daytime low tides. Later in spring and in early summer, light increases dramatically further offshore and initiates the production of prey in habitats, such as eelgrass. Hence, the flats play an important role in the seasonal dynamics of salmon feeding within the Puget Sound nearshore landscape.

Flats often are dissected by numerous small channels, which are used by invertebrates and fish as well as shorebirds, herons, raccoons, otter, mink and other organisms for foraging. Channels "…constitute critical interfaces within the estuary itself, linking littoral and sublittoral, riverine and marine habitats" (Simenstad 1983, page 4). Channels transport organic matter from sources to sinks in the estuary, provide deeper wetted areas for fish (such as juvenile salmon) to reside during low tides, can be highly productive in terms of benthic infauna invertebrates, and are often used by predators, such as wading birds, as a key feeding area. The small channels provide a conduit of access of fish to the productive portions of the intertidal system such as the edges of salt marshes. Fish species that are common on flats include chum salmon, bay goby, Pacific staghorn sculpin, English sole, sand sole, speckled sanddab, and starry flounder (Simenstad et al. 1991). Perhaps the most intense use of flats is by shorebirds. Shorebirds are commonly observed in large numbers feeding on invertebrates produced on the flats. The non-native seagrass *Zostera japonica* has colonized flats since its introduction in the 1930s. It is fed upon extensively by American widgeon. This invading species creates a three-dimensional structure to the otherwise unvegetated flats. Prey resources for salmonids and other fish occur in high densities in *Z. japonica* (Simenstad et al. 1988).

Channels on the flats, which are formed by hydrological processes, can change their location and morphology dramatically. These changes are driven by stream flow, tides, currents and wave energies. Hence, alteration of these processes can affect natural stream number, size and location. 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 consort to distribute and rework sediments on flats. Although sediment composition and sediment dynamics exert primary control over the biological community that develops on flats, variations in light and temperature also appear to drive seasonal abundance of algae and invertebrate prey species (Thom et al. 1989). Simenstad (1983) identified the following sources and mechanism of impact to channels:

- dredging and dredged-material disposal
- fillings, and land reclamation
- jetty, training wall and other construction
- urban and industrial effluent discharge
- log dumping and storage
- commercial or recreational exploitation of fauna and its artificial enhancement
- upstream water diversions and storage reservoirs.

Tidal flats are present below the beach face throughout Bainbridge Island, and are well-developed in such areas as Murden Cove, Manzanita Bay, Rolling Bay, Fletcher Bay, Blakely Harbor, and Eagle Harbor (Substrate Type Map, Appendix A).

4. Tidal Marshes

Tidal marshes include salt and freshwater marsh habitats that experience tidal inundation (Figure IV-5) (Table IV-4). They generally occur at elevations from MHHW and above, and are located where sediment supply is relatively high and accumulation of sediment is facilitated by protection from waves and currents. Marshes commonly develop on deltas of streams and rivers. The root mat created by marshes stabilizes sediment. Marshes tend to prograde outward through time by accumulation of sediment and organic matter

Figure IV-5. Tidal marsh in Eagle Harbor (© WA Dept. of Ecology 2000).

Primary production rates for regional tidal marshes are great, ranging from 529 to 1108 g of carbon per square meter per year (Thom 1981). The organic matter enters the detrital food web in the fall and winter when growth of plants ceases and physical breakdown of marsh vegetation occurs. Marsh plains are used by a variety of bird taxa as well as mammals for nesting and foraging including the American widgeon, black brant, bufflehead, and great blue heron. Juvenile salmon reside in tidal marshes and forage on prey resources produced in and imported to the marsh system, where significant growth of juvenile salmon has been recorded (Shreffler et al. 1992). Tidal marshes are believed to be one of the most important habitats contributing to juvenile salmon growth and survival (Bottom et al. 2001). Juvenile salmon access the marshes primarily during higher tides, when they are able to reach the productive edges of the marsh system. The deeper portions of the channels afford refuge for the fish during low tides. Studies have shown that salmonids feed on insects produced in the marsh, as well as on small crustacea often found associated with the edges of the marsh (Shreffler et al. 1992; Simenstad and Cordell 2000). Juveniles can spend extended times in tidal marsh systems where they may transition from a freshwater to a salt water physiology. Marshes can serve as effective

Table IV-4. Tidal Marsh Habitat

Diagnostic species:
- Pickleweed (*Salicornia virginica*)
- Salt grass (*Distichlis spicata*)
- Seaside arrowgrass (*Triglochin maritimum*)
- Lyngby sedge (*Carex lyngbyei*)
- *Scirpus spp*.
- Several other marsh species

Common Associates:
- Various seaweed species as drift
- Shorebirds, various species
- Waterfowl (e.g., *Anas Americana*)
- Townsend vole (*Microtus townsendii*)
- Chinook salmon (*Oncorhynchus tshawytscha*))
- Chum salmon (*Oncorhynchus keta*)
- Sculpin (e.g., *Leptocottus armatus*)
- Stickleback (*Gasteosteus aculeatus*)

Distribution:
- High intertidal to supratidal, in protected and semi-protected bays, often near sources of sediment such as streams and rivers

Functions:
- 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

Factors controlling functions:
- Light
- Temperature
- Salinity
- Substrata
- Nutrients
- Water motion

Stressors:
- Disturbed community structure
- Disturbed plant growth
- Presence of non-native species
- Buffer encroachment
- Runoff scour
- Alteration of dendritic tidal channels
- Alteration of sediment dynamics
- Loss of upland hydraulic connectivity
- Elevated soil contaminant concentrations
- Presence of man-made debris
- Physical disturbances from dredging, filling and diking
- Chemical contamination

sediment traps and locations of intense nutrient cycling; two processes that can facilitate improvement in water quality.

Most of the tidal marshes in Puget Sound have been lost over the past 150 years (Bortleson et al. 1980). Alterations in hydrology, sediment supply, sea level, or marsh plant production can affect the maintenance of the marsh. Filling, dredging, and diking have destroyed large areas of tidal marshes in Puget Sound. Similar to tidal flats, embayments with additional sediment input (i.e., stream discharge) are likely areas for tidal marsh development, such as Manzanita Bay, Fletcher Bay, Blakely Harbor, Eagle Harbor, Port Madison Bay, and Murden Cove.

5. SUBESTUARIES (RIVER MOUTHS AND DELTAS)

Subestuaries consist of mouths of those streams and rivers that enter a larger estuary (e.g., Puget Sound) (Figure IV-6). Subestuaries are numerous in Puget Sound, although they are often very small where watersheds are short and stream flows are low. Taken in total, subestuaries are an important component of Puget Sound ecosystems. They can form deltas where organic matter accumulates, and flats where shorebirds and fish feed (Table IV-5).

Figure IV-6. Subestuary at Murden Cove (© WA Dept. of Ecology 2000).

Wetlands are associated with subestuaries, which further slow peak flows. These wetland areas also filter runoff, improving the quality of the water before it enters the estuary. Salt marshes in subestuaries, although often small, are important rearing areas for juvenile salmonids, providing refuge and food before they outmigrate. Eelgrass can form in subestuaries. Birds use subestuaries for bathing and drinking, particularly in the late summer months when freshwater is more limited (Norman 1998).

Resources and functions of subestuaries are similar to those for tidal marshes and flats, because they can contain both habitats. Stressors on subestuaries are primarily from upstream and shoreline development, which alters stream flow, surface and groundwater flows, riparian functions, and water quality. Alterations of hydrology from filling and diking can affect the functioning of subestuaries also.

Small deltas are evident in locations such as Lynwood Center and Murden Cove, where small streams meet the surrounding waters of Bainbridge Island. Subestuaries are recipients of upstream organic matter, nutrients, and large woody debris (LWD), and undergo salinity variation important spatially and temporally to nearshore fishes.

Table IV-5. Subestuaries Habitat

Diagnostic species: Sediment-associated diatom flora Sediment-dwelling invertebrates Common Associates: Various seaweed species as drift Dunlin (*Calidris alpina*) Sandpipers (e.g., *Caladris mauri*) Bay goby (*Lepidogobias lepidus*) English sole (*Parophrys vetulus*) Starry flounder (*Platichthys stellatus*) Distribution: Intertidal to supratidal with a freshwater source Functions: Primary production Nutrient cycling Habitat/support for juvenile and adult fish Bivalve production Salmonid osmoregulation Prey production for juvenile salmon, flat fish, and shorebirds Detritus sink Wave dissipation for salt marsh for fish and invertebrates	Factors controlling functions: Hydrology from upland Light Temperature Salinity Substrata Nutrients Water motion Stressors: Unnatural erosion or deposition of sediment Fecal and chemical contamination Physical disturbances from shoreline armoring, marina construction, and harvesting. Shading from overwater structures Competition from non-native species Altered hydrology

6. Sand Spits

Sand spits are relatively rare and unique features in Puget Sound (Table IV-6). They may enclose (partially or totally) intertidal estuarine areas. Substrata are typically sand, silty sand, or gravelly sand (Figure IV-7).

Figure IV-7. Sand spit, marsh and lagoon at Battle Point (© WA Dept. of Ecology 1992).

Table IV-6. Sand Spit Habitat

Diagnostic species: Dune grasses Salt marsh species Common Associates: Dunlin (*Calidris alpina*) Sandpipers (e.g., *Caladris mauri*) Various mammal species Distribution: Supratidal, form embayments Functions: Foraging and nesting areas for waterfowl and shorebirds Prey production for crabs, sculpin, flatfish Bivalve production Primary production Factors controlling functions: Currents and wave dynamics Erosion and deposition forces Stressors: Unnatural erosion or deposition of sediment Physical disturbances from shoreline armoring, marina construction

Low salt marshes can dominate the upper zones of these estuarine, intertidal marsh areas on the protected/landward side of spits. Sediment particles contributing to sand spit formation on Bainbridge Island originate primarily from eroding bluffs. Waves and currents transport this material along the shoreline until it settles out near an embayment, forming a spit. Changes in stream sediment load, tidal currents, and wave action can affect the maintenance of sand spits. Because the sand spit is a protective structure, the embayment behind the spit can develop a marsh/flat/channel system with function similar to those described for these habitats above. Spits are vulnerable to erosion during extreme storm events, and may be overtopped and breached. With appropriate sediment sources, they rebuild rather rapidly. In situations where sediment supply is restricted, spits may erode and not recover.

Several spits are present on Bainbridge Island, including Point Monroe, Battle Point, Fletcher Bay, inner Eagle Harbor, Agate Point, and Wing Point.

7. Beaches and Backshore

A beach is an accumulation of unconsolidated material formed by waves and wave-induced currents in the zone that extends landward from the extreme lower low water line to a place where there is a marked change in material or physiographic form, usually the effective limit of storm waves (Figure IV-8). Beaches include cobble, boulder, sand, and silt areas that comprise most of the shoreline of Puget Sound. They are generally steeper than tide flats described above (Table IV-7).

Figure IV-8. Beach and backshore at Fay Bainbridge State Park (© WA Dept. of Ecology 2000).

Table IV-7. Beaches and Backshore Habitat

Diagnostic species:
Sea lettuce
Rockweed
Common Associates:
Cutthroat trout (*Oncorhynchus clarki*)
Other juvenile salmon (*Oncorhynchus* spp.)
Cormorants (*Phalacrocorax auritus*)
Grebes (*Podiceps auritus*)
Great blue heron (*Ardea herodias*)
Various other shorebirds
Shellfish (e.g., *Mytilus* spp.)
Forage fish (e.g., *Ammodytes hexapterus*)
Distribution:
Intertidal, supratidal
Functions:
Primary production
Nutrient cycling
Refuge for multiple species
Prey production for juvenile salmon and flatfish
Fish habitat, including forage fish spawning
Bivalve production
Factors controlling functions:
Currents and wave dynamics
Erosion and deposition forces
Riparian vegetation
Upland hydrology
Stressors:
Fecal contamination
Chemical contamination
Alteration of natural habitats
Alteration of resource use of natural habitats
Alteration of sediment supply
Alteration of groundwater hydrology
Loss of riparian habitat

Functions supported by beaches are numerous, and are generally similar to those described above for tide flats. However, the level of each function differs from tide flats. Cobble beaches, especially in lower energy environments, can contain large abundances of bivalve shellfish. Densities of clams, such as butter (*Saxidomus giganteus*) and littleneck (*Tapes japonica*), can be as great as several hundred per square meter. Production rates on cobble shorelines can be as high as in eelgrass meadows (Thom et al. 1984). Beaches with finer sediments from pea gravel to coarse sand also can contain extensive shellfish abundances. In addition, these beaches are known to provide optimal spawning habitat for forage fish, such as sand lance and surf smelt (Penttila 1996). It has been shown that forage fish egg survival is partially dependent on moisture retention in the sediment, as well as the shade from overhanging vegetation. Alteration of groundwater flows that surface in the intertidal zone, for example by armoring shorelines, in addition to loss of shade can result in dryer conditions that may reduce egg survival (Levings and Jamieson 2001). Loss or alteration of forage fish spawning beaches is a major concern among resource managers.

Backshore areas are immediately landward of beach face and are zones inundated only by extreme storm-driven tides (Figure IV-8). Backshore areas have not been studied as well as beaches for their ecological functions. However, we do know that woody debris accumulates in the backshore through transport at extreme high tides. It is generally believed that this woody debris can help stabilize the shoreline and provide microhabitats for invertebrates and birds. Backshore areas also support a unique assemblage of vegetation tolerant of wind, salt spray, and shifting substrate.

Shoreline armoring, loss of riparian vegetation, overwater structures, dredging, filling, and resource harvesting are likely the major causes for loss of beach and backshore habitat. Although beaches on Bainbridge Island typically have backshore zones with narrow to no width, these areas can be found contributing to beach habitat on the Island, most notably at Point White (and the area south of Point White), Yeomalt Point, Pleasant Beach area, Crystal Springs, parts of Manzanita and Fletcher Bays, inside Wing Point, and south of Agate Pass.

8. BANKS AND BLUFFS

Banks and bluffs are steep areas located between the intertidal zone and the upland (Figure IV-9). The ShoreZone Inventory (Washington State Department of Natural Resources 2001) identifies cliffs as those areas with a slope of more than 20% grade. Banks and bluffs can be composed of varying grain sizes of sediment and rocks and boulders. As described in more detail in Chapter III, these habitats are formed and maintained by the dynamics of numerous factors, including soils, wind, erosion, hydrology, and vegetative cover (Table IV-8).

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

Figure IV-9. Bank and bluff at Rolling Bay (© WA Dept. of Ecology 2000).

Table IV-8. Banks and Bluffs

Diagnostic species:
Trees and shrubs
Distribution:
Upper intertidal, supratidal
Functions:
Transition between uplands and nearshore
Source of sediments to beaches
Habitat for bluff-dwelling animals
Support of marine riparian vegetation
Source of groundwater seepage into estuarine and marine waters
Factors controlling functions:
Erosion forces – wind and hydrology
Geology
Vegetative cover
Stressors:
Shoreline armoring and development
Alteration of hydrology

Residential development can cause erosion and stability problems, and landslides have been documented over the past few years. 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 (e.g., a bulkhead), the health of the adjacent habitats that are dependent on sediment from the bluffs is affected. The maintenance of these areas is dependent on a source of sediment from eroding bluffs.

The historical distribution of banks and bluffs has not been mapped, although the major obvious changes are likely shoreline armoring and coastal development that directly affect bluffs and their maintenance processes. A number of eroding bluff areas have been identified, including shorelines south of Agate Pass, at Battle Point, north of Fletcher Bay, near Blakely Harbor, near Yeomalt Point and Ferncliff, around Skiff Point to Madison Church, and west of Madison Bay near Agate Point (Geologic Stability Map, Appendix A).

9. MARINE RIPARIAN ZONES

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 (Levings and Jamieson 2001) (Figure IV-10). 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; Knutson and Naef 1997). Riparian vegetation composition, density, and continuity are some of the most important characteristics of riparian systems (Table IV-9).

Figure IV-10. Riparian zone in Seabold area (Source: Applied Environmental Sciences, Inc.).

Table IV-9. Marine Riparian Habitats

Diagnostic species:
Trees and shrubs
Distribution:
Upland bordering tidal zone
Functions:
Water quality protection
Hydrology regulation
Wildlife habitat
Microclimate regulation
Shade
Nutrient and prey input
Bank stabilization
Large woody debris (LWD)
Factors controlling functions:
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
Stressors:
Increased impervious surfaces and runoff
Air and water pollution
Vegetation removal
Exotic & invasive species introduction

Most of what we know about riparian functions and values comes from investigations of freshwater systems, which have been the subject of extensive research (Knutson and Naef 1997). 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). For example, besides providing shade for forage fish spawn, insects produced in the vegetation may be an important source of prey to juvenile salmon and other fish in the nearshore area (Levings and Jamieson 2001). Levings and Jamieson (2001) list as other functions wave energy absorption and provision of structure. Trees and woody debris derived from the marine riparian zone may serve as shelter for fish and invertebrates at all levels of the intertidal zone. They recommend that the value of marine riparian habitat should include consideration of the ability to 1) provide shade, 2) supply and/or filter shore derived sediment, 3) stabilize shorelines, and 4) filter and mineralize non-point organic pollutants such as nitrogen from septic fields.

Marine riparian vegetation provides a buffer analogous to freshwater systems (Desbonnet et al. 1994). Castelle et al. (1994) shows that buffers protect adjacent habitats, such as wetlands. Among the functions listed are moderating the effects of stormwater runoff and soil erosion; filtering suspended solids, nutrients, and harmful or toxic substances; and moderating water level fluctuations. Buffers provide essential habitat for wetland-associated species for use in feeding, roosting, and breeding and rearing young, and provide safe cover for mobility and thermal protection. Buffers with dense vegetation cover on slopes less than 15% are most effective in treating runoff from upland areas. Dense shrub and forested vegetation with steep slopes provide the greatest protection from direct human disturbance. Castelle et al. (1994) reveals that as buffer width increases the effectiveness of removing sediments, nutrients, bacteria, and other pollutants from surface water increases. Furthermore, buffers of less than 50 feet in width are generally ineffective in protecting wetlands. To protect important wetland functions, buffer width on the order of 100 to 300 feet is required. The national review by Desbonnet et al. (1994) of coastal buffers indicates that functional effectiveness increases substantially with high quality buffers at least 75 m (246 feet) in width.

Land clearing occurs with most development projects, including those at the waters edge. Over time, vegetation has been removed for timber, housing and other land development, roads, railroads, port and other commercial and industrial development, view corridors, shoreline armoring, landscaping, beach access, and other land-use practices. 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; thereby altering the functions of the marine riparian zone. 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).

V. NEARSHORE BIOLOGICAL RESOURCES (FAUNAL ASSEMBLAGES)

This chapter describes selected biological resources found in the nearshore waters of Puget Sound. These include benthic macroinvertebrates that are of commercial or recreational significance, selected forage fish, groundfish, and salmonids of concern to WDFW, and key marine birds and mammals of interest to WDFW. A majority of these species are typically found in nearshore habitats of Bainbridge Island. For each species or groups of species, we summarize the life history, nearshore ecology, known or suspected factors that stress or otherwise disrupt nearshore functional dependence, and existing information about Bainbridge Island populations.

A. SELECTED BENTHIC MACROINVERTEBRATES

Invertebrates listed for management by WDFW in Puget Sound include native littleneck, Manila littleneck, butter clam, cockle, Eastern softshell clam, Macoma, geoduck, horse clam, oyster, Dungeness crab, red rock crab, mussels, goose barnacles, sand shrimp, moon snails, and nudibranchs. Here, we briefly summarize the ecology, management, current status, and Bainbridge Island distributions of the more commonly harvested hardshell clam species and Dungeness crab.

1. HARDSHELL CLAMS

The three species of clams generally referred to as hardshell clams in the Puget Sound region include the introduced Manila clam (*Venerupis* [*Ruditapes*] *philippinarum*), the native littleneck clam (*Protothaca staminea*), and the butter clam (*Saxidomus giganteus*) (Scholz 1990). The Manila and native littleneck clams are considered the most important to the commercial fishery because of their better keeping quality. The butter clam is more important to the fishery, where it accounts for the greatest quantity of total weight harvested because of its larger size. Butter clam harvest is frequently closed as a result of high levels of the paralytic shellfish poisoning (PSP) toxin. All clams commercially harvested are regulated for both fecal coliform and PSP. Many areas in Puget Sound are seriously affected by both.

On Bainbridge Island, two areas are noted for hardshell clams. One is located on the western shore of the Island just north of Point White (Appendix A– Shellfish Occurrence Map), and the second is located on the south side of the Island near Rich Passage.

a. Littleneck clam (*Protothaca staminea*)

The native or littleneck clam (Figure V-1) is an important suspension/filter feeder found along most Pacific coast estuaries where appropriate substrates and salinities exist. (Wolotira Jr. et al. 1989; Emmett et al. 1991). It ranges from Baja California to the Alaskan Aleutian Islands (Fitch 1953; Schink et al. 1983; Cheney and Mumford 1986). The littleneck clam prefers firm gravel or clay-gravel sediments, and reaches a length of about 6 cm (Quayle and Bourne 1972; Goodwin and Shaul 1978; Bulthuis and Conrad 1995). It is often associated with butter clams (Paul and Feder 1976) and is normally found intertidally from –1.0 to 1.3 m MLLW (Chew and Ma 1987).

Optimum temperatures for growth appear to be 12 to 18°C with a salinity of 24 to 31 parts per thousand (ppt); however, they may tolerate salinities as low as 20 ppt for extended periods (Quayle and Bourne 1972). Predators of the littleneck clam include oyster drills, moon snails, sea stars, octopus, rock crabs and fishes (Chew and Ma 1987). Littleneck clams are also eaten by sea otters, ducks, and other birds (Schink et al. 1983; Cheney and Mumford 1986). Recruitment is highly variable and may depend on temperature, food supply, predation, currents and appropriate substrate (Peterson 1982). Siltation caused by upland development can cause problems and dredging has been shown to affect subtidal populations (Schink et al. 1983). Similarly, severe weather can affect intertidal populations by producing high freshwater runoff that covers clams with sediment, or alternatively, washing away sediments and exposing them (Cheney and Mumford 1986).

b. Japanese littleneck or Manila clam (*Venerupis[Ruditapes] philippinarum*)
The Manila clam or Japanese littleneck is about the same size as the littleneck clam (Figure V-1), and was originally imported with seed oysters from Japan. It has become well established in the Puget Sound region and is found together with the littleneck clam, although it tends to reside at slightly higher elevations (Bulthuis and Conrad 1995). The Japanese littleneck clam is usually found between 0.9 and 2.4 m MLLW (Quayle and Bourne 1972). Optimum growth conditions are temperatures between 13°C to 21°C and salinities between 24 ppt and 31 ppt. Ideal substrate consists of gravel, sand, some mud, and shell (Anderson et al. 1982), although this species can inhabit a wide range of substrate types. Important predators include the moonsnails, rock and shore crabs, rock and English sole, starry flounder, pile and shiner perch, starfish, ducks, and scoters (Quayle and Bourne 1972; Anderson et al. 1982; Chew 1989). Spat settlement areas are dependent on currents, substrate (Chew 1989), and wave damage; extreme temperatures and siltation can adversely affect population sizes (Bardach et al. 1972; Chew 1989). Commercially, manila clams are considered better "keepers" than littleneck clams, which accounts for recent increases in commercial production and aquaculture ventures (Scholz 1990).

c. Butter clams (*Saxidomus giganteus*)
Butter clams (Figure V-1) are found predominantly in sandy and gravelly mud substrate. They range from Alaska to San Fransisco Bay and are commonly found in Puget Sound. They reach a length of about 10 cm, somewhat larger than the littleneck and Manila clams, however are less desirable to harvest commercially because of shorter shelf life. Although this species may be buried as deep as 30 cm, it is usually found much closer to the surface. It is generally found in the same tidal elevations as the littleneck clam. Predators of this species include moon snails, Dungeness crab, and sea stars (Wolotira Jr. et al. 1989).

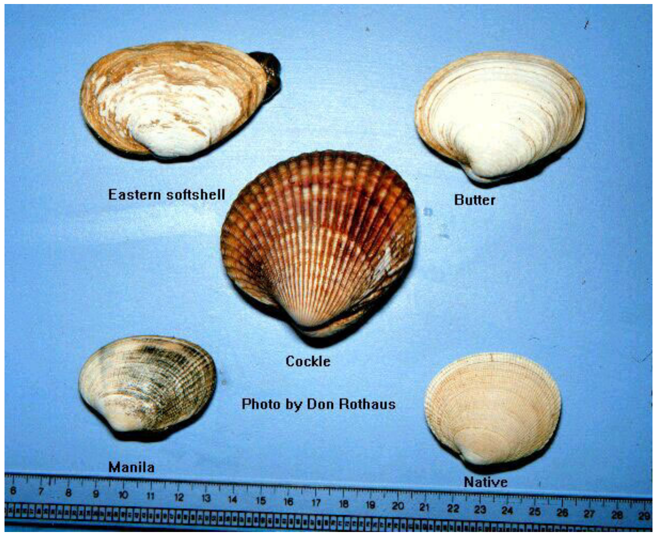

Figure V-1. A variety of hardshell clams.

d. Geoduck (*Panopea abrupta*)

The geoduck clam (Figure V-2) is one of the largest burrowing clams in the world. It ranges from Alaska to Baja California and is commonly found in Puget Sound. Prior to 1970 the clam supported a small intertidal recreational fishery in the Sound; however, legislative changes in 1969 allowed a commercial fishery to be co-managed by WDFW and WDNR (Goodwin 1990). Geoducks now support the largest clam fishery along the west coast of North America. The average commercial geoduck weighs about 2 pounds but can grow to over 10 pounds. They prefer sand and mud substrates from the lower intertidal zone to water depths of at least 360 feet (Goodwin 1990; Sizemore and Ulrich 2000). Geoduck abundance in Puget Sound is inversely proportional to the latitude, hence they are most abundant in the southern parts of the Sound (Goodwin 1990; Sizemore and Ulrich 2000). The average age of geoducks in most commercially harvested beds is between 30 and 60 years. They cannot completely withdraw their soft body parts within their shell and cannot rapidly crawl or dig to avoid predation. Instead, they develop long siphons and bury themselves deeply in the substrate, many over three feet deep. Predators of juvenile geoducks include moon snails, coonstripe shrimp, rock crabs, English, rock, and sand sole, pile perch, spiny dogfish, starry flounder and other flatfish. Sea stars and sunstars feed on juveniles and adults (Sloan and Robinson 1983; Wolotira Jr. et al. 1989). The tips of geoduck siphons are eaten by the Pacific staghorn sculpin (Andersen Jr. 1971), and adults are also excavated and eaten by sea otters. Numerous commercial geoduck tracts are located along the northern, east, and western shoreline of Bainbridge Island (Appendix A – Shellfish Occurrence Map). No tracts are located along the southern shoreline in the Rich Passage area.

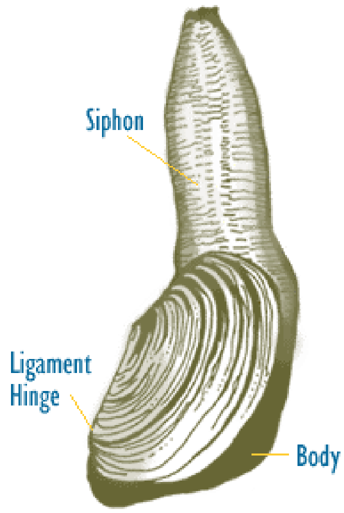

*Figure V-2. Geoduck clam (*Panopea abrupta*) (Source: WA Dept. of Ecology 2002a)*

2. DUNGENESS CRAB (*CANCER MAGISTER*)

Dungeness crab, also known as the Pacific edible crab and market crab, are commonly found in Puget Sound, and range from the Pribilof Islands in Alaska to Santa Barbara in southern California (Pacific States Marine Fisheries Commission 1987) (Figure V-3). They are found from the intertidal zone to depths of more than 250 feet, depending on age and time of year. Dungeness crab are found on a variety of substrates, however prefer sand or sand/mud bottoms. Juveniles are often found intertidally in estuarine areas of soft substrate containing eelgrass (*Zostera* spp.) and bivalve shells (Armstrong and Gunderson 1985). They are important as both a predator of *Crangon* spp. shrimp and bivalves and prey species in nearshore and estuarine habitats. Juvenile crab are prey to many species of fish, sea otters and octopus (Kimker 1985), whereas the adults are consumed by humans, harbor seals, sea lions, and gulls. Estuaries play an extremely important role in Dungeness crab abundance as nursery areas for subyearling and yearling crabs (Shreffler 1995).

*Figure V-3. Dungeness crab (*Cancer magister*) (Source: www.dungeness.com/crab).*

Dungeness crab are harvested for both commercial and recreational use, and are taken commercially by trap or ring net in deeper waters, and recreationally by trap, ring net, and dip net in shallow estuarine and bay waters. The recent (within the last 5 years) average annual harvest is estimated to vary between 80,000 and 100,000 per year, with harvests being equally split between tribal and non-tribal fishers in Puget Sound (Williams et al. 2001) (J. Odell and S. Burton, WDFW, *personal communication*, 2002). In general, Dungeness crab are most abundant in north Puget Sound (Strait of Georgia region) where three quarters of all commercial harvest occurs, and are least abundant in the south sound region near Budd Inlet. However, recreational harvesting is more evenly distributed throughout the entire Puget Sound region (Bumgartner 1990). Around Bainbridge Island, two relatively large areas are noted as "crab occurrence" areas (Appendix A –Shellfish Occurrence Map). One area is along the northern shoreline between Agate Passage and the Port Madison regions. The second area is off the eastern shore from Rolling Bay south to Wing Point.

B. FISHES

In this review, we summarize the best available science on nearshore fish populations associated with the Bainbridge Island nearshore. Because over 200 species of fish are found in regional waters, we focus on several WDFW species of concern that are more common to Bainbridge Island waters (Table V-1).

Many fish populations in Puget Sound are at all-time lows, with some species listed for protection under the Endangered Species Act (ESA) or as candidates for protection. This decline can be attributed to a variety of factors, including changes in environmental conditions, overfishing, shoreline development, loss of estuarine habitat, alteration of freshwater flows, blockage of migration corridors, changes in temperature, industrial pollution, decreased prey availability, and increased marine mammal predation (Williams and Thom 2001). Numerous data gaps exist in our understanding of nearshore fish ecology, making it difficult to thoroughly assess the health of their populations. Information about historical distribution/abundance is often lacking, and the cumulative effects of stressors are unknown. Furthermore, details about the temporal/spatial patterns of nearshore use are often unknown.

1. FORAGE FISH

The more common species identified as forage fish in Puget Sound include surf smelt (*Hypomesus pretiosus*), Pacific sand lance (*Ammodytes hexapterus*), and Pacific herring (*Clupea harengus pallasi*) (Washington State Department of Fish and Wildlife 2002b). All are small schooling fishes that represent a significant component of the prey base for marine mammals, sea birds, and other fish populations in the region. Likewise, forage fish are important as recreational fishing bait and contribute significantly to commercial and subsistence fisheries. Forage fish rely upon a variety of shallow and intertidal nearshore and estuarine habitats, particularly for spawning, and are a valuable indicator of the health and productivity of the marine environment.

Table V-1: Common and Scientific Names of WDFW Priority Fish Species.

Common Name	Scientific Name	WDFW/Federal Population Status
Forage fish		
Pacific Herring *	*Clupea pallasi*	*Depressed*
Surf Smelt *	*Hypomesus pretiosus*	
Eulachon	*Thaleichthys pacificus*	
Longfin smelt	*Spirinchus thaleichthys*	
Pacific Sand Lance *	*Ammodytes hexapterus*	
Salmonids		
Chinook salmon *	*Oncorhynchus tshawytscha*	*Threatened – Puget Sound ESU*
Chum salmon *	*Oncorhynchus keta*	*Threatened – Hood Canal ESU*
Coho salmon *	*Oncorhynchus kisutch*	*Candidate – Puget Sound / Georgia Strait ESU*
Sockeye salmon *	*Oncorhynchus nerka*	
Pink salmon *	*Oncorhynchus gorbuscha*	
Cutthroat trout *	*Oncorhynchus clarki*	
Steelhead *	*Oncorhynchus mykiss*	
Bull trout *	*Salvelinus confluentus*	*Threatened – Coastal - Puget Sound DPS*
Groundfish		
Pacific Cod *	*Gadus macrocephalus*	*Critical*
Walleye Pollock *	*Theragra chalcogramma*	*Critical*
Pacific Hake *	*Merluccius productus*	*Critical/Candidate – Puget Sound ESU*
Lingcod *	*Ophiodon elongatus*	*Above Average*
English Sole *	*Pleuronectes vetulus*	*Below Average*
Rock Sole *	*Lepidopsetta bilineata*	*Average*
Black Rockfish	*Sebastes melanops*	*Unknown*
Blue Rockfish	*Sebastes mystinus*	*Unknown*
Bocaccio Rockfish	*Sebastes paucispinus*	*Unknown*
Brown Rockfish *	*Sebastes auriculatus*	*Depressed*
Canary Rockfish	*Sebastes pinniger*	*Unknown*
China Rockfish	*Sebastes nebulosus*	*Unknown*
Copper Rockfish *	*Sebastes caurinus*	*Depressed*
Greenstriped Rockfish	*Sebastes elongates*	*Unknown*
Quillback Rockfish *	*Sebastes maliger*	*Depressed*
Redstripe Rockfish	*Sebastes proriger*	*Unknown*
Tiger Rockfish	*Sebastes nigrocinctus*	*Unknown*
Widow Rockfish	*Sebastes entomelus*	*Unknown*
Yelloweye Rockfish	*Sebastes ruberrimus*	*Unknown*
Yellowtail Rockfish	*Sebastes flavidus*	*Unknown*

Asterisks denote species covered in text. Herring status based on Port Orchard/Port Madison stocks (Bargmann 1998). WDFW population status for groundfish (Puget Sound Water Quality Action Team 2002) based on South Puget Sound, which includes Hood Canal, central Sound, Whidbey basin, and southern Sound; Federal status indicated where appropriate.

Forage fish populations can fluctuate greatly depending on natural environmental factors. However, reproductive success may also be affected by human shoreline development, such as removal of overhanging vegetation within the riparian zone, loss of spawning substrate, and intertidal beach modification (Williams et al. 2001). For example, filling and shoreline "armoring" (e.g., bulkheading) of beaches into the upper intertidal zone can bury and damage forage fish spawning habitat. Recent studies have also shown that loss of overhanging riparian vegetation along shorelines causes significantly lower mean relative humidity, and higher mean light intensity, air temperature, and substrate temperature which may result in reduced survival of surf smelt eggs and larvae (Penttila 2001; Rice and Sobocinski 2002). Besides these studies, the specific impacts of human activities on spawning success are not well documented in the available literature.

The WDFW considers forage fish to be a key component of the marine ecosystem in Washington. As a result, all known forage fish spawning sites in Washington State are considered "marine habitats of special importance" and have been given enhanced "no net loss" protection in the application of Washington Administrative Code (WAC) "Hydraulic Code Rules" (Shull 2000). All proposed shoreline construction activities are reviewed by state agencies for impacts to forage fish spawning habitat. In cases where no satisfactory redesign or mitigation is possible, a hydraulic permit may be denied. In-water work windows have been established for the protection of forage fish populations (WAC-220-110-271) (Table V-2). The following work windows have been established for the protection of forage fish in the area of Bainbridge Island, based on guidance from the WDFW, National Marine Fisheries Service (NMFS), and the US Fish and Wildlife Service (USFWS) (R. Liera, USACE, *personal communication*, 2002).

Table V-2. In-Water Work Windows for Forage Fish

Species	Work Allowed	No Work Allowed
Surf smelt	April 1-August 31[3]	September 1-March 31
Sand lance	March 2-October 14	October 15-March 1
Herring	May 1-January 14	January 15-April 30

Known forage fish spawning areas on Bainbridge Island have been documented by WDFW (Appendix A – Fish Occurrence Map), although studies confirming the frequency of use within these areas is often limited. In many cases, additional spawning areas are suspected but await documentation. Specific information follows on the general nearshore ecology, habitat requirements, and Bainbridge Island distributions of these three common forage species.

a. Pacific sand lance (*Ammodytes hexapterus*)

Pacific sand lance are highly abundant forage fish that are widely distributed throughout Puget Sound bays and nearshore habitats (Emmett et al. 1991) (Figure V-4). Though poorly known as a species, they have a somewhat unique diurnal behavior pattern involving feeding in the open water during the day and burrowing into the sand at night. Juveniles rear in bays, inlets, and nearshore waters throughout Puget Sound (Lemberg et al. 1997). Adult and juveniles are planktivorous carnivores and prey heavily upon calanoid copepods (Fresh et al. 1981).

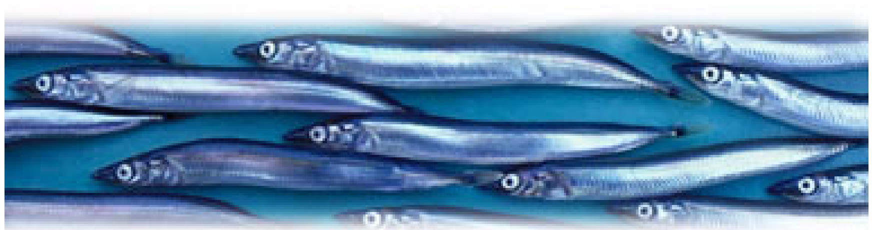

*Figure V-4. Pacific sand lance (*Ammodytes hexapterus*) (Source: WA Dept of Ecology 2002b)*

[3] The Federal work window in Eagle Harbor is year round.

Pacific sand lance populations in Puget Sound are thought to be obligate intertidal spawners (Bargmann 1998). Spawning occurs once a year from November to February at tidal elevations ranging from +5 feet (MLLW) to about MHHW (Washington State Department of Fish and Wildlife 2002b). Sand lance deposit eggs over a variety of beach substrates, including soft sandy beaches, muddy low-energy beaches, and beaches of higher energy with gravel up to 3 cm diameter (Penttila 1995; Washington State Department of Fish and Wildlife 2002b). After spawning, sand lance eggs often acquire a partial coat of sand, which may assist in moisture retention at low tide. Sand lance perennially use isolated patches of suitable spawning habitat, suggesting some degree of active searching behavior by pre-spawning adults (Penttila 1995).

Sand lance spawning activity has been identified on a number of beaches along Bainbridge Island, including Eagle Harbor, Manzanita Bay, and Port Madison Bay, and along the western shorelines of Agate Pass, including Agate Point and Battle Point (Appendix A – Fish Occurrence Map). However, spawning densities and population distributions (age classes and recruitment) are not documented in these areas.

b. Surf smelt (*Hypomesus pretiosus*)

Adult surf smelt are widespread in Puget Sound waters and generally inhabit shallow nearshore habitats over a variety of substrates throughout the year (Emmett et al. 1991; Bargmann 1998) (Figure V-5). They feed on a variety of zooplankton and epibenthic organisms, including planktonic crustaceans and fish larvae (Emmett et al. 1991). Juvenile surf smelt reside in nearshore waters and estuaries where they feed and rear (Emmett et al. 1991; Lemberg et al. 1997).

*Figure V-5. Surf smelt (*Hypomesus pretiosus*) (Source: WA Dept. of Ecology 2002c)*

In Washington, surf smelt are thought to belong to geographically distinct stocks based on their temporal use of spawning grounds, although possible extensions of spawning seasons await investigation. Adult surf smelt may return to the same spawning ground each year and many stocks spawn year-round over two "seasons", which are considered peaks in spawning activity (Lemberg et al. 1997). Surf smelt have specific spawning requirements and generally deposit their adhesive, semi-transparent eggs on beaches composed primarily of coarse sand and pea gravel (1 to 7 mm in diameter). Within Puget Sound, spawning occurs on the highest tides during the early evening, with concentrations usually at tidal elevations between +7.0 feet (MLLW) and the mean higher-high water line (Washington State Department of Fish and Wildlife 2002c; Washington State Department of Ecology 2002c). Freshwater seepage areas are believed to be a preferred spawning habitat because of lower fluctuations in gravel moisture and temperature.

Surf smelt spawning areas have been documented within Port Madison Bay, Manzanita Bay, Eagle Harbor, and Blakely Harbor, as well as along bluff areas along the northeast shoreline of Bainbridge Island (Appendix A – Fish Occurrence Map). Additional spawning areas are suspected but await documentation.

c. Pacific herring (*Clupea harengus pallasi*)

Pacific herring are one of the most widely known and best studied forage fish species in Washington (Bargmann 1998; Stout et al. 2001a) (Figure V-6). At least 18 Pacific herring stocks, defined by spawning ground, occur inside Puget Sound (Lemberg et al. 1997). Some herring stocks appear to have an annual migration from inshore spawning grounds to open-ocean feeding areas, whereas others appear to be resident in the Puget Sound basin year around (Emmett et al. 1991; Washington State Department of Fish and Wildlife 2002a). Juveniles remain primarily in inshore waters during their first summer (Emmett et al. 1991). Pacific herring are selective pelagic plankton feeders, consuming primarily copepods, decapod crab larvae, and chaetognaths in shallow nearshore waters (Fresh et al. 1981). In turn, herring represent a considerable percentage of the diet for several predatory marine fish species, including: Pacific cod (42%), walleye pollock (32%), lingcod (71%), Pacific halibut (53%), and coho and chinook salmon (58%) (Nightingale and Simenstad 2001b).

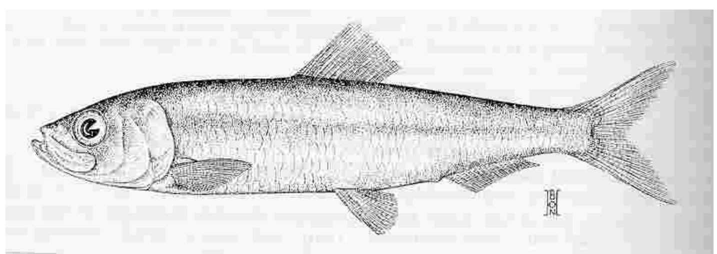

*Figure V-6. Pacific herring (*Clupea harengus pallasi*) (from Hart 1988).*

Adult Puget Sound herring stocks move onshore in schools during winter and spring to holding areas prior to moving to inshore spawning grounds (O'Toole 1995; Lemberg et al. 1997). Adults appear to consistently return to their natal spawning grounds, and during spawning migrations, may greatly reduce or stop feeding (Emmett et al. 1991; Lemberg et al. 1997). Herring deposit their transparent, adhesive eggs on intertidal and shallow subtidal eelgrass and marine algae from mid January to mid April (O'Toole 1995; Stout et al. 2001a; Washington State Department of Fish and Wildlife 2002a). Eggs may be deposited anywhere between the upper limits of high tide to a depth of -40 feet MLLW, but most spawning takes place between 0 and -10 feet MLLW (Washington State Department of Fish and Wildlife 2002a).

Herring spawn along much of the north and northwestern shorelines of Bainbridge Island from north of Battle Point to Point Monroe, including Manzanita and Port Madison Bays (Appendix A – Fish Occurrence Map). Likewise, holding areas for pre-spawn herring occur in Port Orchard (to the southwest) and north of Bainbridge Island. Bainbridge Island spawning grounds are used by the Port Orchard/Port Madison herring stock, which spawn primarily from January through April. The annual spawning biomass for this stock has averaged 1,281 tons/year from 1977-1996; however the current status of this stock is "depressed" considering historic population levels (Bargmann 1998). Pacific herring once spawned in Eagle Harbor and supported a local fishery in the early part of the century, though reports in the 1940's had indicated declines by this time (Chapman et al. 1941).

2. SALMONIDS

Salmonids (family Salmonidae), which include salmon, trout, and char, are an ecologically, economically, and culturally prominent group of fishes in the Pacific Northwest (Groot and Margolis 1991; Spence et al. 1996). All are the focus of regional research, management, and conservation efforts. The eight salmonid species found in Puget Sound include chum (*Oncorhynchus keta*), pink (*O. gorbuscha*), sockeye (*O. nerka*), chinook (*O. tshawytscha*), and coho salmon (*O. kisutch*); as well as steelhead (rainbow trout) (*O. mykiss*), coastal cutthroat trout (*O. clarki clarki*) and bull trout (*Salvelinus confluentus*). All salmonids have anadromous forms, with most species undertaking extensive ocean migrations before returning to spawn in their natal stream. However, sockeye salmon (kokanee), steelhead (rainbow trout), and coastal cutthroat trout also may have non-anadromous life history cycles. The variable life-history characteristics of salmonids have allowed them to take advantage of the environmental variability of the landscapes and seascapes they have occupied over evolutionary time. As a result, salmonids have evolved into complex life-history patterns that sustain viable populations over a broad spectrum of ecosystem change at varying temporal and spatial scales (Wissmar and Simenstad 1998). Particular life-history traits and habitat requirements of each salmonid species, and relevance to Bainbridge Island nearshore habitats, are covered in greater depth later in this section.

Salmon species can be grouped into stocks, defined as groups of fish that are genetically self-sustaining and isolated geographically or temporally during reproduction. A population of fish may include a single stock or a mixture of stocks. Under the Endangered Species Act (ESA), stocks of salmonids may be grouped as Distinct Population Segments (DPSs), as is the case for bull trout under jurisdiction of the USFWS. Stocks may also belong to Evolutionarily Significant Units (ESUs), as is the case for Pacific salmon under the jurisdiction of the NMFS. Chinook salmon (within the Puget Sound ESU), summer-run chum salmon (within the Hood Canal ESU), and bull trout (within the Coastal-Puget Sound DPS) have been listed as threatened under the ESA. Coho salmon (within the Puget Sound/Strait of Georgia ESU) is a candidate species for listing.

a. Life History

The typical salmon life history has five main stages: (1) spawning and egg incubation, (2) freshwater rearing, (3) seaward migration, (4) ocean rearing, and (5) return migration to freshwater to spawn and the deposition of marine derived nutrients into the freshwater ecosystem (Figure V-7). We attempt here to briefly summarize some of the differences in life history and ecology for each species, although a number of references provide more extensive descriptions of the diversity and complexities of particular species (National Research Council 1996). Salmon are dependent upon freshwater habitats that are typically characterized by accessible cool, clean water with abundant woody debris, cover for shade, relatively clean spawning gravel, adequate food supply, and a balanced population of predators (Gross et al. 1988). Because freshwater stream environments in the Pacific Northwest are less productive than the ocean environment (particularly estuaries and coastal upwelling zones), salmonids have evolved an ocean feeding phase in their life history to exploit this productivity. Salmon returning to their natal spawning grounds need adequate flows, water quality, unimpeded passage, and deep pools with cover and structural complexity for resting and shelter from predators (Haring 2000). Most species have a limited time, in some cases as little as 2 to 3 weeks after entering freshwater, to migrate and spawn.

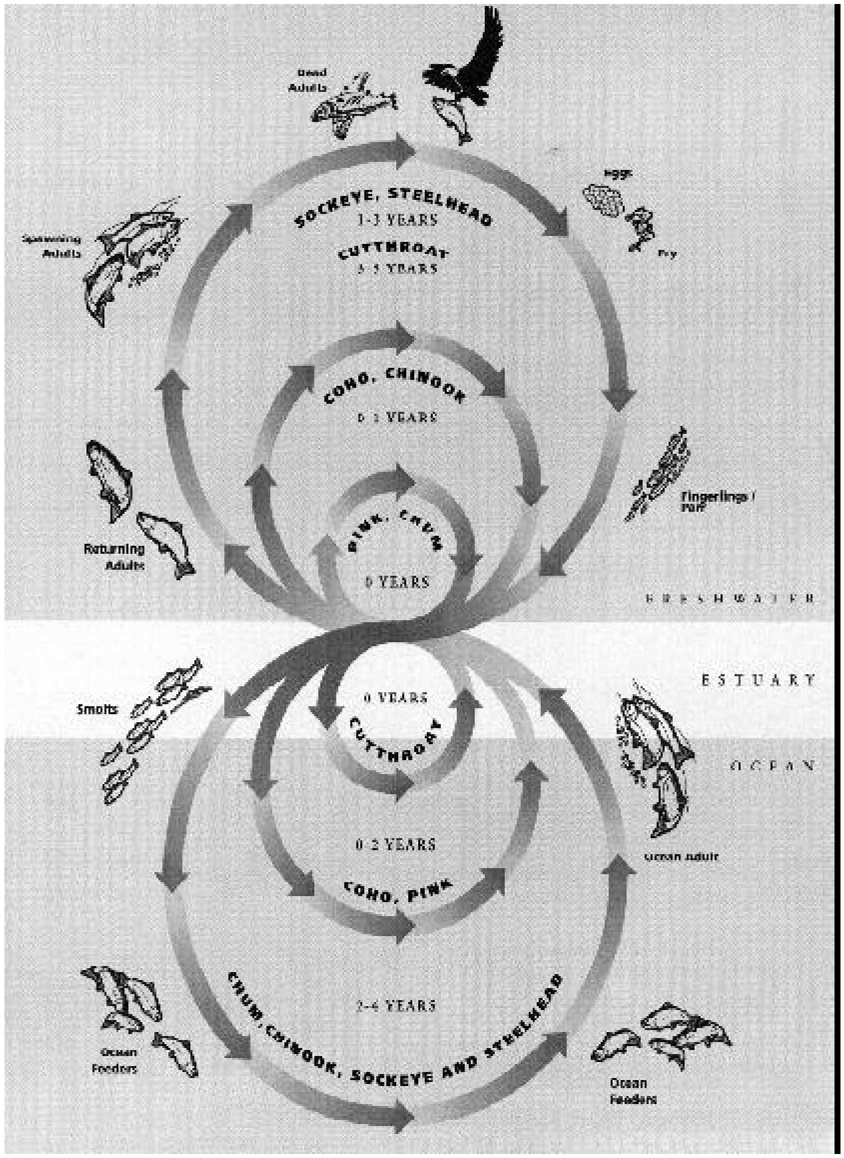

Figure V-7. Temporal phases of anadromous salmon life history (from Cederholm et al. 2000).

Chum, pink, sockeye, chinook, coho, and bull trout typically spawn sometime between August and February, a time when stream flows are increasing and water temperatures are declining. Rainbow and cutthroat spawn between January and June, when stream flows are decreasing and water temperatures are increasing. Chum, pink, sockeye, chinook, and coho salmon all die after their first and only spawning activity, a life history strategy known as *semelparity*. The decaying carcasses of adult salmon in turn, contributes valuable nutrients and organic matter to the stream environment, thereby enriching local productivity for their offspring. An *iteroparous*, or repeat spawning, strategy is more typical of steelhead, cutthroat, and bull trout.

Salmon excavate redds (spawning nests) in the clean gravel of streams, wherein eggs are deposited and fertilized. For successful development of eggs to occur, the spawning gravel must be relatively stable and not choked with fine sediments. After approximately 2 to 4 months of incubation, salmon fry emerge from their gravel nests. Certain species such as chum, pink, and some chinook salmon emerge in late winter-early spring and rapidly migrate downstream to the estuary, whereas sockeye migrate from their gravel nests to larger lake environments. Other species, such as coho, steelhead, bulltrout, cutthroat, and chinook emerge from spring to mid-summer and search for suitable rearing habitat within the stream.

For early stream-resident species (coho, steelhead, bulltrout, and some chinook), flow conditions and fish size determine patterns of habitat use. Quiet water, side margins, and off-channel sloughs are vital early rearing areas, with woody debris and overhead cover providing shelter and nutrient and food inputs. In the summer, juveniles move to deeper, faster areas of the stream as they grow and low flow conditions predominate. Declining streamflow conditions may cause some fish (i.e., chinook, coho) to emigrate to estuaries (Healey 1982; Tschaplinski 1982) where they continue to rear. Upon the first rains and high waters of fall, juvenile forms of coastal species (coho, steelhead, and cutthroat) make a directed migration to seasonally alternate rearing habitats, including side-channel swamps, riverine ponds located along river flood plains, and small "runoff" tributaries (valley-wall tributaries) of rivers. Presumably, these immigrations are designed to avoid high flows and turbidity of main rivers, as well as to take advantage of good feeding conditions during winter.

After completing their freshwater stage, juvenile salmon of all anadromous forms undergo a physiological change, called smoltification, which includes osmoregulatory adjustments that prepare them to enter saltwater. Chum and pink salmon are nearly smolts upon emergence from the gravel, migrating directly to estuaries and the ocean. Chinook and coho may either go directly to the marine environment the first spring or summer of their life or remain in freshwater for an entire year before smolting. Sockeye may rear in freshwater for one or two years before smolting, and steelhead, bull trout, and cutthroat may not smolt for two or three years or more.

b. Nearshore Ecology and Limiting Factors

The importance of estuarine and nearshore marine habitats to the early life-history stages of salmonids has become increasingly apparent to regional conservation and recovery efforts (Williams et al. 2001). Salmonids use the nearshore for physiological transition (adaptation from freshwater to saltwater), as migration corridors, as nursery areas, for juvenile and adult food production and feeding, and as residence and refuge (Haring 2000; Dinnel 2000). Typically cited nearshore habitat requirements of juvenile salmonids include (Simenstad 2000):

- Shallow-water, typically low-gradient habitats with fine, unconsolidated substrates
- The presence of aquatic vegetation, emergent marsh vegetation, and shrub/scrub or forested riparian vegetation

- Areas of low current and wave energy
- Concentrations of small, non-evasive invertebrates.

All juvenile salmon move along the shallows of estuaries and nearshore areas during their outmigration to the sea, and may be found in these habitats throughout the year depending on species, stock, and life-history stage (Table V-3) (Emmett et al. 1991). Shallow estuarine and nearshore habitats are structurally complex (e.g., submerged aquatic vegetation and large woody debris), highly productive, and dynamic. As such, they are critical areas for juvenile salmonids because they provide food, refuge from predators, and a transition zone to physiologically adapt to saltwater existence (Williams and Thom 2001). Juvenile salmonids behaviorally restrict their movements to shallow water (between 0.1 and 2.0 m) until they reach larger sizes that may allow them to exploit deeper channel and open water habitats and associated prey resources. Young salmon also tend to resist large changes in light intensity during migration; although they may readily move under structures that cast shadows, they strongly avoid moving under very dark pier aprons during daylight hours (Nightingale and Simenstad 2001b). While in the nearshore, young salmon are generally opportunistic feeders that prey on an array of marine benthic, epibenthic, and pelagic organisms, as well as terrestrial insects (Simenstad et al. 1979; Fresh et al. 1981; Simenstad and Cordell 2000) (J. Brennan, KCDNR, *personal communication,* 2002).

Table V-3: Salmonids: Summary of Nearshore and Estuarine Habitat Use and Spawning on Bainbridge Island (Adapted fromWilliams et al. 2001).

Common Name	**Scientific**	**Nearshore and Estuarine Use**			**Freshwater Use**
		Juvenile Rearing	**Adult and Juvenile Migration**	**Adult Residence**	**Bainbridge Island Spawn**
Chinook	*Oncorhynchus tshawytscha*	●	●	●	❍
Chum	*Oncorhynchus keta*	●	●	❍	●
Coho	*Oncorhynchus kisutch*	⊕	●	⊕	●
Sockeye	*Oncorhynchus nerka*	❍	●	❍	❍
Pink	*Oncorhynchus gorbuscha*	●	●	❍	❍
Cutthroat	*Oncorhynchus clarki*	●	●	●	●
Steelhead	*Oncorhynchus mykiss*	⊕	●	❍	⊕
Bull Trout	*Salvelinus confluentus*	●	●	●	❍

Notes: ● - extensive use; ⊕ - some use; ❍ - no use or use not known in these areas.

Most young salmon enter and pass through estuaries and the nearshore environment between early March and late June, although there is wide variability in nearshore residence time depending on the species and life stage (Table V-3). Juvenile chum and chinook salmon are considered the most estuarine-dependent salmon species, feeding and rearing in these habitats for extended periods before migrating to pelagic marine habitats. Some chinook remain within Puget Sound year-round, with recent coded-wire tag information supporting extensive nearshore movements far from their natal river (J. Brennan, KCDNR, *personal communication,* 2002). Chum fry migrate seaward almost immediately after hatching and enter the estuary at a relatively small size (30 to 55 mm), whereas chinook fry migrate seaward either soon after yolk resorption (30 to 45 mm), as fry 60 to 150 days post-hatching, or as fingerlings. Both species prefer relatively fine-grained substrate, low gradients, and are oriented to shallow water habitats located close to shore. Because most coho spend 12 to 18 months rearing in freshwater before migrating through estuaries and into marine waters, they are generally much larger than chinook and chum juveniles in nearshore areas (Levy and Northcote 1982; Weitkamp et al. 1995) (Table V-3). However, early outmigrating coho fry (age-0 fry or pre-smolts) also may feed and rear in productive estuarine habitats for extensive periods (up to 114 days) (Miller and Sadro in press). Coho smolts are often found in intertidal and pelagic habitats in estuaries and in shallow nearshore marine habitats, including eelgrass meadows and tideflats.

Other salmon species use nearshore marine habitats to varying degrees (Table V-3). For instance, pink salmon up to 60 to 80 mm in length migrate through and rear extensively in shallow marine waters and nearshore embayments from March until June, feeding on small crustaceans and growing rapidly (Emmett et al. 1991; Levy and Northcote 1982; Hard et al. 1996). They spend little time in estuarine areas but may be abundant in estuarine tidal channels for a short time. Coastal cutthroat trout juveniles and adults can be found over a variety of substrates within nearshore marine and estuarine waters during the spring to fall (Emmett et al. 1991; Gregory and Levings 1996). Gravel beaches with upland vegetation, and nearshore habitats (<10 ft deep) with large woody debris are often used by cutthroat trout during their marine phase for feeding and migration. Coastal cutthroat trout rarely overwinter in saltwater, and can be found in tidal freshwater areas of estuaries as they await favorable conditions to go upstream (Emmett et al. 1991; Johnson et al. 1999). Ongoing research is gradually clarifying the distribution and abundance of bull trout (the anadromous form of char) in Puget Sound estuaries and nearshore waters. In the Skagit River basin, most char smolts outmigrate between April and July, rearing for the summer in estuarine and nearshore waters before moving back into freshwater to overwinter (Williams and Thom 2001). While in nearshore marine areas, char of all ages are typically associated with shallow water, especially in areas of forage fish spawning concentrations.

Other salmonid species less recogized for estuarine dependence are nonetheless reliant on the protective cover of natural nearshore habitats for migration (Table V-3). For example, sockeye salmon smolts outmigrate to the ocean under cover of darkness in the spring to early summer and usually have a shorter residence time in estuaries and nearshore areas than other salmonids (Hart 1973; Emmett et al. 1991; Gustafson et al. 1997). Adult steelhead are epipelagic (found in the upper water column) in coastal waters to a depth of 25 m (Emmett et al. 1991). Like sockeye, juvenile steelhead usually move to sea from April through June and appear to spend little time in estuaries. However, juvenile steelhead in Puget Sound are periodically collected in beach seines over shallow nearshore marine habitats, such as eelgrass meadows and tideflats.

Adult salmon pass through nearshore marine and estuarine habitats during spawning migrations that span several months, and may delay their entry into freshwater or into terminal spawning areas at the end of the marine phase of their life cycle, milling within these habitats for up to 21 days (Johnson et al. 1997) (Table V-3). Returning adults and some resident stocks use nearshore habitats as feeding areas where they consume forage fish (Penttila 1995; Brodeur 1990; Fresh et al. 1981).

The serious decline of several salmon stocks within the Puget Sound region has prompted a series of inventories and analyses to provide science-based policy direction for regional conservation and recovery planning efforts. Contributing to many of the declines are urbanization and anthropogenic activities in nearshore marine and estuarine habitats (Williams et al. 2001). More than 70% of Puget Sound's coastal wetlands/estuaries have been lost to urban and agricultural development. In addition, the degradation or loss of shallow vegetated habitats and modification of shorelines may alter migration corridors and sheltered foraging areas. A recently published document for the Washington State Conservation Commission provides a comprehensive inventory of salmonid habitat limiting factors for Water Resource Inventory Area (WRIA) 15, which includes Bainbridge Island (Haring 2000). Key habitat impacts that limit nearshore marine productivity and likely affect salmon include shoreline armoring and nearshore fill, overwater structures, dredging and conversion of intertidal/shallow subtidal to deepwater habitat, alteration/loss of aquatic plant communities, loss/lack of functional shoreline riparian vegetation, water quality and sediment contamination, and substrate quality modification (Haring 2000).

c. Nearshore Management and Data Gaps

Understanding the nearshore habitat requirements of salmon in Puget Sound is a critical step in managing shoreline activities and restoring populations. Currently, all proposed shoreline construction activities are reviewed by state agencies to assess potential impacts to juvenile salmon. To this end, work windows in marine and estuarine habitats have been established by the State (WAC-220-110-271) to avoid the peak outmigration of juvenile salmon in the nearshore. The USACE follows similar work windows, the dates of which may vary somewhat depending on species of concern and lead agency (i.e., NMFS, USFWS) (R. Thurston, WDFW, *personal communication*, 2003) (Table V-4). It should be noted, however, that outmigration occurs during a period of time around these peaks, as well.

Table V-4. In-Water Work Windows for Salmon in Kitsap County

Species	Work Allowed	No Work Allowed
Salmon		
(USACE)	July 15-February 28	March 1-July 14
(State)	June 15-March 14	March 15-June 14

A great deal of information is still lacking. There is a need for development of standardized methods to assess nearshore habitat quality and function for salmonids (Simenstad 2000). Limited information exists on the distribution and abundance of most salmonids in the nearshore and open waters of Puget Sound. Likewise, information is needed to determine variation in different salmonid species' utilization of the nearshore, salmonid preference of various habitat conditions, and preferences in timing of specific habitat used by each species (Williams et al. 2001). Research needs to be conducted to assess how physical, chemical, and biological processes create and maintain properly functioning conditions in the nearshore. This information can be used to provide estimates of current nearshore carrying capacity and form the scientific basis of habitat protection and restoration programs. Few studies have assessed the shoreline characteristics and associated human modifications that affect survival of juvenile salmonids relative to predator avoidance. As previously noted, there is also a need for comprehensive annual spawning surveys and stock assessments for forage fish (surf smelt, sand lance, and herring) and other resources that serve as salmon prey along the Bainbridge Island nearshore.

d. Bainbridge Island Distribution

There are numerous small, perennial and intermittent streams on Bainbridge Island, most of which are thought to have average flows of less than 1 cubic feet per second (cfs) (Haring 2000). Chum, coho, cutthroat trout, and steelhead, typical species that use small lowland streams, are found within 13 Bainbridge Island subbasins (Haring 2000); Table V-5; Appendix A – Fish Occurrence Map). Coho salmon, cutthroat trout, and to a lesser extent chum salmon, utilize most of these streams, whereas steelhead have been identified in only Fletcher (Springbrook) Creek.

Table V-5. Documented or Presumed Presence of Salmonids in Bainbridge Island Subbasins (from Haring 2000).

Stream Name	Cutthroat	Coho	Chum	Steelhead
Unnamed 15.0319		●		
Dripping Water Creek 15.0320	●			
Murden Cove Creek 15.0321	●	●	●	
Ravine (Canyon, Winslow) Creek 15.0324	●	●	●	
Unnamed 15.0324A	●	●		
Sportsmen's Club Pond Creek 15.0325	●	●	●	
Cooper (Head of Bay) Creek 15.0326	●	●	●	
Blakely Falls Creek 15.0330X	●	●	●	
Macs Dam Creek 15.0331	●	●		
Unnamed 15.0332	●	●		
Schel-chelb Creek 15.0028X	●	●		
Fletcher (Springbrook) Creek 15.0340	●	●		●
Mosquito Bay (Big Manzanita) Creek 15.0344	●	●	●	

Bainbridge Island's shoreline is irregular and composed of numerous bays, harbors, and lagoons, with varied topography and slope. Juvenile salmonid use of these nearshore marine habitats is presumed to be ubiquitous, although there are few documented observations (Haring 2000). Monthly beach seine sampling at Battle Point and Point Monroe documented the seasonal presence of all five species of Pacific salmon, steelhead, and cutthroat (Fresh et al. 1981; Haring 2000). Juvenile chinook and coho have also been consistently encountered in the catches of commercial purse seine fisheries at Apple Cove Point (Haring 2000). Surveys in Blakely Harbor reported the presence of juvenile chum, pink, and chinook salmon, noting that chum and pinks used shallow protected waters for rearing and forage, while larger chinook were observed in deeper habitats feeding upon larval forage fish (Jones and Stokes Associates 1990). WDFW and the Tribes also conduct annual surveys of pink, chum, and chinook salmon fry in nearshore habitats throughout Puget Sound, including several Bainbridge Island locations, although much of this data remains unpublished (D. Hendrick, WDFW, *personal communication*, 2002).

3. GROUNDFISH

Groundfish, which include rockfish species, live in marine waters and spend their lives near or on the bottom. In Washington State, groundfish are legally defined as food fishes, and most are the focus of important fisheries (Palsson et al. 1997). Although many adult groundfish reside within the deeper waters of Puget Sound, many/most rely on shallow nearshore marine and estuarine habitats during part of their life history (Williams and Thom 2001) (Table V-6). Groundfish in nearshore marine and estuarine areas of Bainbridge Island are considered a component of South Puget Sound stocks (Palsson et al. 1997).

Table V-6. Summary of Nearshore Marine Habitat Use by Important Groundfish Species in Washington State (from Williams et al. 2001).

Common Name	Scientific Name	Nearshore Marine Use		
		Adult Spawning	Residence & Migration	Juvenile Rearing
Pacific Cod	*Gadus macrocephalus*		●	●
Walleye Pollock	*Theragra chalcogramma*		●	●
Pacific Hake	*Merluccius productus*		●	●
Lingcod	*Ophiodon elongatus*	●	●	●
English Sole	*Pleuronectes vetulus*		●	●
Rock Sole	*Lepidopsetta bilineata*	●	●	●
Brown Rockfish	*Sebastes auriculatus*	●	●	●
Copper Rockfish	*Sebastes caurinus*	●	●	●
Quillback Rockfish	*Sebastes maliger*	●	●	●

Changing water temperatures, decreases in prey availability, marine mammal predation, as well as overharvest are considered the primary stressors to groundfish species. Pacific cod, walleye pollock, and Pacific hake are short lived and susceptible to overfishing that reduces age class diversity and abundance; stocks are then susceptible to collapse during years of naturally poor recruitment (West 1997). English sole in contaminated areas of Puget Sound exhibit high rates of disease, increased parasite loads, and impaired reproductive success (Schmitt et al. 1994). Similarly, shoreline development has altered intertidal spawning beaches for rock sole. Rockfishes are susceptible to the loss of critical nearshore habitat for settlement, feeding, and refuge and are likely susceptible to fragmentation of the links between nearshore marine habitats that are critical to various life history stages (Williams et al. 2001). Losses and alteration of shallow nearshore habitats throughout Puget Sound may affect juvenile stages of all species, but have generally not been considered in the literature.

Specific information follows on the general nearshore ecology, habitat functional requirements, and Bainbridge Island distribution of selected groundfish species.

a. Pacific Cod (*Gadus macrocephalus*)

In late summer, juvenile Pacific cod metamorphose from their larval stage and settle in shallow vegetated habitats (eelgrass beds and macroalgae) where they find shelter and prey resources, which include copepods, amphipods and mysids (Matthews 1989). Adults concentrate in shallow embayments during the winter to spawn before dispersing to deeper waters to feed during the remainder of the year (Williams et al. 2001) (Figure V-8). A distinct stock of Pacific cod existed historically in South Puget Sound, centered around Agate Pass spawning grounds (West 1997). This stock, considered the southern limit of fishery-exploitable populations, once supported commercial fisheries before precipitous declines in catches during the 1980s (Palsson 1990; Schmitt et al. 1994; Palsson et al. 1997). Currently, Pacific cod populations in South Puget Sound are considered of "critical" status (Puget Sound Water Quality Action Team 2002) (Table V-1).

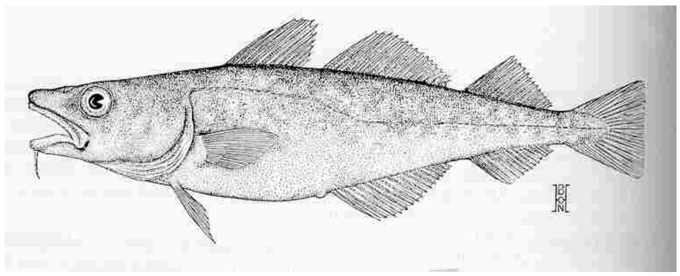

*Figure V-8. Pacific cod (*Gadus macrocephalus*) (from Hart 1988).*

b. Walleye Pollock (*Theragra chalcogramma*)
Juvenile walleye pollock settle near the bottom and then migrate inshore to eelgrass and shallow gravel and cobble habitats for their first year (Williams et al. 2001). Juvenile pollock feed primarily on small crustaceans (mysids, calanoid and harpacticoid copepods, gammarid amphipods, and juvenile shrimp), progressing to small fishes as they grow larger. Adult walleye pollock inhabit midwater or nearbottom cold-water environments and form spawning aggregations from February to April in localized deep water areas (Schmitt et al. 1994). Walleye pollock in South Puget Sound have experienced severe declines in recent years and are considered of "critical" status (Palsson et al. 1997) (West 1997) (Table V-1).

c. Pacific Hake (*Merluccius productus*)
Juvenile and immature Pacific hake may aggregate in inshore waters and mainland inlets, where they feed and grow away from concentrations of adults (Schmitt et al. 1994). Spawning occurs from March to May at mid-water depths of 50 to 350 m. They are opportunistic carnivores and feed primarily on small forage fishes. A small genetically distinct resident hake population in southern Puget Sound migrates seasonally between Port Susan and Saratoga Passage. Currently, the status of Pacific hake in South Puget Sound is considered "critical" because of the sharp decline in abundance observed in annual hydro-acoustic surveys (Palsson et al. 1997) (Table V-1)(West 1997). Pacific hake have been retained as a candidate species for ESA listing pending further genetic and other studies.

d. Lingcod (*Ophiodon elongatus*)
Juvenile lingcod move to benthic habitats in late spring-early summer, settling in shallow water, vegetated (kelp or eelgrass) habitats (Buckley et al. 1984; Cass et al. 1990). Age 1-2+ juveniles are commonly observed in high-current, soft-bottom, or shell-hash habitats near the mouths of

bays and estuaries (Doty 1993). Juvenile and adults are carnivorous, feeding on crustaceans and fishes (Emmett et al. 1991). Lingcod are typically associated with rocky reefs or other complex substrata with high current velocities and are found throughout Puget Sound, including Bainbridge Island (West 1997). They are considered nonmigratory, with mostly self-replenishing local stocks (Cass et al. 1990). They are found from the intertidal zone to 200 m, but are most abundant at depths between 10 and 100 m. Adult lingcod spawn between December and March, laying adhesive eggs in nests found in rocky crevices in shallow areas with strong water circulation. Lingcod catches have steadily and substantially declined in Puget Sound since the early 1980s, primarily due to overharvest (West 1997). However, the most recent assessment for South Puget Sound suggests that lingcod populations are at above average levels (Puget Sound Water Quality Action Team 2002) (Table V-1).

e. English Sole (*Pleuronectes vetulus*)

Juvenile and larval English sole distribution patterns suggest active migration or directed transport to estuary or shallow nearshore marine areas for settlement between March and May (Shreffler 1995). After metamorphosis, they remain in protected coastal and estuarine areas where they feed on abundant prey resources. Juvenile English sole use a variety of shallow nearshore marine and estuarine habitats, but tend to prefer shallow (<12 m deep) mud and sand substrates in Puget Sound (Emmett et al. 1991). Juveniles exhibit distinct patterns of depth segregation, with smaller fish generally restricted to shallow waters and larger fish being found progressively deeper. They are opportunistic benthic carnivores, feeding on harpacticoid copepods, gammarid amphipods, polychaetes, small bivalves and siphons, and cumaceans (Emmett et al. 1991; Williams 1994). Adult English sole occur over flat-bottom coastal habitats, primarily at shallow depths during the summer and down to 250 m during the winter (Schmitt et al. 1994). English sole in central Puget Sound exhibit significant homing and tend to remain within localized geographic regions. They are currently found throughout most soft-bottom habitats in Puget Sound, including Bainbridge Island. Recreational catch rates of English sole and trawl survey data indicate the adult population is at below-average levels in South Puget Sound (Palsson et al. 1997) (Table V-1).

f. Rock Sole (*Lepidopsetta bilineata*)

Rock sole are a right-eyed flatfish commonly found throughout Puget Sound, primarily over cobble, gravel, and sand substrates. Juveniles and adults are abundant in nearshore marine habitats at depths ≤15 m (Donnelly et al. 1984). Rock sole feed on molluscs, polychaete worms, crustaceans, brittle stars, and fishes (Simenstad et al. 1979). Adults spawn on upper intertidal beaches, but may also spawn at subtidal depths as well (Penttila 1995). Documented intertidal rock sole spawning is relatively infrequent and largely confined to the region south of Seattle. Rock sole are one of the more common flatfishes harvested by recreational anglers, and catch trends indicate that stocks in South Puget Sound, which includes Bainbridge Island, are at average levels (Palsson et al. 1997) (Table V-1).

g. Rockfish (*Sebastes spp.*)

Over 20 species of rockfish inhabit Puget Sound, but only three, copper, quillback, and brown rockfish, are commonly caught by recreational fisheries in nearshore marine habitats of Central and South Puget Sound (West 1997). Within Puget Sound, juvenile rockfish settle initially into shallow, vegetated habitats of bull kelp, macroalgae and eelgrass during their first year (Doty et al. 1995). They are commonly found in nearshore habitats throughout the summer and fall.

Upon reaching adult size, rockfish move to rocky reefs, boulders, offshore pinnacles, and other hard, high relief substrates (Matthews 1989). Most species are relatively sedentary and generally do not venture over 30 m^2 from preferred high-relief habitat (West 1997). Rockfish generally display slow growth, late maturation (>4 years), and long life spans; females' fecundity (reproductive capacity) increases with increasing size. Rockfish may be locally abundant in some locations in Puget Sound, but are prone to severe depletion from overfishing due to their habitat specificity (West 1997). Currently, copper, quillback, and brown rockfish populations in both north and south Puget Sound, including Bainbridge Island, are characterized as "depressed" (Puget Sound Water Quality Action Team 2000b) (Table V-1). A more recent federal status review of Puget Sound stocks concluded that none of these species are at risk of extinction, but the level of available information leaves substantial uncertainty in this determination (Stout et al. 2001b).

C. Marine Birds

Marine birds are present as breeding residents and as migrants in Puget Sound. Their distribution and relative abundance vary seasonally with highest numbers and greatest species diversity occurring during winter (Cummins et al. 1990). Both the UFWS and WDFW have legal mandates and regulatory authority to protect and manage marine birds.

In 1991, WDFW was given responsibility to design and implement monitoring plans for marine birds, waterfowl, and marine mammals under the Puget Sound Ambient Monitoring Program (PSAMP). The goals for marine birds and waterfowl were to monitor the abundance of selected avian species to identify any significant changes or trends related to pollution, habitat loss, or disturbance, and to monitor reproductive success and contaminant levels in birds. Aerial surveys have been conducted between 1992 and 1999 and trends in density compared to 1979 to 1980 data from the Marine Ecosystem Analysis (MESA) program (Nysewander et al. 2001). The Bainbridge Island shoreline is included in this survey; however, trends discussed below are based on the larger Puget Sound region. Trends in changing density have been examined for the following species or groups:

Goldeneye (*Bucephala islandica* and *B. clangula*)
Scoters (*Melanitta persipcillata*, *M. fusca*, and *M. nigra*)
Pigeon guillemot (*Cepphus columba*)
Common murre (*Uria aalge*)
Rhinoceros auklet (*Cerorhinca monocerata*)
Marbled murrelet (*Brachyramphys marmoratus*)
Western grebe (*Aechmophorus occidentalis*)
Red-necked grebe (*Podiceps grisegena*)
Horned grebe (*Podiceps auritus*)
All cormorants combined (*Phalacrocorax penicillatus, P. pelagicus*)
Double-crested cormorant (*Phalacrocorax auritus*)
Brant (*Branta bernicla*)
All gulls combined (*Larus* sp.)
Bufflehead (*Bucephala albeola*)
Oldsquaw (*Clangula hyemalis*)

Greater and lesser scaup (*Aythya marila* and *A. affinis*)
Harlequin duck (*Histrionicus histrionicus*)
Mergansers (*Cophodytes cucullatus, Mergus merganser, M. serrator*)
Common loon (*Gavia immer*)
All loons combined (*Gavia immer, G. pacifica, G. stellata, G. arctica*)

Their selection is based on one of the following criteria: 1) highly dependent on the marine waters of Puget Sound, 2) the peaks of abundance occur during survey windows, or 3) concerns exist due to limited numbers or vulnerability to human caused mortality. Significant decreases have been noted for grebes, cormorants, loons, pigeon guillemot, marbled murrelets, scoters, scaup, oldsquaw, and brant. Stable or slowly decreasing patterns are noted for goldeneyes, buffleheads, and gulls. Increasing patterns are noted for harlequin ducks and probably mergansers (Nysewander et al. 2001). It is uncertain whether documented changes relate to cycles of change such as the North Pacific Decadal Oscillation or to more local changes in forage fish stocks. Bird species that either eat fish or depend upon certain spawning events of Puget Sound forage fish appear to have declined more than species that emphasize feeding on other parts of the food chain, such as crustaceans and invertebrates (Puget Sound Water Quality Action Team 2002).

Data from Kitsap County can be found through the Audubon Society, specifically the Christmas bird counts (National Audubon Society 2000). Table V-7 lists species reported in 2000 and 2001. A number of species recorded are included as part of the PSAMP monitoring effort.

Table V-7. 101st and 102nd Christmas Bird Counts, December, 2000 and 2001.

Species	2000	2001	Species	2000	2001
Red-throated Loon	27	28	Black Scoter	163	152
Arctic Loon	2	0	Long-tailed Duck	54	59
Pacific Loon	49	425	Bufflehead	532	828
Common Loon	39	45	Common Goldeneye	1472	937
loon sp.	4	0	Barrow's Goldeneye	318	306
Pied-billed Grebe	9	21	Hooded Merganser	153	114
Horned Grebe	298	549	Common Merganser	141	153
Red-necked Grebe	135	200	Red-breasted Merganser	194	194
Western Grebe	2001	2595	Ruddy Duck	20	21
Brandt's Cormorant	3	100	Bald Eagle	25	28
Double-crested Cormorant	517	475	Sharp-shinned Hawk	5	6
Pelagic Cormorant	81	146	Cooper's Hawk	2	5
cormorant sp.	9	176	Red-tailed Hawk	3	5
Great Blue Heron			Merlin	1	0
(Blue form)	87	61	Peregrine Falcon	1	3
Greater White-fronted Goose	3	0	American Coot	66	128
Ross's Goose	1	0	Black-bellied Plover	12	3
Canada Goose	342	512	Killdeer	180	109
Canada Goose			Greater Yellowlegs	12	32
(small races)	22	21	Spotted Sandpiper	1	3
Mute Swan	0	1	Black Turnstone	12	124
Wood Duck	0	7	Western Sandpiper	60	0
Gadwall	0	2	Sanderling	0	30
Eurasian Wigeon	12	22	sandpiper sp.	0	382
American Wigeon	3118	4456	Dunlin	5	250
Mallard	902	876	Bonaparte's Gull	2	11
Northern Shoveler	83	8	Mew Gull	84	157
Northern Pintail	23	20	California Gull	2	16
American Green-winged Teal	113	113	Herring Gull	0	10
Canvasback	1	1	Thayer's Gull	1	6
Ring-necked Duck	29	205	Western Gull	95	87
Greater Scaup	235	298	Glaucous-winged Gull	1442	1380
Lesser Scaup	179	70	Glaucous-winged Gull X		
scaup sp.	16	129	Western Gull (hybrid)	0	3037
Harlequin Duck	14	19	gull sp.	210	398
Surf Scoter	1158	1715	Pigeon Guillemot	55	102
White-winged Scoter	786	1094	Marbled Murrelet	33	34
			Belted Kingfisher	58	58

D. MARINE MAMMALS

A number of marine mammals are found in Puget Sound waters, including Harbor Seals (*Phoca vitulina*), California sea lion (*Zalophus Californianus*), Steller (Northern) sea lion (*Eumetopias jubatus*), harbor porpoise (*Phocoena phocoena*), killer whale (*Orcinus orca*) and the gray whale (*Eschrichtius robustus*). Although some populations are considered stable and have grown recently, such as harbor seals, others have declined in recent years, partially due to human impacts such as high concentrations of contaminants found in food supplies, and incidental deaths due to commercial fishing operations (Calambokidis and Baird 1994; Puget Sound Water Quality Action Team 2002).

Harbor seals (*Phoca vitulina*) are the most abundant marine mammal in the Puget Sound region (Harley 1998) (Figure V-9). Washington's harbor seal populations are considered abundant and healthy, numbering in excess of 30,000 seals (inland stocks +14,000 seals) (Jeffries et al. 2001). They are considered nonmigratory, are opportunistic foragers and feed on a wide variety of fish species, and to a lesser degree on cephalapods and crustaceans (Calambokidis and Baird 1994). The diet of harbor seals in Hood Canal was determined during the fall and spring of 1998 and 1999 from haulout sites at Quilcene Bay, Dosewallips River, Duckabush River, Hamma Hamma River and Skokomish River. Based on frequency of occurrence, Pacific hake, Pacific herring, and salmon (variety of species) were the most predominant food items found in the fall. Northern anchovy and three-spine stickleback were additional prey species identified during the spring (Lance et al. 2001). During the fall of 1998-2000, WDFW and Washington Cooperative Fish and Wildlife Research Unit began efforts to evaluate potentially negative effects of predation by harbor seals on the recovery of summer chum salmon runs in Hood Canal. Results indicated documented harbor seal predation on returning adult salmon off the mouths of the Quilcene, Dosewallips, Duckabush, and Hamma Hamma River systems. Seals were observed consuming summer chum, coho, and fall chum all three years (London et al. 2001).

*Figure V-9. Harbor seal (*Phoca vitulina*) (Source: www. dnr.metrokc.gov/wlr/waterres/ marine/img/).*

Harbor seals are the only pinniped that breeds in Puget Sound waters. Pups are born in eastern bays of Puget Sound between late June and August, and between mid-July and September in Southern Puget Sound. Harbor seals can potentially use any beach in Puget Sound as a haulout site for pupping; however, documented haulout sites known as rookeries are commonly used. Aerial, boat, and ground surveys conducted since 1978 indicate more than 200 haulout sites in the Strait of Juan de Fuca, San Juan Islands, Puget Sound and Hood Canal. Near Bainbridge Island, haulout sites have been noted at Blakely Rocks and Orchard Rocks (Jones and Stokes Associates 1990).

VI. EFFECTS OF NEARSHORE MODIFICATIONS

This chapter describes the effects of human modifications to nearshore habitats, with special attention to shoreline stabilization structures (e.g., armoring). overwater and inwater structures (e.g., docks), dredging and filling, and pollution. For each category, we describe the specific types or sources of modification, provide a regional perspective for Bainbridge Island, outline the impacts to physical and biological processes, and summarize management recommendations. As noted in Chapter II, a conceptual model approach is used to help predict or understand effects on nearshore ecosystem functions, especially where empirical data is lacking.

A. SHORELINE STABILIZATION STRUCTURES

1. TYPES OF STRUCTURES.

Shoreline stabilization structures are designed to alter physical processes by modifying hydraulic forces and controlling sediment movement and supply. A wide variety of shoreline stabilization structures have been designed to dissipate wave energy, maintain navigation channels, control shoreline erosion, repair storm damage, protect from flooding, and store or accumulate sediment (Cox et al. 1994). Shoreline stabilization may be established through the use of “hard” and/or “soft” structures. “Hard” solutions, or armoring, typically involve the addition and arrangement of materials that would not naturally occur at the site (Macdonald et al. 1994). Hard structures include bulkheads, seawalls, revetments, groins, and breakwaters (Canning and Shipman 1995a; Williams and Thom 2001) (Figure VI-1). “Soft” solutions are dynamic approaches to preventing or reducing erosion using naturally occurring materials (Cox et al. 1994). They include the placement of beach material (sediment “nourishment”), large woody debris (i.e., beach logs), drainage control, and shoreline vegetation (Canning and Shipman 1995a; Macdonald and Witek 1994; Macdonald et al. 1994) (Figure VI-2).

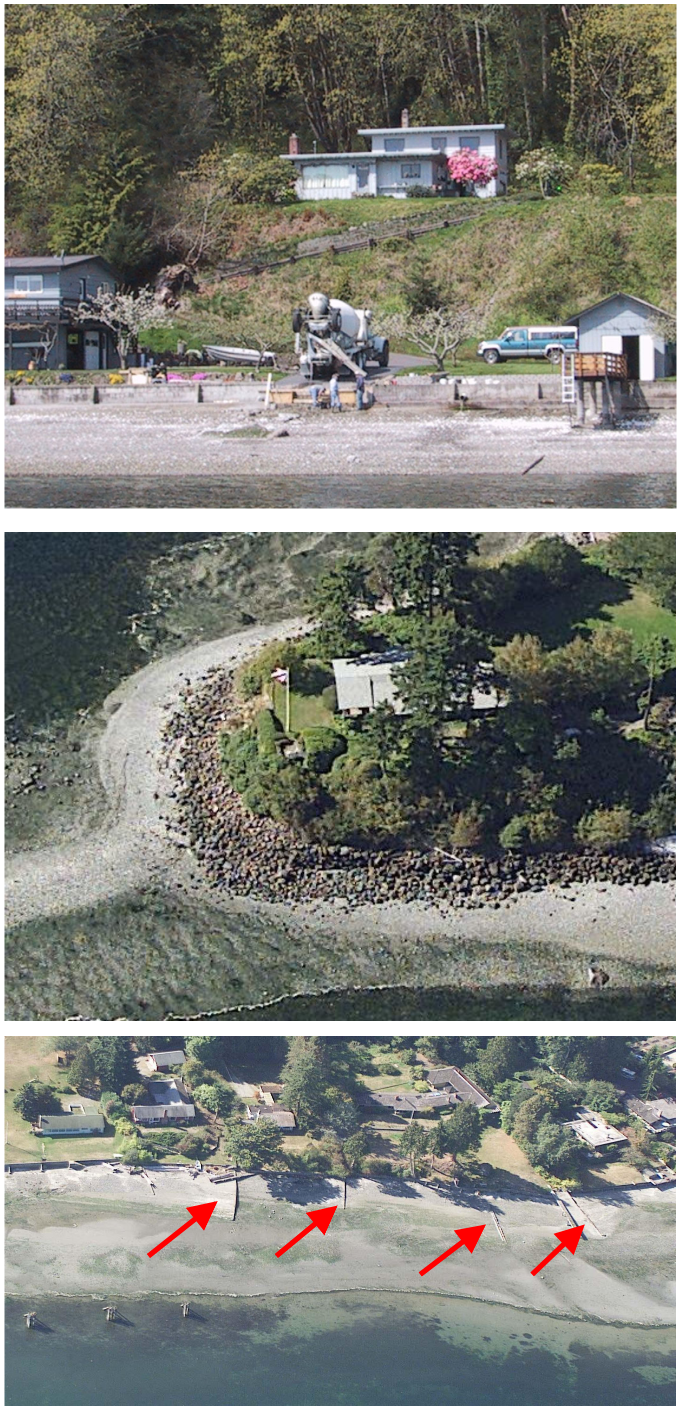

Figure VI-1 Illustrations of hard approaches to shoreline stabilization. Top: vertical smooth bulkhead (Applied Environmental Services, Inc.); Middle: revetment; and Bottom: groins (© WA Dept of Ecology 2000/2001).

Figure VI-2 Illustrations of soft approaches to shoreline stabilization. Top: nourishment with gravel and sand; Middle: large woody debris; and Bottom: vegetation (from Zelo and Shipman, 2000).

2. Regional Focus - Bainbridge Island

"Hard" shoreline stabilization or "armoring" is one of the more prevalent forms of nearshore modification in Puget Sound resulting from rapid population growth that has caused a surge in commercial and private development. By the mid-1990s, over 29% of Puget Sound's shoreline had been armored, with 1.7 miles of Puget Sound shoreline being newly armored each year (Canning and Shipman 1995b). In King County, armoring comprises 75% to 87% of the coastline (Washington State Department of Natural Resources 2001; Williams et al. 2001; Bumgartner 1990). Of 2262 shoreline parcels on Bainbridge Island, over 82% have been developed, with single-family residential use representing the vast majority of these cases (P. Best, COBI, *personal communication*, 2002). Approximately 52% of the Bainbridge Island shoreline has some type of armoring or modification according to the WDNR ShoreZone Inventory (2000). However, more recent surveys by the City of Bainbridge Island suggest that this number may be higher.

Vertically oriented bulkheads are the most common shoreline stabilization structures encountered on Bainbridge Island (P. Best, COBI, *personal communication*, 2002) (Figure VI-3; Figure VI-4). Bulkheads are vertical shoreline structures designed to prevent sliding or erosion of the land behind it, primarily by protecting it against waves and currents (Williams and Thom 2001). Functionally, bulkheads provide a vertical separation of land from water and are built to protect adjacent uplands from erosion and create shoreline real estate. Predominant bulkhead designs used in Puget Sound are vertically oriented concrete, rock, or wood structures that are in direct contact with water action (Downing 1983; Cox et al. 1994; Canning and Shipman 1995a).

Figure VI-3. Vertical bulkheading along Rolling Bay (© WA Dept of Ecology, 2000).

Figure VI-4. Vertical bulkheading along Port Orchard Bay (Source: Applied Environmental Services, Inc.).

Similar structures that are used to prevent landslides and to protect uplands from wave action include seawalls, which are self-supporting, and revetments, which are placed on or against an existing sloping embankment. Seawalls are large freestanding structures designed to protect bluff and bank habitats exposed to moderate to very severe waves; they are not a common structural feature along the shores of Bainbridge Island. A revetment is an armored slope built to protect existing shorelines or embankments against the erosive forces of current, wave action, or storms (Anchor Environmental 2000). Revetments generally parallel the contours of the shoreline and are commonly composed of riprap (randomly placed rock rubble), gabions (rectangular steel wire baskets filled with stones), interlaced concrete forms, or grout- (concrete) filled bags (Downing 1983; Cox et al. 1994). Revetments are generally used for protecting bank and bluff habitats on residential parcels, are relatively easy to construct and maintain, and usually do not extend beyond the mean low water (MLW) mark (Cox et al. 1994). In general, there are very few revetments on Bainbridge Island, none of which reach MLW (P. Best, COBI, *personal communication,* 2002).

Groins are rigid, self-supporting structures built out at an angle from the shore (usually perpendicular) to protect it from erosion or to trap sand. They commonly function to provide or maintain a beach by trapping littoral drift sediment and reducing the rate of sediment loss. Groins on Bainbridge Island generally are narrow, made of concrete or quarried rock, of varying lengths, and may be spaced at intervals along the shoreline in what are referred to as "groin fields" (See Figure VI-5 and VI-6).

Figure VI-5. Groin (Source: Applied Environmental Services, Inc.).

Figure VI-6. Groin field (© WA Dept of Ecology 2001).

Breakwaters and jetties are constructed to dissipate wave energy, channel tidal action, and/or to protect and stabilize navigation channels and harbor areas. Neither type of structure is typically found along Bainbridge Island shorelines.

Soft armoring approaches strive to reduce impacts to nearshore habitats associated with hard armoring methods and are considered a preferred approach to rebuilding beaches or protecting shorelines from erosion. Beach nourishment serves as a “soft,” sacrificial barrier that functions to prevent beach recession, provide protection from storms and flooding damage, and enhance recreational opportunities (Williams and Thom 2001). Additional advantages include the preservation of beach aesthetic values and an increased supply of sediment to downdrift beaches. Beach nourishment in Puget Sound typically uses gravel-sized material placed by truck or barge along the upper beach, and spread to the design contour by bulldozer (Shipman 1998). A number of shoreline restoration projects around Bainbridge Island have used small-scale beach nourishment (less than 1000 cubic yards of placed material) to control erosion (Zelo and Shipman 2000).

Other soft approaches use natural vegetation and large woody debris to reduce soil erosion, increase slope stability, trap sediment, and absorb wave energy along shorelines (Myers 1993; Macdonald et al. 1994; Manashe 1993; Macdonald et al. 1994). Along sloping shorelines and backshore areas, this approach involves planting vegetation to harness the hydrological and mechanical benefits of plant foliage and root systems to stabilize soil. Stumps, drift logs, and tree root masses are a natural component of Pacific Northwest shorelines and can form semi-permanent stockpiles, which trap beach sediment and promote the establishment of vegetation (Downing 1983) (Figure VI-7). However, soft techniques to stabilize shorelines are less common in practice, with fewer than 20 known sites located on Bainbridge Island (P. Best, COBI, *personal communication*, 2002) (Zelo and Shipman 2000). Most of these projects consist of cabled logs and discretely placed boulders as alternatives to bulkheads.

Figure VI-7. Naturally occuring large woody debris stabilizing shoreline (Source: Applied Environmental Sciences, Inc.).

3. Impacts – Physical Processes and Biological Considerations

Shoreline stabilization structures have a variety of physical and biological impacts to the nearshore environment that often depend on the location (both along the beach profile and shoreline), design, type of material used, and size of the structure. These structures may cause profound impacts to nearshore geomorphology, hydrology, and wave energy, some of the most important factors controlling the development and distribution of nearshore habitats (Conceptual Model, Figure II-3).

Possibly the most significant effect of stabilization structures is a direct impact to regional geomorphology via the impoundment of potential natural sediment sources (Macdonald et al. 1994). These structures can induce three main types of sediment loss (Macdonald et al. 1994):

- Erosion of fine-grained sediment from the active beach, causing it to become narrow and coarser
- Erosion or impoundment of sediment, stored in backshore areas, which is usually added to the longshore transport system during severe storm events.
- Impoundment of sediment from adjacent upland sources (e.g., feeder bluffs), that previously reached the beach, but is now trapped behind the structure beyond the reach of waves.

This impoundment of natural sediment sources can influence erosion processes that alter the structure and function of native habitats (and properties) at areas both near and distant from the site of impact. Shoreline structures designed to affect shoreline sediment transport (e.g., groins) will cause similar beach erosion and accretion impacts in adjacent areas (Pilkey and Wright III 1988).

Placement of structures below the ordinary high water mark may exert their most chronic impacts on nearshore hydrological processes, which include altered wave energy and current patterns, obstruction of littoral drift and longshore sediment transport, and altered fluctuations of temperature, salinity, and water levels (Williams and Thom 2001). Hardened shorelines with vertical or recurved slopes also alter hydrology by deflecting wave energy downward, causing scouring of the bottom sediment at the toe and periphery (Macdonald et al. 1994) (Figure VI-8) and may alter groundwater dynamics relative to the upland. According to this representation, wave reflection forces increase as armoring methods intensify. This wave reflection ultimately results in elevation loss and habitat change (e.g., loss of eelgrass). Studies conducted by the WSDOT in Rich Passage along the south shore of Bainbridge Island revealed that armored shorelines reflected larger breaking waves, causing increased scour in the upper intertidal zone (Anchor Environmental 2001).

Placement of hard structures also radically alters the distribution and extent of existing habitats, resulting in a large-scale replacement of soft beach substrates with hard, rocky shore habitats that support different animal communities (Williams and Thom 2001). One of the more widely recognized biological impacts is the permanent loss of fish (e.g., surf smelt, Pacific sand lance, and rock sole) spawning and shellfish habitat on upper intertidal beaches. Exacerbating these direct impacts is the indirect loss of additional spawning habitat from downdrift beach coarsening and erosion, and the loss of shading riparian vegetation (Macdonald et al. 1994; Thom et al. 1994b; Macdonald 1995; Antrim and Thom 1995; Penttila 1996; Allee 1982; Macdonald 1995; Antrim et al. 1995).

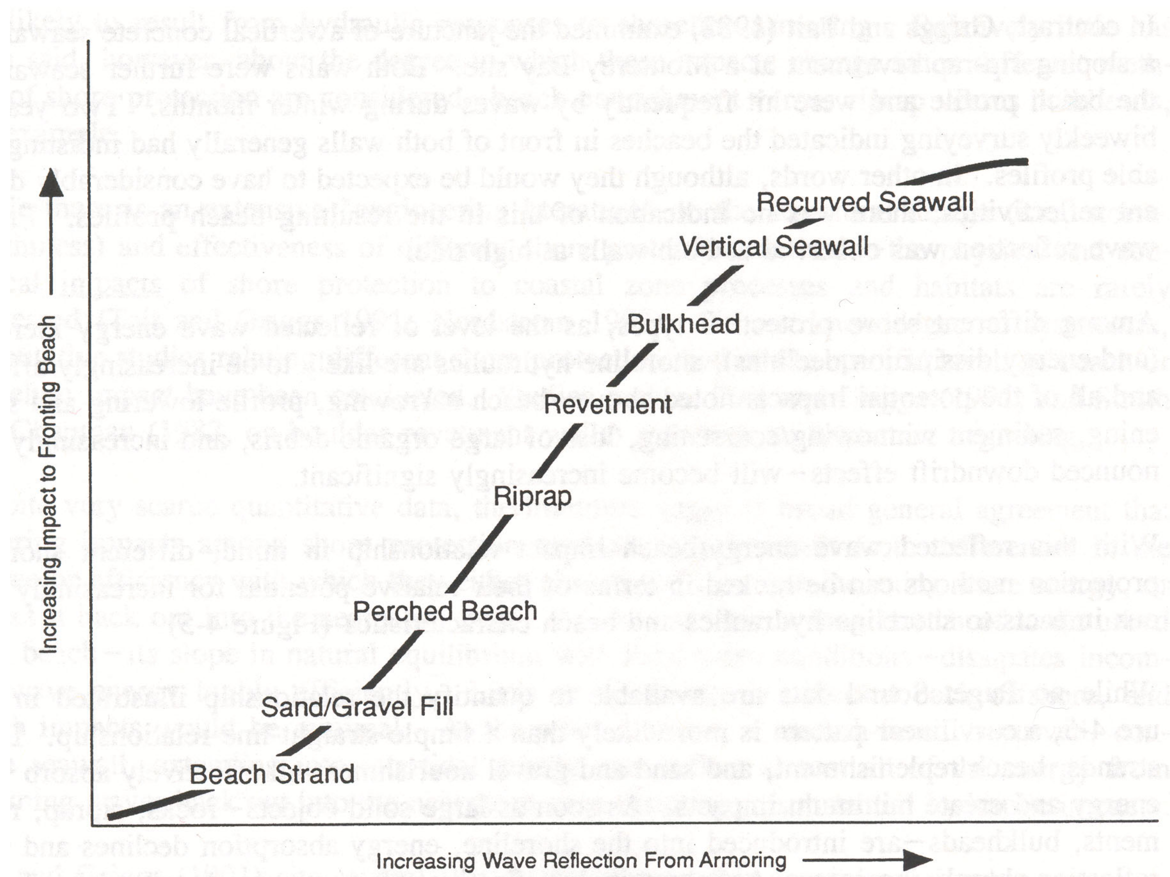

Figure VI-8. Relative beach impacts versus shore protection method (from Macdonald et al. 1994).

Direct physical disturbance associated with construction of all shoreline stabilization structures temporarily causes several types of direct impacts, which vary with the size and extent of the structure and the time needed to build it (Williams and Thom 2001). In the short term, heavy equipment associated with construction causes local noise (e.g., pile driving), which can disrupt nesting waterfowl and alter animal behavior and distributions. Air and water pollution from machinery and watercraft exhaust emissions may also cause local impacts (Mulvihill et al. 1980; Kahler et al. 2000). Other construction impacts include temporary bottom disturbance, which increases sediment suspension, erosion, sediment compaction, and turbidity. Other obvious and immediate impacts associated with construction include burial or excavation of both subtidal and intertidal habitats and fauna, trampling, and direct mortality from heavy equipment operation (e.g., dredging or barge groundings) (Armstrong et al. 1991).

Water quality may degrade in areas of extensive shoreline modifications. Residential and commercial development and impervious surfaces in upland habitats and watersheds can increase stormwater runoff, sediment erosion, and loading of nutrients and toxic pollutants (Williams and Thom 2001). Shoreline development can increase local nutrient loading to the point of eutrophication, with removal of vegetative buffers exacerbating these problems (Short and Burdick 1996).

Ambient light levels in nearshore habitats are increased when structures replace riparian vegetation, which provides shade to the upper intertidal zone. Shade reduces temperature and desiccation stress to insects, marine invertebrates, and fish eggs laid by intertidal spawning fish species (Penttila 1996; Penttila 2000). Likewise, the increase in artificial lighting that often accompanies anthropogenic shoreline alterations can modify salmon behavior and predator avoidance (Simenstad et al. 1999; Azuma and Iwata 1994). Conversely, overwater shading by anthropogenic shoreline alterations may also unnaturally reduce local light levels, reducing primary productivity rates and eliminating critical shallow-water vegetated habitats.

Shoreline stabilization methods may affect the recognized functions of estuarine and nearshore marine habitats for juvenile salmon by altering substrate, hydrologic, and water property conditions that affect prey production (Williams and Thom 2001). Shoreline modifications usually involve riparian vegetation removal, which displaces trees and shrubs that normally overhang onto beaches. More current research is clarifying the important role of leaf litter and insect fall from this riparian vegetation in nearshore detritus production and salmon food webs (Simenstad and Cordell 2000; Levings and Jamieson 2001) (unpublished data, KCDNR 2002). Structures may fragment the nearshore landscape, thereby altering natural patterns of habitat use and movement by fish, as well as by animals that use upland habitats (e.g., birds and mammals) (Castelle et al. 1994; Desbonnet et al. 1994). Shoreline structures that intrude into the intertidal zone also affect patterns of detritus and large woody debris recruitment (Hugh Shipman, WDOE, *personal communication*, 2002). Though not well studied in marine nearshore habitats, large woody debris provides added structural complexity that provides shelter and refuge for a variety of species in freshwater systems (Knutson and Naef 1997; Kahler et al. 2000).

As shown above, shoreline stabilization has substantial effects on physical processes that reduce the number and diversity of habitats, as well as the intertidal habitat area (Douglass and Pickel

1999). These modifications have substantial effects on nearshore processes and the ecology of many species, including spawning habitat for forage fish such as surf smelt, sand lance, and herring, as well as prey production and refuge areas for salmonids (Macdonald et al. 1994; Allee 1982). Thom et al. (1994b) summarized the potential effects of shoreline armoring to selected nearshore resource species in Puget Sound based upon knowledge of critical links between physical effects, habitats, and biological resources (Table VI-1).

The seawall constructed at Lincoln Park in West Seattle provides the best-documented example from Puget Sound of the direct (e.g., alteration of upper beach substrata) and indirect impacts (e.g., lowering of beach and coarsening of substrata) of a hard shoreline structure on nearshore habitats (Figure VI-9). The lesson learned at Lincoln Park was that the seawall, which was originally located above the influence of the tide, had major effects on seaward habitat conditions well into the subtidal zone. The effects were evident and extensive for decades after placement of the seawall, and only re-nourishment of the beach with sand and gravel could begin to restore some of the original (pre-seawall) habitats and functions. This beach continues to need periodic renourishment to maintain some historic habitat elements. However, the process of renourishment has its own associated impacts on plant and animal communities that recolonize over an extended period of time.

Table VI-1. Summary of Armoring Effects to Resource Species in Puget Sound (from Thom et al. 1994b).

	ARMORING EFFECTS						
RESOURCE SPECIES	Armoring-related Habitat Shift	Loss of Spawning Habitat	Loss of Shoreline Riparian Vegetation	Loss of Wetland Vegetation	Loss of Large Organic Debris	Changes in Food Resources	Loss of Migratory Corridors
Surf Smelt	●	●	●		⊕		
Pacific Sand Lance	●	●	●		⊕		
Rock Sole	●	●	●		⊕		
Juvenile Salmonids	●		●	●	●	●	●
Pacific Herring	⊕	⊕					
Hardshell Clams	●	⊕				●	
Geoduck	❍						
Oysters	❍	❍				❍	
Dungeness Crab	⊕	⊕				⊕	
Sea Cucumber	❍					❍	
Sea Urchins	❍					❍	

● Well-documented evidence of negative effects
⊕ High potential for negative effects, but not documented
❍ some potential for long-term effects, but not documented

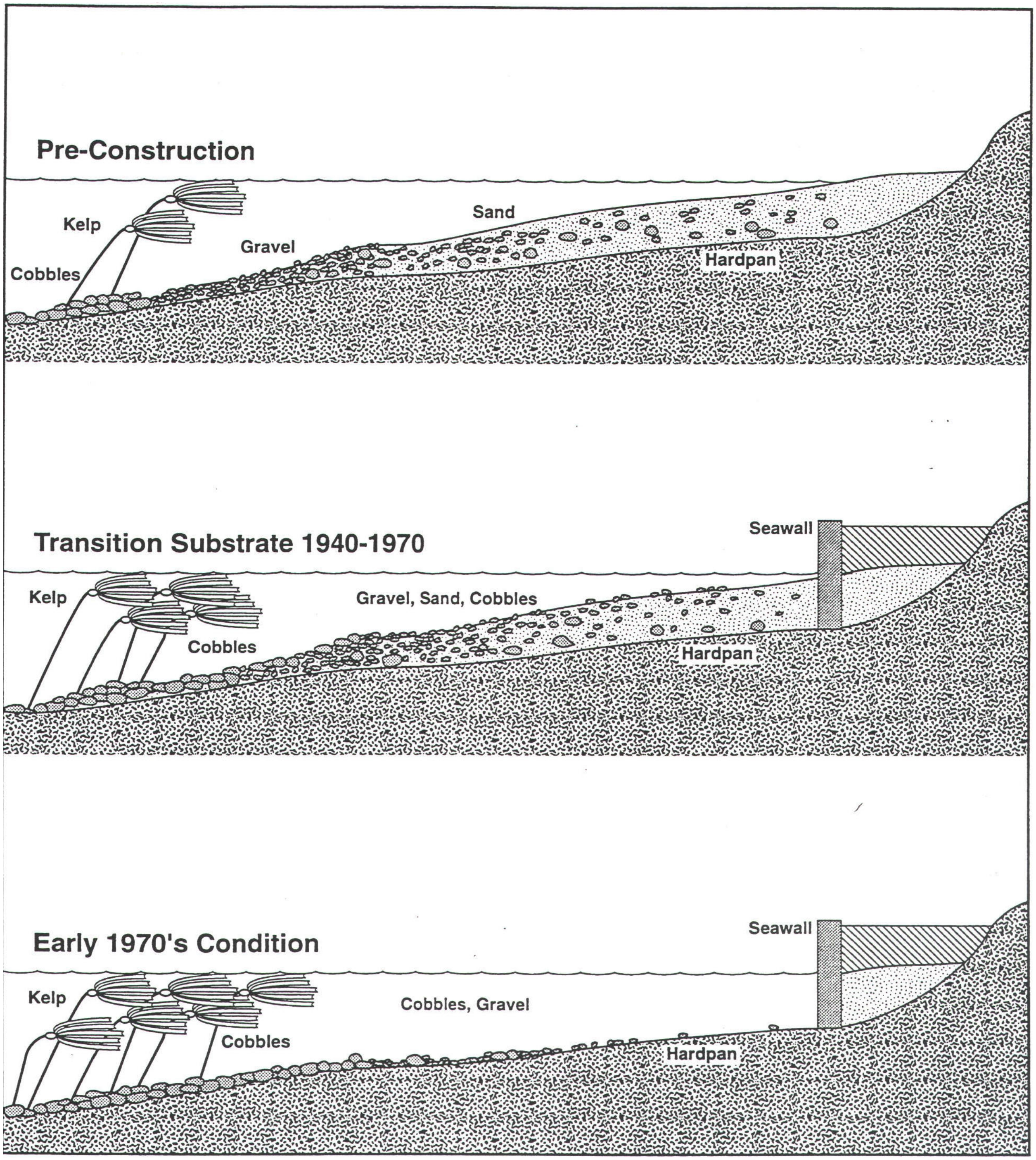

Figure VI-9. Changes in the beach at Lincoln Park following seawall construction in the mid 1930s (from Thom et al. 1994b).

4. MANAGEMENT RECOMMENDATIONS

A broad array of habitat protection and mitigation techniques can minimize or limit the impact of shoreline modifications to estuarine and nearshore marine areas (Williams and Thom 2001). Actions that can mitigate these impacts include avoidance (i.e., no shoreline modification), minimization of impacts by using alternative structural modification strategies, land-use management, and compensation via restoration of other degraded sites. Downing (1983) summarizes some of the advantages and disadvantages of various approaches not only to the property owner, but also to local beach conditions and the nearshore ecosystem (Table VI-3).

Table VI-3. Summary of the Advantages and Disadvantages of Various Shore Protection Alternatives (from Downing 1983).

	Advantage to Property Owner					**Disadvantage to Property Owner**					**Advantage to Beach / Ecosystem**			**Disadvantage to Beach / Ecosystem**		
Method of Erosion Control	Stops upland erosion	Improves scenic value	Low maintenance cost	Improves slope stability	Beach accretes rapidly	Does not stop erosion	Reduces scenic value	Requires maintenance	Subject to failure	Potential legal problems	Does not impede beach material supply	Does not destroy benthic habitat	Improves natural sand supply	Reduces supply of sand	Destroys benthic habitat	Promotes beach erosion seaward of structure
Bulkhead	●		●	●			●	●	●	●				●	●	●
Revetment	●		●	●			●	●	●	●				●	●	⊕
Groin			●		●	●	●		●	●				●	●	⊕
Construction setback		●		●		●					●	●				
Vegetation			●	●		⊕		●	⊕		●	●				
Beach nourishment	⊕	●		●	●	⊕		●			●		●		●	

Notes: Filled circles represent cases where this method applies; cross-filled circles indicate some intermediate level of applicability.

In general, soft structures are believed to result in less long-term and fewer cumulative impacts to the nearshore ecosystem than do hard structures. However, beach nourishment should be used with caution because the relatively limited amount of regional study devoted to this approach. For example, nourishment does not address the underlying cause of erosion and should be undertaken with an ongoing commitment for periodic maintenance (Shipman 1998). In some cases, homogeneous gravel mixtures may provide few of the intended ecological benefits in some intertidal habitats, resulting in steepened beach slopes (Downing 1983), little moisture retention when drained, and instability under minor wave action. In these cases, beaches may not support desired infauna or epibiota, primary production, or appropriate surf smelt spawning habitat (Williams and Thom 2001).

Some soft structures, such as placement of large woody debris, may enhance the ecological functions provided by the shoreline. Again, the appropriate placement of large woody debris needs more study and should be used with caution. Under extreme tide and wave conditions wood may become unstable and cause damage to property (Williams and Thom 2001).

Revegetation has shown in several cases to improve biological productivity and enhance nearshore conditions (Zelo and Shipman 2000). Dune grass and berm vegetation can greatly increase the resilience of beaches to storm waves. Riparian vegetation is also a key element of shoreline ecological function and has a significant influence on habitat value, both in the riparian zone itself, and in adjacent aquatic and terrestrial areas. Marine riparian zones serve many of the same beneficial functions as freshwater systems (Naiman et al. 1992), while likely providing additional functions unique to nearshore systems (Brennan and Culverwell in prep).

A preferred alternative is to follow guidelines for building setbacks, which is the process of constructing sensitive shoreline structures (i.e., homes) a safe distance from eroding shorelines or bluffs (Terich 1987). Setbacks are considered the safest and least expensive alternative to avoiding hazards along Washington's erosive coastlines (Terich 1987; Downing 1983; Komar 1998b).

Management of upland groundwater and vegetation also provides a preferred approach that minimizes the need for shoreline stabilization structures. Surface and groundwater management can reduce erosion around sensitive shoreline structures and property (Myers 1996). Water is one of the most common agents of slope instability and erosion, and water supplementation should be kept to a minimum on erosion-prone hillsides and slopes (Myers 1993). Upland and riparian vegetation management should strive to maintain buffers of native vegetation, which may encompass planting of deep-rooted upland vegetation to increase soil stability and reduce erosive hydrologic forces on shorelines (Manashe 1993).

B. Overwater/In-Water Structures

1. Types of Structures

There are many types of overwater structures that currently exist within the nearshore zone of Puget Sound and Bainbridge Island. This discussion focuses primarily on four popular floating and fixed structures within the nearshore, including floating docks, fixed piers, marinas, and mooring buoys. Pilings are generally associated with these structures to support their load. Many of these structures are designed for boat use, which have associated impacts (anchor chain drag, prop wash/scour, grounding, and accidental littering/discharge) that are also addressed here.

Floating docks and fixed piers provide access to water resources for commercial and recreational activities. A fixed pier is an overwater structure supported by pilings that extends out above the water from the shoreline (Mulvihill et al. 1980). A fixed pier may or may not have a floating dock associated with it (Figure VI-10). Floating docks are generally composed of a frame mounted on floats of encapsulated styrofoam or wood, anchored in place to pilings via sliding hardware (Figure VI-11). Mooring buoys are floating surface structures used for private and commercial vessel moorage. These buoys are typically anchored outside of the intertidal zone in areas where boats will not ground on benthic substrate. Pilings, which are associated with several of these structures, are long timber, steel, reinforced concrete or composite posts that have been driven, jacked, or cast vertically into the ground to support a load (Mulvihill et al. 1980). Marinas are typically a collection of fixed piers, breakwaters, and floating docks that provide moorage for private and commercial marine vessels. Marinas are typically located close to or along a shoreline, with a fixed pier that connects the shoreline with a series of floating docks containing moorage slips.

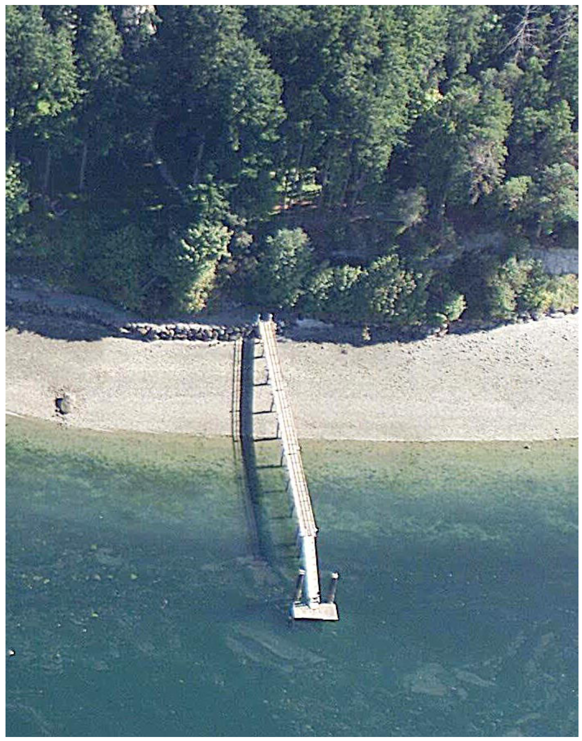

Figure VI-10. Pier with float. (© WA Dept of Ecology 2000).

Figure VI-11. Floating dock. (Source: Applied Environmental Services, Inc.).

2. Regional Focus - Bainbridge Island

Bainbridge Island has several marinas, most of which are concentrated in Eagle Harbor, a high water-traffic area with a variety of commercial and recreational overwater structures (Figure VI-12). Eagle Harbor also houses a WSDOT ferry terminal and a ferry maintenance facility (Figure VI-13). Other areas with significant concentrations of overwater structures include Port Madison Bay (FigureVI-14), Fletcher Bay, and Manzanita Bay. Open-water moorages are more common on the western shorelines of Bainbridge and in protected embayments. They generally consist of mooring buoys, located just outside of the intertidal zone, and floating docks (Figure VI-15).

FIgure VI-12. Marina in Eagle Harbor. (© WA Dept of Ecology 2000).

Figure VI-13. Washington State Ferry Maintenance Facility (© WA Dept of Ecology 2001).

Figure VI-14. Docks in Port Madison Bay. (© WA Dept of Ecology 2001)

Figure VI-15. Open water moorage in Eagle Harbor. (© WA Dept of Ecology 1992)

3. IMPACTS – PHYSICAL PROCESSES AND BIOLOGICAL CONSIDERATIONS

Nightingale and Simenstad (2001b) provide a comprehensive summary of the primary literature related to the physical and biological impacts of overwater structures, which we attempt to summarize here. Overwater structures can alter a variety of the physical processes controlling the development and distribution of nearshore habitats. These include the ambient light regime, hydrology, substrate conditions, physical disturbance, and water quality (Conceptual Model, Figure II-3). However, reduction of ambient light conditions (e.g., light attenuation and shading) is one of the primary mechanisms by which ecological impacts are often ascribed to docks, floats, pilings, and moored vessels.

Light reduction, or shading, by overwater structures has implications for both vegetation and animals. For submerged aquatic plants such as eelgrass (*Zostera marina*), shading reduces levels of photosynthetically active radiation (PAR) necessary for survival. As previously discussed

(Chapter IV), eelgrass is considered a critically important habitat in Puget Sound, serving primary production, feeding, refuge, and reproductive functions to a variety of marine species. Light regimes show considerable variation, depending upon the characteristics of the structure itself, including height above the bottom, orientation, piling density, and construction material. Increased dock height diminishes the intensity of shading by providing a greater distance for light to diffuse and refract around the dock surface before reaching the eelgrass canopy (Nightingale and Simenstad 2001b). Comparatively, floating docks allow no light to penetrate beneath them and the water's surface. Marinas may further enlarge the shade footprint through the increased water surface area covered by floating moorages and vessels. A north-south dock orientation has been shown to increase underwater light availability by allowing varying shadow periods as the sun moves across the sky, thereby reducing stress imposed on eelgrass. The PAR variations may also affect epiphyte and macroalgae production. High densities of support pilings, which serve as attachment substrate for macroalgae themselves, may increase shading to benthic substrates and eelgrass beds.

Light is a determining factor in fish migration, prey capture, and predator avoidance (Nightingale and Simenstad 2001b). Overwater structures, such as piers, floating docks, and marinas, may substantially reduce light levels necessary to these functions. A variety of studies have shown that salmon fry migrate along the edges of shadows rather than penetrate them (Simenstad et al. 1999). Prey abundance and capture rate may also be reduced under piers as compared with open-water areas for some fish species (Duffy-Anderson and Able 1999). Light behavior criteria identified by Nightingale and Simenstad (2001b) suggest that feeding and schooling behavior of some fishes may not be sustained at the low light levels observed under some industrial docks. Overwater structures may also increase the exposure of juvenile salmon to potential predators by providing predator habitat, reducing refugia such as eelgrass, and diverting juveniles into deeper waters, although little empirical evidence exists to support these hypotheses. Fish distribution studies have also documented the affinity of small juvenile fish for protected embayments that include marinas, although this preference likely reflects their reliance on shallow nearshore habitats and avoidance of under-dock areas.

Overwater structures may also influence local hydrology. Pilings change the flow of water over adjacent substrates, causing scouring, changes in bathymetry, and alteration of sediment transport, especially at high piling densities (Nightingale and Simenstad 2001b). Floating piers are also known to affect sediment movement and are not recommended in areas of significant littoral transport.

Bottom substrates associated with some overwater structure features can be impacted by encrusting communities. For example, support pilings provide surface area for mussels, barnacles, and other sessile organisms. Predation by sea stars and crab results in a large deposition of shell hash on the adjacent substrates and changes in biological communities associated with these substrates (Nightingale and Simenstad 2001b). Changes in benthic substrate composition impacts eelgrass production, and may increase disturbance of eelgrass meadows by seastars and burrowing crab.

Overwater structures also may cause physical disturbances to local habitats. Construction activities associated with the driving and insertion of pilings directly affects benthic communities, whereas noise associated with piling driving operations may affect the distribution and behavior of salmon and other fish and wildlife species (Feist et al. 1996). Indirect habitat impacts associated with improperly sited structures include grounding, scouring, and prop-wash effects. Low tides present the greatest risk of contact between floating structures (floating docks, mooring buoys) and marine vegetation and substrates. Grounding of floating docks, mooring buoys, and vessels often leads to the total loss of eelgrass beds and alteration of the benthic invertebrate community (Nightingale and Simenstad 2001b). Heavy fastening chains or anchor lines that drag across the bottom during tide or wind events can cause scouring and disturbance of vegetation. Vessels commonly associated with many overwater structures can cause prop scouring of sediment, disturbing submerged vegetation and benthic communities.

Water-quality impacts are another potential issue associated with overwater structures. Marinas and covered moorages are typically associated with heavy boat traffic and human use, and may subject adjacent waters to potentially more frequent exposure to petroleum, household cleaning, pesticide, and herbicide products (Nightingale and Simenstad 2001b) and sewage. Similarly, boat paint and maintenance products can pose an increased risk of contamination to the marine food web through accidental spills. Poor water circulation in marinas can create a buildup of organic sediment, low dissolved oxygen concentrations, and dinoflagellate blooms.

Wood pilings treated with creosote, ACZA (Ammoniacal Copper Zinc Arsenate), and CCA Type C (Chromated Copper Arsenate) pose an additional risk of leaching contaminants into the water column (Poston 2001). These wood preservatives may release contaminants into aquatic habitats via three mechanisms: rain or snow melt runoff, dislodging of treated wood fibers by activities, or leaching into sediment. Exposure of aquatic organisms can occur in the water column, in adjacent sediment, or via direct attachment of tissue or eggs. All of these compounds have various levels of toxicity to marine organisms (Poston 2001). Port Madison Bay is one of three locations in Puget Sound where mass mortality of herring spawn has been documented (Jim West, WDFW, *personal communication*, 2002). Preliminary studies have suggested a link between a waterborne toxic substance, such as polynuclear aromatic hydrocarbon (PAH) compounds, and these mortalities, though definitive studies have yet to be conducted.

4. Management Recommendations

Light reduction, which affects the growth, distribution, and abundance of submerged aquatic vegetation, is one of the most significant impacts associated with an overwater structure, and should be avoided if possible. When avoidance is not an option, light penetration can be enhanced by increasing structure height over the water's surface (in the case of docks), increasing pile spacing, modifying structure orientation (a north-south orientation maximizes solar penetration), and minimizing the structure's surface area and number of pilings (Short and Burdick 1996; Nightingale and Simenstad 2001b). Floating dock designs that allow minimal light penetration and ground at low tide should be discouraged. Light penetration can be enhanced under many dock structures by using grating as surface material, glass blocks, reflective material, or artificial lighting (Blanton et al. 2001).

Other considerations include placing mooring buoys and floating docks in deeper water to avoid grounding on low tides, substrate modification, and light limitation from vessel props and scouring. Properly installed mooring buoys have the least impact when midline floats prevent the anchor line from contacting the bottom substrate (Nightingale and Simenstad 2001b). Other considerations include the use of proper line lengths relative to maximum water depth, as well as the size and type of line and anchor used.

Alternatives to the proliferation of docks and pilings for residential and commercial use are the establishment of carefully placed community-use docks in areas of low potential impact. The use of treated wood pilings should be minimized where possible; a variety of alternative materials exist, including concrete, metal, or composites. Sleeves may also be placed over pilings to isolate the structure and prevent direct exposure to attached organisms or their eggs. Another approach would be to remove the pilings, although consideration should be given to the additional dispersal of contaminated sediment near the piling.

Design and placement studies should be conducted for proposed marinas to maximize current and circulation patterns and to minimize habitat loss. Other ideas include upland boat storage as an alternative to in-water moorings, excavation of upland basins rather then shallow nearshore areas, and placing marinas in areas of low biological abundance and diversity that will not interfere with littoral drift processes or natural wave energy. Existing water quality issues associated with the operations of docks and marinas can also be minimized via catchment systems, which collect runoff and divert it to treatment facilities.

C. DREDGING/FILLING

1. TYPES OF MODIFICATION

Dredging is typically conducted to provide and maintain adequate depth for vessels in navigation channels, slips, and berthing areas. Depending upon the location and proposed depth, dredging may convert intertidal and shallow subtidal habitat to deepwater habitat (Haring 2000). Dredging and disposal are regulated through state and federal permit systems. Dredged material containing low levels of contaminants may be disposed at designated open-water disposal sites under the Puget Sound Dredged Disposal Analysis (PSDDA) program. Dredged material with higher contaminant loads must be treated or disposed at a confined facility. Confined disposal sites are generally located in upland (i.e., landfill) areas.

Large filling projects are not as common in Puget Sound today. Historically, filling of nearshore areas was conducted to create new upland areas for development, which frequently resulted in loss of wetlands, beaches, and other habitat. However, small-scale filling of nearshore areas waterward of the MHHW line may occur during shoreline armoring, which buries nearshore habitat. Modern filling projects usually are conducted to create or restore habitat (i.e., beach nourishment; see section above) (Zelo and Shipman 2000), or to cap contaminated sediment.

2. REGIONAL FOCUS - BAINBRIDGE ISLAND

Dredging on Bainbridge Island has historically occurred within Eagle Harbor and Fletcher Bay. Dredging equipment typically used in Puget Sound (including Bainbridge Island) involves mechanical bucket dredges, rather than hydraulic or hopper type dredges. Marinas and navigation channels will likely require future maintenance dredging related to the accumulation of sediment.

Shoreline armoring represents one of the most common types of filling that occurs on Bainbridge Island, although accompanying estimates of lost intertidal habitat remain undocumented. As previously noted, a number of Bainbridge Island nearshore restoration projects have included beach nourishment (Zelo and Shipman 2000) (P. Best, COBI, *personal communication*, 2002). Finally, contaminated sediment capping is occurring at the Eagle Harbor Superfund Site.

3. IMPACTS – PHYSICAL PROCESSES AND BIOLOGICAL CONSIDERATIONS

Disruption and displacement of benthic communities is an unavoidable impact of dredging, although recolonization generally occurs within 3 to 5 years (Williams et al. 2001). Benthic habitat characteristics, such as elevation and grain size, can be changed by dredging and alter the original biological community. Benthic or demersal fishes, such as sand lance, sculpins, and pricklebacks, are particularly susceptible to dredge entrainment (Nightingale and Simenstad 2001a), and the loss and disturbance of benthic communities can affect food-web interactions. Elevated turbidity levels have been shown to affect fish behavior, such as avoidance responses, territoriality, and feeding and homing (Nightingale and Simenstad 2001a). Dredging and shoreline construction activities can also disrupt migration pathways of juvenile salmon as a result of loud inconsistent noises, water turbulence, and other associated obstructions (Pacific States Marine Fisheries Commission 2001).

One potential environmental impact of dredging in nearshore areas is a temporary increase in turbidity from sediment resuspension, which may reduce dissolved oxygen and can also adversely affect fish and other aquatic species. While mechanical dredging generally maintains most of the dredged material in the bucket in a cohesive clump, some sediment loss and resuspension into the water column occurs. Because marinas are protected from strong currents and have reduced water circulation, the majority of suspended sediment generated in marina dredging projects likely remains in the immediate vicinity. Although the effects of dredging on nearshore habitats and species are known in a general sense, few quantitative data link dredging to changes in habitats and species.

Filling immediately alters the bathymetry and topography at the site and can also bury or displace existing organisms (Williams and Thom 2001). In cases where the change in bathymetry or topography is substantial, these organisms may not be able to recolonize a site, and historic opportunities offered by the site (e.g., forage fish spawning) are lost. Filling may substantially change beach profiles, marsh channel morphology, and habitat connectivity. If fill materials are different from the original substrate at the site, changes in sediment types and/or sizes will influence the composition of local plant and animal communities. In general, few long-term studies have specifically examined how historical fill activities change biological resources and functional interactions.

4. MANAGEMENT RECOMMENDATIONS

Dredging and removal of contaminated sediment for either confined aquatic disposal or landfill disposal, and capping of *in-situ* contaminated sediment with clean sediment, can improve the health of nearshore habitats (Williams et al. 2001). To minimize impacts to salmon, dredging in most nearshore areas should be restricted to those times of the year (activity windows) when migrating juvenile salmonids are least likely to be present.

Currently, nearshore filling to expand and develop upland areas is not a preferred practice in Puget Sound. In general, nearshore filling activities should be limited to well-designed and monitored beach nourishment projects.

D. POLLUTION

1. SOURCES

Water and sediment pollution can come from point sources or non-point sources (NPS). Point-source pollution is defined as any discernible, confined, and discrete conveyance, such as sewage outfalls or industrial discharges (U.S. Environmental Protection Agency 2001). Sewer outfalls in particular are known to discharge a variety of heavy metals, toxic compounds, organic nutrients, and solids. Industrial discharges generally involve the direct discharge of chemical pollutants from industrial operations. Non-point source pollution differs from industrial and sewage treatment plant pollution because it originates from many diffuse sources. NPS pollution may be caused by overland runoff that carries natural and human-made contaminants (e.g., nitrates, phosphates, pesticides, petroleum, sediment from cleared soil, and fecal coliform bacteria) into receiving water bodies, such as rivers, lakes, groundwater, and nearshore habitats (U.S. Environmental Protection Agency 1997; Masterson and Bannerman 1994). Sources include construction, agriculture, and stormwater runoff (Newton et al. 1997). Residential NPS pollution is associated with everyday activities, such as operating motor vehicles, washing equipment and structures, fertilizing home gardens, and controlling pests. Leaking septic tanks also allow contaminants to enter groundwater that can eventually enter nearshore waters. Of the two, point-source pollution is most identifiable and can be remediated with a higher level of certainty.

2. REGIONAL FOCUS - BAINBRIDGE ISLAND

Industrial contamination on Bainbridge Island is largely confined to the Wycoff creosote wood treatment facility at the mouth of Eagle Harbor. Elevated levels of PAHs, a component of creosote, were discovered in Eagle Harbor in 1984 (U.S. Army Corps of Engineers 2001b). Other toxins besides PAHs reported to be found in Eagle Harbor are naphthalene, flouranthene, acenaphthalene, phenanthrene, anthracene, flourene, PCB-1254, benzo(a)pyrene, benzo(a)anthracene, chrysene, benzo(k)flouranthene, dibenzo(a,h)anthracene, ideno(1,2,3-c,d)pyrene. These toxins far exceed the sediment management standards for marine sediment (U.S. Army Corps of Engineers 2000). PAH contamination is also known to occur in Blakely Harbor (Jones and Stokes Associates 1992).

Point-source pollution on Bainbridge Island has historically been concentrated near active or recently active sewer outfalls located at Wing Point, Skiff Point, Lynwood Center, and Fort Ward State Park (Figure VI-17). None of these are combined sewer outfalls, which combine sewer and stormwater flows within the same system. Current shellfish harvesting closure advisories exist in the vicinity of these outfalls (Kitsap County Health District 2002). Two of the currently operating outfalls service secondary treatment facilities: the Bainbridge Island municipal treatment facility, which discharges at Wing Point on the north of Eagle Harbor, and the Kitsap County Sewer District # 7 treatment facility, which discharges near Fort Ward State Park at the south of the Island. A small, privately owned treatment facility that services an adult convalescent home (Messenger House) discharges sewage from an outfall located off of Skiff Point. We are currently unaware of its treatment level, although it is likely primary because of the age of the system. The Lynnwood Center outfall, which discharged into Rich Passage, was closed in 1999, and services were combined with the Fort Ward treatment facility. Bainbridge Island is currently proposing a sewer plan for the south end of the Island that includes expansion of services to shoreline areas, including Point White and Rockaway Beach (P. Best, COBI, *personal communication*, 2002).

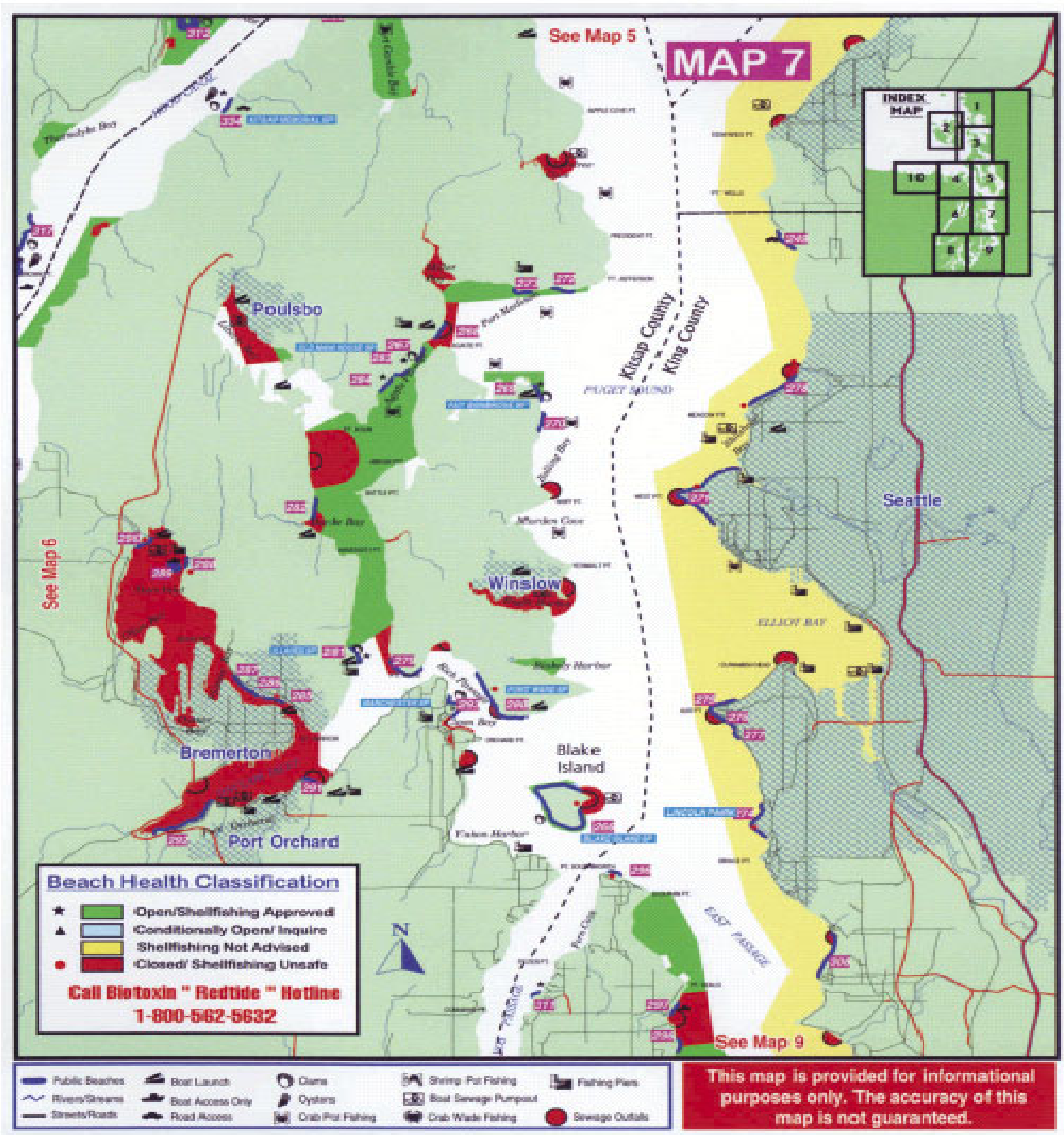

Figure VI-16. Outfall locations for Bainbridge Island (Source: WA Dept of Health, 2001).

The majority of NPS pollution on Bainbridge Island comes from stormwater runoff and a small amount of agricultural activity (Grellner et al. 1997). The relatively small drainage basins that exist on Bainbridge Island may carry contaminants into nearshore areas in higher concentrations than watersheds with larger basins. Contaminants traveling smaller distances and the lower water volumes of smaller urban drainages result in reduced dilution potential. Although development has increased in recent years, sediment contamination has decreased. Sediment sampling in 1997 and 2000 of nearshore areas around Bainbridge Island and throughout the Central Puget Sound observed a decrease in contaminant concentrations from prior sampling events, possibly a result of improvements in waste-management technologies, cleanup of contaminated sites, and natural processes (Long et al. 2000; Grellner et al. 1997).

Many private residences on Bainbridge Island use single-family septic systems, and a number of embayments house marinas and houseboats. These residential land and aquatic uses have the potential to contribute wastewater discharges into the nearby waters, especially when septic systems fail or are not maintained adequately. Almost all benthic sediment contains some level of contamination from wastewater and stormwater inputs from past and/or current anthropogenic activities (Puget Sound Water Quality Action Team 2001).

3. Impacts – Physical Processes and Biological Considerations

The introduction of chemicals, such as polychlorinated biphenyls (PCBs) and creosote, into nearshore areas has documented effects on sediment contamination and subsequently on organisms that utilize benthic habitats. Bottom-dwelling flatfish, such as the English sole (*Pleuronectes vetulus*), have shown an increase in liver abnormalities linked to contaminants that collect in marine sediment within Puget Sound (Puget Sound Water Quality Action Team 2002). Over time, those toxins settle to the bottom sediment. When resuspended, for example during dredging activities, they are once again released into the water column (Newton et al. 1998).

The discharge of raw sewage into nearshore environment can elevate levels of contaminants, such as fecal coliform bacteria, disease-causing bacteria and viruses, dissolved material, solid matter, and heavy metals. Impacts to the nearshore community arise from scouring, organic enrichment, and physiological effects of the chemicals themselves (National Oceanic and Atmospheric Administration 2000; Williams et al. 2001). Contaminants released into the water column will adhere to other particles and sink, which subsequently results in low levels of pollutants in the water column and bioaccumulation in organisms as evidenced by tumors on flatfish (Newton et al. 1995). As a result, organics and metals are generally observed in higher concentrations in local sediment than in the water column.

Organic enrichment is caused by the presence of excess amounts of organic carbon, which acts as a food source for invertebrate communities. If a benthic community is inundated with a large amount of organic carbon, it may be directly smothered or undergo organic enrichment. The effects of organic enrichment have been studied for 50 years, and much is known about how enrichment affects benthic communities (Word 1990; Williams et al. 2001). If the nearshore habitat consists of sand, there will be a shift in community structure from a suspension or surface detrital feeding community to one dominated by surface or subsurface deposit feeding organisms. Sensitive species (amphipods, echinoderms) will decrease in abundance, while tolerant species will increase. If the nearshore habitat consists of fine silts and clays, the community may undergo a shift to tolerant species (e.g., capitellid and spionid polychaetes) that thrive in habitats with high organic carbon content.

Changes in nearshore communities caused by chemical contamination are more difficult to document (Williams et al. 2001). These effects can be masked by the presence of organic carbon, which can have a stimulatory effect on the nearshore community. Catastrophic input of chemicals into the nearshore environment will have an immediate, acute impact on the community resulting in the immediate loss of all but the most tolerant individuals. Little is known about the chronic input of low levels of chemicals to this habitat. Evidence suggests that sensitive species will decrease in richness and abundance (as described above), whereas there may be no change in the condition of tolerant species (Word et al. 1981). However, this inference was based on an examination of the deep subtidal benthic community in the erosional environment off the West Point outfall, rather than a true nearshore community.

Non-point pollution affects nearshore ecosystems in several ways. Pollutants contained in untreated runoff enter nearshore marine waters and degrade water quality. Leaking septic tanks and other NPS sewage contaminate shellfish beds. Almost 33% of Washington's shellfish beds have been impacted by fecal pollution, with failing septic systems, animal waste, stormwater runoff, and boat discharge identified as the primary sources (Puget Sound Water Quality Action Team 2002; Kitsap County Health District 2002). Commercial or residential development involves clearing land of vegetation and increasing the area of impervious surfaces, exacerbating stormwater runoff into nearshore waters. Increases in stormwater runoff can elevate erosion, with subsequent sediment inputs and increased organic nutrient loads, causing eutrophic effects on receiving water bodies (Puget Sound Water Quality Action Team 2002). Local eutrophication can intensify algal blooms, increase turbidity, and reduce dissolved oxygen levels, especially in estuaries. Increased growth of macroalgae species such as *Ulva* may degrade nearshore habitat by limiting eelgrass (*Zostera* spp.) distribution through competition (Puget Sound Water Quality Action Team 2000a).

Exhaust, maintenance waste, and spills associated with boating activities also pollute waters directly. Commercial marinas affect nearshore habitat by increasing boat traffic and decreasing water quality. Boaters noticeably affect water quality in several ways. Small amounts of leaking oil can contaminate many gallons of water, and paint scrapings and many boat solvents are toxic to nearshore fish and wildlife (Puget Sound Water Quality Action Team 2000b). Untreated sewage that is pumped overboard introduces bacteria and viruses to the nearshore and may contaminate shellfish. Together, these additional forms of NPS pollution can have large negative impacts on the nearshore ecosystem.

4. Management Recommendations

Direct discharges from industrial or sewage outfalls can be monitored and controlled through proper discharge management programs, such as the National Pollutant Discharge Elimination System (NPDES) permit program. Clean up of contaminated sites has become a priority reflected in federal policies. In 1980, Congress enacted the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), also known as the 'Superfund' Act, which required the EPA to create new processes, policies, and procedures, and develop new technical capabilities for treating and containing hazardous substances.

Although the direct release of industrial pollutants has been reduced to low levels as a result of permit restrictions required by the Clean Water Act, the effects of historical discharges remain in marine sediment throughout the Puget Sound (Swader and Adams 1994). The CERLA process has provided funding for contaminated sediment capping and remediation projects such as the Wycoff/Eagle Harbor Superfund Site on Bainbridge Island (U.S. Army Corps of Engineers 2001b). Remediation of the Eagle Harbor site also involves the reconstruction of approximately two acres of intertidal beach habitat adjacent to the project.

As previously noted, managing NPS pollution is a more difficult problem. Local governments may require extensive water quality and water quantity monitoring programs as part of the development approval process to protect aquatic resources. A good example of this process on Bainbridge Island is the Hidden Cove Estates subdivision upland of Port Madison Bay. As part of its plat approval from the City of Bainbridge Island, the City and developer instituted safeguards, best management practices (BMPs), and monitoring of stormwater to protect the water quality of Port Madison Bay (P. Best, COBI, *personal communication*, 2002).

Pollution identification and correction projects are currently conducted by the Bremerton-Kitsap County Health District's On-Site Sewage/Water Quality (OSSWQ) Program to determine the causes and sources of bacterial water pollution in specific geographical areas (Kitsap County Health District 2002). Common sources of bacterial pollution include failing on-site sewage systems and animal waste. The OSSWQ has developed a prioritized list of areas in Kitsap County that are in need of pollution identification and correction, although no ongoing projects currently occur on Bainbridge Island. Projects are generally funded by the Kitsap County Surface and Stormwater Management Program and grants from the State Department of Ecology.

VII. Conclusions and Recommendations

The objective of this report was to produce a review of the best available science (BAS) relative to the nearshore ecosystem of Bainbridge Island by incorporating nearshore information common to Puget Sound, with data specific to Bainbridge Island as appropriate. The scope of this BAS review effort is defined in WAC 365-195-900 through 365-195-925. Although not specifically required in the WAC, there are several conclusions and recommendations that can be derived from the BAS review effort. It is our intention to promote a better understanding of the nearshore ecosystem surrounding Bainbridge Island and to provide that basis for future efforts in collecting data and improving management of the nearshore zone.

The following conclusions and recommendations are based on the BAS (specific to Bainbridge Island and outside sources) and professional judgment. We have attempted to focus our conclusions toward the scientific data for specific nearshore habitats, processes, and species that reside there. Recommendations have been presented as an extension of the conclusions to assist Bainbridge Island with the next steps toward nearshore technical assessment and improved management.

A. Conclusions

1. <u>Virtually all coastal and estuarine habitat types described for Washington State are found on or adjacent to Bainbridge Island.</u> These habitat types include tidal freshwater marshes, river and coastal riparian vegetation, salt marshes, flats, channels, eelgrass meadows, rocky shores, and kelp forests.

2. <u>Bainbridge Island's nearshore ecosystem plays a critical role in support of a wide variety of biological resources, many of which are commercially, culturally, aesthetically, and recreationally important to the people of the island.</u> These resources include numerous species of invertebrates (e.g., shellfish), finfish (e.g., salmonids, baitfish, groundfish), and birds, as well as the living resources that provide feeding and refuge functions for these species. Baseline investigations of these resources, such as herring stocks and shellfish populations, for example, have been historically collected by state and federal agencies. Some of this information is dated or incomplete. Continued monitoring of these biological resources will be required to predict trends in further degradation or recovery of species.

3. <u>Nearshore and estuarine habitats of Bainbridge Island have been impacted by shoreline modifications.</u> Over 82% of Bainbridge Island's shoreline is currently developed, predominated by single-family residential use. Major modifications include shoreline armoring (e.g., bulkheading), fill, removal of riparian vegetation, overwater structures, and marina development. Most watersheds that connect to the coastline have been modified through the removal of riparian vegetation and alteration of hydrology. Most of the small bays are fully developed for residential or industrial use. Only two areas, Blakely Harbor and segments along the western shoreline of Bainbridge Island, are relatively unmodified.

4. Chemical contamination has probably affected some nearshore habitats. Evidence indicates that seaweed blooms (i.e., green tides) have affected eelgrass in Eagle Harbor and cause odor problems in some back bays. These blooms have been linked to heavy inorganic nitrogen load emanating from small streams, as well as to domestic waste discharges. Creosote seepage from the area surrounding Bill Point has been documented and may be affecting the quality of eelgrass and cobble habitats in the vicinity of the Point.

5. The available data regarding Bainbridge Island nearshore resources are dated and lack accuracy across all elements. Technical studies specific to Bainbridge Island are few and varied in detail and study objectives. Most were not designed to specifically address nearshore processes and targeted one habitat type or species group. New data has been collected by the City of Bainbridge Island but are not available for this report. Further data evaluation or additional studies will be required to address known data gaps. Ranking and prioritization for the filling of data gaps is critical to the City for long-range planning purposes, and has not been performed.

6. Many studies have linked the effects of shoreline modifications to changes in nearshore biological functions. Modifications affecting nearshore areas on Bainbridge Island, such as armoring, riparian vegetation removal, overwater structures, marinas, and hydrological alterations, exert effects at varying degrees on an ecosystem's controlling factors (e.g., water depth, substrate type, light level, and wave energy). Impacts that affect controlling factors within an ecosystem may be reflected in changes to habitat structure, and ultimately may be manifested as changes to functions supported by the habitat. For example, armoring-induced erosion of beaches will change the ability of the beach to support spawning of forage fish.

7. Shoreline modifications can have direct, indirect, and cumulative impacts to estuarine and nearshore marine biological resources at a site, as well as to areas well beyond the location of the modifications. In general, it is known that as the number and size of modification increases the region affected can increase. With some modifications, such as armoring of eroding feeder bluffs, the length of shoreline impacted by loss of feeder material can exceed the length of shoreline that is armored. From a landscape perspective, the cumulative impact of losses in connectivity among natural nearshore and estuarine habitats remains difficult to measure and untested.

8. Relatively little controlled research has been directed at documenting and understanding the functional impacts of shoreline modifications to biological resources. Few studies have applied rigorous, hypothesis-based testing that confirms the impacts reported in the literature. Most of the data gaps highlighted in previous reviews remain today with little advancement of the scientific database. This conclusion is presented by several other nearshore investigators (Williams and Thom 2001).

9. The best way to protect sensitive shoreline habitat is to maintain it in a natural condition. Modifications to upland, riparian, estuarine, and marine shoreline habitats can affect areas both adjacent to and far removed from the immediate site of impact. The

cumulative effects of many small modifications also have the potential to produce interactive or synergistic impacts, rather than merely additive impacts, although this remains untested.

10. <u>The design and location of shoreline structures can significantly affect relative impacts to nearshore biological resources.</u> For example, seawalls and bulkheads with solid vertical surfaces (e.g., concrete, wood, and steel) built waterward of MHW may have greater impacts on shoreline biological processes than gradually sloping, rock riprap revetments built above MHW (Williams et al. 2001). Hardened structures have more impact than soft (e.g., coarse sand/large woody debris) armoring alternatives. Additionally, dock structures that are supported above the substrate by piles appear to result in less impact to the nearshore than those built to rest on the substrate. For further reference on this topic, refer to *Overwater Structures: Marines Issues* by Nightingale and Simenstad (2001b). Similarly, overwater structures that are constructed with light-penetrating materials affect the photic zone of the nearshore to a lesser degree than those without those features.

11. <u>Alternatives to hard shoreline armoring, such as beach nourishment and marine riparian vegetation enhancement, use natural materials and may often be a better alternative to minimize damage to habitats and resources.</u> Armoring should be avoided if not necessary. There is a need to systematically examine the long-term success or relative benefits of these natural shoreline components as habitat to nearshore species.

12. <u>Properly designed estuarine restoration projects can return a habitat to a close approximation of its condition prior to disturbance.</u> Restoration, enhancement and creation of estuarine areas are promoted by local, state and federal agencies to improve fish habitat. However, restoration actions vary widely in their “success” rate. The potential for success varies depending on the degree of disturbance that exists at the site and within the landscape where the restoration site is located. In addition, the process of restoring a site may have associated negative impacts in the short term and should be carefully considered in the project evaluation. Additional guidance on this topic can be found in Williams and Thom (2001).

13. <u>Bainbridge Island has some experience and success with smaller nearshore restoration projects.</u> The City should continue to monitor and learn from this experience and seek additional opportunities for restoration and enhancement.

B. RECOMMENDATIONS

1. A baseline inventory of Bainbridge Island nearshore habitat and processes should be produced from Island-specific data supplemented with other databases. This inventory should be used for determining habitat trends, locating critical areas for protection or restoration, and identifying nearshore ecosystems most at risk to cumulative impacts. Base maps should be continually updated for all marine and estuarine shorelines of Bainbridge Island to promote increased understanding and better management.

2. Bainbridge Island should strive to fill data gaps by working independently and in close coordination with other jurisdictions and agencies. Investigators should follow established, accepted methods to collect data (WDNR, WDOE, WDFW, EPA). The city should coordinate data available from agencies and Tribes. If appropriate, Bainbridge Island residents and volunteer groups should be involved in collection and management of data.

3. Bainbridge Island should develop a realistic nearshore management strategy for the Island. The goal of this plan would be to reduce or eliminate new human-induced stressors to the nearshore environment, coupled with restoration and protection of existing systems. The City should identify usable management units for this effort. Units may be drift cells based upon physical parameters, shoreline characteristics reflective of current zoning characteristics, or other methodologies. The City should work in concert with other regional nearshore management activities and strategies (e.g., Kitsap and King Counties, Puget Sound Nearshore Science Team sponsored by the US Army Corps of Engineers) to stay current with progress made by neighboring jurisdictions. This management plan should include the following items, some of which are not yet developed by the City:
   a) A section to educate and inform residents of Bainbridge Island about the importance of the nearshore environment
   b) Policies that promote nearshore protection and impact avoidance and provide incentives to support policy
   c) A nearshore monitoring/adaptive management strategy.

4. Sensitive marine nearshore and estuarine habitat and ecological functions should be protected and restored by avoiding shoreline structural modifications altogether. Protection and conservation of ecologically important natural areas must be prioritized from a landscape perspective, especially those sites recognized for their importance to shoreline processes (e.g., sediment dynamics) and biological functions (e.g., fish migratory corridors or spawning and nursery habitats).

5. Bainbridge Island should evaluate and update current policies to reflect Best Available Science. Best available science is not static. New information is published continuously. Policy and regulation development, to be truly adaptive, must be updated frequently with new information.

6. Bainbridge Island should identify and pursue restoration and preservation projects. This should include the prioritization of areas targeted for restoration and protection. These areas should be identified as sensitive, and policies associated with these areas should reflect long-term protection goals.

7. Phased restoration of natural processes and ecological functions should be achieved through the strategic removal of unnecessary shoreline structures, especially in areas with particularly high rates of shoreline armoring and habitat structural modification. Restoration project planning must be complete and include a site assessment to ensure that the site is as correct as possible for the type of restoration planned and that any modifications needed to correct problems with the site are fully understood and carried out. Restoration is intended to result in a net benefit to the ecosystem, but restoration actions should be considered relative to the potential for success in order to maximize the net benefits.

8. A thorough physical and biological assessment on a site-specific basis must be carried out to fully understand and document the potential direct, indirect and cumulative impacts prior to permitting any shoreline modifications around Bainbridge Island. Evaluations of potential effects of proposed shoreline modifications for a section of Bainbridge Island must consider carefully how these functions will be affected prior to allowance of any modifications to take place. The assessment must be site-specific, landscape sensitive, and scientifically rigorous enough to fully document the need for the modification, balanced by potential (including cumulative) impacts. Measures for protecting critical habitats must incorporate principles of landscape connectivity and extend to activities outside of their conveniently defined boundaries.

9. When definitive scientific information is lacking but potential impacts are likely to occur, the City of Bainbridge Island should err on the side of caution to reach conservative decisions that favor natural ecological functions. The nearshore, including the riparian areas, has been extensively altered, and any unaltered or mildly altered areas likely have enhanced value to preserving remaining habitat functions. Enhancing and restoring these areas to provide a net benefit to habitat functions should be strongly considered.

10. Where new shoreline modifications must occur, impacts should be minimized by pursuing alternative techniques (e.g., setbacks, vegetation, beach nourishment) and natural structure placement strategies. The pressure to allow shoreline armoring along Bainbridge Island is expected to continue and possibly increase as more difficult properties are targeted for development. The City should develop solid professional relationships with scientists and local agencies to maintain up-to-date knowledge of new techniques, options for armoring, and proper avenues to review and process permit applications.

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IX. GLOSSARY OF TERMS

This glossary of terms is a compilation of previous glossaries presented by several publications (Williams and Thom 2001, Nightingale and Simenstad 2001, Komar 1998). It is provided to assist the reader with interpretation of technical terms. Some of these terms may not appear in the text of the BAS document but are provided for completeness.

ACCRETION - Natural accretion is the buildup of land, solely by the action of the forces of nature, on a beach by deposition of water- or airborne material. Artificial accretion is a similar buildup of land by reason of an act of man, such as the accretion formed by a groin, breakwater, or beach fill deposited by mechanical means.

AERIAL - Portion of a plant that remains above the soil surface, such as the leaves.

ALGAE - Simple plant form having no true roots, stems or leaves; ranging in size from microscopic, single-celled plants (microalgae) to seaweeds (macroalgae)

ALONGSHORE - Parallel to and near the shoreline. (LONGSHORE)

AMPHIPOD – Crustaceans in the Order Amphipoda, of subclass Malacostraca.

ANADROMOUS - Fish that reproduce in fresh water, but spend a portion of their life in salt water.

AQUATIC ECOSYSTEM - Bodies of water, including wetlands, that serve as the habitat for interrelated and interacting communities and populations of plants and animals.

ARMORING - Physical modifications to the shoreline implemented by man.

ASSEMBLAGE - The group of species generally associated with a given habitat type.

BACKFILL - Material used to fill behind a small structure such as a seawall or bulkhead. Also, the act of placing material behind a small structure such as a seawall or bulkhead.

BACKSHORE - Zone of beach lying between foreshore and coastline acted upon by waves only during severe storms.

BAITFISH - See forage fish.

BANK – A land surface above the ordinary high water line that adjoins a body of water

BAR - A submerged or emerged embankment of sand, gravel, or other unconsolidated material built on the sea floor in shallow water by waves and currents.

BATHYMETRY - The measurement of depths of water in oceans, seas, and lakes. Also, information derived from such measurements.

BEACH - The zone of unconsolidated material that is moved by waves, wind and tidal currents, extending landward to the coastline.

BEACH FACE - The sloping nearly planar section of the beach profile below the berm, which is normally exposed to the swash of waves

BEACH NOURISHMENT - The process of replenishing a BEACH by artificial means; e.g., by the deposition of dredged materials, also called beach replenishment or beach feeding.

BEACH PROFILE - A vertical cross section of a beach measured perpendicular to the shoreline.

BEACH RESTORATION AND ENHANCEMENT - The alteration or improvement of selected attributes of terrestrial and tidal shorelines or submerged shorelines for the purposes of stabilization, recreational enhancement, or aquatic habitat creation or restoration.

BENTHIC - Growing on or associated principally with the water bottom.

BERM (BEACH BERM) - The nearly horizontal portion at the beach or backshore formed by the deposition of sediments by waves. Some beaches have more than one berm at slightly different levels, separated by a scarp (not very frequent around Bainbridge Island).

BEST MANAGEMENT PRACTICE (BMP) - Method, activity, maintenance procedure, or other management practice for reducing the amount of pollution entering a water body. The term originated from the rules and regulations developed pursuant to Section 208 of the federal Clean Water Act (40 CFR 130).

BIOACCUMULATION - The accumulation of contaminants in the tissues of organisms through any route, including respiration, ingestion, or direct contact with contaminated water, sediment, or dredged material.

BIOTA - The animal and plant life of a region.

BIVALVE - An aquatic invertebrate animal of the class Bivalvia. Bivalves, such as clams and oysters, have two shells (valves) and most are filter feeders.

BLUFF – A high, steep bank or cliff.

BREAKER - A wave that has become so steep that the crest of the wave topples forward, moving faster than the main body of the wave.

BREAKER ZONE - Zone of shoreline where waves break.

BREAKWATER - Structure protecting shore area, harbor, anchorage, or basin from waves. See JETTY.

BUFFER - A strip of land that is designed and designated to permanently remain vegetated in an undisturbed and natural condition to protect an adjacent aquatic or wetland site from impacts

BULKHEAD - Structure or partition built to protect the shoreline from wave erosion. It is normally vertical or consists of a series of vertical sections stepped back from the water. A bulkhead is ordinarily built parallel or nearly parallel to the shoreline. See also SEAWALL, RIPRAP.

CAPPING - Covering up of contaminated sediment in order to prevent toxic release into the environment.

CHANNEL - A natural or artificial waterway of perceptible extent which either periodically or continuously contains moving water, or which forms a connecting link between two bodies of water.

COAST - A strip of land of indefinite length and width (may be tens of kilometers) that extends from the shoreline inland to the first major change in terrain features.

COASTAL PROCESSES - Collective term covering the action of natural forces on the shoreline, and the nearshore seabed.

COASTLINE - (1) Technically, the line that forms the boundary between the coast and the shore. (2) Commonly, the line that forms the boundary between land and the water. (3) The line where terrestrial processes give way to marine processes, tidal current, wind waves, etc.

COASTAL ZONE - Includes coastal waters and the adjacent shorelands designated by a State as being included within its approved coastal zone management program. The coastal zone may include open waters, estuaries, bays, inlets, lagoons, marshes, swamps, mangroves, beaches, dunes, bluffs, and coastal uplands. Coastal-zone uses can include housing, recreation, wildlife habitat, resource extraction, fishing, aquaculture, transportation, energy generation, commercial development, and waste disposal

COMMUNITY - Association of plants and/or animals in a given area or region in which various species are more or less dependent upon each other.

CONTROLLING FACTOR – Physical processes or environmental conditions that control local habitat structure and composition, including where habitat occurs and how much is present (see Williams and Thom 2001)

COPEPOD – Crustacean in the subclass Copepoda; includes both pelagic (Calanoida, Cyclopoda) and benthic/epibenthic (Harpacticoida).

CREST - The seaward limit of a berm. Also, the highest part of a wave.

CROSS-SHORE – Movement in a direction perpendicular to the shoreline, up or down the BEACH PROFILE.

CUMULATIVE EFFECTS - The combined environmental impacts that accrue over time and space from a series of similar or related individual actions, contaminants, or projects. Although each action may seem to have a negligible effect, the combined effect can be significant.

CURRENT - A flow of water.

DEMERSAL - Pertaining to an organism, such as a fish, living close to or on the bottom of a body of water; describing the habitat close to or on the bottom

DENSITY - The number of organisms per unit of area or volume

DEPOSITION - The deposit of sediment in an area through natural means such as wave action or currents; may also be done by man through mechanical means.

DESSICATION - Critical loss of fluids; drying out.

DIFFRACTION – The phenomenon by which energy is transmitted laterally along a wave crest.

DISCHARGE - The release of wastewater or contaminants to the environment. A direct discharge of wastewater flows directly into surface waters while an indirect discharge of wastewater enters a sewer system.

DISTURBANCE - Any natural or man-caused impact to an ecosystem.

DOWNDRIFT - The direction of predominant movement of littoral materials.

DRAFT - The vertical distance on a vessel from the waterline to the bottom of the keel of a boat.

DREDGE - To deepen by removing substrate material. Also, mechanical or hydraulic equipment used for excavation.

DRIFT CELL – A segment of shoreline along which littoral, or longshore, sediment movement occurs at noticeable rates. It allows for an uninterrupted movement, or drift, of beach materials. Each drift sector includes: a feed source that supplies the sediment, a driftway along which the sediment can move, an accretion terminal where the drift material is deposited, and boundaries that delineate the end of the drift sector. (Also called a DRIFT CELL or LITTORAL CELL).

ECOLOGICAL FUNCTIONS – The use and benefits of habitats to associated biological communities. Those natural physical, chemical, and biological processes that contribute to the proper functioning and maintenance of aquatic and terrestrial ecosystems.

ECOSYSTEM - The organization of all biotic and abiotic factors in an area, usually delineated by natural geographic barriers.

EELGRASS (HABITAT) -Intertidal and shallow subtidal, unconsolidated sand to mud shores that are colonized by aquatic, submerged rooted vascular angiosperms (seagrasses) of the genus *Zostera*. Two species predominate in the Pacific Northwest: *Zostera marina*, the endemic eelgrass, and *Z. japonica*, an introduced cogener

EMBANKMENT - Artificial bank such as a mound or dike, generally built to hold back water or to carry a roadway.

ENTRAINMENT - When an organism is trapped in the uptake of sediments and water being removed by dredging machinery.

EPIBENTHOS - Organisms that live on the surface of the bottom sediment. (EPIBENTHIC)

EROSION - The wearing away of land by natural forces, such as gravity and hydraulic action. On a beach, the carrying away of beach material by wave action, tidal currents, or littoral currents.

ESTUARY - Region near river mouth where freshwater mixes with saltwater; as defined seaward by the measurable dilution of seawater, upstream by the limit of tidal influence, and landward by MEAN HIGHER HIGH WATER, but including transition riparian and upland habitat margins (ESTUARINE)

FACE - The front or exposed area of a slope or structure.

FEEDER BLUFF OR EROSIONAL BLUFF - Any bluff or cliff experiencing periodic erosion from waves, sliding or slumping that, through natural transportation, contributes eroded earth, sand or gravel material via a driftway to an accretion shoreform. These natural sources of beach material are limited and vital for the long-term stability of driftways and accretion shoreforms (e.g., spits, bars, and hooks).

FETCH - The distance over unobstructed open water on which waves are generated by a wind having a constant direction and speed.

FIXED PIER - A fixed structure supported by pilings

FLOATING PIER (FLOATS) - A floating structure that is moored, anchored, or otherwise secured in the water, but which is not connected to the shoreline.

FORAGE FISH - Group of fish that are important to salmonids as food, such as herring, sandlance, and surfsmelt (BAITFISH).

GABION - Hollow cylinder or wire mesh basket filled with earth or stone, used to build REVETMENTS or BULKHEADS.

GEOMORPHOLOGY - The shape or form of a natural surface or object. Also, the study of the forms of the land surface and the processes producing them.

GROIN - A rigid structure built at an angle (usually perpendicular) from the shore to protect it from erosion or to trap sand. A groin may be further defined as permeable or impermeable depending on whether or not it is designed to pass sand through it.

GROUNDWATER - Underground water supplies, also called aquifers. Water soaks into the ground until it reaches a point where the ground is not permeable. Ground water usually then flows laterally toward a river or lake, or the ocean.

HABITAT - Interacting physical and biological factors that provide at least minimal conditions for one organism to live or for a group of organisms to occur together.

HABITAT FUNCTION – The use and benefits of physical and biological factors to associated biological communities or organisms (ECOLOGICAL FUNCTION, HABITAT).

HABITAT STRUCTURE – The physical composition of HABITAT (see Williams and Thom 2001). In aquatic systems, habitat structur, and its three-dimensional complexity, is manifested in many features (e.g., rocks, sediment, vegetation, woody debris, coral, oyster reefs) and increases available surface are, thereby resulting in potential for increased resource diversity for organisms.

HARBOR AREA - Area of navigable tidal waters as determined in Section 1 of Article 15 of the Washington State Constitution, which is forever reserved for landings, wharves, streets, and other conveniences of navigation and commerce.

HYDRAULIC - Of or pertaining to water.

HYDROLOGY - The dynamics of water movement through an area, including over and through land.

IMPACT - An action producing a significant causal effect of the whole or part of a given area.

IMPERVIOUS SURFACE - A surface that cannot be easily penetrated. For instance, rain does not readily penetrate asphalt or concrete pavement and groundwater cannot readily penetrate clay or bedrock.

IMPOUNDMENT - The retention or trapping of sediment in a location, either by natural or structural means.

INFAUNA - Organisms that live within the sediment underlying a body of water.

INSHORE – The zone of the bench profile extending seaward from the foreshore to just beyond the breaker zone.

INTERTIDAL – Pertaining to the area exposed at low tides and inundated at high tides; defined as the area between between MHHW and MLLW.

INVERTEBRATES - Animals that lack a bony or cartilaginous skeleton.

JETTY – A structure extending into a body of water and designed to prevent shoaling of a channel by littoral materials and to direct or confine the stream or tidal flow.

LAND USE - The way land is developed and used in terms of the types of activities allowed (agriculture, residences, industries, etc.) and the size of buildings and structures permitted. Certain types of pollution problems are often associated with particular land-use practices, such as sedimentation from construction activities.

LWD - Large woody debris.

LITTORAL - Of or pertaining to the shore

LONGSHORE CURRENT – The littoral current in the breaker zone moving essentially parallel to the shore.

LONGSHORE TRANSPORT – Transport of sedimentary material parallel to the shore.

MACROFAUNA - Animals that are of a visible size, generally with lengths equal to or larger than 0.5 mm (sometimes 1.0 mm).

MARINA - A public or private facility providing boat moorage space, fuel, or commercial services. Commercial services include, but are not limited to, overnight or live-aboard boating accommodations.

MACROINVERTEBRATES - Invertebrates that are of visible size, such as clams and worms.

MARINE - Water that contains high salt content (>30 ppt), as opposed to freshwater.

MARSH - An area of soft, wet, or periodically inundated land, generally treeless and usually characterized by grasses and other low growth.

MEAN HIGHER-HIGH WATER - The average of the measured higher-high water levels typically over a 19-yr period.

MEAN HIGH WATER - The average of all measured high water levels, including both the higher-high and lower-high recorded levels, typically over a 19-yr period.

MEAN LOW WATER - The average of all measured low water levels, including both the higher-low and lower-low recorded levels, typically over a 19-yr period.

MEAN LOWER-LOW WATER: The average height of the lower-low water levels, typically over a 19-yr period.

MEAN SEA LEVEL: The average height of the surface of the sea for all stages of the tide over a 19-year period, usually determined from hourly height readings.

MICROCLIMATE - The physicochemical conditions generally observed in a small, specific region such as an estuary or under a rock.

MIGRATION - The seasonal travel of an animal between habitats.

MIGRATORY CORRIDOR - The physical pathway through which animals migrate.

MUDFLAT - Low, unvegetated mud substrate that is flooded at high tide and uncovered at low tide.

NEARSHORE or NEARSHORE ZONE - In beach terminology an indefinite zone extending seaward from the shoreline well beyond the breaker zone.

NON-POINT SOURCE POLLUTION – Pollution that enters water from dispersed and uncontrolled sources (such as surface runoff) rather than through pipes. Non-point sources (e.g., forest practices, agricultural practices, on-site sewage disposal, and recreational boats) may contribute pathogens, suspended solids, and toxicants. While individual sources may seem insignificant, the cumulative effects of nonpoint source pollution can be significant.

NOURISHMENT - Process of replenishing a beach; naturally by longshore transport or artificially by deposition of imported material. (BEACH NOURISHMENT)

NUTRIENTS—essential chemicals needed by plants or animals for growth. If other physical and chemical conditions are optimal, excessive amounts of nutrients can lead to degradation of water quality by promoting excessive growth, accumulation, and subsequent decay of plants, especially algae. Some nutrients can be toxic to animals at high concentrations.

OFFSHORE – Term to describe the area seaward of the breaker zone, extending in a direction seaward from the shore.

ORDINARY HIGH WATER MARK: That mark that will be found by examining and ascertaining where the presence and action of waters are so common and usual, and so long continued in all ordinary years, as to mark upon the soil a character distinct from the abutting upland, in respect to vegetation as that condition exists on June 1, 1971, as it may naturally change. Thereafter, or as it may change thereafter in accordance with permits issued by a local government or the department [of ecology]: provided, that in any area where the ordinary high water mark cannot be found, the ordinarily high water mark adjoining salt water shall be the line of mean higher high tide (WAC 173-27).

OSMOREGULATION – (1) Maintenance of optimal and constant osmotic pressure in the body of a living organism (Webster's II New College Dictionary, 1999). (2) The maintenance of internal body fluids at a different osmotic pressure (usually higher) than that of the external aqueous environment; i.e., the salt concentration of internal body fluids is maintained at a different level from that of the environment.

OUTFALL - Structure extending into a body of water for the purpose of discharging an effluent (sewage, storm runoff, cooling water).

OUTMIGRATION - Refers to the act of anadromous salmonids when leaving freshwater and migrating to the sea for part of their life.

OVERWATER STRUCTURES - Man-made structures that extend over all or part of the surface of a body of water, such as a pier.

PAH – Polyaromatic hydrocarbons.

PHOTIC ZONE - The surface waters of the ocean that receive light. Includes the euphotic and disphotic zones. For Puget Sound / Bainbridge Island this is usually –10 m to –30 m MLLW depending on turbidity.

PIER - A fixed, pile-supported structure secured to the shoreline

PILE - Long, heavy timber or section of concrete or metal driven or jetted into earth or seabed for support or protection.

PILING - Group of piles.

PLANKTON - Suspended microorganisms with relatively little power of locomotion that drift in water and are subject to action of waves or currents.

POINT - A low profile beach promontory, generally of triangular shape whose apex extends seaward

POINT SOURCE POLLUTANT - Pollutants from a single point of conveyance such as a pipe. For example, the discharge from a sewage treatment plant or a factory outfall is a point source pollutant. See also NON-POINT SOURCE POLLUTANT, POLLUTANT.

POLLUTANT - A contaminant that adversely alters the physical, chemical or biological properties of the environment. The term includes pathogens, toxic metals, carcinogens, oxygen demanding materials, and all other harmful substances. With reference to non-point sources, the term is sometimes used to apply to contaminants released in low concentrations from many activities that collectively degrade water quality. As defined in the federal Clean Water Act, pollutant means dredged spoil, solid waste, incinerator residue, sewage, garbage, sewage sludge, munitions, chemical wastes, biological materials, radioactive materials, heat, wrecked or discarded equipment, rock, sand, cellar dirt, and industrial, municipal and agricultural waste discharged into water.

PRIORITY HABITAT—a habitat type with unique or significant value to one or more species. An area classified and mapped as priority habitat must have one or more of the following attributes:

A. Comparatively high fish and wildlife density;

B. Comparatively high fish and wildlife species diversity;

C. Important fish and wildlife breeding habitat;

D. Important fish and wildlife seasonal ranges;

E. Important fish and wildlife movement corridors;

F. Limited availability;

G. High vulnerability to habitat alteration; or

H. Unique or dependent species. A priority habitat may be described by a unique vegetation type or by a dominant plant species that is of primary importance to fish and wildlife (such as, oak woodlands, eelgrass meadows).

A priority habitat may also be described by a successional stage (e.g., old growth and mature forests). Alternatively, a priority habitat may consist of a specific habitat element (such as, consolidated marine/estuarine shorelines, talus slopes, caves, snags) of key value to fish and wildlife. A priority habitat may contain priority and/or non-priority fish and wildlife.

PRIORITY SPECIES—fish and wildlife species requiring protective measures and/or management guidelines to ensure their perpetuation. Priority species are those that meet any of the following criteria:

A. State-listed or state candidate species. State-listed species are those native fish and wildlife species legally designated as endangered (§232-12-014 WAC), threatened (§232-12-011 WAC), or sensitive (§232-12-011 WAC). State candidate species are those fish and wildlife species that will be reviewed by the department of fish and wildlife for possible listing as endangered, threatened, or sensitive according to the process and criteria defined in §232-12-297 WAC.

B. Vulnerable aggregations. Vulnerable aggregations include those species or groups of animals susceptible to significant population declines, within a specific area or statewide, by virtue of their inclination to congregate. Examples include heron rookeries, seabird concentrations, marine mammal haulouts, shellfish beds, and fish spawning and rearing areas.

C. Species of recreational, commercial, and/or tribal importance. Native and nonnative fish, shellfish, and wildlife species of recreational or commercial importance and recognized species used for tribal ceremonial and subsistence purposes that are vulnerable to habitat loss or degradation.

D. Species listed under the Endangered Species Act as either threatened or endangered. Federal candidate species are evaluated individually to determine their status in Washington and whether inclusion as a priority species is justified.

PRODUCTION—the amount of organic matter generated per unit of time or area by a plant or an animal

PRODUCTIVITY—the rate at which plants or animals generate organic matter

RAMP - A uniformly sloping platform, walkway, or driveway. The ramp commonly seen in the coastal environment is the launching ramp, which is a sloping platform for launching small craft.

REEF - An offshore chain or ridge of rock, shell, or sand at or near the surface of the water.

REFRACTION – The process by which the direction of a wave moving in shallow water at an angle to the contour is changed, causing the wave crest to bend toward alignment with the underwater contour.

REFUGE - Habitat area that provides protection from predators or disturbance.

RELIEF - The elevational features of a surface.

RENOURISHMENT - The follow-up nourishment of a beach NOURISHMENT or fill project, often required in high energy areas with rapid erosion.

RETAINING WALL - Wall built to keep bank of earth from sliding or water from flooding.

REVETMENT - A sloped facing built to protect existing land or newly created embankments against erosion by wave action, currents, or weather. Revetments are usually placed parallel to the natural shoreline.

RIP CURRENT - A strong surface current flowing seaward from the shore.

RIPARIAN - Pertaining to the terrestrial fringe of vegetation along a body of water.

RIPRAP - Layer, facing, or protective mound of stones placed to prevent erosion, scour, or sloughing of structure or embankment. May be used in construction of a REVETMENT or BULKHEAD (ARMORING).

RUBBLE - Rough, irregular fragments of broken rock.

RUNUP - The rush of water up a structure or beach on the breaking of a wave.

RUNOFF - The liquid fraction of dredged material or the surface flow caused by precipitation on upland or nearshore dredged material disposal sites.

SALINITY - A measure of the concentration of dissolved salts in water, usually expressed as parts per thousand (ppt.)

SALMONID – Includes all species of fishes in the family Salmonidae (trout and salmon). Salmonids are the dominant fishes in the cold-water streams and lakes of North America and Eurasia. Most Puget Sound salmonids are ANADROMOUS.

SANDFLAT - Area extending from shoreline seaward that exhibits primarily sand substrate.

SCOUR - The removal of underwater material by waves and currents, especially at the base or toe of a structure.

SEAWALL – Substantial structure separating land and water areas, primarily designed to protect land against damage from wave action. See also BULKHEAD.

SEDIMENT - Material, such as sand, silt, or clay, suspended in or settled on the bottom of a water body. Sediment input to a body of water comes from natural sources, such as erosion of soils and weathering of rock, or as the result of anthropogenic activities, such as forest or agricultural practices, or construction activities. The term dredged material refers to material that has been dredged from a water body, while the term sediment refers to material in a water body prior to the dredging process.

SEDIMENT DYNAMICS - The physical processes that sediment particles are subject to in an area, such as longshore drift.

SEDIMENT SOURCE - A point or area on a coast from which beach material arises, such as an eroding cliff, or river mouth.

SEMI-DIURNAL TIDE – A tide with two high and two low waters in a tidal day with comparatively little diurnal inequality.

SHORE – The narrow strip of land in immediate contact with the sea, including the zone between high and low water lines. A shore of unconsolidated material is usually called a beach.

SHORELINE - The intersection of a specified plane of water with the shore or beach.

SHORELINE DEVELOPMENT - As regulated by the Shoreline Management Act (Chapter 90.58 RCW) the construction over water or within a shoreline zone (generally 200 feet landward of the water) of structures such as buildings, piers, bulkheads, and breakwaters, including environmental alterations such as dredging and filling, or any project which interferes with public navigational rights on the surface waters.

STORM SURGE – A rise above normal water level on the open coast due to the action of wind forces on the water surface or to atmospheric pressure reduction.

STORM WATER - Water that is generated by rainfall and is often routed into drain systems in order to prevent flooding. See also NON- POINT SOURCE POLLUTION.

STORM WAVE – Wave generated by strong winds during a storm event that can attain height.

STRUCTURE – A permanent or temporary edifice or building, or any piece of work artificially built or composed of parts joined together in some definite manner on, above, or below the surface of the ground or water, except for vessels.

SUBSTRATE - Solid material upon which an organism lives or to which it is attached.

SUBTIDAL - The marine environment below low tide.

SURF ZONE - The area between the outermost breaker and the limit of wave uprush.

SURFACE WATER - Water that travels across the surface of the ground, rather than infiltrating.

SUSPENDED SOLIDS - Organic or inorganic particles that are suspended in water. The term includes sand, silt, and clay particles as well as other solids, such as biological material, suspended in the water column.

SWELL – Wind-generated waves that have traveled out of their generating area. Swell characteristically exhibits a more regular and longer period and has flatter crests than waves within their fetch.

TERRESTRIAL - Growing or living on or peculiar to the land, as opposed to the aquatic environment.

TIDAL CHANNEL – A channel through which water drains and fills intertidal areas or connects two bodies of water.

TIDAL CURRENT – The alternative horizontal movement of water associated with the rise and fall of the tide caused by the astronomical tide-producing forces.

TIDAL FLAT - The sea bottom, usually wide, flat, muddy, and unvegetated which is exposed at low tide; marshy or muddy area that is covered and uncovered by the rise and fall of the tide.

TIDAL RANGE – The difference in height between consecutive high and low water.

TOE - The lowest part of a bluff, bank, or shoreline structure, where a steeply sloping face meets the beach.

TOMBOLO - A causeway-like accretion spit connecting an offshore rock or island with the main shore

TOPOGRAPHY - The configuration of a surface, including its relief and the positions of its streams, roads, buildings, etc.

TRAINING WALL - A wall or jetty to direct current flow.

TRANSPORT - The movement of sediment along a current pathway.

TURBIDITY - A measure of the clarity of water, indicating quantities of suspended material. Higher turbidity results in lower levels of light penetration throughout the water column.

UNDERTOW - A current below water surface flowing seaward; the receding water below the surface from waves breaking on a shelving beach.

UPLANDS - The land above a shoreline.

URBAN GROWTH – Growth that makes intensive use of land for the location of buildings, structures, and impermeable surfaces to such a degree as to be incompatible with the primary use of land for the production of food, other agricultural products, or fiber, or the extraction of mineral resources, rural uses, rural development, and natural resource lands designated pursuant to §36.70A.170 RCW. A pattern of more intensive rural development, as provided in §36.70A.070(5)(d) RCW, is not urban growth. When allowed to spread over wide areas, urban growth typically requires urban governmental services. "Characterized by urban growth" refers to land having urban growth located on it, or to land located in relationship to an area with urban growth on it as to be appropriate for urban growth.

WATER COLUMN - The water in a lake, estuary, or ocean which extends from the bottom sediments to the water surface.

WATERSHED - The geographic region within which water drains into a particular river, stream or body of water. A watershed includes hills, lowlands and the body of water into which the land drains. Watershed boundaries are defined by the ridges of separating watersheds.

WAVE – A ridge, deformation, or undulation of the surface of a liquid.

WAVE ENERGY - Force exhibited by waves, which culminates in impact to an object or surface.

WAVE HEIGHT – The vertical distance between a crest and the preceding trough.

WAVE PERIOD – The time for two successive wave crests to pass a fixed point.

WAVE STEEPNESS - The ratio of the wave height to the wavelength.

WETLANDS - Lands transitional between terrestrial and aquatic systems where the water table is usually at or near the surface or the land is covered by shallow water.

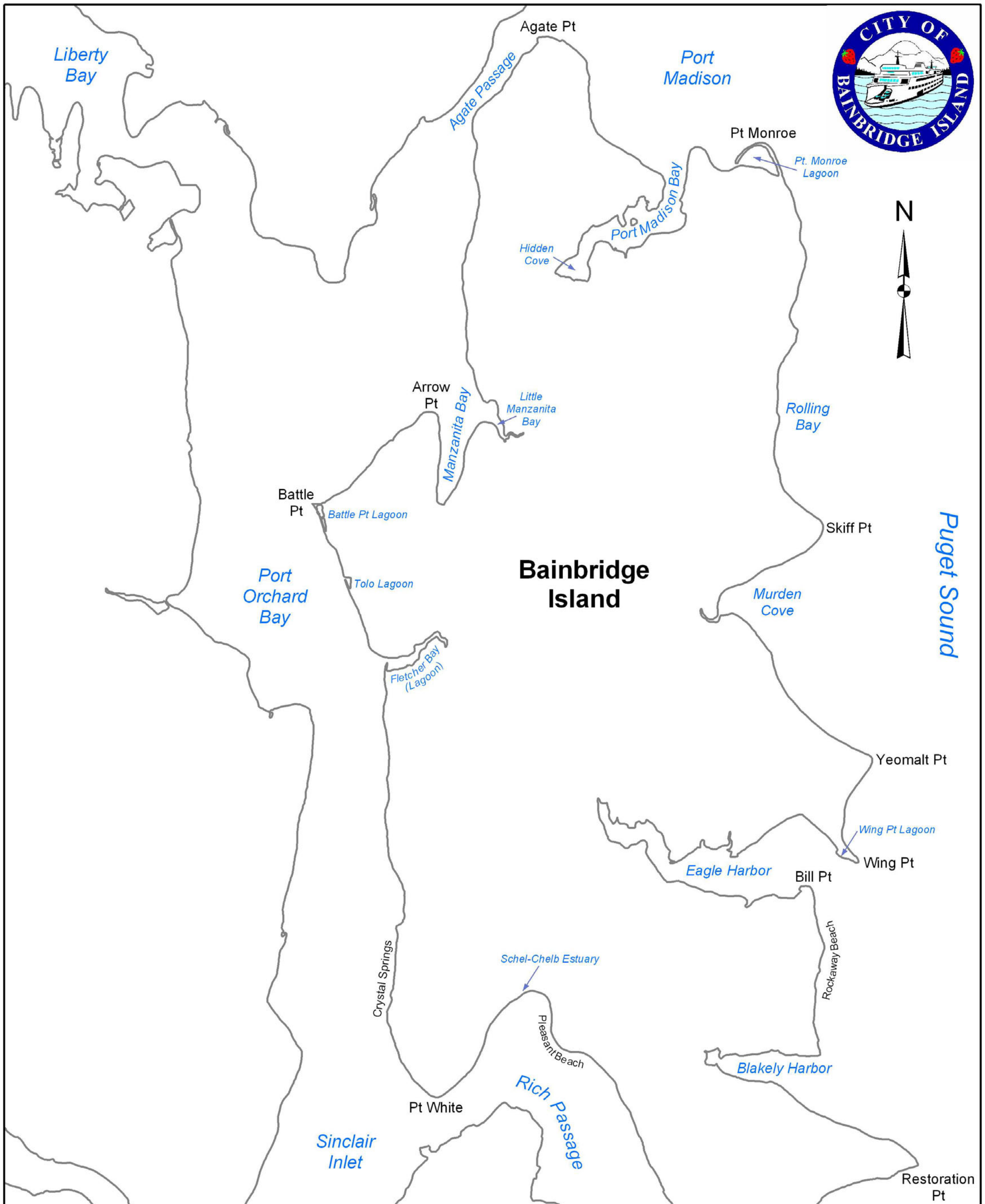
YOUNG-OF-THE-YEAR - Animals at 0 + years of age (i.e. less than one year of age)

ZONING - To designate, by ordinances, areas of land reserved and regulated for specific land uses.

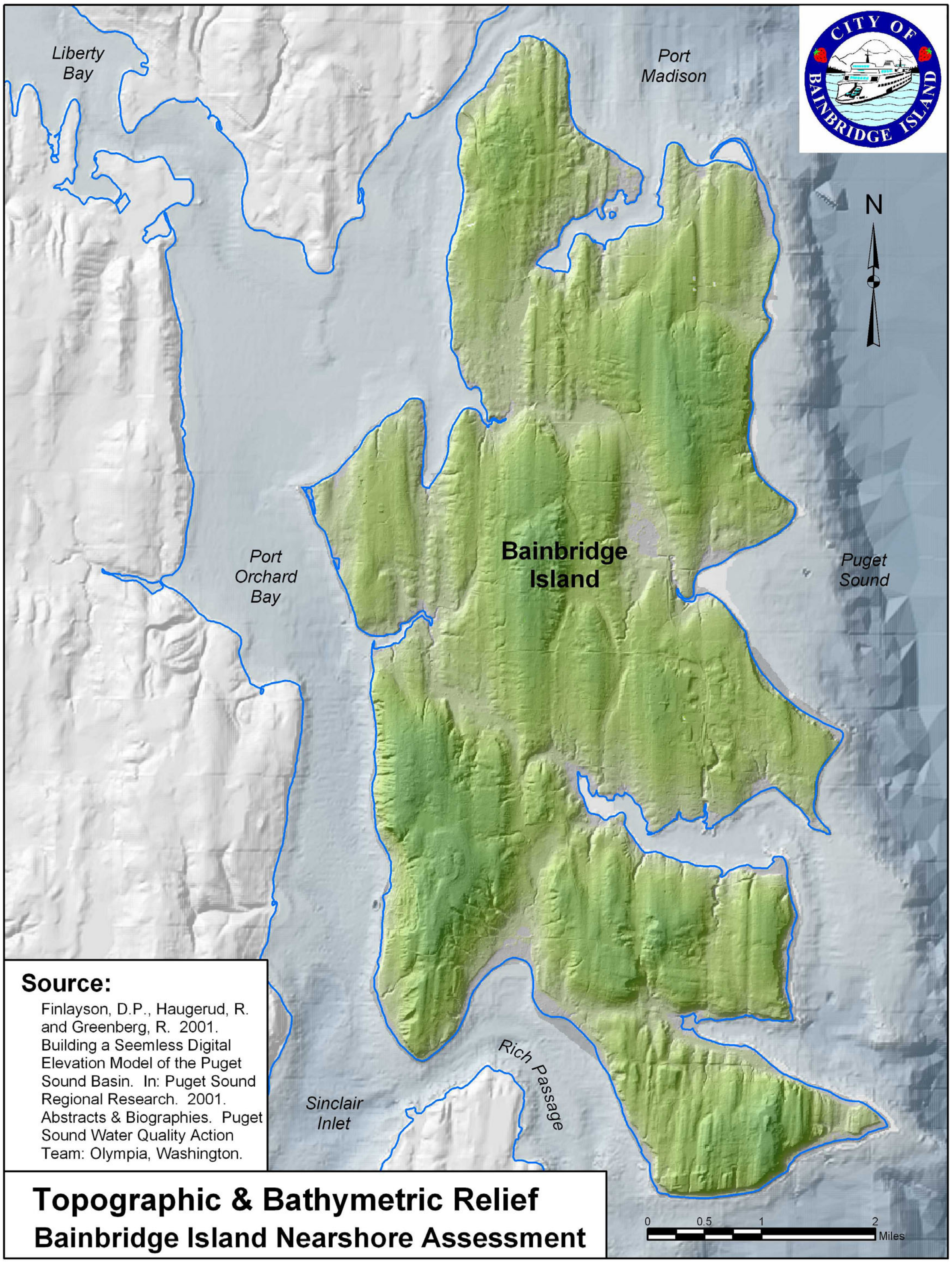
ZOOPLANKTON - The group of small, primarily microscopic, passively suspended or weakly swimming animals in the water column.

X. APPENDICES

A. BAINBRIDGE ISLAND NEARSHORE ASSESSMENT MAPS



Nearshore Geography
Bainbridge Island Nearshore Assessment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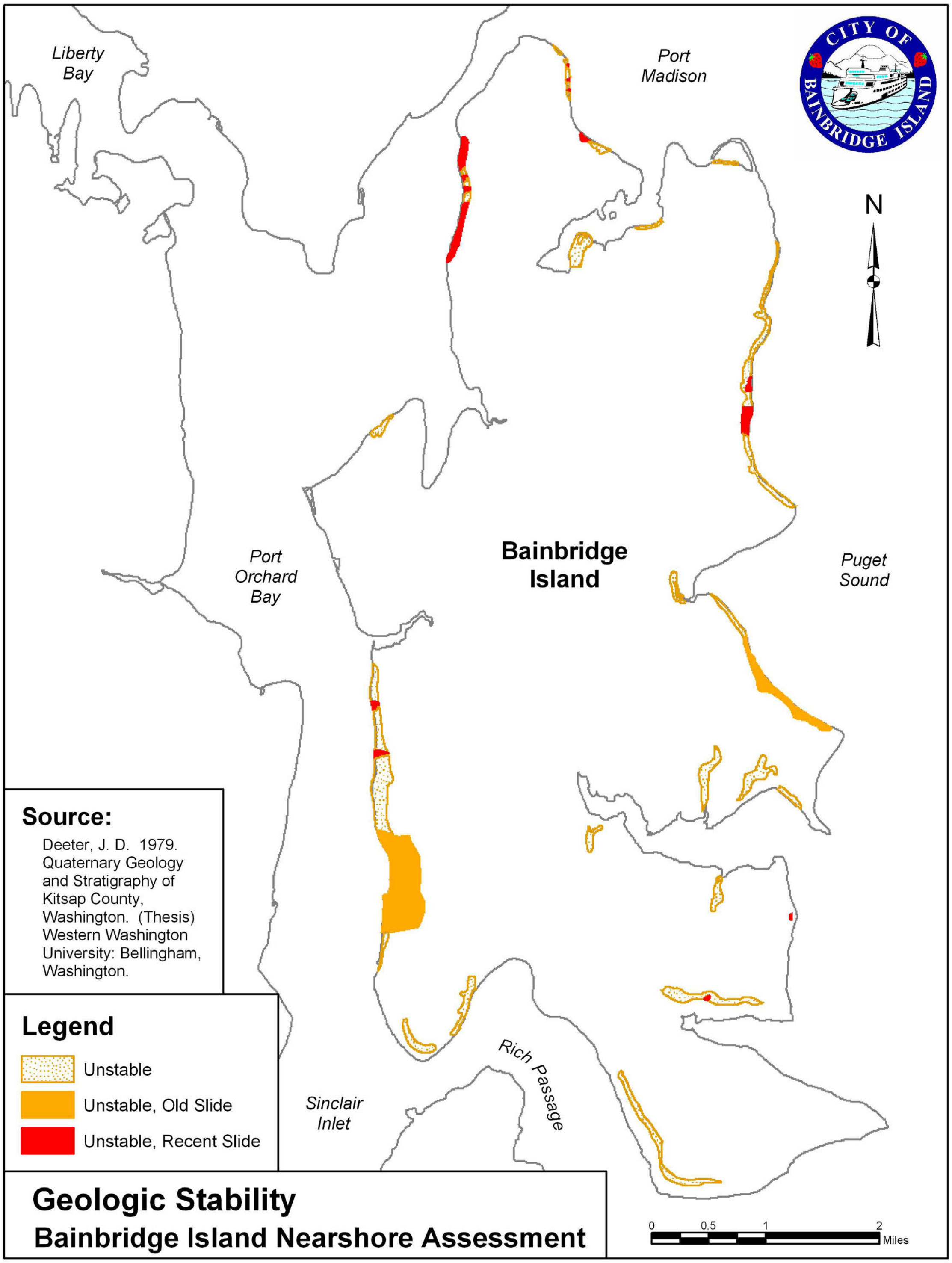
Port Madison
CITY OF BAINBRIDGE ISLAND
N
Port Orchard Bay
Bainbridge Island
Puget Sound
Sinclair Inlet
Rich Passage
Source:
Finlayson, D.P., Haugerud, R. and Greenberg, R. 2001. Building a Seemless Digital Elevation Model of the Puget Sound Basin. In: Puget Sound Regional Research. 2001. Abstracts & Biographies. Puget Sound Water Quality Action Team: Olympia, Washington.
Topographic & Bathymetric Relief
Bainbridge Island Nearshore Assessment
0 0.5 1 2
Miles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Port Madison
CITY OF BAINBRIDGE ISLAND
N
Port Orchard Bay
Bainbridge Island
Puget Sound
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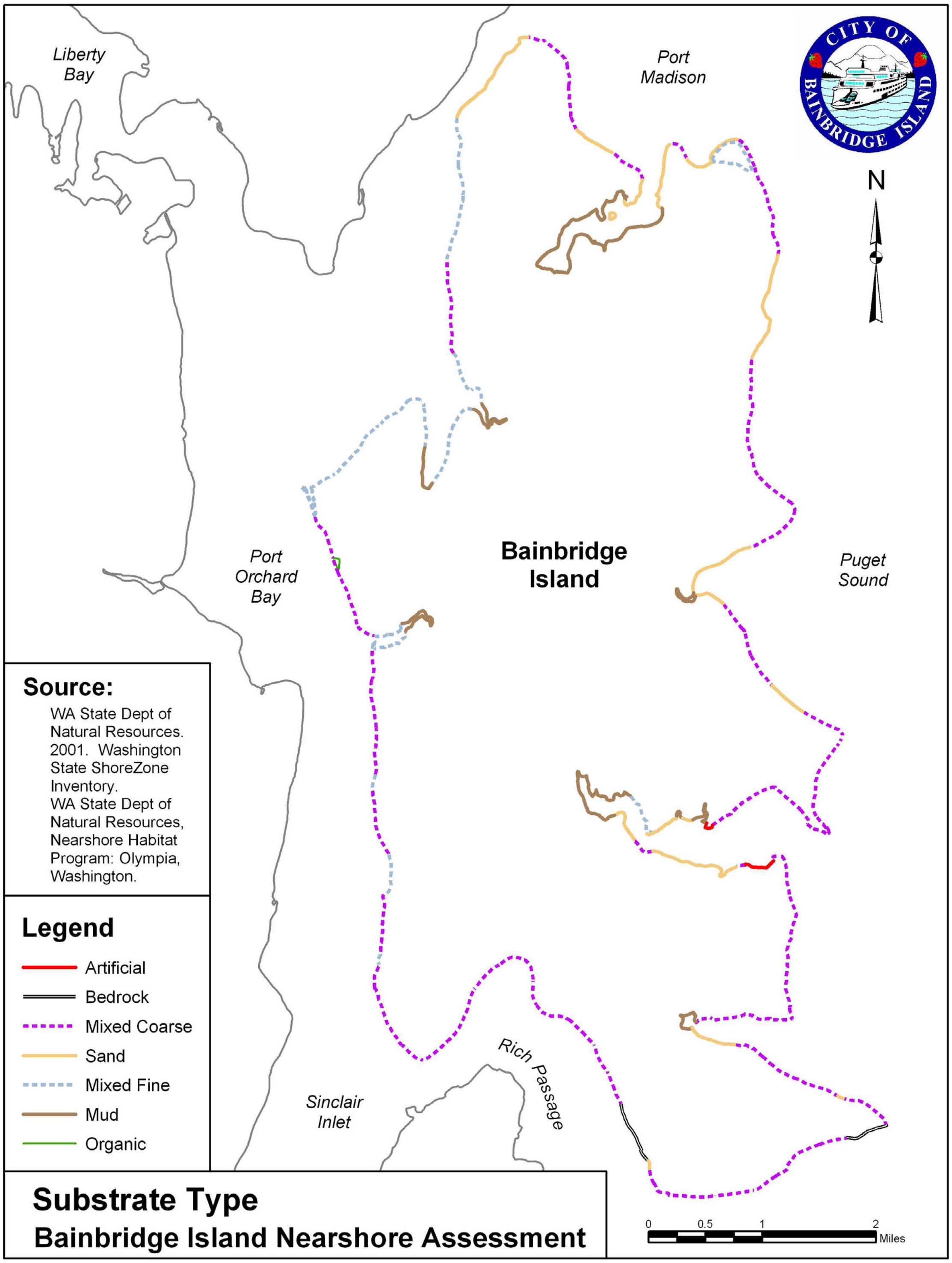
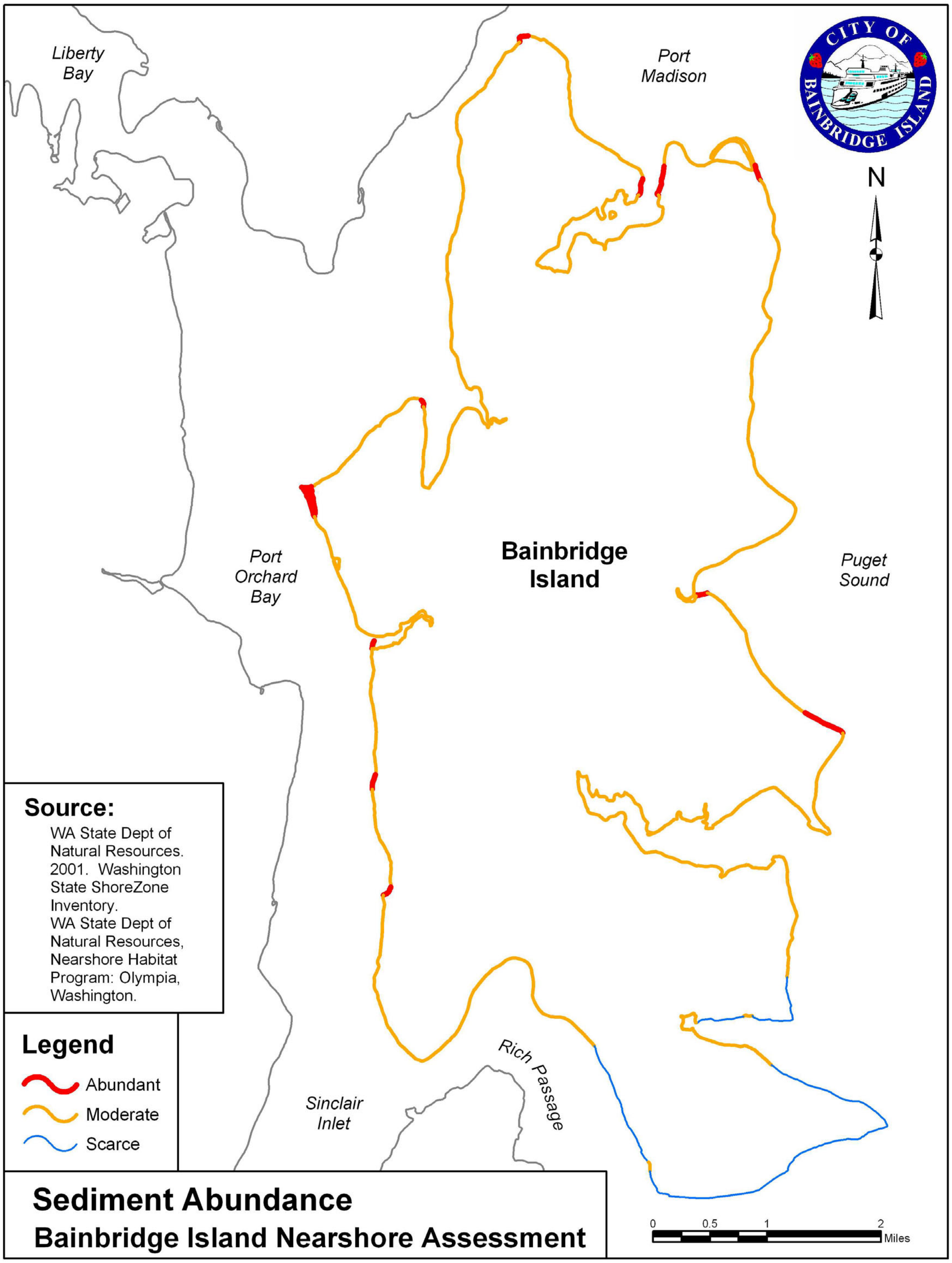
Deeter, J. D. 1979. Quaternary Geology and Stratigraphy of Kitsap County, Washington. (Thesis) Western Washington University: Bellingham, Washington.
Legend
Unstable
Unstable, Old Slide
Unstable, Recent Slide
Sinclair Inlet
Rich Passage
Geologic Stability
Bainbridge Island Nearshore Assessment
0 0.5 1 2 Miles


Liberty Bay
Port Madison
CITY OF BAINBRIDGE ISLAND
N
Port Orchard Bay
Bainbridge Island
Puget Sound
Source:
WA State Dept of Natural Resources. 2001. Washington State ShoreZone Inventory.
WA State Dept of Natural Resources, Nearshore Habitat Program: Olympia, Washington.
Legend
Artificial
Bedrock
Mixed Coarse
Sand
Mixed Fine
Mud
Organic
Rich Passage
Sinclair Inlet
Substrate Type
Bainbridge Island Nearshore Assessment
0 0.5 1 2 Miles


Liberty
Bay
Port
Madison
CITY OF BAINBRIDGE ISLAND
N
Port
Orchard
Bay
Bainbridge
Island
Puget
Sound
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WA State Dept of Natural Resources, Nearshore Habitat Program: Olympia, Washington.
Legend
Abundant
Moderate
Scarce
Rich Passage
Sinclair
Inlet
Sediment Abundance
Bainbridge Island Nearshore Assessment
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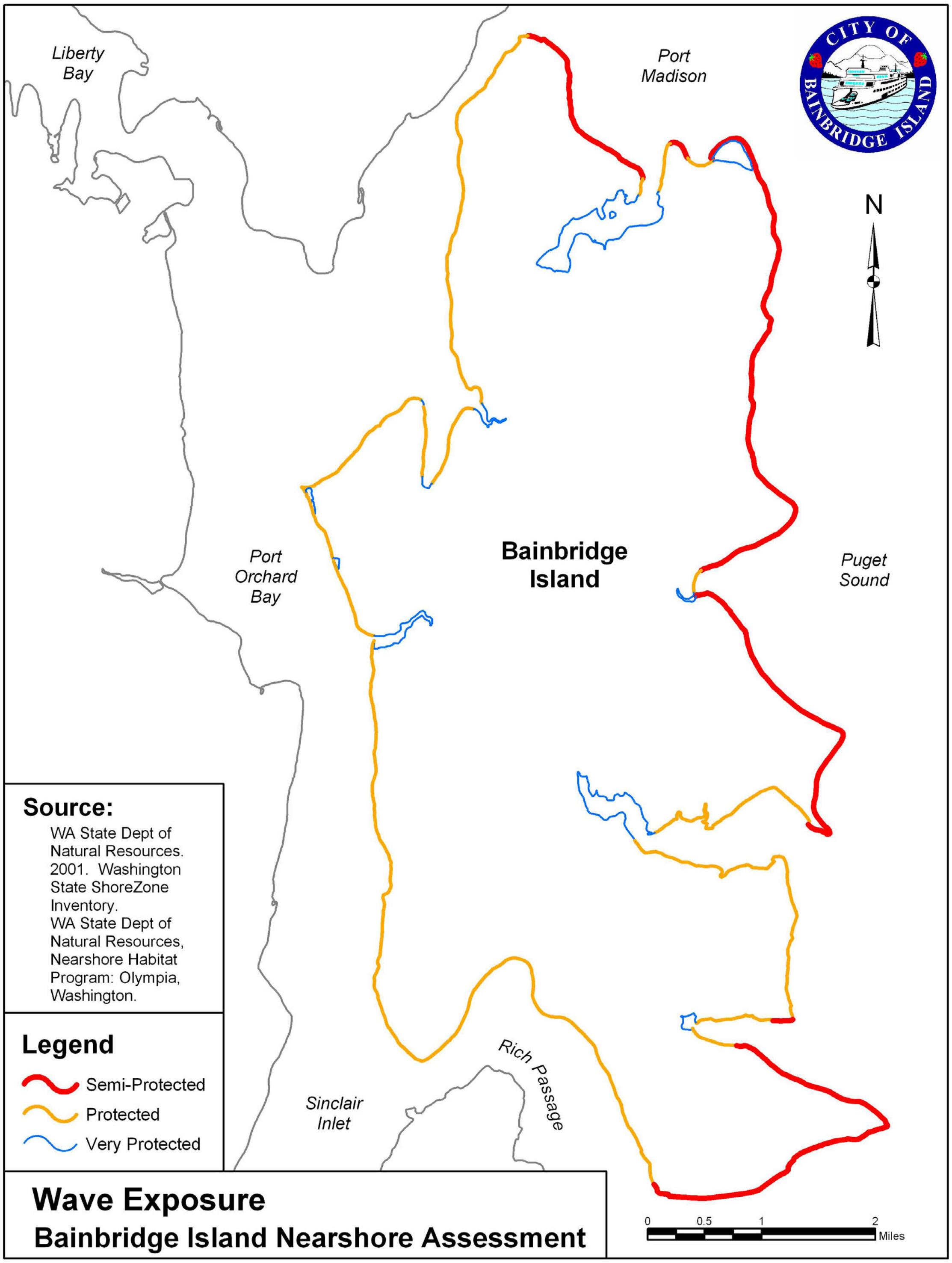
0.5
1
2
Miles


Liberty Bay
Port Madison
CITY OF BAINBRIDGE ISLAND
N
Port Orchard Bay
Bainbridge Island
Puget Sound
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WA State Dept of Natural Resources, Nearshore Habitat Program: Olympia, Washington.
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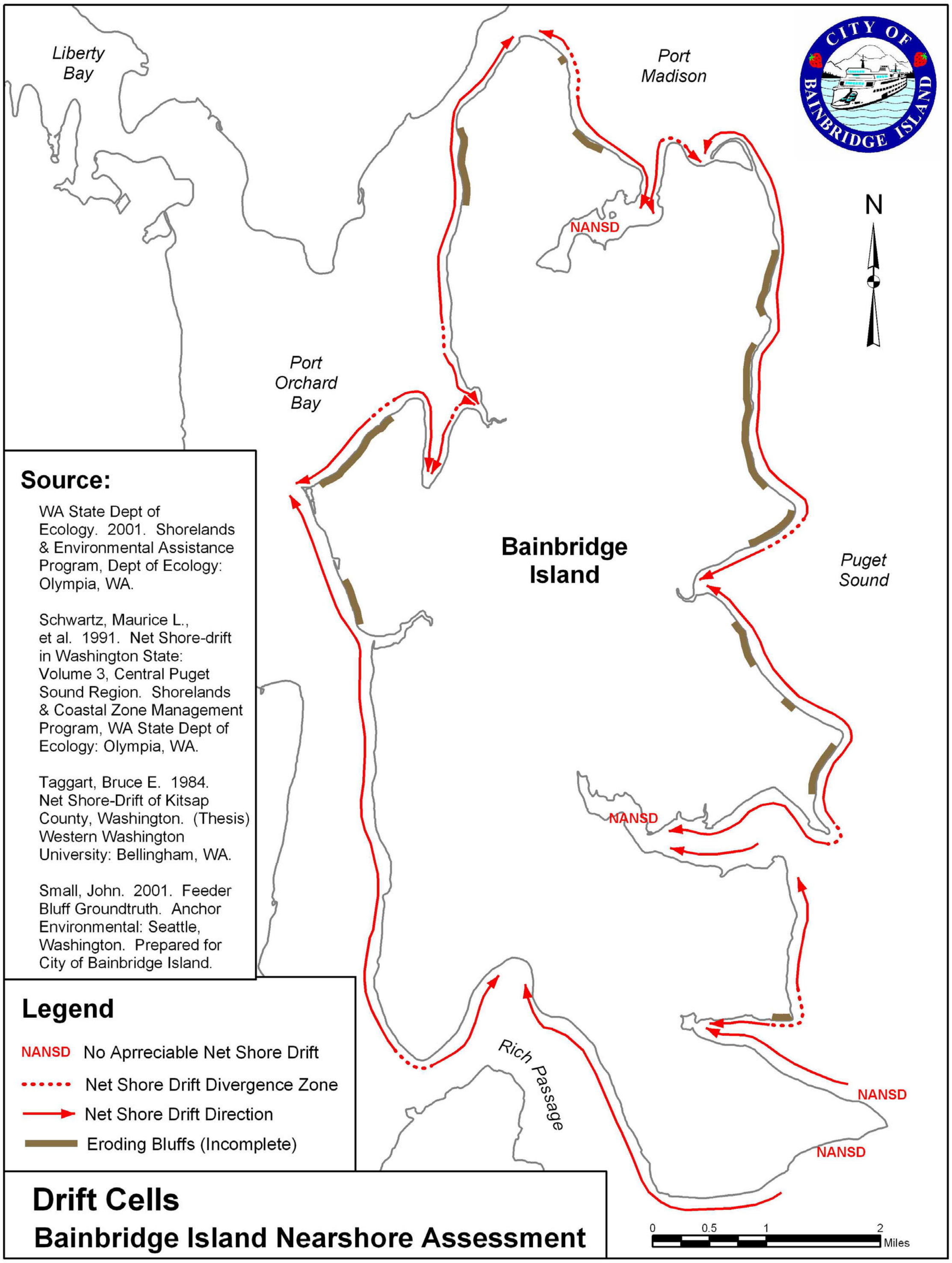
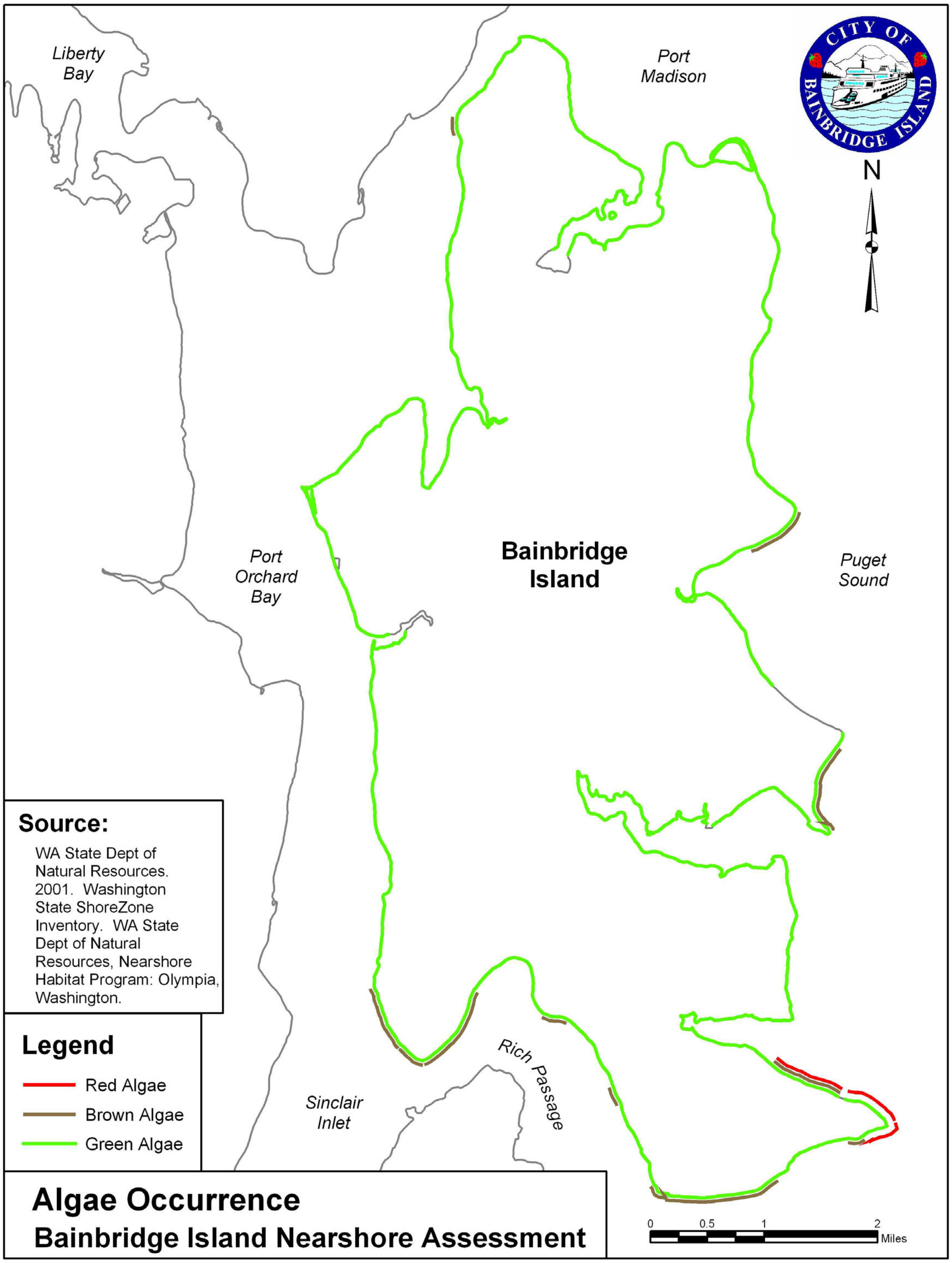
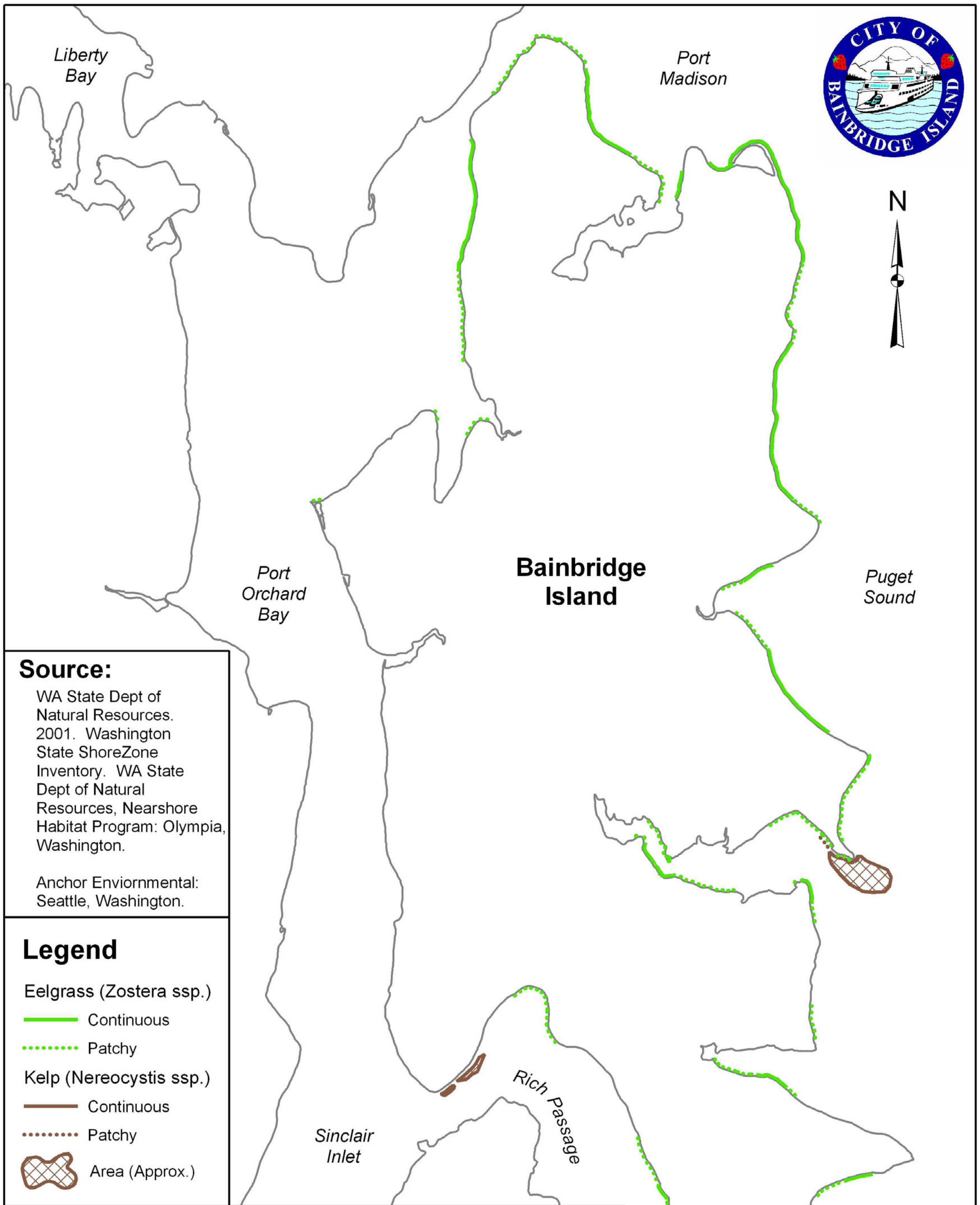
Semi-Protected
Protected
Very Protected
Rich Passage
Sinclair Inlet
Wave Exposure
Bainbridge Island Nearshore Assessment
0 0.5 1 2 Miles



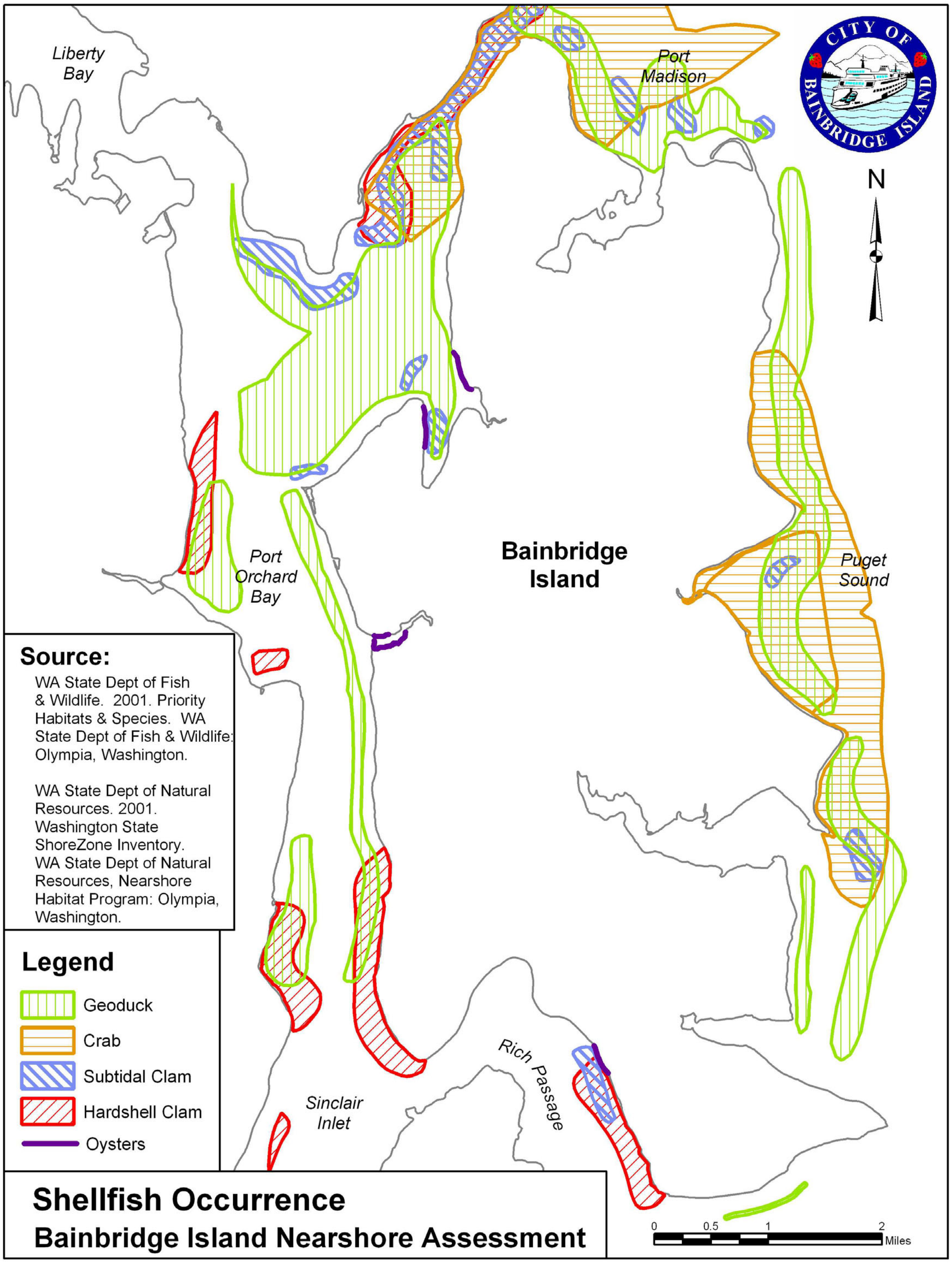
Drift Cells
Bainbridge Island Nearshore Assessment

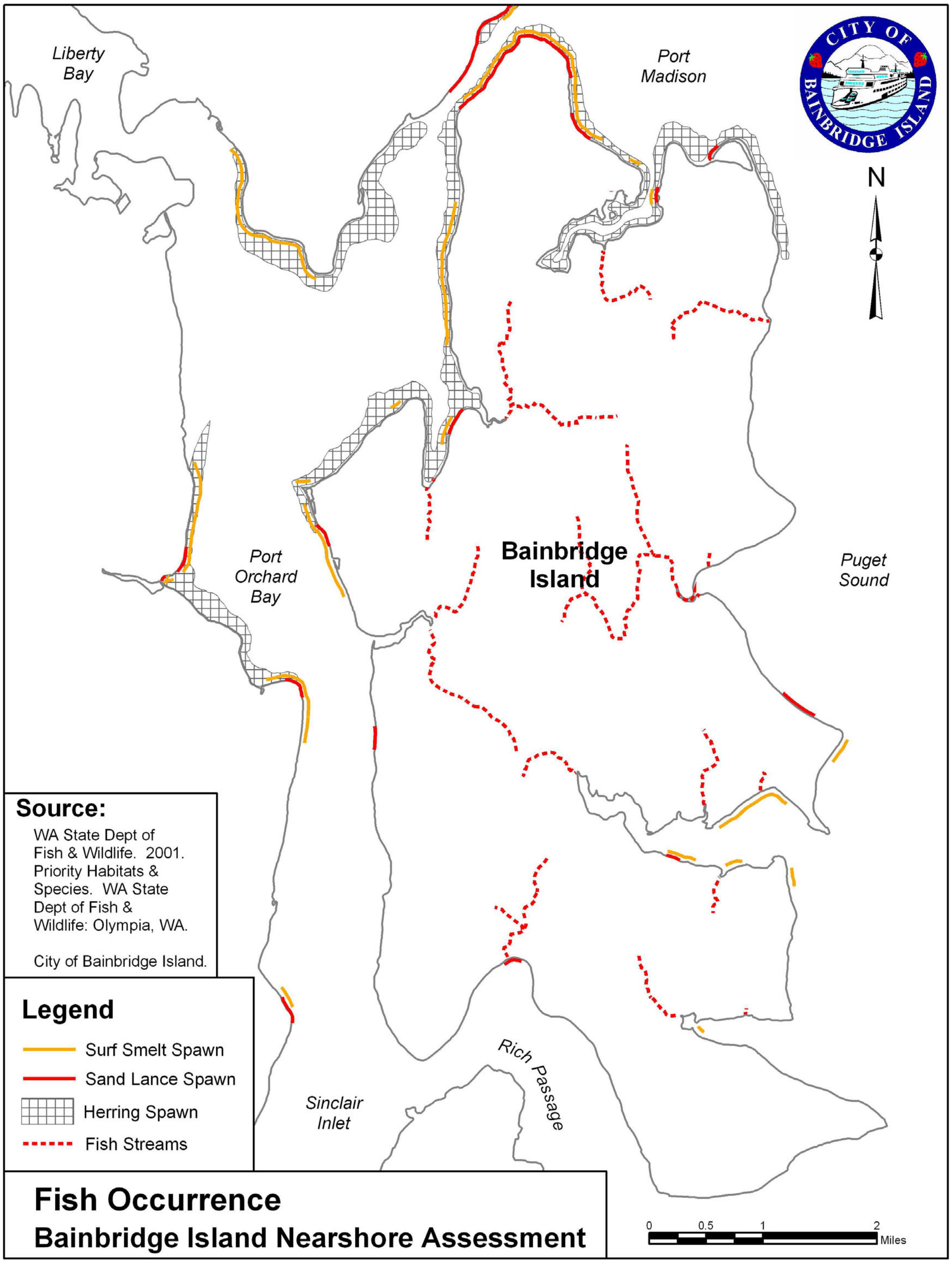


Liberty Bay
Port Madison
CITY OF BAINBRIDGE ISLAND
N
Port Orchard Bay
Bainbridge Island
Puget Sound
Source:
WA State Dept of Natural Resources. 2001. Washington State ShoreZone Inventory. WA State Dept of Natural Resources, Nearshore Habitat Program: Olympia, Washington.
Legend
Red Algae
Brown Algae
Green Algae
Rich Passage
Sinclair Inlet
Algae Occurrence
Bainbridge Island Nearshore Assessment
0
0.5
1
2
Miles



Eelgrass & Kelp Occurrence
Bainbridge Island Nearshore Assessment


Liberty Bay
Port Madison
Port Orchard Bay
Bainbridge Island
Puget Sound
Rich Passage
Sinclair Inlet
N
CITY OF BAINBRIDGE ISLAND
Source:
WA State Dept of Fish & Wildlife. 2001. Priority Habitats & Species. WA State Dept of Fish & Wildlife: Olympia, Washington.
WA State Dept of Natural Resources. 2001. Washington State ShoreZone Inventory. WA State Dept of Natural Resources, Nearshore Habitat Program: Olympia, Washington.
Legend
Geoduck
Crab
Subtidal Clam
Hardshell Clam
Oysters
Shellfish Occurrence
Bainbridge Island Nearshore Assessment
0
0.5
1
2
Miles


Liberty Bay
Port Madison
CITY OF BAINBRIDGE ISLAND
N
Port Orchard Bay
Bainbridge Island
Puget Sound
Source:
WA State Dept of Fish & Wildlife. 2001. Priority Habitats & Species. WA State Dept of Fish & Wildlife: Olympia, WA.
City of Bainbridge Island.
Legend
Surf Smelt Spawn
Sand Lance Spawn
Herring Spawn
Fish Streams
Rich Passage
Sinclair Inlet
Fish Occurrence
Bainbridge Island Nearshore Assessment
0
0.5
1
2
Miles

B. NEARSHORE CLASSIFICATION SYSTEMS

SYSTEM	SUBSTRATE	WAVE ENERGY	DEPTH	PLANTS
Marine-intertidal	rock	exposed, partially exposed, semi-protected	eulittoral	rockweed, algae, kelps, surfgrass
	rock	all exposures	backshore	algae
	cobble	partially exposed		algae
	mixed-coarse	semi-protected exposed		seasonal drift algae
	gravel	partially exposed		none
	gravel	semi-protected		algae
	sand	exposed, partially exposed		none
	sand	semi-protected, protected		eelgrass, algae
	mixed-fines	semi-protected, protected		eelgrass, algae
	mud	protected		eelgrass, algae
Marine-subtidal	mixed-coarse	mod to low energy	shallow	surfgrass, eelgrass, algae
	gravel	high energy	shallow	
	mixed-fines	moderate to high energy	shallow	algae
	mud, mixed-fines	low energy	shallow	algae
Estuarine-intertidal	rock, hardpan	open		algae
	mixed-coarse	open	eulittoral	algae; often eelgrass beds lie just subtidally of these beaches
	gravel	partly enclosed	eulittoral (marsh)	pickleweed, saltwort, rockweed
	sand	open	open	eelgrass, gracilaria
	sand, mixed fines, mud	partly enclosed lagoon	eulittoral (marsh)	vascular plants, bulrush, sedge, pickleweed (depending on salinity)
	mud	partly enclosed, enclosed		eelgrass
	organic, sand, mixed-fines, mud	partly closed, partly enclosed	backshore (marsh)	sedge, grasses, vascular plant (species depending on salinity), high marsh plants
	mixed-fines, mud	channel/slough		eelgrass, lined with marsh plants
Estuarine-subtidal	rock, cobble	open	shallow	algae
	sand	open	shallow	eelgrass
	mixed-fines	open	shallow	eelgrass, algae, kelp
	mud	open	shallow	eelgrass, algae
	mud	partly enclosed	shallow	
	sand, mud	channels		

C. Acronyms and Abbreviations

ACZA	Ammoniacal Copper Zinc Arsenate
BAS	best available science
BMP	best management practices
CCA	Chromated Copper Arsenate
CEM	Coastal Engineering Manual
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
cfs	cubic feet per second
CHL	Coastal and Hydraulics Laboratory, Army Corps of Engineers
COBI	City of Bainbridge Island
DPS	Distinct Population Segment
ELLW	extreme lower low water
EPA	Environmental Protection Agency
ESA	Endangered Species Act
ESU	Evolutionary Significant Unit
IPCC	Intergovernmental Panel on Climate Change
LWD	large woody debris
MESA	Marine Ecosystem Analysis
MHHW	mean higher high water
MLLW	mean lower low water
MLW	mean low water
NOAA	National Oceanic and Atmospheric Administration
NMFS	National Marine Fisheries Service
NPDES	National Pollutant Discharge Elimination System
NPS	non-point source
OSSWG	On-Site Sewage/Water Quality Program
PAH	polynuclear aromatic hydrocarbon
PAR	photosynthetically active radiation
PCB	polychlorinated biphenyls
PMEL	Pacific Marine Environmental Laboratory, NOAA
ppt	parts per thousand
PSAMP	Puget Sound Ambient Monitoring Program
PSDDA	Puget Sound Dredged Disposal Analysis Program
PSP	Paralytic Shellfish Poisoning
USACE	U.S. Army Corps of Engineers
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
WDFW	Washington State Department of Fish and Wildlife
WDOE	Washington State Department of Ecology
WDNR	Washington State Department of Natural Resources
WSDOT	Washington State Department of Transportation
WSF	Washington State Ferries