Deschutes River Estuary Restoration Study
Biological Conditions Report

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Thurston Regional Planning Council

Submitted by
Ralph J. Garono, Erin Thompson, and Michele Koehler

Wetland & Watershed Assessment Group
Earth Design Consultants, Inc.
230 SW Third St., Suite 212
Corvallis, OR 97333
(541)757-7896
(541)757-7991 FAX
http://www.earthdesign.com

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Table of Contents

List of Figures

List of Tables

Executive Summary

This report describes results of two separate studies: the Reference Estuary Study and Biological Conditions Report. In this report we also combine data we collected from southern Puget Sound reference estuaries with a hydrodynamic and sediment transport model, developed by USGS, to predict estuarine communities that could occur in a restored Deschutes Estuary. The overall goal of this suite of studies is to evaluate the feasibility of restoring the Deschutes River Estuary from Capitol Lake, a freshwater impoundment in downtown Olympia, WA.

The Reference Estuary Study consists of field sampling of environmental variables and biological variables in southern Puget Sound estuaries close to Capitol Lake. We sampled 90 sites in five reference estuaries and used multivariate statistics on the data gathered to describe patterns in the expected biological communities and to identify the environmental gradients that structured the communities. We used a geographic information system to combine our analysis of the field data with results from the USGS hydrodynamic and sediment transport model and the Biological Conditions study to describe the communities that will likely develop in the restored estuary.

The Biological Conditions section of this report describes important ecological processes that occur within southern Puget Sound estuaries and their watersheds, primarily gathered from the literature. The aim of this portion of the report was to combine the field and modeling work together in an effort to answer the overarching question of whether an estuarine community, with diverse populations of plants and other organisms can be reestablished in Capitol Lake. The Biological Conditions report also addresses uncertainties in reestablishing an estuary within the current Capitol Lake basin.

The five southern Puget Sound subestuaries selected for characterization in the Reference Estuary Study were Woodard Bay, Ellis Cove, and Mud Bay in Thurston County, and Kennedy Creek and Little Skookum Bay in Totten Inlet in Mason County. At each estuary, sixteen to twenty-one sampling points were located haphazardly. At each sampling point, biological and physical parameters were measured. We collected percent cover of vegetation and sediment types in a 1 m^2 quadrat, measured salinity, temperature, dissolved oxygen concentration, and pH, and measured elevation using a laser level calibrated to established benchmarks at each sampling point. Sediment cores were also collected for later laboratory assessment of bulk density, sediment grain size, and total organic content. Field crews also collected empty/dead invertebrate shells present near the sampling point plot center. The location of each site was also recorded with a high precision global positioning system. To analyze the field data, we used a combination of cluster analysis and ordination to visualize patterns in our data sets. We then used discriminant analysis to assess factors responsible for the observed patterns in the reference estuaries.

The results of our estuary sampling show that the range of physical conditions predicted by the USGS model for the four Capitol Lake restoration scenarios do occur across the five reference estuaries. Salinities predicted for the restored Capitol Lake and from the reference estuaries ranged from fresh water to polyhaline, while elevations ranged from eulittoral to backshore. Silt loam sediments were the primary predicted sediment types for a restored Deschutes Estuary, and were also the most common in reference estuary sampling.

We used ordination and CLUSTER analysis to create 'habitat bins' from the physical variables measured at our reference estuary sites. We then matched up these 'habitat bins' with biological community data we collected to see how well communities could be predicted from the physical habitat variables. Our ordinations were successful at arranging sample sites, according to their degree of similarity, along principal components analysis axes 1 and 2. Additionally, we mapped sediment types associated with each sample point in ordination space and observed a pattern that grouped sites with similar sediment characteristics. We then used discriminant analysis to match habitat bins with the biological community data we collected. We found, however, that only 52% of the sites were correctly classified. We believe that many of the communities sampled, e.g., diatoms (a type of algae) and filamentous algal mats, were ubiquitous among the habitat types we sampled. Therefore, the discriminant analysis failed to match specific algal communities with the habitat bins we previously defined. We believe that our study would have benefited from a larger number of samples made across a wider range of habitat types and from a more detailed analysis of algal communities. In addition, analysis of benthic fauna, in addition to algae, may have helped discriminate among communities present at the reference estuaries.

Based on the primary variables and modifiers that structure estuarine communities described in the Biological Conditions report, several community types observed in the southern Puget Sound reference estuaries are expected to develop in a restored Deschutes Estuary: high and low salinity marshes, mud flats, mixed (sand and mud) flats, and sandy channels. Shallow areas of the restored Deschutes Estuary will exhibit marsh, mud and mixed flats while the deeper areas will exhibit sandy channels. Other habitats will certainly exist at the periphery of these communities and some blending between these communities is expected. The occurrence of mesohaline and polyhaline vegetated high marsh areas around the peripheries are expected to be limited. Based on observations made at five references estuaries, we believe that the restored estuary will be intermediate to Mud Bay and Kennedy Creek but likely have sandier channels and more mixed sand and mud flats than either of these two reference estuaries.

Undoubtedly, the community types predicted for a restored Deschutes Estuary may not occur, or may occur in different spaces or proportions than expected. There are some key uncertainties associated with these predictions – land use and water management, climate change, native and nuisance species recruitment and management, and human disturbances – that we suspect will also be important in the development of estuarine communities in a restored Deschutes Estuary. Other unknowns, such as the variability of reference estuary salinities and sediments throughout the seasons, stakeholder and community support, and the fact that our reference estuaries were from much smaller watersheds than the Deschutes are considerations beyond the scope of this study. However, based on our experience, the USGS model results, and a review of the literature, we believe that a restored Deschutes Estuary will harbor organisms mainly associated with oligo-mesohaline mud and sand flats, and that areas dominated by vegetated salt marsh communities will be rare.

This study is unique in that reference estuary conditions and modeled site conditions were combined with regional literature to predict what a restored Deschutes Estuary may be. However, the urban setting of Capitol Lake in itself poses some difficult obstacles for achievement of estuarine communities even if tidal flow is reestablished. We believe that with realistic restoration goals combined with active, adaptive management, these uncertainties can be overcome and estuarine communities can be reestablished in the Capitol Lake area.

Chapter 1: Introduction

Factors that Structure Biological Communities in Puget Sound Estuaries

Ecology is the science that attempts to describe patterns in the abundance and distribution of organisms, and to find the underlying factors that can be used to explain these patterns. The distribution of organisms and ecological communities can be influenced by resources (nutrients, substrate, physical conditions, etc.), presence or absence of other organisms, physical processes, and/or by ecological and anthropogenic disturbance. In estuaries, the primary physical factors responsible for the distribution of organisms are sediment composition, salinity, and elevation (Dethier 1990). Elevation is a surrogate for wetting and drying and light attenuation for plants, while the range of salinity is important to the distribution of estuarine organisms due to their salt tolerances. Also, some organisms adapt to certain types of sediment and can only thrive in those sediment types while other organisms occur across a wide range of sediment types. These factors seldom act alone in structuring estuarine communities, however. This section of the report describes the biological conditions and important ecological processes that occur in estuaries.

Sediments

In estuaries, bidirectional tidal and riverine currents meet to trap, transport, and deposit sediments. The mixing of fresh and marine water also influences salinity patterns, which in turn affects the flocculation of fine sediments (Baker 1978). Thus, fine sediments may be transported differently in freshwater than they are in seawater. Morphology, sediment type and size, water chemistry, and local weather patterns also influence sediment movement in estuaries (Baker 1978). Sediment grain size can also affect the distribution of estuarine organisms. Consequently, the biological conditions in estuarine habitats are often dictated by sediment conditions.

Sediments are often characterized by measuring grain size, bulk density and organic content. Bulk density is a mass measurement of sediment that includes information on the amount of solids and pores and is measured as the mass of a unit volume of dry sediment. Sediments that have low bulk density typically are more porous. Lower bulk densities (i.e., higher porosity soils) are typically associated with finer-textured sediments like clays, clay loams, and silt loams (Hackney *et al.* 1996; Brady and Weil 1999). This is because the fine grains of clay and silt are organized in porous granules, so that there is microporous space within a granule and macroporous space between granules. In contrast, sandy sediments usually have lower total pore space and higher bulk densities.

Porosity affects several things but of particular importance in estuarine systems is how the number of pores affects the exchange rates of oxygen, nutrients, and particulates between overlying water and benthic organisms. For example, in fine sediments with high organic content, sediments can become anaerobic and toxic compounds like hydrogen sulfide and ammonia are produced as microbes use dissolved oxygen (Little 2000). In addition to having low rates of oxygen exchange, when sediment porosity is low and density is high, sediments can also become compacted. Although compacted sediments erode more slowly, and, therefore, may be more stable, they are more difficult for organisms to burrow in than sandy sediments (Little 2000). Sediments that are mainly sand, however, may lack the cohesiveness necessary to maintain the integrity of a burrow. In Puget Sound, a good example of the relationship between benthic invertebrate distribution and sediment composition is that of the ghost shrimp, *Neotrypaea californiensis*, which occurs primarily in sandy sediments when compared to the blue mud shrimp, *Upogebia pugettensis*. While both species are common to intertidal areas of the Pacific Northwest (PNW) in mixed sand and mud sediments, the blue mud shrimp is associated with muddier areas (Horning *et al.* 1989) than the ghost shrimp. Thus, the distribution of benthic animals can be affected by sediment size (Anderson *et al.* 2004), organic content, and density of the sediment.

Salinity

Salinity is widely recognized as having an important role in the biological community composition of estuaries (Eilers 1975; Jefferson 1975; Ewing 1983; Crain *et al.* 2004; Heatwole 2004). The biological conditions that occur along salinity gradients are important in structuring species assemblages in estuaries.

In Puget Sound, the difference between high and low tide can be greater than 12 feet[1] (Jennings *et al.* 2003). This results in a large amount of water moving around and mixing within the estuary during tidal exchange. The range of physical and chemical conditions existing within the estuary can be influenced by the following: freshwater flow from land, tidal currents, the bathymetric and geometric dimensions of the estuary, and the Coriolis effect (Simenstad 1983). Generally, less-dense freshwater from land (surface and ground water) enters the estuary and flows over heavier, saline seawater. In Puget Sound, the brackish water layer can range from 30 to 190 feet deep (Jennings *et al.* 2003). As the different bodies of water mix, friction and turbulence create a surface layer of mixed salinity or brackish water, also known as the salt wedge. A salt wedge can influence the distribution of organisms by allowing salt tolerant species to move up into the estuary or by causing suspended sediments to form a dense flocculent layer just above the bottom thereby decreasing available oxygen; this is known to occur even in well-mixed macrotidal[2] estuaries (Little 2000).

[1]Appendix I Unit Conversion Table provides conversion factor between metric and U.S. Customary units.
[2]Macrotidal estuaries are those that have a tidal exchange greater than 4 m.

The interplay of fresh and saline waters can have profound affects on sediment transport and deposition patterns. As previously mentioned, salt water can cause flocculation of some fine sediment particles (Baker 1978) thereby altering transport patterns of some sediments. For example, estuarine circulation patterns suspend and transport millions of tons of sediment from freshwater rivers and fine sediments lining Puget Sound (Parrish *et al.* 2003). Sediment may also be transported in boundary flow along the bottom as bed load (Simenstad 1983). The geometry of Puget Sound further complicates this mixing reaction. In deep parts of the Sound, dense marine waters may gather and seldom be disturbed by moving tides, and in other areas, underwater ridges may protrude and disrupt the circulation of the brackish water and sediments. Islands, narrow passages, and dramatic changes in depth also effect the local movement of the salt wedge and sediments. In Puget Sound's main basin, only a fraction of the particles initially present in the surface water are carried out of the Sound (Parrish *et al.* 2003). The dynamic mixing of estuarine waters causes physical characteristics, such as salinity, to vary on tidal, seasonal, and annual cycles.

While the relationship between estuarine fauna and salinity is not well-studied, estuarine flora distribution along a salinity gradient has been investigated more thoroughly. However, surface water salinity varies with tide and season and is not often found to strictly correlate with estuarine communities (Dethier and Hacker 2005). When studying estuarine plant communities, soil salinity, or the salinity the roots of plants experience, is most frequently studied. Soil salinity is also referred to as pore water salinity. Pore water and sediment salinity can be measured by taking samples directly from the sediment and measuring salinity with a refractometer or salinity probe. When estuarine ecologists describe salinity it is typically done in the following three zones: oligohaline (0.5 to 5 ppt), mesohaline (5 to 18 ppt), and polyhaline (18 to 30 ppt; Simenstad *et al.* 1991; Dethier 1992).

Salinity is important to plants because excessive salt can inhibit water uptake, slowing basic cellular metabolic functions such as photosynthesis or respiration. Many estuarine plants have adapted to some level of salt tolerance as a strategy for exploiting sub-tidal habitats where competition from other plants is reduced due to the level of environmental stress associated with salinity. For example, *Salicornia europea* and *Distichlis spicata* were found to be salt-tolerant in both greenhouse and marsh experiments (Crain *et al.* 2004). However, at very high salinities, even estuarine vascular plants cannot live; these areas in estuaries are often only populated with diatoms or benthic algae.

There are certain plants common in Puget Sound for which salinity tolerance is defined (Table 1). For example, *Carex lyngbyei* (Ewing 1986) and *Potentilla pacifica* cannot tolerate high salinities and are only found at low salinities (0.5-18 ppt, Dethier 1992), while *Salicornia virginica* (Heatwole 2004) and *Distichlis spicata* (Crain *et al.* 2004) can tolerate higher salinities (18-40 ppt, Dethier 1992). However, salinity seldom acts alone in influencing the distribution of plants throughout an estuary (Ewing 1983; Crain *et al.* 2004; Heatwole 2004). Elevation/ inundation, sediment composition, and sediment redox potential are also factors that organize plant communities in Puget Sound estuaries (Ewing 1983). Not all factors, however, affect all plant communities in the same way in all estuaries. That is, this complex relationship of physical parameters varies within any estuary yet does not vary to the same extent in each estuary (Ewing 1983). While these factors are all measurable,

Table 1. South Sound plant species with preferred salinity, elevation, and sediment types and with predicted locations for these associations in a restored Deschutes Estuary. All physical parameter data are from Dethier 1992, except the exotic species.

Species	Salinity	Elevation	Sediment Type(s)	Possible Restored Deschutes Estuary Location(s)
Carex lyngbyei	mesohaline, oligohaline	low marsh, high marsh, backshore	sand, mixed sand and mud, mud	South and Middle Basins backshore and eulittoral habitats
Deschampsia caespitosa	mesohaline	high marsh, backshore	sand	*may not occur*
Distichlis spicata	mesohaline	high marsh, backshore	mixed sand and mud	Middle Basin and North Basin backshore and eulittoral habitats
Grindelia integrifolia	mesohaline	high marsh, backshore		Middle Basin backshore habitats
Jaumea carnosa	polyhaline	low marsh	sand	North Basin eulittoral habitats
Juncus balticus	polyhaline, mesohaline	high marsh, backshore	mud	Middle Basin and North Basin backshore and eulittoral habitats
Potentilla pacifica	mesohaline, oligohaline	high marsh, backshore		South and Middle Basins backshore and eulittoral habitats
Salicornia virginica	euryhaline, polyhaline	low marsh, high marsh, backshore	sand, mixed sand and mud	Middle Basin and North Basin backshore and eulittoral habitats
Scirpus americanus	oligohaline	low marsh	sand	*may not occur*
Scirpus maritimus	oligohaline	low marsh	mud	Middle Basin, eulittoral habitats
Triglochin maritimum	polyhaline	low marsh	mixed sand and mud, mud	North Basin eulittoral habitats
Typha spp.	oligohaline to fresh	backshore	sand, mud	South Basin backshore habitats
Exotic Species				
Spartina anglica[1]	oligohaline	low elevation	mud	South and Middle Basins eulittoral habitats
Lythrum salicaria	oligohaline to fresh			South Basin
Myriophyllum spicatum[2]	mesohaline			South Basin

1. Source: Dethier and Hacker 2005.
2. Source: American Rivers 2006.

Table 2. Details and assumptions of restoration scenarios considered for Deschutes Estuary hydrodynamic modeling by USGS (George *et al.* 2006). All scenarios based on 2004 and 2005 bathymetry and shoreline data developed by USGS.

Scenario	Opening to Budd Inlet (m)	North and Mid Basin Opening (m)	Percival Cove Opening (m)	Other aspects
A	150	---	---	
B	150	150	---	
C	150	---	60	
D	150	---	---	North Basin split along north-south axis

the degree to which each factor affects a plant community may vary among study sites. Plant communities in different areas are often influenced, however, by a common suite of environmental variables, with salinity being a very important factor in this suite. In fact, estuarine classification systems have been developed using salinity, elevation, and sediment type to define expected communities (see Cowardin *et al.* 1979; Ewing 1983).

For restoration purposes (Table 2), it is feasible to first consider salinity, elevation, and marsh geometry when predicting restoration outcomes (Heatwole 2004). We can use the relationship between these variables and estuarine flora to predict the likely community types and species composition of restored plant communities.

Elevation/ Inundation

Tidal amplitude varies around the world and is influenced by the physical setting of the estuary bottom and shape of the nearshore, mean sea level, winds, currents, atmospheric pressure, temperature, salinity, river inputs, and the pull of various earth forces (NOAA 2004). The range of elevations across the estuarine bottom directly influences water levels during tidal cycles. Due to the relatively large tidal amplitudes in Puget Sound, many areas completely dewater during low tide. Consequently, many of the plants and animals have adapted to desiccation. This section describes the biological conditions of estuaries related to elevation.

Many estuarine ecologists recognize three distinct elevational zones, backshore, eulittoral, and subtidal, in tidally influenced ecosystems. The landward extent of estuarine communities is generally limited by the influence of tides or of salt spray and the seaward extent by the ocean. These lines are often blurred. Puget Sound intertidal ecosystems are bounded by high and low water; more specifically between extreme low water of spring tides (ELWS) and the upper limit of salt spray or any other influence of ocean salts (Dethier 1990; Voigt 1998). The backshore area described by Dethier (1990) includes high salt marshes and other areas that are above the mean high water line of spring tides (MHWS) and are influenced by marine waters through spray or irregular flooding. The eulittoral zone is bounded by elevations between the MHWS and ELWS. The eulittoral zone is regularly influenced by tides (Dethier 1990). Dethier uses ELWS instead of MLLW because the distribution of many species appears to be limited by the desiccation they experience when tide level falls below MLLW, as it does in extreme low tides of spring (Dethier 1990). The ELWS zone is still considered intertidal, but transitional. Subtidal systems are those areas below 0 m (MLLW, i.e., height of lower low waters) and are divided into shallow (15 m or less below MLLW) or deep areas (>15 m below MLLW) (Voigt 1998; Dethier 1990).

Elevation affects estuarine community structure in Puget Sound (Ewing 1983), although no research specific to this exists for South Sound estuaries. However, research does exist for Skagit Bay and on Whidbey Island (Crescent Harbor and Lake Hancock) and we discuss those studies. Organisms at lower elevations experience longer, deeper, and more frequent periods of inundation than higher elevation organisms (Ewing 1983). Because the higher marsh areas are subject to saline and inundation stress, higher plant diversity has been observed in high marsh communities in Skagit Bay (Ewing 1983).

Other research on environmental gradients of plants in Skagit Bay (e.g., Ewing 1983; Ewing 1986) reveals patterns in plant communities relative to their elevation. For example, here emergent plants exist at elevations of 2 m above MLLW and higher. Elevations greater than -2 m with sandy bottoms supported seasonal algal blooms (Ewing 1986). The common plant *C. lyngbyei* was not present at low elevation, polyhaline sites (Ewing 1983). Another common plant, *S. americanus*, was not present at higher elevation, freshwater sites (Ewing 1983).

Some of the scant research on inundation times occurred recently on Whidbey Island. Here, inundation at 143 sites at Crescent Harbor and Lake Hancock was measured as percent of summer flooding duration (Heatwole 2004). In this study, *S. virginica* and *D. spicata* occurred where the marsh was flooded 43% and 33% of the time, respectively, which were the highest flooding durations observed. *Triglochin maritimum* and *Jaumea carnosa* occurred at an intermediate level of inundation, 30%. *P. pacifica* and *Juncus balticus*, were found at some of the lowest levels of inundation, with flooding at 15% and 10% respectively (Heatwole 2004).

When drawing conclusions about environmental factors in estuaries, it is infrequent that one variable is solely responsible for community composition. However, for given combinations of sediment, elevation and salinity, community patterns exist. Given this information for Capitol Lake, we attempt to predict estuarine communities that could occur in a restored Deschutes Estuary.

Southern Puget Sound Estuaries

Estuaries in Puget Sound share many commonalities. However, the estuaries of southern Puget Sound also differ from those found in northern Puget Sound and from other PNW estuaries. Therefore, some of the lessons learned from studies in northern Puget Sound and other PNW estuaries may not be totally relevant to the Deschutes Estuary. Puget Sound is commonly divided into "north" and "south" Sound based largely on current geomorphology and glacial history. The basin area of Puget Sound south of the City of Tacoma is known as "The Narrows" and is considered the south Sound (Albertson *et al.* 2002). Both northern and southern Puget Sound shorelines have urbanized and recreational areas. Consequently, north and south Sound coastlines share many of the same ecological problems including, increased pollutants, nutrient loading, coastal erosion and excessive armoring, overfishing and other challenges due to climate change (Snover *et al.* 2005).

Southern Puget Sound estuaries are characterized by macrotide ranges (4 m between MHHW and MLLW) (LOTT 1998; Little 2000), soft, and silty sediments. Shallower depths, slower flushing times, strong stratification, warmer summer surface water (Snover *et al.* 2005), complexity in shape, and the large number of inlets found in the southern Sound act together to limit the ability of southern waters to exchange and dilute nutrients and often lead to lower oxygen concentrations (Albertson *et al.* 2002). Higher than average nitrogen loads have also been documented from the south Sound watershed (Albertson *et al.* 2002) which may compound water quality issues due to other physical characteristics of the south Sound. Consequently many of the species abundant in northern Puget Sound are absent from south Sound.

Budd Inlet is a good example of a developed southern Puget Sound estuary. Budd Inlet, the mouth of the Deschutes River Estuary, is approximately seven miles long, one mile wide at its mouth, and two miles wide near its center. At its head lie two small bays, West Bay and East Bay, divided by a peninsula. The City of Olympia lies adjacent to these two bays. This long, thin inlet exhibits the second greatest tidal range of all of Puget Sound, 4.4 m/ 14.56 ft (LOTT 1998).

Sea level affects northern and southern Puget Sound differently because of complex geologic formations. Tectonic subsidence in southern Puget Sound leads to more rapid submergence in southern Puget Sound than in northern Puget Sound. Land in southern Puget Sound is sinking at rates of eight inches per century while rates in the north Sound are slower (near zero in/century; Canning 1991). With a combination of sinking land and the rates of sea level rise predicted for the globe, forecasted levels of sea rise in south Sound may be double the global average, approximately 3.3 ft by the end of the century (Snover *et al.* 2005).

Differences in tidal range in the southern Sound are also influenced by the fact that tidal range increases with distance from the Pacific Ocean. Therefore, average tidal range in southern Puget Sound estuaries, such as Budd Inlet, can be almost two times that in northern Puget Sound. For example, the average tide range (i.e., difference between MHHW and MLLW) at Port Townsend is 8.4 ft at the mouth of Puget Sound while the range in Budd Inlet, Puget Sound's southernmost marine water body (i.e., much further from Pacific Ocean than Port Townsend) is 14.4 ft (LOTT 1998; USACE 2000).

The physical differences between the south and north Sound dictate the flora and fauna observed. Generally, less-diverse species assemblages are observed in south Puget Sound than in north Sound; patterns of wave action, tidal range, salinity and sediments contribute to this (Hacker and Dethier 2006). For example, Schoch *et al*. (2001) found macroscopic algae and invertebrate species richness decreased from north to south Sound. Eelgrass, *Zostera marina*, is a species common in the north Sound but is generally uncommon in the south Sound. Eelgrass is not observed south of McAllister Creek in Thurston County (Berry *et al.* 2001a; Mumford 2006). Some of these differences between the north and south Sound are further described below as disturbances present in Puget Sound are discussed.

Disturbance

Understanding the disturbance factors of ecosystems is important in any restoration study. An ecological disturbance is an event that causes a sustained disruption in the physical structure, ecological responses, and functioning of an ecosystem (Potter *et al.* 2005). There are physical disturbances, such as fires, floods, droughts, and lava flows; biological disturbances, such as the impacts of herbivorous insects, grazing mammals, or viruses; and anthropogenic disturbances. Disturbances can be natural (generally thought to exist with a 'natural' range of variability) or caused by man. Pollution, logging, deforestation, draining wetlands, and introduction of invasive and nonnative species are all examples of anthropogenic disturbances. Anthropogenic disturbances can often move an ecosystem beyond its 'natural' range of variability thereby dramatically altering ecosystem structure and processes. Natural resource managers must evaluate the effects of both natural and anthropogenic disturbances upon the characteristic structure, and flows of energy and material of ecosystems considered for restoration. Disturbance affects estuarine biological conditions, just as other physical characteristics of estuaries do.

Disturbance can be proximate or distal, frequent or sporadic. But disturbances are a regular component of most ecosystems and may actually maintain critical ecological conditions or combinations of species (Foster 2006). Effects of disturbance have consequences and are detectable at the smallest scales, down to the microbial level, where most of the ecosystem energy and nutrient flow is mediated (Paerl 2006). Ecological disturbances impact ecosystems by interrupting important processes, removing vital resources, culling weak individuals, or changing community structure. These changes are often long lasting, especially in terms of anthropogenic disturbances. For example, an area that was once converted to agricultural use and plowed may possess a species composition and relative abundance very different from unplowed lands up to 100 years post disturbance (Foster 2006).

Marine pollution is said to be the most "universal" of all ecological disturbances, with organic enrichment of marine waters being the best-documented example of this type of disturbance (Pearson and Rosenberg 1978). At one time, fluctuations in organic input were thought to be one of the principal causes of faunal changes in a marine environment (Pearson and Rosenberg 1978). Today, many estuaries are under additional, increasingly well-understood stressors other than eutrophication. Excessive sedimentation, contamination, changes to watershed hydrology, and climate change all impact communities in nearshore ecosystems. In this section we describe types of anthropogenic disturbances and the consequences on estuarine communities in the Puget Sound basin.

Patterns of anthropogenic disturbance in Puget Sound

Puget Sound's intertidal areas are habitats for species of commercial value, in addition to those of recreational, biotic, and aesthetic values (Berry and Ritter 1997). With two-thirds of Washington's 5.9 million people living within the drainage basin, human influence is great. The major river deltas of Puget Sound have suffered a collective 80% loss of tidal marsh habitats in the past 150 years (Dean *et al.* 2001). One-third of Puget Sound's shorelines have been altered or reinforced with bulkheads, and 25% of the intertidal zone has been modified (Parrish *et al.* 2003). In Thurston County, an average of 36% of the shorelines of county inlets have been armored (Herrera 2005). In the Olympia area of Budd Inlet, up to 94% of the shoreline is armored (Herrera 2005). Today, largely due to the large-scale development in Puget Sound, nearshore habitat degradation and loss are recognized as major threats to the health of the Sound (Copping *et al.* 1994).

The Sound has been altered from its pre-European settlement state by natural resource extraction, urban development throughout the basin, and point and non-point sources of pollution. Changes to upper portions of watersheds from timber harvesting, agriculture, and urban development have significantly modified the hydrologic cycling of water, water quality, nutrient delivery, and sediment transport in Puget Sound estuaries (Fresh *et al.* 2004). Other aspects of development, such as commercial fisheries, aquaculture, agriculture, and the introduction of invasive species have negatively impacted Pacific Northwest estuaries (Fresh *et al.* 2004).

In southern Puget Sound, Budd Inlet and Capitol Lake are also affected by anthropogenic disturbances. Eutrophication, contamination, sedimentation, hydrologic cycle alteration, and introduction of nonnative species are the primary disturbances to the south Sound. The City of Olympia, population 43,330, surrounds Capitol Lake which is met with the Deschutes River (TRPC 2005). The Deschutes River/Budd Inlet watershed is nearly half forested (51%), with approximately 8% urban area (8,864 ac; Figure 1; TRPC 2001). These land uses effect nutrients and sedimentation, among other things. And as these land uses change over time with increases in development, population growth, and changes in forestry and agricultural practices, the effects of these changes on estuaries and watersheds will increase.

Additional disturbances to Capitol Lake include changes in hydrology and nutrient loading. The hydrology of Budd Inlet was altered when the Black Lake Drainage ditch was created in 1922 (Morrison 1985; Turner *et al.* 1993) and the Deschutes River was dammed in 1951 as part of the State Capitol Campus design. Non-point source pollution such as fecal coliform bacteria and high phosphorus concentrations occur in Capitol Lake (WDOE 2004a; WDOE 2004b). High algal growth in the lake due to increased phosphorus loading (WDOE 2004a) can reduce oxygen concentrations in the water and make the lake uninhabitable for certain organisms. There are several municipal wastewater treatment facilities within Budd

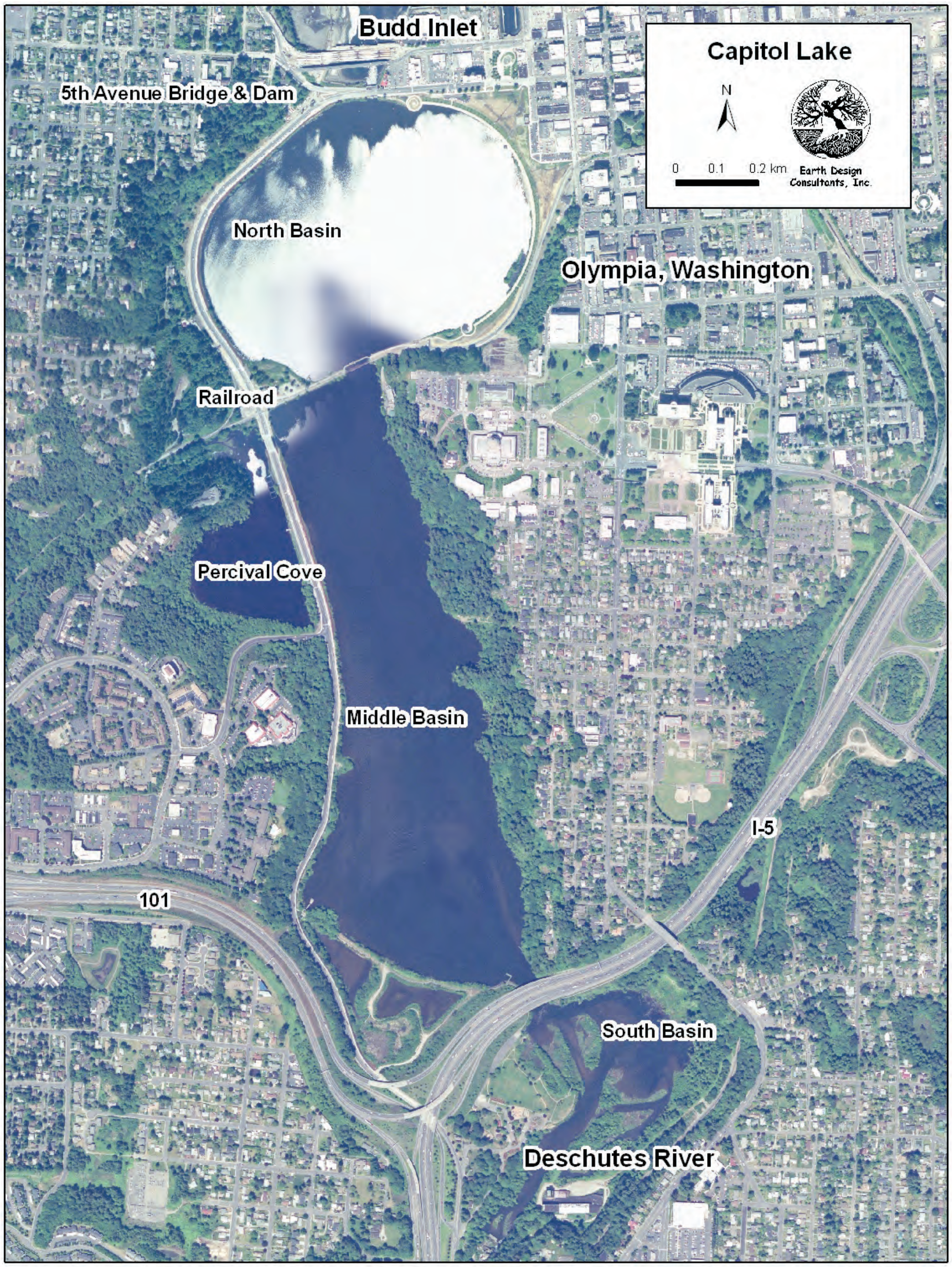

Figure 1. Digital Ortho photo (2003) of Capitol Lake, showing Budd Inlet, the 5th Street Dam, basins, and the Deschutes River. Capitol Lake is located in downtown Olympia at the southern end of Puget Sound in Washington State.

Inlet that discharge treated wastewater through permitted outfalls including the LOTT facility discharging into southern Budd Inlet, the Boston Harbor facility at the northern boundary of the inlet, and Tamoshan and Seashore Villa facilities (LOTT 1998; WDOE 2004b). However, recent data suggest that low dissolved oxygen concentrations may no longer be a problem within the lake (Thurston County Public Health and Social Services Dept. 2003). In fact, the study reported high levels of dissolved oxygen (>97% saturation) during August and October 2003 sampling periods (Thurston County Public Health and Social Services Dept. 2003). The Capitol Lake ecosystem is affected by many of the anthropogenic disturbances found throughout Puget Sound.

The recurring themes in Capitol Lake and southern Puget Sound community responses to anthropogenic disturbances are several. Organisms exposed to disturbance will likely experience a decrease in fitness and biomass, and biological communities may experience a loss of species diversity. Sensitive organisms will be replaced with hardier species and then eventually by entire taxonomic families (Pearson and Rosenberg 1978). Most disturbances cause habitat loss that then translates into changes in estuarine community structure. Because anthropogenic disturbances are frequent and ongoing in Puget Sound estuaries and because of their impacts to the nearshore environment and entire watersheds, management entities should recognize disturbances as components of estuarine ecosystems. Anthropogenic disturbances, particularly in terms of land use, are incorporated into this study through the use of land cover spatial data. In the methods and results sections describing reference estuary watersheds (Chapter 2: Geospatial Methods), major land use categories are summarized and incorporated into analysis of biological conditions and community responses to the restoration scenarios proposed for Capitol Lake.

Eutrophication

Excessive nutrient input leading to increases in primary production, or eutrophication, in nearshore areas is a common stressor in Puget Sound. Sources of these inputs include runoff from landscaping and other urban and residential sources, stormwater discharges, agriculture and livestock, and illegal sewage discharge into storm water systems (Thurston County Public Health and Social Services Dept. 2005; Paerl 2006). Many of these sources of nutrients are concentrated within the urban settings of the southern Sound. For example, inner and outer Budd Inlet have been and both still are listed by WDOE 303(d) as limited by dissolved oxygen concentration (WDOE 2004a), which is attributed to high primary productivity (and subsequent oxygen consumption) in the inlet due to anthropogenic sources (Eisner and Newton 1997; Newton *et al.* 1998; WDOE 2004a). Wastewater treatment plants with outfalls can be a source of excess nutrients that may cause eutrophication in Puget Sound (Newton and Van Voorhis 2002). In south Puget Sound, atmospheric deposition, tributary inflows, point source discharges, non-point source inputs, and sediment-water exchange may also contribute to heavy nutrient loads (Albertson *et al.* 2002).

Excessive nutrient inputs change estuarine planktonic communities in many ways. Excess nutrients promote phytoplankton growth and increased algal blooms, accumulation of organic matter, and oxygen uptake by decomposing bacteria leading to hypoxia and anoxia (Paerl 2006). Nutrient addition may affect community composition. For example, in Puget Sound, predictable shifts in phytoplankton species composition and succession have been observed in response to elevated nutrient concentrations associated with seasonal changes in light availability and temperature, and changes in other environmental conditions (Newton *et al.* 1998; Newton and Van Voorhis 2002). Besides reduced oxygen concentrations, increases in phytoplankton populations can also result in reductions in water clarity (Newton and Van Voorhis 2002), which reduce the ability for other plants and algae to photosynthesize.

Excess nutrients may affect populations of estuarine animals and may alter food webs (Albertson *et al*. 2002). A decrease in available oxygen, facilitated by eutrophication, can cause some populations of species not adapted to anoxic conditions to experience decreases in numbers. Moreover, accumulation of organic matter on bottom sediments may affect habitat quality for some burrowing organisms. When oxygen concentration is lowered in marine benthos, an increase in anaerobic bacteria that release toxic hydrogen sulfide or ammonia can occur (Albertson *et al.* 2002). Consequently, organisms can be eliminated from the community directly by altered oxygen availability or indirectly by habitat degradation. As community species composition changes, so too do the relationships between interacting populations of species, e.g., predators and their prey.

Sedimentation and Sediment Contamination

Sedimentation is a naturally occurring process but when excessive it is considered a type of disturbance that changes the biological conditions of nearshore communities in Puget Sound. Sediments can enter estuaries from watershed or marine sources. Natural communities in estuaries respond to changes in the levels of sedimentation occurring in a watershed (Anderson *et al.* 2004). Increased sedimentation in estuaries may be caused by upper watershed activities such as logging, road failures, or development of land for commercial or housing purposes. It can also be the result of disposal of dredged material (Simenstad 1983; Parrish *et al.* 2003). If rates of sediment accretion are too high, sediments can reduce viable nearshore habitat by smothering benthic invertebrates and plants (see Chapter 1: Salinity). As sediment deposition rates change, desirable prey species may be replaced by less desirable prey species, such as nematodes and annelids (Pearson and Rosenberg 1978).

Some organisms themselves can alter rates of sediment accretion in estuaries thereby altering the community composition. For example, the introduced cordgrass, *Spartina alterniflora*, in Willapa Bay, WA, may trap sediments and increase sediment accretion. As sediments accrete, tidal flat elevations also increase. As tide flats become vegetated and increase in elevation, burrowing organisms typical of PNW mud flats may give way to those of higher elevation salt marshes. In this way, an invasive, nonnative plant can dramatically affect both plant and animal communities of PNW estuaries.

Sediment quality in estuaries is also disrupted by the introduction of toxic contaminants or metals. Many Puget Sound sediments have concentrations of chemicals higher than pre-industrial levels as a result of point and non-point pollution from human activities (PSAT 2002). This is often the result of activities such as disposal of contaminated dredge material (Simenstad 1983; Parrish *et al.* 2003) and upstream industrial or household inputs into the watershed. In southern Puget Sound, inner Budd Inlet is listed by the Washington State Department of Ecology as impaired by the following pollutants: benzo (a) anthracene, chrysene, total PCBs, benzo (k) fluorine, and benzo (b) fluorine (WDOE 2004a). In the Duwamish River Estuary, sediments have very high concentrations of carcinogenic PAHs and PCBs (Simenstad *et al.* 2005). Other estuaries in Puget Sound, such as Commencement Bay, are also listed on Washington's Impaired Waterways List (WDOE 2004a).

The decrease in population fitness of native fauna due to types and amounts of chemicals in estuarine sediments in Puget Sound can ultimately alter the composition of invertebrate communities within these estuaries (PSAT 2002). This is a well-known pattern also explained by Pearson and Rosenberg (1978). With constant toxic input, less resistant fauna may die off gradually. The organisms are replaced by hardier, but less desirable or exotic, fauna that can better tolerate toxic sediments to a certain level. However, once toxic compounds reach a high enough level all organisms may die off in the contaminated sediments (Pearson and Rosenberg 1978).

Changes in sediment composition, amount, or quality cause a change or reduction in habitat and eventually changes in biological community composition in estuaries. A serious issue for Puget Sound, these changes can be compounded by increases in nutrient input, human activities, or decreases in water quality in estuaries (Fresh *et al.* 2004). Estuarine communities themselves may offer some protection from disturbance by pollution. Estuaries with intact communities are less susceptible to contamination than those that have suffered habitat loss. For example, nearshore, marsh, and riparian ecosystems act as filters and processors for sediments and contaminants. When these communities are removed, contaminants can gather and remain trapped in estuarine sediments (Fresh *et al.* 2004). Estuarine restoration plans should consider upstream and adjacent ecosystems.

Hydrologic Modifications

Alteration of hydrologic patterns is another cause of disturbance in nearshore communities. Alterations to flow of surface and ground waters within a watershed are most frequently due to anthropogenic changes to rivers and streams themselves, such as channelization and damming (Hopkinson Jr and Vallino 1995), conversion of wetlands to farmland, increases in impervious surfaces (May 1998), and forestry practices. Hydrologic modification to watersheds is a disturbance that affects biological conditions throughout the drainage basin, all the way to the estuary. These activities can decrease or change the timing of freshwater flow to estuaries and reduce water quality in estuaries.

Loss or reduction of freshwater to estuaries can increase water salinity, which is also a type of disturbance (Burke *et al.* 2000). Since salinity has a major role in the distribution of estuarine species (Chapter 1: Salinity), changes in this physical parameter can have significant effects on community composition. Changes in the timing and amount of freshwater flow also changes primary production, such as the production of phytoplankton in estuaries, and in water clarity by disrupting water column stratification (Newton and Van Voorhis 2002; Scavia *et al.* 2002; Dowty *et al.* 2005). An increase in primary production can increase the oxygen demand by such an amount that benthic substrates become anoxic. Thus, organisms that require higher concentrations of oxygen than are available begin to suffer from anoxic conditions. This pattern is similar to that observed when eutrophication occurs. Flushing rates can also affect primary production. Increases in freshwater flow reduce primary production and an estuary may experience community changes due to a lack of phytoplankton production.

Human-induced hydrological changes such as the loss of estuarine wetlands due to extensive agriculture, urban development, and diking have caused habitat loss in estuaries. This has altered the ability of estuarine systems to absorb water and has made extreme flooding more likely (Fresh *et al.* 2004). Habitat loss is also blamed in part for the decline of several estuarine-dependent fish species (Beamer *et al.* 2005). For example, three anadromous salmonid species that use the nearshore habitats in Puget Sound (Chinook salmon [*Oncorhynchus tshawytscha*], summer chum salmon [*O. keta*], and bull trout [*Salvelinus confluentus*]) are listed as threatened or endangered under the United States Endangered Species Act (ESA; Fresh *et al.* 2004).

Climate Change

Another ecological disturbance attributed mainly to anthropogenic causes is climate change. As climatic patterns change, this disturbance will cause species' ranges to be geographically adjusted, changing the biological conditions of estuaries by introduction of new species, or local or large-scale extinctions of species (Scavia *et al.* 2002). Warming global temperatures will allow some species to extend their ranges northward (Little 2000). The predicted increase in rates of sea-level rise are serious threats to shoreline and wetland ecosystems (Scavia *et al.* 2002). Across Puget Sound, sea level rise is documented to have been occurring at rates of just over 2 mm yr^{-1} (Zervas 2001). In southern Puget Sound, these rates in sea level rise are predicted to continue and a rise of approximately 3.3 ft is expected at the end of this century (Snover *et al.* 2005). This change in sea level will disrupt the mix of fresh and saline waters in estuaries, where many organisms are dependent upon certain salinity characteristics (Chapter 1: Salinity). Warming waters may also cause shifts in organism ranges and productivity levels, which in turn will effect predators and prey of individual species (Scavia *et al.* 2002; Snover *et al.* 2005). Climate change will also affect estuarine vulnerability to eutrophication (Scavia *et al*. 2002) and decrease ability to store sediment (Herrera 2005).

Another effect of sea level rise due to climate change is the change in water quality. Biological communities can be expected to respond to this change. For example, warmer water temperatures that may increase winter stratification and dissolved oxygen concentration at depths would be expected to decrease. The resulting increase of hypoxic areas in bottom waters would be expected to affect the flora and fauna dependent upon certain levels of dissolved oxygen in the sediments, again causing stress or elimination from the community. Another example of a decrease in water quality is an increase in fecal coliform bacteria concentrations and associated water-borne pathogens. Increases in septic leakages may be exacerbated by sea level rise (Snover *et al.* 2005), causing a greater amount of water borne pathogens to enter estuaries. Also, the predicted increase in winter precipitation may cause an increase in storm water runoff and sewer overflow events, again exacerbating pathogen contamination (Snover *et al.* 2005).

Not only climate change, but also the general intra- and inter-annual climatic conditions and recent trends in Puget Sound have an influence on estuarine conditions and population dynamics, and should be considered when interpreting ecological data and developing water management policies (Scavia *et al.* 2002; Dowty *et al.* 2005; Ward *et al.* 2005). El Nino and La Nina events are examples of inter-annual climatic trends; the shift between such weather events is predicted to occur every 10-20 years and is referred to as the Pacific Decadal Oscillation (PDO). Shifts between these weather events have been shown to affect estuarine conditions and therefore estuarine species. For example, Thom *et al*. (2003) documented an increase in eelgrass, *Zostera* spp., density, biomass, and flowering associated with narrow temperature ranges (i.e., warmer winters and cooler, moderated summers) between the most recent El Nino and La Nina transition. The plant density of eelgrass (shoots/meter) was also found to be inversely correlated with water temperature (Thom *et al.* 2003).

Climate change is a disturbance that will act to compound, and in many cases intensify, other disturbances. For example, the loss of eelgrass described above then affects other species, such as the black and western high arctic brants (Ward *et al.* 2005). Shifts in the winter distribution of the Pacific Flyway birds are thought to be related to changes in eelgrass numbers and distribution due to climate change. Eelgrass is an important food source for these birds and changes in food affects bird reproductive success (Ward *et al.* 2005).

The exact responses of estuarine communities to climate change are difficult to predict because the variety of physical and geological factors found in each individual estuary varies (Scavia *et al.* 2002). This is of particular importance in an area such as Capitol Lake, where many uncertainties exist about biological communities and ecological conditions upon alteration. But understanding current conditions, the natural range of variability, and relationships between ecosystem components will help managers predict changes to the estuary in response to climate change. Additional information about how climate change will affect Puget Sound can be found in (Snover *et al.* 2005).

Nonnative and Invasive Species

Invasive species are generally nonnative species[3] that spread rapidly and out-compete, prey on, and otherwise reduce or eliminate other species populations (Groom *et al.* 2006). Nonnative, or exotic, species are any species that are not indigenous to a particular ecosystem. They are not necessarily invasive, but often can be. Nonnative species affect native species populations and may alter the flow of energy and materials within the food web (see earlier example of *Spartina* in PNW estuaries). They are usually introduced or their spread is facilitated by human activities, therefore nonnative species are a type of anthropogenic disturbance. Nonnative species pose a significant threat to the biological conditions of PNW

[3]Sometimes invasive species can be native species with populations that become unchecked in disturbed communities. For example, Reed Canarygrass (*Phalaris arundinacea*) is generally thought to be native to many parts of the U.S.; it has developed the ability to become invasive in some areas.

estuaries. They affect native community composition by changing the physical habitat, competing for vital resources, or altering food web dynamics (PSAT 2002), just like other anthropogenic disturbances. The effects of nonnative species can also be compounded by the presence of other stressors in estuaries such as contamination, eutrophication, or habitat fragmentation.

Nonnative species have been introduced to Puget Sound estuaries in several ways. Some species were transported by ocean currents. Boat vehicles traveling between water bodies are also responsible for the transport of some species. Species were also purposely brought into the area to control erosion, as a food source, or for aesthetic beauty. Today, the most significant pathway for nonnative species introductions in the U.S. is through ballast water from large ships. However, a rapid survey of exotic organisms in Washington estuaries in 2000 found as many or more exotic species in estuaries that are not commercial shipping centers but that are used extensively for aquaculture (PSAT 2002). This suggests that aquaculture activities may historically have been as effective as ship-associated mechanisms in moving nonnative organisms across oceans and between bays (PSAT 2002). Aquaculture activities can transport pests and parasites of shellfish alongside oyster seeds. On Washington's coast, commercial aquaculture is considered to be a possible mechanism for introducing 35 of the 40 exotic species collected in the 2000 expedition, while shipping is possibly responsible for introduction of 28 of these species (PSAT 2002).

Capitol Lake has already been invaded by two well-known nonnative plant species: purple loosestrife (*Lythrum salicaria*) and Eurasian watermilfoil (*Myriophyllum spicatum*). Other nonnative species found in the Deschutes River watershed are Japanese knotweed (*Polygonum sachalinense*), Himalayan blackberry (*Rubus discolor*), and reed canarygrass (*Phalaris arundinacea*). Capitol Lake could be susceptible to invasion by other nonnative species found in Puget Sound estuaries, should it be returned to an estuarine state. These species of concern are cordgrass (*Spartina alterniflora*), the European green crab (*Carcinus maenas*), and the Chinese mitten crab (*Eriocheir* spp.). Invasive and exotic species that are either present in Capitol Lake or exist as a threat for the lake are described below.

Purple Loosestrife, *Lythrum salicaria*

Purple loosestrife was first discovered in Capitol Lake in 1986 (American Rivers 2006). Loosestrife is described as a showy plant and was introduced to the U.S. and Canada in the 1800s for ornamental and medicinal uses (Coombs *et al.* 2004). Loosestrife disrupts the ecological function of wetlands by easily adapting to new wetland environments, out-competing native plants, and decreasing plant diversity, which affects the composition and total biomass of wetland invertebrates (Coombs *et al.* 2004; Garono 2005). Loosestrife takes over native grasses consumed by local wildlife, yet has limited food value for most wildlife species (Coombs *et al.* 2004); it is another example of food web alteration caused by disturbance.

Several types of control have been tested for purple loosestrife, including some in Capitol Lake. Outbreaks in Capitol Lake were first treated by clipping the flower heads from the stems of the plants. Because plant roots remained, the plant was not eradicated (American

Rivers 2006). In 1999, biological control of loosestrife in Capitol Lake was attempted with a release of host-specific beetles in the area. In 2000, an 80% reduction in purple loosestrife was noted (American Rivers 2006). However, lack of continuous control has ensured the persistence of this invasive plant in Capitol Lake and elsewhere in the Puget Sound area.

Eurasian Watermilfoil, *Myriophyllum spicatum*

Eurasian watermilfoil was discovered in Capitol Lake in September 2001 (WDGA 2005; American Rivers 2006). Eurasian watermilfoil originated in Europe and Asia and was once commonly sold as an aquarium plant. Milfoil is now found throughout the United States. Due to its wide distribution and difficulty to control, milfoil can drastically disturb the function of aquatic ecosystems. While milfoil is mainly a problem in freshwater systems, it can tolerate salinities typical up to 15 psu and is a continual threat to estuarine ecosystems in Puget Sound.

Milfoil forms very dense mats of vegetation on the surface of the water. These mats rob oxygen from the water by preventing wind mixing between the oxygenated surface and deeper waters. This decreases the fitness and success of many benthic organisms. The milfoil mats also increase sedimentation. When milfoil invades new territory, the total species diversity of aquatic plants typically declines. Despite concerns over low dissolved oxygen concentrations caused by milfoil, 2003 surveys within Capitol Lake indicate dissolved oxygen concentrations to be at or above those adequate for aquatic life (Thurston County Public Health and Social Services Dept. 2003).

In 2002, General Administration attempted to eradicate milfoil through mechanical extraction but control was difficult and milfoil was more widespread than was previously thought (WADGA 2005, American Rivers 2006). In 2004, a treatment of the herbicide triclopyr was applied to the north and middle basins of the lake. This treatment appeared successful, controlling regrowth of most of the milfoil in 2005. The remaining populations were hand removed. Even with control efforts, it will be difficult to completely eradicate milfoil from the lake.

Canada geese, *Branta canadensis*

Resident, non-migratory Canada geese (*Branta canadensis*) are currently a nuisance species within Capitol Lake and several other lakes within Thurston County. In past years, an increase in the number of geese was documented by USDA surveys within Thurston County lakes and the Audubon Society Christmas Bird Count (CLAMP 1999). The Interlocal Waterfowl Management Committee was created in order to control the number of geese and along with USDA and WADFW has produced a target number of 100 geese for Capitol Lake (CLAMP 2002). Control measures to reach this number include paintballs, pyrotechnics, and signage educating the public to not feed geese. The USDA has also been conducting an annual round-up and disposal of geese (CLAMP 2002). The geese prefer open, grassy, flatter areas which around Capitol Lake include Marathon and Heritage Parks, Deschutes Parkway, and along Percival Cove. Canada geese in groups can be noisy and often harass humans. In addition, geese feed on and subsequently damage the grass in these parks. Waste from high numbers of geese can also negatively impact water quality in urban areas by contributing to fecal coliform levels, phosphorus loading, and the organisms causing swimmer's itch (a trematode parasite) (CLAMP 2002). More information on Canada geese in Capitol Lake can be found in the CLAMP Plan 1999-2001 (1999) and the CLAMP 10-Year Plan (2002).

Nutria, *Myocaster coypus*

Nutria (*Myocaster coypus*) are nuisance rodents inhabiting areas where land and water interface (LDWF 2003). Indigenous to South America, nutria were introduced to the United States for fur farming and trapping industries. They were marketed as a control technique for undesirable vegetation. Nutria are found in western Oregon and north through Puget Sound, as well as other states but are most abundant in Louisiana and Texas. As herbivores, nutria feed primarily on wetland plants, in particular at the base of stems and digging for roots in winter months. If feeding is extensive and vegetation is removed, wetlands soils are exposed and more vulnerable to erosion. Scouring and a lowering of elevation are then possible. Large populations are responsible for fragmenting wetlands and the loss of marsh lands in Louisiana and Maryland. Populations of nutria can increase quickly because females are capable of having two litters per year with an average of five young per litter. Various control techniques are available and more information can be found through university extension services websites or on the web.

Knotweed, *Polygonum* spp.

Several species of invading knotweed (Family: Polygonaceae) are of growing concern in the PNW and federally designated as noxious weeds. These species include Japanese knotweed (*Polygonum cuspidatum*), giant knotweed (*P. sachalinense*), Himalayan knotweed (*P. polystachyum*), and a hybrid of giant and Japanese (*P. bohemicum*). Populations of these knotweed species can spread rapidly by reproducing vegetatively through root sprouts and by root fragments as small as ½ inch. The ability to reproduce from such small root fragments is of particular concern in areas with flooding because fragments are transported and spread along waterways. Knotweed is damaging in numerous ways, both ecologically and economically. These costs include: loss of native plant diversity, destruction of critical fish and wildlife habitat, reduction of insect diversity, the potential for increased erosion and flooding, slowing decomposition rates, necessity of herbicide and other control measures, disposal of plant material, and revegetation following removal (Shaw and Seiger 2002; Grevstad 2006). For example, knotweed invasion may also contribute to increased soil erosion and flooding because as the plant dies back at the end of the growing season, river banks are often exposed and bare during wet winter months (Shaw and Seiger 2002). Therefore, like purple loosestrife, knotweed can also lead to aquatic ecosystem degradation. In another estuarine area, Tillamook Bay, concerns of knotweed invasion are reduction in water quality due to the loss of the native riparian buffer, increased runoff and associated high fecal bacterial loading, and sediment erosion during winter months due to the lack of riparian vegetation. Knotweed was documented by The Nature Conservancy along the Black River in Thurston County (WSDA 2005). The 0.2 acre area was treated but demonstrates the close proximity of this invasive to the Deschutes River and Estuary.

Himalayan blackberry (*Rubus discolor*) and reed canarygrass (*Phalaris arundinacea*)

Himalayan blackberry is native to Western Europe (Hickman 1993), but since the middle of the 20th century was naturalized along the West Coast of the United States. It frequently grows in riparian areas and can tolerate periodic inundation by fresh or brackish water. It can be found in intertidal habitats such as the lower Sacramento River (Katibah *et al.* 1981). Himalayan blackberry disrupts native ecology by reducing light so much that growth of native plants is rapidly reduced and they are eventually displaced (Hoshovsky 1989). Because the plants grow in nearly impenetrable thickets, blackberries also hinder medium-sized to large mammals from gaining access to water in wet areas. This also limits recreational access to water bodies.

Reed canarygrass is another botanical threat to wetland ecosystems. Reed canarygrass forms dense, productive monoculture stands that can inhibit and/or eliminate native species and destroy the seed banks of previously existing native vegetation (Apfelbaum and Sams 1987). While possibly native to North America, European cultivars have been widely introduced for use as hay and forage in the United States and all species are now considered to be invasive. Reed canarygrass is a vigorous grower; it also disrupts wetland food webs by removal of native plants and destroys habitat by growing so thickly that small mammals and waterfowl cannot inhabit the invaded areas (Maia 1994). The species is also known to increase siltation along irrigation banks and ditches (Marten and Heath 1973).

Both Himalayan blackberry and reed canarygrass can reduce native flora and fauna fitness, abundance, and diversity. Therefore, the occurrence of these plants in a restored Capitol Lake should be strictly monitored. Stands of these riparian and wetland invaders should be removed to enhance native estuarine flora and fauna. This should be a part of an aggressive adaptive management plan for the Capitol Lake restoration project.

Smooth cordgrass (*Spartina alterniflora* and *Spartina angelica*)

While not currently found in Capitol Lake or Budd Inlet, cordgrass is an aggressive colonizer of estuarine areas and should be considered a threat to restored and natural estuaries in this system. Cordgrass has dramatically altered the Willapa Bay estuary by colonizing mud flats. In Puget Sound, known cordgrass infestations occur or have occurred along the Strait of Juan de Fuca; in Hood Canal; in the San Juan Islands; along the shorelines of Skagit Island; and Snohomish, King, and Kitsap counties (PSAT 2002). Cordgrass has not been found south of the Tacoma Narrows, the border between north and south regions of Puget Sound (PSAT 2002). Cordgrass aggressively colonizes mudflats and salt marshes, displaces native plant and animal species, and alters the ecological landscape by transforming mudflats into salt marshes (Parrish *et al.* 2003). This is the primary process by which *Spartina* could alter a recovering estuarine system in Capitol Lake.

Cordgrass is controlled in Puget Sound by a rigorous physical removal program run by the Washington Department of Agriculture (PSAT 2002). However, its poses a threat to all PNW estuaries and should not be overlooked in development of a management plan for a healthy estuary.

European Green Crab (*Carcinus maenas*) and Chinese Mitten Crab (*Eriocheir* spp.)

The European green crab was discovered in the late 1990s in the PNW (Parrish *et al.* 2003). Green crabs have been found from California to British Columbia, although not in every drainage in this range. Chinese mitten crabs are burrowing crabs native to the Yellow Sea estuaries and coastal rivers of China and Japan (Parrish *et al.* 2003). They have been found in the PNW mainly in California waters. The primary threats from these invasive species are thought to be through competition for food with native fish and bird species. They are also expected to displace native Dungeness crab, a commercially important species, and reduce clam and oyster fisheries (PSAT 2002). Through monitoring efforts, a special watch for these species should be conducted in a restored Capitol Lake.

Because of the extensive disruption nonnative species can cause in estuaries, they are a management concern in all PNW states (Parrish *et al.* 2003). An understanding of the abundance and distribution of current nonnative species and how these species disturb the habitats they invade is essential to their management (Hacker *et al.* 2003; Dethier and Hacker 2005; Hacker and Dethier 2006).

Other Disturbances

There are other anthropogenic stressors of the biological conditions of estuarine communities in Puget Sound. For example, commercial fishing and shellfish aquaculture can destroy subtidal habitats and alter community composition by competition for resources. Also, access to estuaries can increase human awareness of these delicate ecosystems, but the effects of human recreation on estuaries may be detrimental. For example, Erickson *et al*. (2003) found that areas in Olympic National Park with high human access had a greater percent cover of bare rock than those with low human access. Although these disturbances mainly cause habitat loss, they can be caustic to estuaries when compounded with other anthropogenic disturbances.

Previous Studies in Puget Sound Estuaries

Puget Sound is culturally, economically, recreationally, and aesthetically important to the region and the nation (Berry and Ritter 1997; Goetz *et al.* 2004) and so resource managers are charged with the difficult task of balancing physical and biological requirements of Puget Sound with anthropogenic consumption of and/or effects on the resources. To help resource managers address the diverse and complex ecological and anthropogenic characteristics, numerous entities and partnerships have conducted research to further our understanding of the ecology of Puget Sound. Several studies have also examined the possibility of a decline in habitat quality, the effects of anthropogenic factors, and the mitigation of habitat degradation and/or loss (e.g., Berry *et al.* 1998; Dean *et al.* 2001; Fresh *et al.* 2004; Goetz *et al.* 2004; Tanner *et al.* 2005).

Groups investigating the complexity of Puget Sound often include tribal, state, federal or local municipalities, universities or federal non-profit organizations. Most of these interdisciplinary, collaborative groups include top regional scientists and the use of technologically advanced methods to investigate the complexity of the Sound. Other groups focus on public perception of Puget Sound ecological issues or the economic impact of human activities. The studies cover a broad array of topics including habitat inventories, mapping projects, hydraulic models, and biological characteristics of Puget Sound nearshore areas. Data produced are available in various formats including spatial and tabular Geographical Information Systems (GIS) data, biological data, physical models, aerial photos, and technical reports. These projects are funded by a variety of groups, including government, non-profit, and private foundations. Often, these groups are additionally fueled by public support due to the recreational and aesthetic values society holds for the region.

Understanding current and past ecological investigations in Puget Sound is essential to new work performed in the area. Many techniques and technological innovations have been used in these studies and, therefore, will be of interest to those concerned with the restoration of the Deschutes River Estuary. Here we present a brief review of projects relevant to the Deschutes River Estuary/ Capitol Lake Reference Estuary Study and Biological Conditions Report[4]. Some of these studies molded the study design and methods of the Reference Estuary Study; others will help predict potential outcomes for Capitol Lake restoration in the Biological Conditions Report.

WA DNR Shoreline Inventory

The Washington Shore Zone Inventory was instigated by the Nearshore Habitat Program at the Washington Department of Natural Resources (WA DNR) and its purpose was to conduct a survey of the entire state's saltwater shorelines. The goal of this project, funded by WA DNR, was to describe the physical and biological characteristics of the inter- and sub-tidal shorelines for management needs and to further understand these sensitive ecosystems. The inventories were conducted between 1994 and 2000. Video imagery of the shoreline was recorded *via* helicopter as biologists and other researchers recorded the type of shoreline, dominant vegetation and substrate types, shoreline morphology, and biota (Berry *et al.* 2001a). A complete inventory data set is available from the Shore Zone Inventory in spatial and tabular form; all data are available to download at http://www2.wadnr.gov/nearshore. A User's Manual (Berry *et al.* 2001a) and Data Dictionary (Berry *et al.* 2001b) were published to assist data users.

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[4]A comprehensive annotated bibliography was also produced as part of this project: It is available as a separate document.

PRISM

The Puget Sound Regional Synthesis Model, or PRISM, is a multi-disciplinary program at the University of Washington, Seattle. This program seeks to better understand human influences on the nearshore in Puget Sound by developing sediment and hydrologic models. To this end, PRISM integrates numeric environmental models together to create an information system for Puget Sound including data on atmosphere, land processes, physiography, sea state, circulation, water resources, human forcing, and biotic resources.

The program also hopes to play a role in supporting threatened and endangered fish stocks in the Puget Sound area. An essential part of the PRISM program is education through courses, seminars, and presentations at the University of Washington (http://www.prism.washington.edu/index.html). Funding for this program, started in 2001, has come from many sources, including Washington Sea Grant, USGS, and internal funds from the University of Washington. Data from the PRISM project are to be available to classrooms, researchers, and the general public. However, at this point, a method for dissemination of the information is still being established. Specific data available includes models of marine circulation, marine biogeochemistry, regional water supply forecasts, salmon populations, Puget Sound bathymetry along with biannual hydrographic surveys (CTD data) of the Sound, and monthly cruises at the Sound entrance.

LOTT Wastewater Management Partnership

The LOTT Alliance (municipal governments of Lacey, Olympia, Tumwater, and Thurston County) manages wastewater and reclaimed water production for 85,000 people in urban areas of north Thurston County, Washington. The central treatment plant for the LOTT system is located in Budd Inlet, just northeast of the north end of Capitol Lake. LOTT services include flow management, and replacement and improvement of facilities through several programs which involve multiple projects. The alliance is managed by a board of four directors elected from partner governments, an executive director, and staff. An 18-month scientific study of Budd Inlet, conducted by scientists and modelers from consulting firms and state and academic institutions, funded largely by LOTT, was published in 1998 and provides information on water quality issues (dissolved oxygen concentration, nitrogen and nutrient concentrations, circulation) associated with treatment plant wastewater outflows. An overview of findings from this study, other documents, and general information about LOTT can be found at http://www.lottonline.org/.

Washington Natural Heritage Program

The Washington Natural Heritage Program (WNHP) was established in 1982 to collect data about existing native ecosystems and species in an aim to maintain natural biological and ecological diversity in the State. The creation of the WNHP was mandated by the State of Washington's Legislature to help prevent further loss of rare species and ecosystems. The program is run by the WA DNR.

The WNHP aims to provide an objective and scientific basis for protection of threatened flora and fauna and to develop strategies for the protection of habitats where these organisms exist. Data on threatened species and natural diversity in Washington are collected through referrals and field inventories. This is often done collaboratively with other agencies and natural resource organizations.

A result of the WNHP is a database called the Natural Heritage Information System. The presence, population, condition, protection status, and distribution of ecosystems and species important to the State's natural diversity are included in the database. The information is available in a variety of formats, including Geographic Information Systems and other databases available online (http://www.dnr.wa.gov/nhp/).

Puget Sound Nearshore Partnership

The Puget Sound Nearshore Partnership and Puget Sound Nearshore Ecosystem Restoration Project (PSNERP) are a collaborative group of local, state, federal, and tribal entities; industries; environmental organizations; and the U.S. Army Corps of Engineers (USACE) that began in 2001. This WA Department of Fish and Wildlife sponsored project has the goal of protection and restoration of Puget Sound shorelines. They accomplish this by working in collaboration with the Puget Sound Action Team (PSAT) on habitat restoration issues identified in PSAT's Work Plan. To this end, the groups involved have developed restoration guidance (Fresh *et al.* 2004) and strategic principals (Goetz *et al.* 2004) documents, work and management plans, an annotated bibliography and LIDAR data for Puget Sound, all available on their website (www.pugetsoundnearshore.org).

Puget Sound Action Team

The Puget Sound Action Team (PSAT) authorized in 1996 by the Washington State Legislature, consists of state, federal, tribal and local government leaders with responsibility for Puget Sound health. The Action Team serves as a coordinating mechanism among those agencies, carries out estuary restoration priorities as part of the National Estuary Program and produces the Puget Sound Water Quality Management Plan and biennial recovery plans to implement priority actions. Among the coordinating functions is the Puget Sound Ambient Monitoring Program (PSAMP). The Puget Sound-Georgia Basin Transboundary Program has similar multi-agency efforts. In recent years, PSAT has sponsored studies on shellfish impacts from urbanization, low impact development, alternatives to hard armoring and regional nearshore aspects of salmon recovery.

PSAMP

The WA DOE has an established Marine Sediment Monitoring Team (MSMT) who has combined with the Puget Sound Ambient Monitoring Program (PSAMP). They sample the marine benthos for effects associated with toxicants in Puget Sound. Data are available through several reports available through WA DOE. PSAMP also has a program called the Submerged Vegetation Monitoring Project, which monitors eelgrass, an important habitat in the nearshore (Dowty *et al.* 2005). The Submerged Vegetation Monitoring Project is also run in cooperation with the WA DNR.

SCALE

The Spatial Classification and Landscape Extrapolation of Intertidal Biotic Communities in Central and South Puget Sound (SCALE) program was developed to further knowledge of biological organisms in Puget Sound (Berry *et al.* 1998). This is being done by monitoring communities using a statistically rigorous protocol. The project includes physical mapping and biological sampling at several estuaries throughout the Sound. Cobble beaches were chosen as focus habitats for site selection; to date, biota at 110 cobble beaches have been sampled. Work began in 1997 and continues each summer. The Aquatic Resources Division of the WA DNR heads this project and has also funded the work. SCALE's protocol and reports can be found at: http://www2.wadnr.gov/nearshore/scale/index.asp.

Thurston County Digital Shoreline Inventory

In 2001, the Thurston Regional Planning Council began to investigate the condition of beaches in the county in relation to forage fish, which are prey species for salmonids. Within this project, a digital map of the County's marine shoreline was created in GIS using data from multiple sources. The County also conducted an extensive bulkhead inventory along county shores. The results of these efforts are posted online in a GIS data base and interactive map at www.trpc.org/programs/environment/water/nearshore.htm. This work was funded by the Salmon Recovery Funding Board.

Washington Department of Ecology Programs

Shoreline Aerial Photos

The Washington Department of Ecology (WA DOE) maintains an online database of color aerial photos of the State's 2,500 miles of shoreline. The photos, collected from 1992 through 1997, are available for download (under copyright laws) or for purchase *via*: http://apps.ecy.wa.gov. The project was supported by the WA DOE and NOAA's Office of Ocean and Coastal Resource Management.

Digital Coastal Atlas

The WA DOE also maintains an online geospatial database of the entire coast of Washington. The data are available online and users are able to query the databases that are very user-friendly and do not necessitate use of separate GIS software. The maps were compiled using paper maps converted into digital layers. Further information can be found at http://www.ecy.wa.gov/programs/sea/sma/atlas_home.html.

Marine Water Quality Monitoring

The WA DOE monitors water quality at several stations state-wide, including in Puget Sound. Parameters monitored include temperature profiles, salinity, density, dissolved oxygen concentration, light transmission, pH, bacteria, chlorophyll [a], phaeopigment, nitrate, nitrite, ammonium, orthophosphate, silicate, and Secchi disk depth. These data are available via the Washington State Marine Water Quality report at http://www.ecy.wa.gov/programs/eap.mar_wat/mwm_intr.html. Raw data are also available for download at the same site.

Pacific Northwest Ecosystems Region Study

The Pacific Northwest Ecosystems Region Study (PNCERS) was a seven year program focusing on natural and anthropogenic forces on outer coastal systems in Washington and Oregon, not including Puget Sound (Parrish *et al.* 2003). The biogeographical area covered by the project was estuaries and the nearshore environment, to the outer edge of the continental shelf. This work, funded by NOAA's Coastal Ocean Program, was an interdisciplinary attempt to define the totality of the system. PNCERS included diverse disciplines such as human-caused changes, biological and socioeconomic responses, and was a collaboration of established researches in several disciplines (e.g., physical oceanography, environmental economics). PNCERS also placed emphasis on the dissemination of emerging information on ecosystem processes (Parrish *et al.* 2003). The four study estuaries for PNCERS were Grays Harbor and Willapa Bay in Washington and Yaquina and Coos Bays of Oregon. Data from this project were largely published in a special edition of Estuaries (Volume 26, 2003).

EDC Hyperspectral Mapping Project

Recognizing the importance of eelgrass beds to migrating juvenile summer chum salmon (*Oncorhynchus keta*), scientists at Earth Design Consultants, Inc. and the University of Washington initiated a study to map eelgrass beds along the intertidal shoreline of Hood Canal in Western Puget Sound. This study, funded by the Point No Point Treaty council, used high spatial resolution, hyperspectral imagery to map 11 habitat cover classes along 150 km of Hood Canal including eelgrass and green macroalgae (Garono *et al.* 2004). This study produced several spatial data sets describing the abundance and distribution of intertidal habitat cover types. Data are available from the Point No Point Treaty Council.

Padilla Bay NERR

Padilla Bay is the bay at the edge of the Skagit River delta in Washington. The bay is shallow and flat and supports an 8,000 acre plot of eelgrass (Bay 2006). In 1980, the state and federal governments recognized this area should be protected and dedicated 64 acres of uplands as the Padilla Bay National Estuarine Research Reserve (NERR). The reserve is a cooperative effort between NOAA and the WA DOE. The Reserve maintains education, stewardship, and research programs, as well as an extensive in-house library. It is one of the largest estuarine restoration projects in Puget Sound, and although very different from the Deschutes and other South Sound estuaries, it is a useful source of information about restoration. More information is available at www.padillabay.gov.

Nisqually Wildlife Refuge

The Nisqually River Estuary opens into Puget Sound just northeast of the City of Olympia. In this area, the Nisqually National Wildlife Refuge (NWR) was established in 1974, covering 3,000 acres of salt marsh, mudflats, freshwater marshes, open grasslands, riparian woodlands, and upland forests. It is one of the largest, least-disturbed estuaries in Washington. The Refuge is currently restoring freshwater marsh, riparian woodland, and upland forest habitats. Future restoration plans for the Refuge include dike breaching, downgrading, and reconnection of historic slough channels. Ongoing research in the area is also being conducted; for example the Nisqually Indian Tribe is currently studying juvenile salmon at the NWR. Restoration and monitoring efforts taking place here may serve as helpful models for activities in Capitol Lake. More information can be found in the comprehensive conservation plan and environmental impact statement for the Nisqually Delta at http://www.fws.gov/nisqually/ccp.html.

Description of Study

The goal of this study is to evaluate the feasibility of restoring the Deschutes River Estuary as an alternative to managing Capitol Lake, a freshwater impoundment in Olympia, WA. Capitol Lake was created by impounding the Deschutes River where it enters Budd Inlet and southern Puget Sound. Although planned in the early part of the 20th century, the lake was created in 1951 when a dam was built across the northern end of the Deschutes Estuary to form a reflecting pool for the State Capitol building (Figure 1). While the lake has achieved this objective, today it is a water body listed for high total phosphorus and fecal coliform levels (WDOE 2004a), with sediment loading levels from the Deschutes River watershed threatening water quality of the lake.

To make informed management decisions about the restoration of Capitol Lake, an interdisciplinary team of state and municipal agencies, the Capitol Lake Adaptive Management Plan (CLAMP) Steering Committee was created to advise the State on the management of the basin. The CLAMP Steering Committee is evaluating several possible restoration scenarios for the lake, including restoring the lake to a tidal estuary, to address management concerns over what actions are necessary to maintain a lake in this setting. CLAMP has initiated studies to determine the feasibility of such a restoration. This document, the Reference Estuary Study and Biological Conditions Report, outlines the findings of an exercise in combining data from reference estuaries and a hydraulic and sediment transport model to predict estuarine communities that could occur in a restored Deschutes Estuary.

The Reference Estuary Study and Biological Conditions Report, in conjunction with other studies, are components of the Deschutes River Estuary Feasibility Study (DEFS, Figure 2). Individual studies are to be completed during mid-2007 with the final report on the estuary feasibility project completed in mid-2008. Other components of the DEFS include a hydrodynamic and sediment transport model, a Net Benefits Analysis, and an Engineering Design and Cost Estimate Study (Figure 2). In the current study, we attempted to predict physical and biological conditions in the Deschutes Estuary post-restoration. To do so, we sampled biological and physical variables from several reference estuaries. The environmental variables included: elevation, sediment grain size/characteristics, sediment and vegetation cover, and water quality parameters including salinity. We then used multivariate statistics to develop empirical relationships between estuarine habitat types and the environmental variables. These relationships were combined with output from the hydrodynamic and sediment transport model to predict the likely outcome of restoration scenarios in the Deschutes River Estuary.

Rather than using indicators or single variable approaches to evaluate each of the restoration scenarios, we used multivariate statistics to describe patterns in the expected

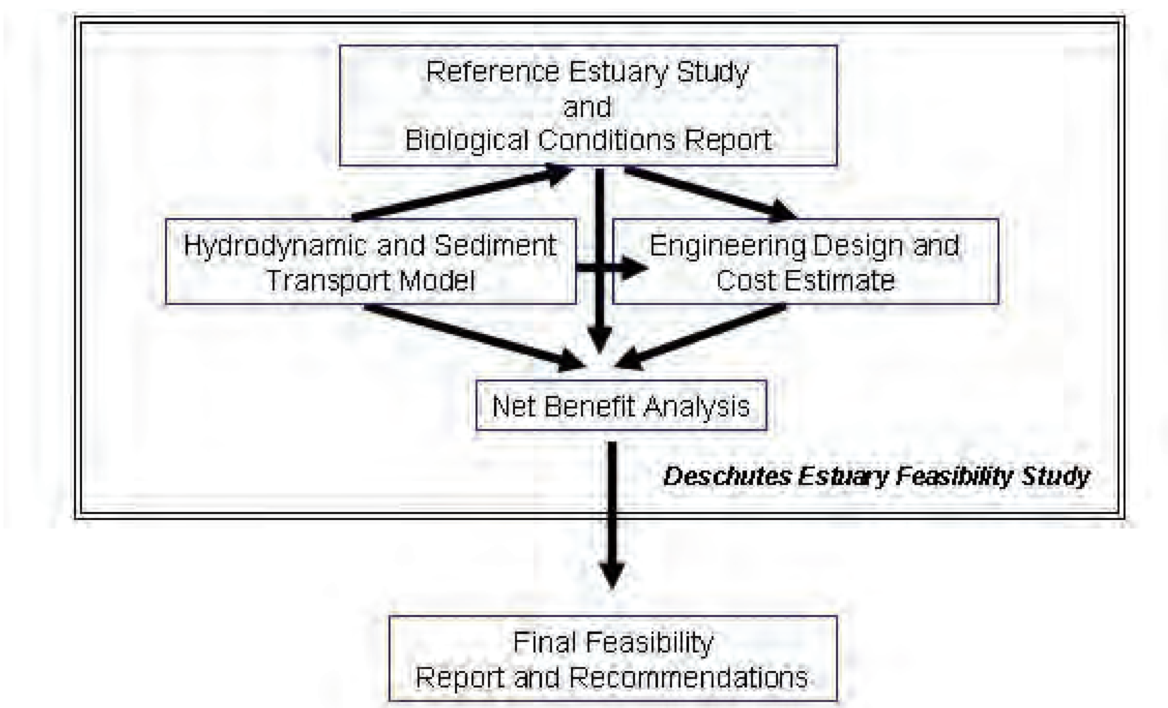


Figure 2. Components of the Deschutes Estuary Feasibility Study.

biological communities and to identify the environmental gradients that structured the communities. We also used the relationships between habitats and measured environmental gradients to visualize the consequences of each restoration scenario using prescriptive mapping. Previous studies caution against inferring too much about ecosystem function from form (e.g., Simenstad and Thom 1996). Therefore, the habitats created as a result of the proposed restoration actions may not actually function as intended. We suggest that the physical and biological data in this project be used to develop meaningful restoration targets. Restoration success will be realized through continued monitoring. Results from our study will be applicable in the Net Benefits Analysis of the Capitol Lake restoration and in future studies to prioritize proposed restoration scenarios. This suite of studies will be used to develop a recommended action plan for Capitol Lake.

The results from the USGS hydrodynamic and sediment transport model were used to describe where sandy channels, mud flats, and marsh benches will form under the various restoration alternatives, while the Reference Estuary Study aims at characterizing biological communities that are likely to be found in the restored estuary. The Biological Conditions section of this report describes important ecological processes that occur within southern Puget Sound estuaries and their watersheds.

The Biological Conditions Report brings the field and modeling work together in an effort to answer the overarching question of whether a self-maintaining estuarine community, with diverse populations of plants and other organisms, can be reestablished in Capitol Lake. The Biological Conditions report also addresses uncertainties, insofar as the physical and biological systems are concerned, that lie in the path of reestablishing an estuary within the current Capitol Lake basin. In this report, the Biological Conditions assessment is finalized in the Chapter 4: Discussion.

USGS Model

The United States Geological Survey (USGS) developed a hydrodynamic and sediment transport model to evaluate four Capitol Lake restoration scenarios (George *et al.* 2006). The DELFT 3D model was selected for this project. DELFT 3D is a numerical model that is composed of distinct modules describing hydrodynamics, water quality, and sediment transport. The model uses a grid as a "skeleton" to simulate conditions across Capitol Lake. In this case, we imported model results in this grid format into a geographic information system so that comparisons between restoration scenarios could be made and specific habitats could be mapped. For more information on the DELFT 3D model see George *et al*. (2006) and Appendix II of this report.

Deschutes River Watershed

The Deschutes River Watershed drains an area of 126,609 acres (Turner *et al.* 1993) into southern Puget Sound at Budd Inlet *via* a reservoir, Capitol Lake, in Olympia, WA. The Deschutes River is the major waterway in the Capitol Lake watershed; it begins in the

Bald Hills of Lewis County, then flows into the southern part of Thurston County. The river flows through a gently rolling glaciated plain along most of its length before entering the lower basin/Capitol Lake. The Deschutes River basin is approximately ten times as long as it is wide (Figure 3). The maximum elevation in the watershed is in the Bald Hills; Cougar Mountain is the highest point there, 3,840 ft above sea level (Orsborn *et al.* 1975). The topography of the watershed varies from the relatively flat lower watershed and mildly sloped mid-watershed to a steeper upper watershed (McFarland 1997). The predominant geology of the watershed is glacial outwash deposits which are unconsolidated and prone to relatively high erosion rates (McFarland 1997).

Historically, the Deschutes River Watershed was dominated by coniferous forests in the uplands and wetlands and estuaries in the low-lying portions. Prior to European colonization, the Squaxin, Nisqually, S'Klallam, and other Native American tribes used the area for its bountiful natural resources – fresh water, forests, and abundant food from the sea (salmon and shellfish) and from the forest (berries and mammals). Fisheries were also noted as abundant by the early settlers. The Deschutes River at Tumwater Falls was claimed to be an excellent fishing grounds (Callender 2004).

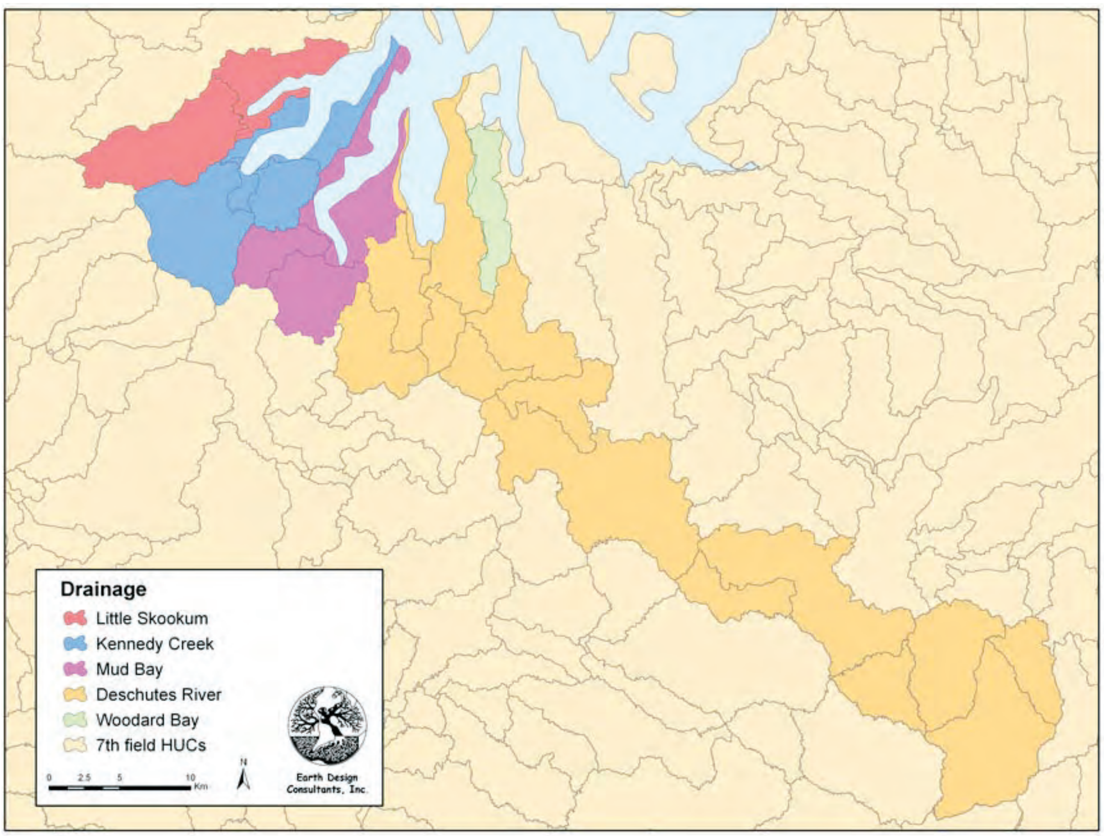


Figure 3. Seventh field HUC (hydrologic unit code) watersheds for the major reference estuary drainages where sampling was conducted in southern Puget Sound. HUC data coverage was developed from PRISM DEM (2005) data. These drainages were used in determining land cover / land use and drainage size for the major inlets used in field sampling.

Today, the upper Deschutes River watershed is heavily forested with land owned by state and private entities. Overall, forested land in the Deschutes watershed accounts for 33,229 acres or 59% (TRPC 2001). The mid-Deschutes watershed is characterized by agricultural and rural residential uses, with some forested land. The lower watershed is urbanized and characterized by dense residential, industrial and commercial land uses, and reduced agricultural and forested lands (McFarland 1997). The Cities of Olympia, Tumwater, and Lacey occupy the areas around the lower watershed. The land use around Capitol Lake and Budd Inlet is predominantly commercial, industrial, and urban and suburban residential.

The weather in the Deschutes watershed is temperate, but varies seasonally. Temperatures range from 50 to 75^{0}F during the warmest month, August, and 32 to 45^0 F during December and January, the coldest months. In the summer months (June through September), warm temperatures dominate, with little rainfall. However, from fall through spring, cooler temperatures occur with the majority of rainfall occurring during these seasons. On average, 52 inches of rain per year are recorded in the lower Deschutes River watershed and 90 inches per year are recorded in the upper watershed (McFarland 1997).

Capitol Lake and Reference Estuaries

Capitol Lake is a 260 acre water body created in 1951 by a dam placed at 5th Avenue in downtown Olympia, WA, at the mouth of the Deschutes River (Figure 1). Historically, Capitol Lake was a tidal estuary, where the Deschutes River met Budd Inlet (McFarland 1997; CLAMP 1999). The lake was meant to be a reflecting pool for the Capitol building, which sits above the lake to the east, and to provide recreational opportunities. The dam at 5th Avenue blocks saltwater intrusion from Budd Inlet into Capitol Lake through two tide gates; and has a five foot wide fish ladder for migrating Chinook and coho salmon, and cutthroat trout (CLAMP 1999; Callender 2004).

Capitol Lake depths range from -8 to 6 meters (NGVD29)[5] based on USGS bathymetry sampling within the lake (George *et al.* 2006). The deepest waters are found in the north basin though generally it is characterized as a shallow lake environment (CLAMP 1999). Normal summer water levels in the lake are 6.45 ft MSL, while during the winter water levels are generally lower (5.45 ft MSL) (CLAMP 1999). Ten-year, 50-year, and 100-year flood levels for the lake range from 10.50 to 11.00 ft MSL (CLAMP 1999). Water residence time is roughly two days during the winter and about 11 days in the summer months (CLAMP 1999).

The Deschutes River is the major tributary to Capitol Lake, but Percival Creek also drains into the lake from the west. The Deschutes River accounts for about 85% of the total

[5]This project reports elevation referenced to several different vertical datums (e.g., MLLW, NGVD, NAVD, etc.). Generally, we used NGVD29 in this report because the data supplied by USGS were referenced to this vertical datum plane. Elvations can be converted from one reference system to another. Please see http://www.nwd-wc.usace.army.mil/nws/hh/tides/ for more information.

yearly flow into the lake, although flows vary seasonally (CLAMP 1999). The Deschutes River also contributes an estimated 35,000 cubic yards of sediment per year into Capitol Lake (CLAMP 2002; Callender 2004). Percival Creek is a much smaller creek, and contributes 12% of annual flows into Capitol Lake and the remainder of water coming into the lake is from local drainage (discharge and precipitation) (CLAMP 1999).

Capitol Lake has a host of ecological concerns. High sediment loading from the Deschutes River and non-point source pollution from stormwater runoff and sewer/septic malfunctions has caused a decrease in lake water quality. Often sediment runoff stems from land use and logging in upper watersheds but according to Collins (Collins 1994) the predominate source of sediment in the Deschutes River system is mainstem erosion of glacial outwash terraces and also landslides, bank erosion, and road erosion in steep headwater tributaries in the very upper watershed above RM 35.

Consequences of the non-point source pollution are fecal coliform bacteria and high phosphorus concentrations that designate Capitol Lake as an impaired water body (WDOE 2004a; Thurston County Public Health and Social Services Dept. 2005). Fecal coliform bacteria are indicators of human health risk due to water borne pathogens. High algal growth in the lake due to increased phosphorus loading can lead to reduction in dissolved oxygen concentrations which makes the water uninhabitable for many organisms. Older reports indicate that low dissolved oxygen concentrations were an issue within Capitol Lake. And although Eurasian milfoil is present, a survey conducted in 2003 indicated dissolved oxygen concentration is at or above levels adequate for aquatic life (Thurston County Public Health and Social Services Dept. 2003).

Many of the water quality problems described for Capitol Lake arise from the lack of tidal flushing that result from the installation of the dam in 1951. The USGS DELFT 3D model and supporting data can be used to understand the subsidence and filling of Capitol Lake. For example, when 1949 and 2004 bathymetry and sediment records were compared, the total area of the lake had decreased by 300,000 m^2. The lake's volume dropped 1,200,000 m^3. These losses represent 21% of the area and 26% of the volume of the lake, respectively (George *et al*. 2005). This result supports the concern that Capitol Lake is filling with sediments from the Deschutes River. Lake managers have dealt with sediment loading in the past by dredging. However, logistical constraints on dredging make this option increasingly difficult. These include the cost of dredging and locating storage facilities for dredge material. The presence of purple loosestrife (see Chapter 1: Purple Loosestrife) in the lake also has raised concerns over the spreading of the noxious weed from dredge material. Dredging also disturbs and can redistribute contaminants in sediment. Because of purple loosestrife seeds possibly being present in the lake sediments, dredge spoils would likely not be accepted at the marine deep water dredged disposal site near Steilicoom. This would require placing the dredged spoils at an approved upland site.

The overall goal of the reference estuary study, the biological conditions report, and the USGS hydraulic and sediment transport model are to examine two possible outcomes of restoration alternatives selected by the CLAMP steering committee. The reference estuary study was set up to describe patterns in the abundance and distribution of organisms in south Sound estuaries and to understand the factors that are responsible for those patterns (i.e., elevation, salinity, and sediment gradients). If patterns are found and can be related to environmental factors, then biologists can use the relationships to predict how organisms will respond to the restoration actions planned for Capitol Lake.

Chapter 2: Methods

Field Sampling Methods

Five southern Puget Sound subestuaries were selected for characterization in the reference estuary study. Woodard Bay, Ellis Cove/Priest Point, and Mud Bay/Eld Inlet in Thurston County, as well as Kennedy Creek of Totten Inlet and Little Skookum Bay in Mason County were also chosen by the CLAMP Technical Committee members because of their southern Puget Sound location, proximity to Budd Inlet and the Deschutes River Estuary, and similar geomorphology, tidal amplitude, and general shape (long and narrow; Figure 3). Within each estuary, two or three 100,000 m^2 sampling areas were designated to be used as boundary guidelines for field teams to ensure different areas of the subestuaries were visited during sampling. When on site, field teams located the approximate boundaries of each sampling area and then sampled at six to nine points within that boundary. Sampling points were chosen haphazardly as field teams traversed the estuary, trying to sample at various elevations and on various sediment and vegetation types within that sampling area. At each sampling point, biological and physical parameters were measured.

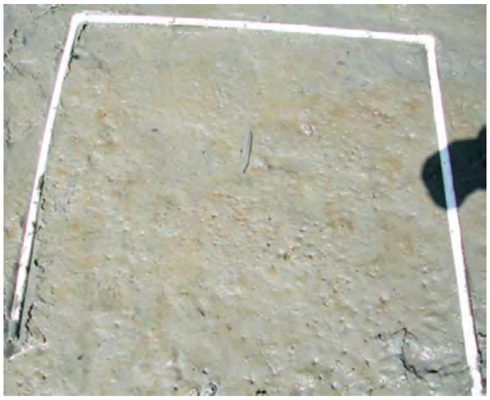
Vegetation/ Sediment Cover Plots

We measured vegetation cover (as percent cover) and sediment types in a 1 m^2 quadrat. The quadrat was positioned haphazardly within 5 m of plot center at each sampling point. Three quadrats were sampled at each sampling point. Vegetation and substrate cover were estimated within the frame to the nearest 5%. We recorded cover of plant species, diatoms, green algae, and the following substrate classes: gravel, mud, sand, and mixed mud and sand (Figure 4 a-l). Notes were recorded regarding unusual species or deviations from the sand and mud categories (i.e., mixed, silty sand, gritty mud, etc.).   For vegetated sites, such as salt marsh sites, herbaceous species were recorded and a voucher specimen collected if necessary. A digital photograph was taken of each quadrat and examples are in Figure 4 a-l.

Pore Water/ Surface Water Measurements

Salinity (practical salinity units, psu), temperature (degrees Celsius), dissolved oxygen concentration (% and mg/L), and pH were measured in pore water at each sampling point (Figure 5). At each site, we dug a hole to a maximum depth of ~50 cm until water seeped

A

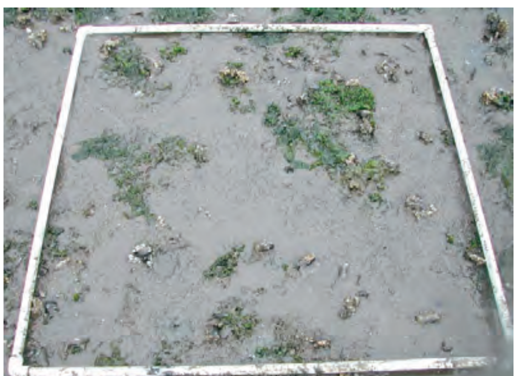


Diatoms (gold-green sheen) covering ca. 25% of the $1m^2$ quadrat at an Ellis Cove Site.

B

Algal and bacterial mat covering ca. 100% of the $1m^2$ quadrat at a Kennedy Creek Site. Note: The color of this mat ranged from dark green to black and often exhibited cracking.

C



Ulva spp. covering ca. 25% of the $1m^2$ quadrat at a Woodard Bay Site

D

Enteromorpha spp. covering ca. 25% of the $1m^2$ quadrat at an Ellis Cove at Site.

E

Filamentous green algae covering ca. 70% of the $1m^2$ quadrat at a Kennedy Creek site.

F

Carex lyngbyei covering ca. 70% of the $1m^2$ quadrat at a Kennedy Creek site.

Figure 4a-f Examples of vegetation cover observed at sampling locations in reference estuaries.

G

Distichlis spicata covering ca. 90% of the $1m^2$ quadrat at a Kennedy Creek site. *Carex lyngbyei* also present.

H

Salicornia virginica covering ca. 90% and *Atriplex patula* (large leaf) covering ca. 5% of the $1m^2$ quadrat at a Kennedy Creek site.

I

Puccinellia maritima covering ca. 55% at a Little Skookum site.

J

Juncus spp. covering ca. 80% at a Little Skookum site.

K

Potentilla anserina ssp. *pacifica* covering ca. 75% at a Kennedy Creek site.

L

Jaumea carnosa covering ca. 95% at a Mud Bay site.

Figure 4 g-l. Examples of vegetation cover observed at sampling locations in reference estuaries.

Figure 5. Field sampling during September 2005 in five south Puget Sound reference estuaries. Collecting sediment cores and GPS location (top, left); measuring height of laser above benchmark used to determine sampling site elevation (top, right); collecting sediment cores used to determine bulk density (bottom, left), particle size distribution (texture), and organic content; and collecting pore water quality data with multi-parameter probe (bottom, right).

in. Bailing was conducted to exchange the water and to avoid influence from surface water. Water parameters were measured using a Eureka Environmental Manta multiparameter probe linked to a Microsoft Windows based Amphibian hand-held PC (Figure 5). If the pore water hole did not fill with water while we were conducting other sampling at the point, pore water data were not recorded. In addition to or instead of pore water measures, if pore water was not available, surface water from a tidal channel located near the sampling point was sampled. The same parameters as for pore water were collected. These data were downloaded daily onto a laptop computer.

Site Elevation

Elevation was measured at each sampling point using a laser level calibrated to established benchmarks with known elevations. At each sampling box, the laser was placed on a tripod at the established benchmark, balanced and the height of the laser was recorded (Figure 5). At each sampling point, the laser detector was attached to a surveyor's rod and the level where the detector received the laser beam from the benchmark was recorded. All measurements within a reference estuary were referenced to the same vertical datum, NVGD29[6] (Figure 6).

Sediment Samples

Bulk Density

At each sampling point, a transparent coring cylinder (8.2 cm interior diameter, i.d.) was gently pushed by hand 6 cm into sediment, careful to not expel air or water, or compress sediment during the process. The core was carefully removed and its entire contents were transferred to a sample jar. Any sample remaining in the coring cylinder was scraped or rinsed and added to the container. The sample container was placed in a cooler with ice. The volume of the core was: $3.14*4.1^2*6 = 316.7\ cm^3$. At the end of the field day, the sample jar was transferred to a freezer and held for processing.

Grain Size Distribution and Total Organic Content

To sample sediments for grain size and total organic content at each sampling point, a metal coring cylinder (i.d. 5.4 cm) was pushed by hand into the sediment to a depth of 10 cm (Figure 5). The contents of the coring cylinder were transferred to a sample jar and the process repeated so that two cores were collected. The contents of the cores were placed together in a sample jar. The sample jar was placed in a cooler with ice. The volume of the sample was: $2(3.14*2.72*10) = 457.81^2\ cm^3$. At the end of the field day, the sample jar was transferred to a freezer and held for processing.

[6]See footnote 5.

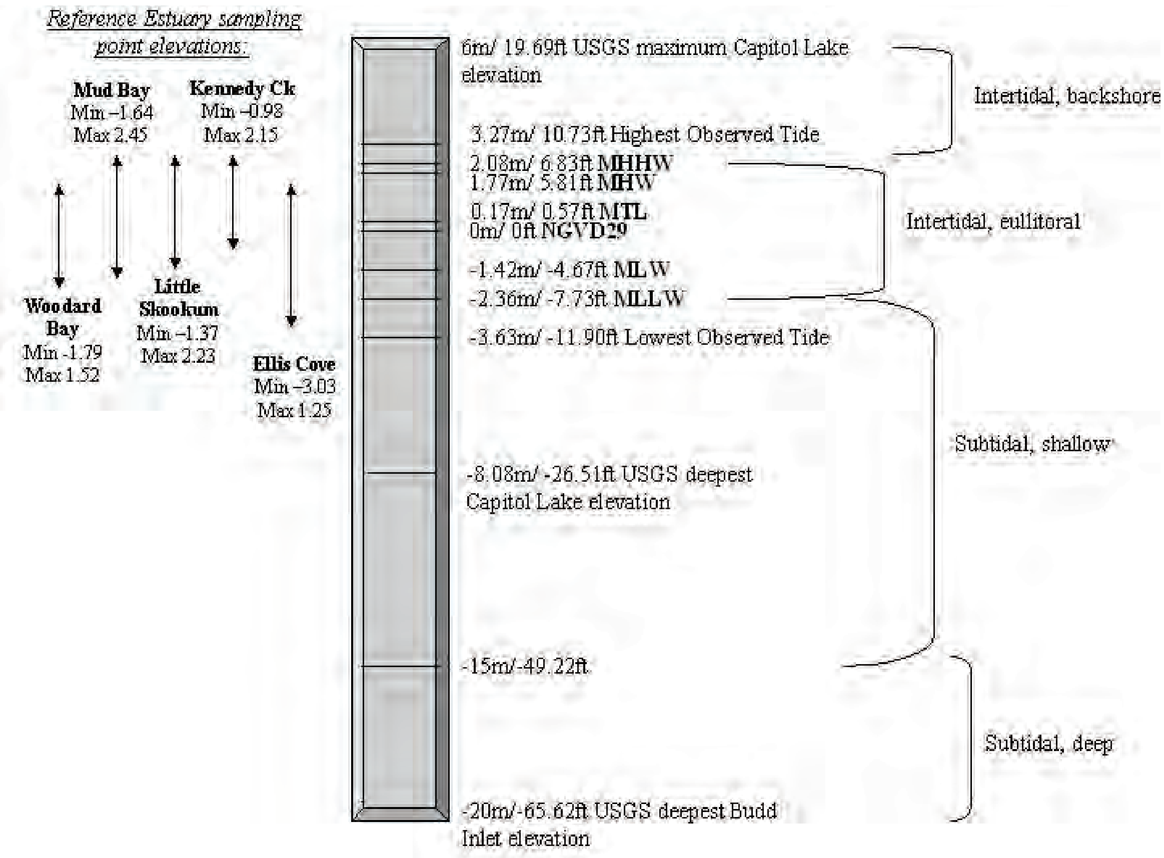


Figure 6. Tidal elevation values for Budd Inlet displayed in reference to zero in vertical datum NGVD29, not MSL or MLLW (NOAA 2003, USACE 2000). Values for lowest and highest observed tides, MLLW, MLW, MTL, MHW, MHHW, and range of elevations of sampling points within five southern Puget Sound reference estuaries and Capitol Lake are displayed in reference to NGVD29 datum. Dethier (1990) estuarine natural community types are along the right side of the diagram. Mean high water spring MHWS) is near 3 m or the highest observed tide within Budd Inlet.

Shell Collection

Crews collected empty/dead invertebrate shells present within 2 m of the sampling point plot center. No live specimens were collected and crews did not dig to collect shells. Shells were placed in sealed, labeled plastic bag to be identified in the laboratory.

GPS Site Location

We measured the location of each sampling point using a global positioning system (GPS). The latitude and longitude of each sampling point was recorded in WGS 1984 Coordinate System (Figure 5). The majority of GPS locations were taken with the Trimble Recon GPS unit with the Beacon-on-the-Belt backpack antennae. Due to equipment malfunction, locations were also logged with a Trimble Rover unit with backpack antenna or a

Garmin GPS12 unit. Whenever possible, positions were recorded when Precision Dilution of Precision (PDOP) was 3.00 or below. Logging was done at a rate of one reading per second until at least 180 readings were recorded for each individual sampling point location.

Laboratory Methods

Grain Size Analysis

We used a variety of techniques to perform the full sediment grain size analysis according to the USDA Soil Classification Standards (Laboratory 1989). Samples were processed at the Oregon State University Soils Laboratory using the following procedures. Samples were air-dried, aggregates broken up, and homogenized. The sediment sample was passed through a 2 mm sieve and coarse fragments (>2 mm diameter) were retained. The coarse fraction was washed with distilled water to remove fine particles; the fraction washed through the 2 mm sieve was preserved for later analyses. After washing, the coarse fraction was dried overnight at 105^0 C and weighed.

Organic matter was digested from fraction passing through the 2 mm sieve by a mix of distilled water and 30% hydrogen peroxide applied with heat to 50 g of the sample. The sample was then oven dried at 105^0 C for 24 hours. The dried fraction was then dispersed by adding 5% sodium hexametaphosphate (HMP) and distilled water solution to 10 g of the dried fraction. The sample was sealed and shaken at a low speed for 12 hours.

The sand fraction (2.0-0.5 mm) was then removed from the sample by thorough washing to remove all fines with distilled water through a #270 mesh sieve (0.53 mm mesh). The sand fraction was then dried at 105^0 C until all water was evaporated. This fraction was then cooled in a desiccator and weighed. The sand fraction was then split into very coarse sand (2.0-1.0 mm), coarse sand (1.0-0.5 mm), medium sand (0.5-0.25 mm), fine sand (0.25-0.10 mm), and very fine sand (0.10-0.05 mm) using stacked sieves placed on a mechanical shaker for five minutes. Each fraction remaining on different sieves was weighed.

The fraction that passed through the #270 mesh sieve was the fines (silt and clay, <0.05 mm) and subject to further analysis using the pipette technique (Laboratory 1989). This technique began with the fine fraction being brought up to a volume of 1,000 ml using distilled water. The samples were covered and allowed to come to room temperature before continuing. The sample was then mixed using a plastic plunger. Then, 20 ml of each sample was collected at specific time intervals based on the temperature of the room. The 20 ml sub sample was collected at a 10 cm depth in a 1,000 ml cylinder. The pipette-collected sample was transferred to a weighed vial and the pipetting procedure was performed at the specific room temperature based time intervals. All pipette samples were dried in an oven at 105^0 C for 24 hours and then weighed. For quality assurance purposes the pipette method was also run on laboratory blanks (i.e., 1,000 ml cylinders filled with only water and containing no sediment).

The percent of the sediment sample falling into sand and gravel texture size class was calculated using the weight of the sample retained on a given sieve, the moisture content of a given sample, and total dry weight of a sample. The percentage of silt and clay was determined by a series of successive equations involving weights of samples collected in pipettes at different time intervals and weights of dispersants used in analysis. The moisture content of the sample was determined by weighing a small amount of sediment, from which organic matter has been removed, into a weighed dish, drying for 24 hours at 105^0 C, and weighing again. The formula for calculating moisture content was [(wet weight of soil – dry weight of soil)/ dry weight of soil] X 100%.

Bulk Density

We measured dry bulk density for sediment samples based on a core volume of 316.7 cm^3 using standard American Society of Testing and Materials procedures (Laboratory 1989). Sediment samples taken for bulk density were oven dried at 105^0 C until a constant weight was reached; this weight was recorded. Bulk density was then determined by dividing the oven dried weight of the sample, in grams, by the core volume, in cm^3.

Organic Content

We used a standard Loss on Ignition technique (Laboratory 1989) to measure organic matter content of sediments. Samples were homogenized and a 10-20 g sample was measured into a tared, cleaned and dried container, and weighed (soil weight). Samples were then dried in an oven at 100^0 C for two to three hours, removed, cooled, and weighed to the nearest 0.1 g. All samples were then placed in a muffle furnace set to 550^0 C for four to five hours. The sample was cooled in a desiccator and weighed (burn weight). The percentage of organic matter was calculated as follows: % OM = [(soil weight – burn weight)/(soil weight – tare weight)] X 100 %.

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Shell Identification

Shells collected at each sampling point were identified using taxonomic and photographic keys. Shells were cleaned of any remaining sediment, identified to genus or species, and the results were catalogued. Taxonomic keys used included Light's Manual: Intertidal Invertebrates of the central California Coast (Smith and Carlton 1975) and Marine Invertebrates of the Pacific Northwest (Kozloff 1996).

Vegetation and Sediment Cover Calculations

We recorded the sediment, algal, and vegetation cover classes observed by visual estimation within three 1 m^2 quadrats at each sampling point (Figures 4 a-l). We calculated average percent cover for the three quadrats. This averaged value was used in all subsequent analyses.

Pore Water/ Surface Water Measurements

For all field-collected pore or surface water variables, an average value for each field-sampled variable was calculated for the logged data. This average was used for data analysis and estuary characterization.

Elevation Calculations and Vertical Datum Conversions

Using known elevations of established benchmarks, elevations of temporary benchmarks, height readings at each sampling point, and the height of a laser above a benchmark, the tidal elevation of each sampling point was calculated. To do so, the height of the laser level was added to the elevation of the benchmark. The height reading at each site was subtracted from this number to determine the site elevation. For example: (Benchmark elevation + height of laser above ground) - height on surveyor rod where detector registered laser beam = site elevation; (3.84 + 5.21) – 7.25 = 0.80 ft. Not all temporary benchmarks were referenced to the same vertical datum[7].

Benchmark elevations at reference estuary sites were in two different fixed vertical datums, NAVD88 and NGVD29. Both of these are based on mean sea level (MSL), as opposed to a tidally-derived surface of mean low or high water (NOAA 2004). We chose NGVD29 as our reference datum because this was the datum used by Thurston County where the majority of our study estuaries are located. This was also the datum used by the USGS model.

The conversion factor, or difference between the two datums, varies within and among estuaries. NOAA VDatum (version 1.06) vertical datum conversion software was used to determine the conversion factor between NAVD and NGVD elevations. The elevation of each benchmark was determined in NGVD by entering the exact GPS location of the benchmark and the height of the benchmark in NAVD feet. The software then computed the elevation in NGVD feet. The final elevation for each sampling point was determined using the NGVD elevation for the appropriate benchmark referenced while at the sampling point (Figure 6).

Geospatial Methods

GPS

After returning from the field, Trimble GPS location files were downloaded and differentially corrected in Trimble GPS Pathfinder Office version 3.0 with files from the CORS Tumwater Hill base station. Once corrected, location files were exported in shapefile format using Pathfinder Office export tools.

Four GPS locations collected with a Garmin GPS12 handheld unit, due to equipment malfunction during field sampling, had to be handled differently. The latitude and longitude

[7]See footnote 5.

of these four files were entered into a Microsoft Excel file, saved in a comma-delimited format, imported into Notepad, and saved as a text file. In ArcView 3.3, the Add Event Theme tool was used to include these four locations into a created shapefile.

GIS

Shapefile of Reference Estuary Sample Locations

The shapefile of sampling points produced in Pathfinder Office was joined with the shapefile containing the four sampling point locations collected with the handheld GPS unit in ArcView 3.3 was then projected into Washington State Plane Coordinate System 1983 (South Zone) projection using ArcMap 9.0. Using ArcView, we added additional data, such as field and laboratory measurements, to the attribute table of the sampling point shapefile using the join function. Metadata was developed using ArcCatalog.

Reference Estuary Watershed Characterization

In order to characterize the reference estuaries and their respective watersheds, we determined the boundaries for watersheds draining into each reference estuary. We did so by using the PRISM bathymetric digital elevation model (DEM) (Finlayson 2005) and a 1:24,000-scale streams layer obtained from the Regional Ecosystem Office (REO) to derive boundaries for 7th level HUC watersheds (hydrologic unit codes) in ARCMap (Figure 3). We used program defaults during the preprocessing of the DEM, but chose a catchment threshold of 17,778 cells (approximately 16 km^2) to approximate the size of 7th level HUC watersheds. We arrived at this value through trial and error, and made comparisons with an existing, partial 7th level watershed coverage. From our derived 7th level watershed coverage, we selected only those watersheds that drain into the estuaries in which we sampled. Seventh level watersheds were grouped into five separate drainages: Little Skookum, Kennedy Creek, Eld Inlet/Mud Bay, Deschutes River which includes Ellis Cove and Budd Inlet, and Woodard Bay. We then summarized various physical characteristics of each major inlet drainage.

Land cover for the major inlet drainages where sampling occurred was summarized using the NOAA Pacific Coast Land Cover Analysis (NOAA 2001) data for Washington State. Major cover classes, such as urban, conifer forest, hardwood forest, mixed forest, water, and wetlands were used. We developed these major cover classes by grouping similar and more detailed cover classes from the NOAA (2001) data set into the appropriate major class. This method was necessary because our sampling sites were within inlets that were located in two counties. Current land cover data is available for Thurston County watersheds (TRPC 2001), but only incomplete data was available for the Little Skookum inlet and drainage area in Mason County. In order to have comparable land cover data for all reference estuaries, we summarized land cover according to the 7th level HUC's we delineated.

Statistical Methods

We used a combination of cluster analysis and ordination to visualize patterns in our data sets. Both of these statistical techniques are frequently used and describe patterns in complex multivariate data sets (Gauch 1982; McCune and Grace 2002). In the case of this study, we characterized each sampling point by measuring: elevation, salinity, distribution of sediment grain sizes, bulk density, and organic matter content as described above. We also collected information on algal and aquatic macrophyte cover. We used a combination of multivariate statistical approaches to (1) group our sample points into 'habitat bins' based on their physical features (i.e., environmental variables) and (2) group sample sites based on the abundance and distribution of the organisms observed. We then used correlation analysis to empirically relate the observed patterns in biological communities to the underlying environmental gradients that structure those communities. These relationships were used to interpret the USGS model output for Capitol Lake/ Deschutes River estuary and towards the overall study goal of predicting the types of organisms that will inhabit specific areas in the estuary under different restoration scenarios.

We used the CLUSTER routine in the statistical software package, PRIMER 6.0, to group sample sites from all of the reference estuaries into 'habitat bins' using only environmental data. We used this approach to define groups of sample sites, or 'habitat bins,' for the discriminant analysis, which was required as a component of this study. Rather than define habitat types before sampling occurred, the CLAMP technical work group was interested in capturing the variability in elevation, salinity, and sediments that existed at each reference estuary. Because of the relatively small number of samples collected during this study, we decided to collect samples haphazardly along transects that approximately followed elevation and sediment gradients. Therefore, sample groups, or habitat bins, were not identified *a priori* but afterwards from the data we collected.

We constructed a 'Site X Environmental Variable' data matrix to conduct the cluster analysis. Cluster analysis is a multivariate statistical technique that describes patterns in complex multivariate data sets based on sample similarity calculated from the data, which in this case, are the environmental data collected during field surveys. We included the following variables in the data matrix: elevation, organic matter content, percent coarse fragments, percent sand, percent silt, percent clay, bulk density, and pore water salinity. Because pore water samples were collected from only two thirds of all sites, this analysis is not based on the complete data set (See Appendix III: Salinity). Due to different scales used to record various parameters (e.g., pore water salinity vs. percent sand), the distribution of observations for each variable, and because this type of cluster analysis does not automatically re-scale or adjust the data, we 'pre-treated' the data matrix in the following ways. First, we removed negative numbers from the elevation measurements by adding a value of 10 for each measurement[8]. We performed a square root data transformation on the data matrix to re-scale the data. This transformation was necessary to scale data so that differences in measurement scales between variables would not dramatically affect the outcome of the analysis. We

[8]This step was necessary because many transformations cannot be calculated for data that have negative values.

also normalized the data by subtracting the mean and dividing by the standard deviation separately for each matrix entry for each variable. Normalization was necessary to move the data towards more normal distributions, which is an assumption of the analysis. These data manipulations were recommended in the PRIMER manual (Clarke and Gorley 2006). Since data transformations ultimately affect the outcome of the analysis, we avoided more heavy-handed approaches that may obfuscate interpretation.

We also used PRIMER to conduct a principal components analysis (PCA) ordination using the same data matrix. Ordinations are useful tools to visualize patterns in complex data sets because they collapse multiple dimensions into two or three dimensions, which can be more easily examined. In this case, we ordinated a seven dimension data matrix. We used PCA to determine how well sample points were spread out in ordination space. We evaluated each ordination to see whether sample points were evenly distributed or if a few outliers cause points to be tightly clustered. Ideally, sample points should be well distributed in ordination space so that groups (habitat bins) having approximately equal numbers of members can be defined. We tried different combinations of variables and several types of data transformations in an iterative fashion. We eventually decided upon a data matrix that contained all of the variables associated with sediments, elevation, and salinity in our analysis using the transformation and normalization steps described above.

We also used discriminant analysis (DA) as a tool for assessing patterns in the reference estuary data. DA is a multivariate statistical technique that is used to classify a categorical variable (in this case, 'habitat bins') based on values of continuous variables, in this case, plant cover data from 1 m^2 plots (Sall *et al.* 2005). Like regressions, DA shares the usual assumptions of linearity, homogeneity of variances, and normally distributed data. Discriminant analysis is most effective when there are large differences in the means of each of the groups. A discriminant function is calculated for each group during the analysis. These discriminant functions can be used to predict group membership for new observations. For example, this study aims to develop discriminant functions for each of the different habitat bins. These discriminant functions can then be used to predict the plant and algal cover types for different elevation, sediment, and salinity combinations that may exist throughout Capitol Lake under each of the restoration scenarios. In addition to the discriminant functions, DA also produces a classification matrix where the predicted group membership is compared with the actual group membership. The success of this procedure can be evaluated on the basis of correctly predicted group membership.

We used the JMP IN 5.1 statistical software package to perform a DA on data collected at 63 sample points for which we had pore water salinity data from the five reference estuaries. For the categorical variables, we used the eight 'habitat bins' that were produced during the cluster analysis. At each sample point we collected cover data (percent cover) of the following cover classes in three 1 m^2 quadrats: (1) diatoms, (2) algal mat, (3) *Ulva* spp., (3) *Enteromorpha* spp., (4) other green algae, (5) filamentous green algae, (6) *Carex lyngbyei*, (7) *Distichlis spicata*, (8) *Atriplex patula*, (9) *Salicornia virginica*, (10) *Puccinellia maritima*, (11) *Juncus* spp., (12) *Potentilla anserina* ssp. *pacifica*, (13) *Jaumea carnosa*, (14) *Triglochin maritimum*, (15) *Zannichellia palustris*, and (16) wrack/duff/dead plant material. Since several of the cover types were only present at one or two sites, we aggregated cover types into the following cover classes: (1) diatoms, algal and bacterial mat, (2) *Ulva* spp., (3) *Enteromorpha* spp., (4) other green macroalgae (green algae and filamentous algae), (5) *Carex lyngbyei*, (6) *Distichlis spicata*, (7) *Atriplex patula*, (8) *Salicornia virginica*, (9) *Puccinellia maritima*, (10) *Juncus* spp., (11) *Potentilla anserina* ssp. *pacifica*, (12) *Jaumea carnosa*, (13) *Triglochin maritimum*, (14) *Zannichellia palustris*. We omitted the wrack cover class. Examples of each cover type are shown in Figure 4 a-l. We calculated the average cover for each site using data from three quadrats.

Chapter 3: Results

Sample Sites

All reference estuaries were sampled during August 19-21 and September 11-18, 2005, at low tide periods during daylight hours. We collected data at 90 sites throughout the five southern Puget Sound subestuaries (Figures 3 and 7a-e). The 90 points were distributed within each reference estuary as follows: Ellis Cove, 18 sites; Woodard Bay, 18 sites; Mud Bay, 21 sites; Kennedy Creek, 17 sites; and Little Skookum Inlet, 16 sites (Figure 7a-e, Table 3). GPS locations, elevations, data from three cover plots, and sediment and invertebrate cores were collected at all sampling locations. However, pore water salinity was only measured at 63 points because several of our sites had elevations that precluded pore water from entering the holes during the low tide period when we were at the site.

GIS Watershed Characterization

Spatial data layers collected from various sources were used to summarize land cover and other physical aspects of the Deschutes River and reference estuary watersheds. The Deschutes River/Budd Inlet drainage, which includes the reference estuary of Ellis Cove and Capitol Lake, drains the largest area of all inlets in this study. Budd Inlet drains 126,798 ac of a primarily forested (49%) drainage that also has large cultivated areas (17%) and the second largest amount of developed area (7%; NOAA 2001, Table 4, Figures 3 and 8).

The other four estuaries include Little Skookum, Kennedy Creek, Mud Bay, and Woodard Bay. The watershed that drains into Woodard Bay is similar to the Deschutes/Budd Inlet drainage in its proportions of land cover, reporting a high percentage of developed area (18%; Table 4, Figures 3 and 8). The Woodard Bay drainage area is the smallest (5655 ac; Table 4, Figure 3).

The remaining three estuaries have higher proportions of forested area, including mixed, coniferous, hardwood forests (>57%; Table 4, Figures 3 and 8). The Little Skookum Inlet drains a slightly smaller area (18,988 ac) compared to Kennedy Creek and Mud Bay (23,364 and 20,032 ac, Table 4, Figure 3).

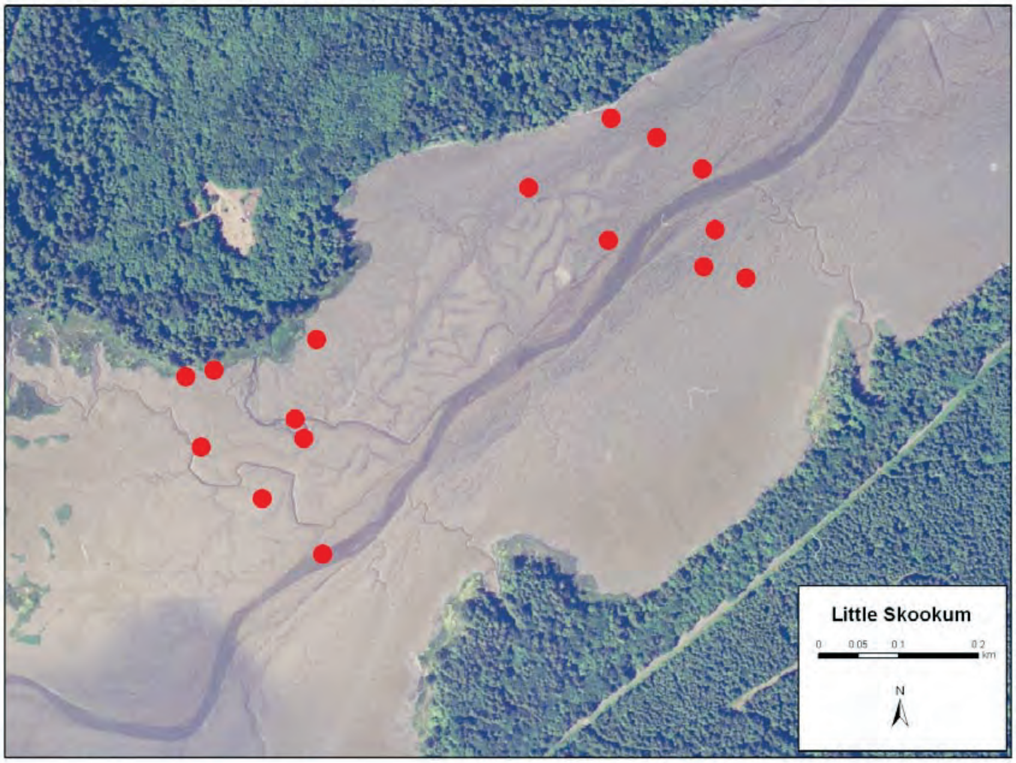

Figure 7 a. Digital Ortho photo (2003) of Little Skookum Inlet reference estuary showing specific locations of sampling points visited during September 2005.

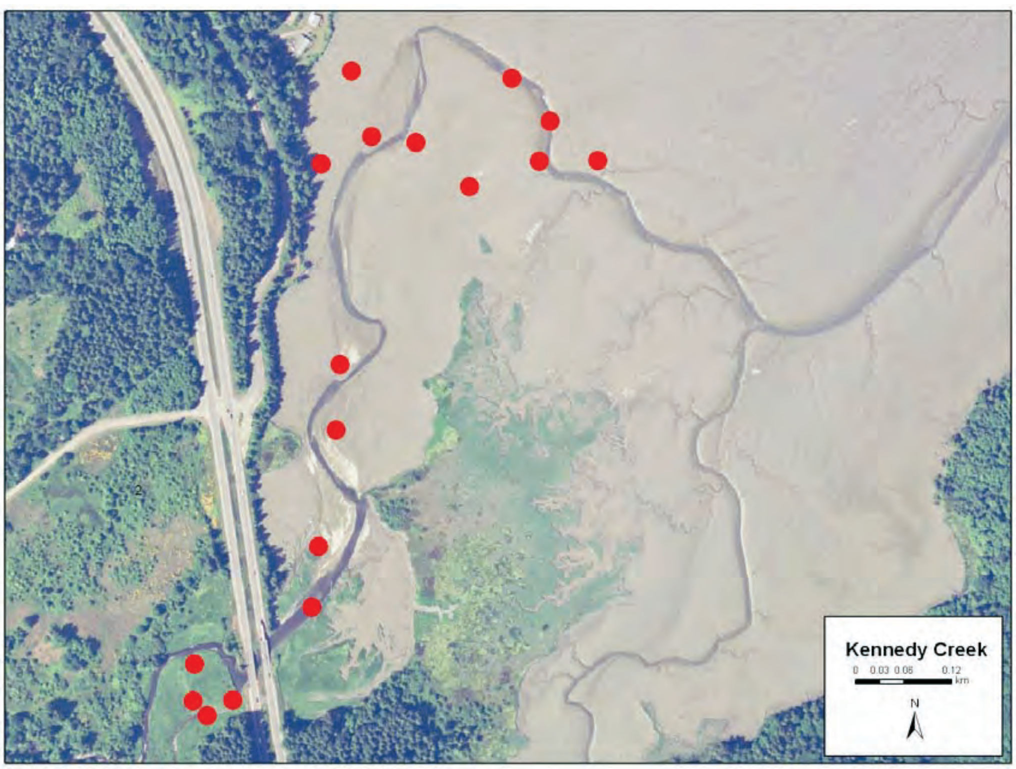

Figure 7 b. Digital Ortho photo (2003) of Kennedy Creek reference estuary showing specific locations of sampling points visited during September 2005.

Figure 7 c. Digital Ortho photo (2003) of Eld Inlet/ Mud Bay reference estuary showing specific locations of sampling points visited during September 2005.

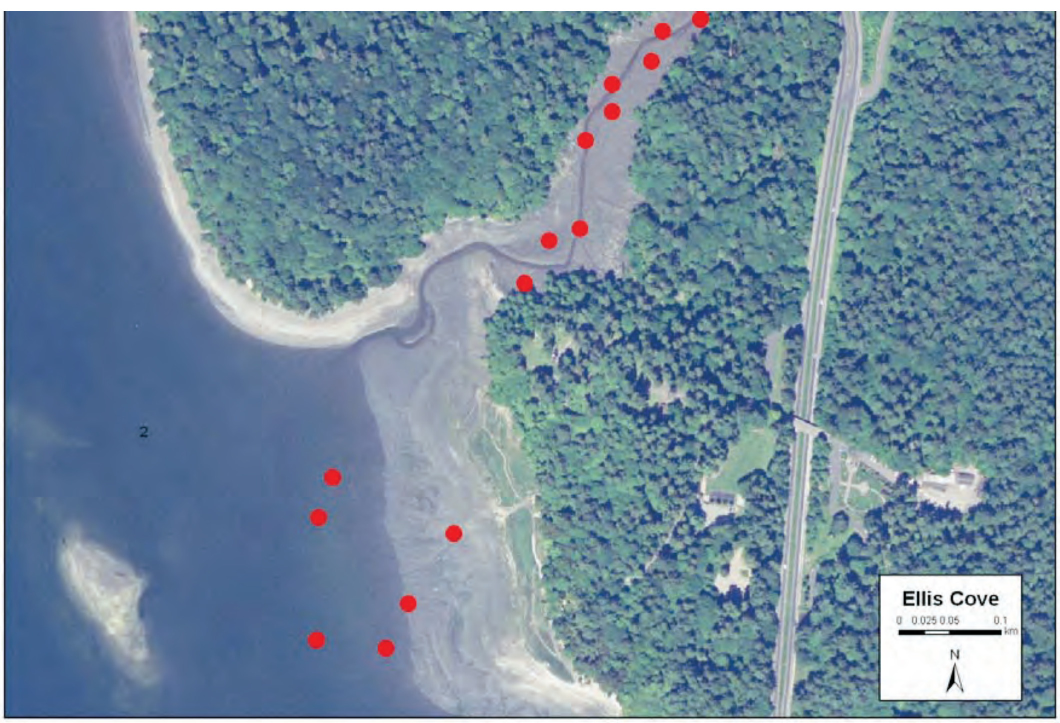

Figure 7 d. Digital Ortho photo (2003) of Ellis Cove reference estuary showing specific locations of sampling points visited during September 2005.

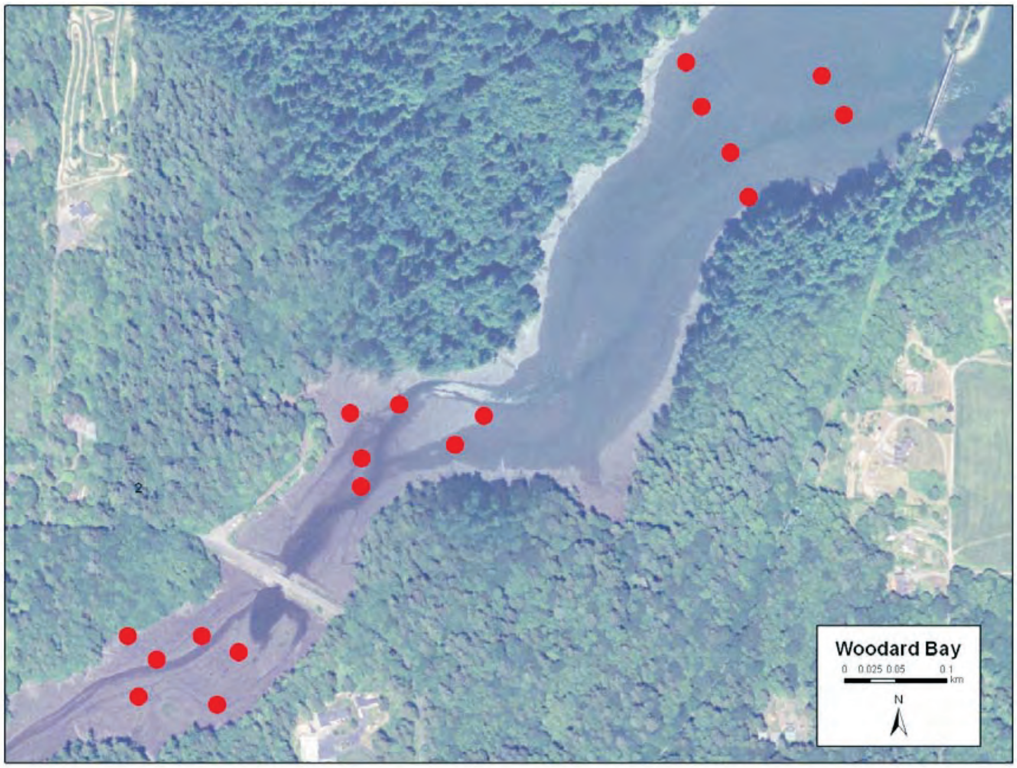

Figure 7 e. Digital Ortho photo (2003) of Woodard Bay reference estuary showing specific locations of sampling points visited during September 2005.

Results for Salinity, Elevation, Sediments, Habitat, and Communities

Salinity

Of the 90 sites sampled during low tide, we were able to measure pore water salinity at 63 (70 %) of the sites. The remaining sites did not have pore water present at approximately 50 cm depth during low tide at the time the sites were sampled. Field-sampled pore water salinities ranged from 2 psu to 28 psu (Figure 9). The overall mean value was 20.1 psu and median 21.8 psu. Data for each reference estuary are presented in Table 3. Also, saline pore water (>18 psu) was observed in all sampling areas within each estuary. Pore water data were skewed towards meso- and polyhaline salinities (Figure 9), where pore water samples were more easily obtained due to the lower elevation and therefore more likely presence of water present at low tides.

Elevation

The elevations of the sites we sampled in the reference estuaries ranged from -3.0 m in Ellis Cove/Priest Point to 2.5 m NGVD29 in Mud Bay (Table 3, Figure 10). The average

Table 3. Summary of physical and biological variables measured within reference estuaries. Mean, median, standard deviation, minimum, and maximum values are presented for all variables except sediment texture (most abundant texture). Values are averaged over all the sampling points within each reference estuary.

	mean	median	stdev	min	max	mean	median	stdev	min	max	mean	median	stdev	min	max
	Ellis Cove					**Kennedy Creek**					**Little Skookum**				
sample size	n=18					17					16				
Elevation m NGVD29	-0.7	-0.3	1.2	-3.0	1.3	0.9	0.9	0.9	-1.0	2.2	-0.2	-0.5	1.1	-1.4	2.2
OM %	5.0	5.5	2.0	1.92	8.27	10.1	8.6	4.6	4.2	21.6	10.2	6.5	12.3	2.8	50.6
Coarse %	1.6	0.5	3.0	0.03	12.57	16.5	1.1	26.7	0.0	85.4	5.1	0.1	10.1	0.0	35.5
Sand %	59.6	65.0	24.9	14.2	90.9	25.8	15.5	25.7	2.9	79.2	44.2	42.4	21.8	16.4	81.5
Silt %	31.7	27.4	21.5	6.3	71.6	57.6	62.4	23.9	12.6	81.8	39.3	38.3	17.1	11.0	64.1
Clay %	8.8	8.4	3.9	2.7	14.4	16.6	16.1	4.9	8.3	27.0	16.6	13.8	10.8	7.5	48.3
Bulk Density g/cm3	1.09	0.99	0.32	0.72	1.77	0.67	0.50	0.46	0.30	2.15	0.83	0.76	0.37	0.19	1.69
Salinity-Lab	3.9	4.0	1.2	2	6	8.2	8.5	3.3	3.0	15.0	7.3	5.0	7.5	3.0	31.0
Salinity-Field psu	17.2	17.3	45.4	2.7	24.5	22.9	24.2	5.0	14.2	26.5	25.2	27.6	6.1	6.3	27.9
no. porewater points	n=18					5					12				
Sediment Texture	sandy loam					silt loam					sandy loam/silt loam				
	mean	median	stdev	min	max	mean	median	stdev	min	max	mean	median	stdev	min	max
	Mud Bay					**Woodard Bay**					**Overall**				
No.sample points	21					18					90				
Elevation m NGVD29	-0.2	-0.2	1.2	-1.6	2.5	-0.7	-1.0	0.9	-1.8	1.5	-0.2	-0.3	1.19	-3.0	2.5
OM %	11.0	9.0	8.9	4.7	47.8	5.5	3.9	5.5	2.2	26.7	8.4	6.7	7.79	1.9	50.6
Coarse %	2.6	0.3	5.0	0.0	15.9	2.0	0.4	3.0	0.0	10.1	5.3	0.4	13.61	0.0	85.4
Sand %	24.7	20.4	17.1	7.0	67.9	60.3	60.2	19.7	14.5	83.9	42.5	38.5	26.6	2.9	90.9
Silt %	59.8	66.7	17.1	20.2	79.9	31.3	31.1	16.5	9.9	63.1	44.4	44.1	22.8	6.3	81.8
Clay %	15.5	14.7	5.6	8.9	36.6	8.4	7.8	4.2	3.4	22.5	13.1	12.6	7.2	2.7	48.3
Bulk Density g/cm3	0.67	0.60	0.26	0.20	1.33	0.96	0.97	0.25	0.18	1.29	0.84	0.79	0.37	0.18	2.15
Salinity-Lab	9.6	10.0	4.1	4.0	24.3	5.0	4.0	3.9	3.0	20.0	6.9	5.0	4.8	2.0	31.0
Salinity-Field psu	16.2	15.4	6.5	5.2	26.3	21.2	22.8	6.3	4.2	28.5	20.1	21.8	6.7	2.7	28.5
No. porewater points	11					17					63				
Sediment Texture	silt loam					sandy loam					silt loam				

Table 4. Land Use and Land Cover in percent area for each southern Puget Sound inlet sampled. Data are presented for Little Skookum and Kennedy Creek Inlets, Eld Inlet (i.e. Mud Bay), Budd Inlet which drains the Deschutes River and also contains Ellis Cove, and Woodard Bay. Data are not meant to solely represent those areas draining into where individual sampling points are located but to represent the entire watershed draining into the larger inlets where sampling occurred. Drainage/Watershed boundaries are those presented in Figure 3. Source of land cover data is NOAA Pacific Coast Land Cover Analysis 2001 using data for Washington State produced from 30 meter resolution Landsat Thematic Mapper and Landsat Enhanced Thematic Mapper satellite imagery (NOAA 2001).

	Little Skookum	**Kennedy Creek**	**Eld Inlet/Mud Bay**	**Deschutes/Budd Inlet**	**Woodard Bay**
Orientation	**SW to NE**	**SW to NE**	**S to N**	**S to N**	**SW to NE**
High Intensity Developed	0.12%	0.05%	0.08%	1.12%	3.47%
Low Intensity Developed	1.65%	1.20%	2.05%	5.66%	14.21%
Urban/Developed	**1.77%**	**1.25%**	**2.12%**	**6.78%**	**17.68%**
Agriculture	**0.00%**	**0.19%**	**0.00%**	**0.22%**	**0.00%**
Hardwood Forest	5.51%	6.51%	9.25%	4.25%	12.05%
Conifer Forest	41.44%	44.67%	38.00%	36.25%	7.76%
Mixed Forest	10.02%	15.57%	17.01%	9.42%	14.65%
Forest	**56.97%**	**66.75%**	**64.26%**	**49.92%**	**34.46%**
Unconsolidated Shore	1.54%	0.79%	0.49%	0.27%	0.01%
Scrub/Shrub	15.96%	13.67%	16.13%	17.61%	12.00%
Bare Land	1.88%	1.83%	0.57%	1.47%	0.05%
Grassland	12.42%	8.13%	10.02%	17.06%	28.58%
Nonforest	**31.80%**	**24.42%**	**27.21%**	**36.42%**	**40.64%**
Wetland	**8.83%**	**4.96%**	**6.37%**	**5.45%**	**7.15%**
Water	**0.62%**	**2.42%**	**0.04%**	**1.21%**	**0.07%**
Total acres	**18,988**	**23,364**	**20,032**	**126,798**	**5,655**

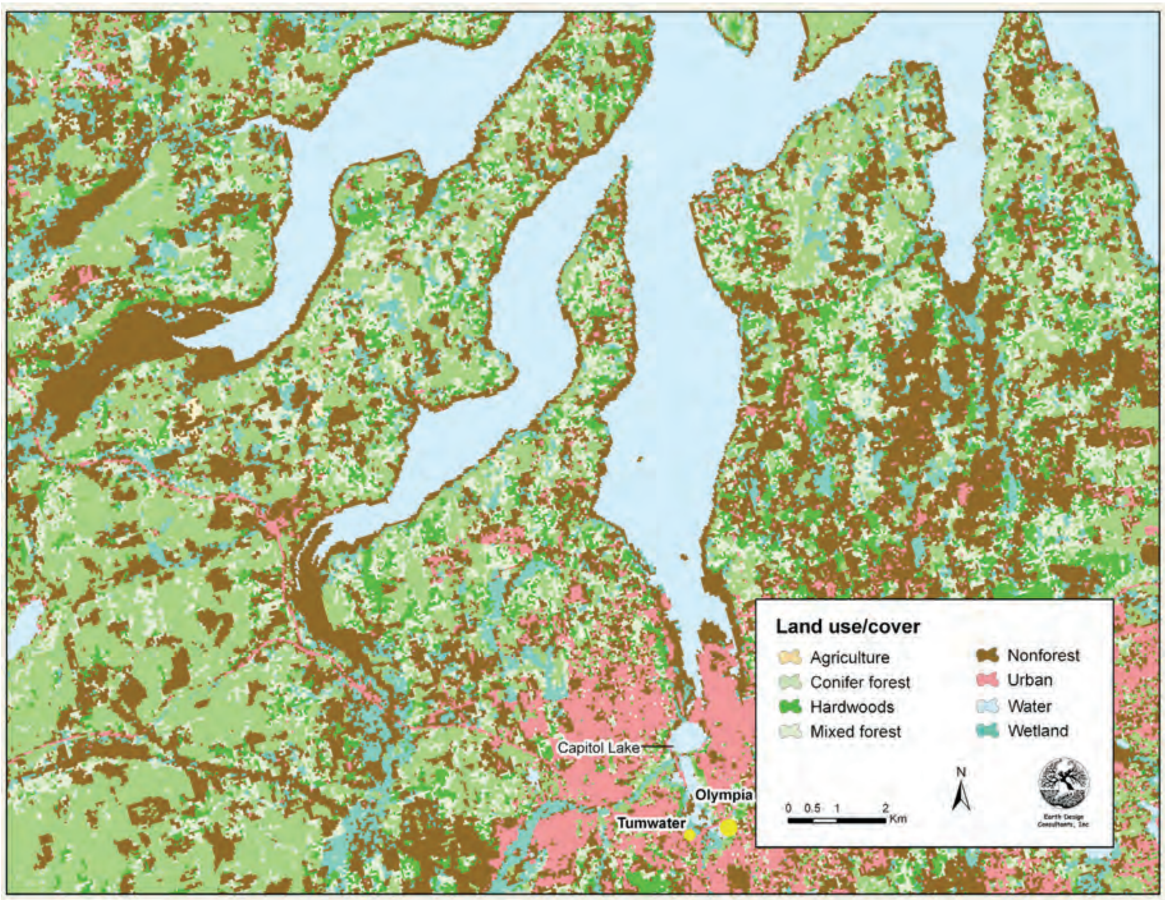

Figure 8. Major Land Use/ Land Cover classes (NOAA, 2001) of the study area. Shown are Capitol Lake, Olympia, Tumwater, and reference estuaries in southern Puget Sound, Washington.

elevation of sampled sites was -0.2 m NGVD29. The largest proportion of our sites fell in the middle range (Figure 10); the median value for these data was -0.27 m NGVD29.

Sediment

Sediment Type and Grain Size Distribution

Sediment samples were collected from each of the 90 reference sites. Sand and silt were the most dominant components of the sediment and while clay was present it was in lower proportions (Figure 11). Most sites were dominated by silt or sandy loam (Figures 12 and 13, Table 5). From the reference estuary samples, there appears to be a split between samples dominated by sands and those dominated by silts (Figure 11). Percent sand and silt ranged from 2.9% to 90.1% and 6.3% to 81.8%, respectively (Figure 14, Table 3). At an average of 42.5%, the proportion of sand was similar to silt, which averaged 44.4% at all sites (Figures 11 and 14, Table 3). However, the median value for sand was 38.5%, lower than the

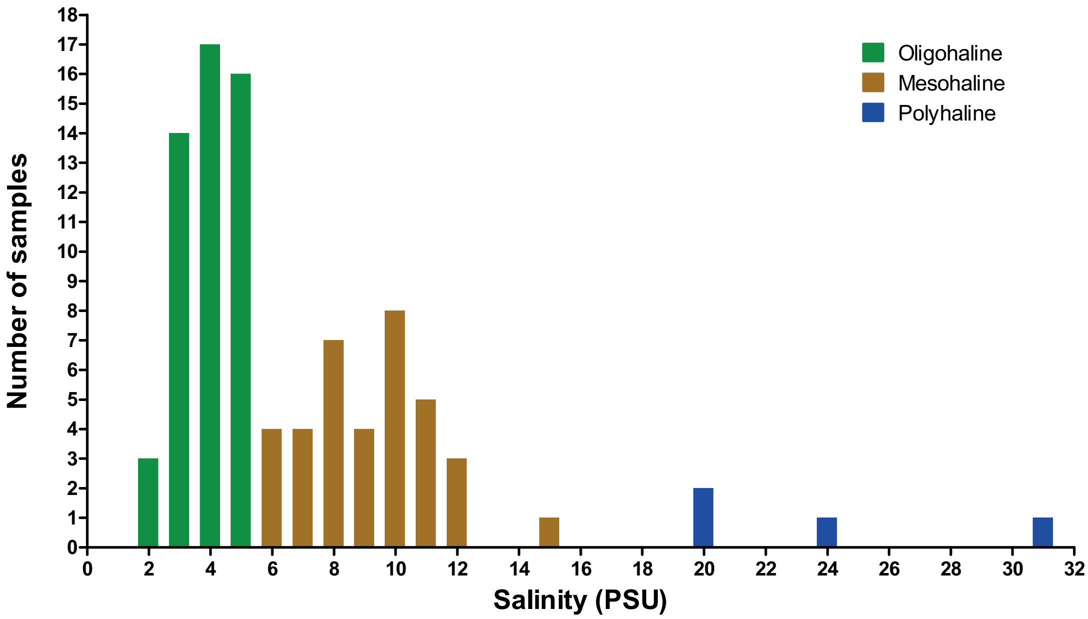

Figure 9. Frequency histogram for field-measured pore water salinity (psu), color-coded as oligohaline, 0.5-5 psu, mesohaline, 5 to 18 psu; or polyhaline, 18 to 30 psu, at 63 sites in five south Puget Sound reference estuaries in September 2005.

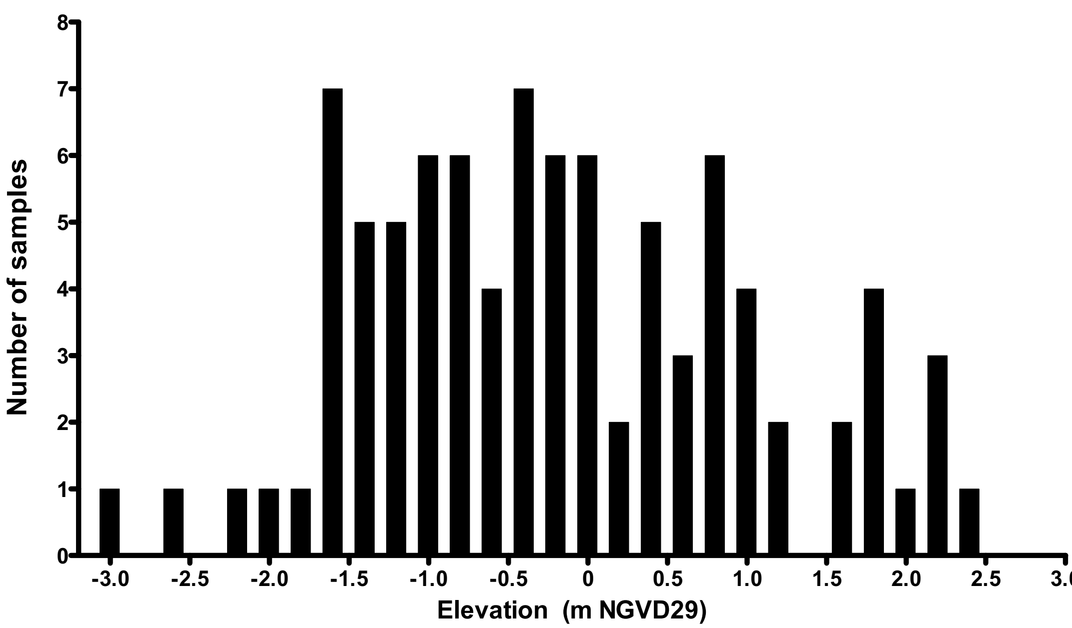

Figure 10. Frequency histogram for tidal elevations (meters, NGVD29 vertical datum) measured during field sampling at 90 sites in five south Puget Sound reference estuaries in September 2005.

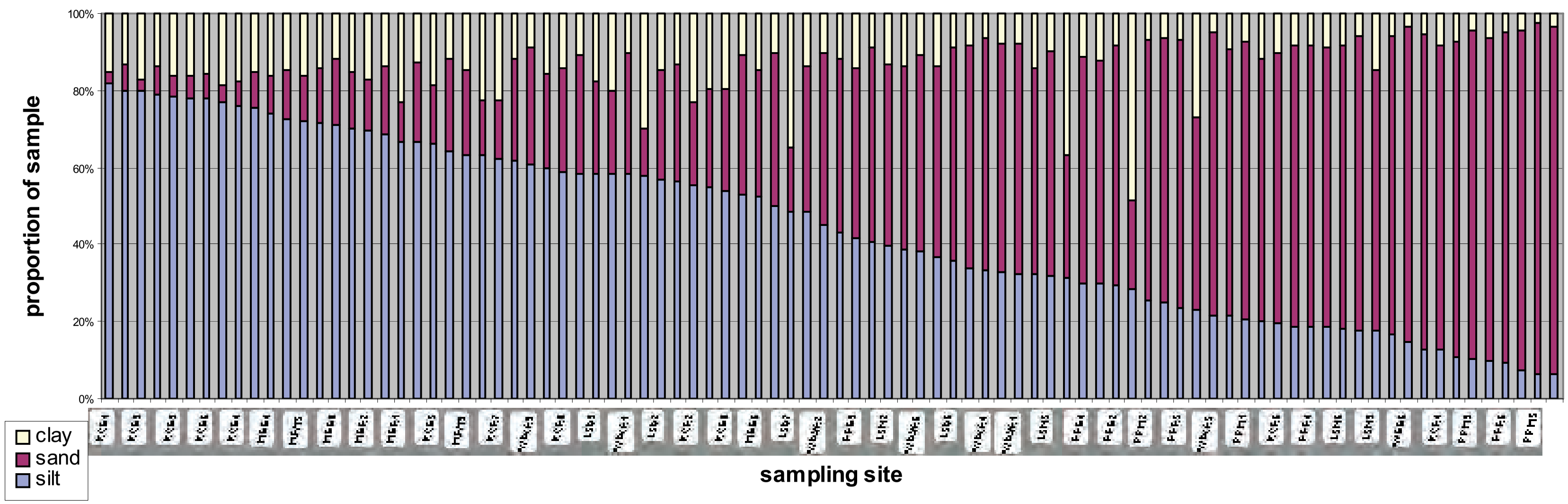

Figure 11. Composition of sediment samples collected from 90 sites at five south Puget Sound reference estuaries in September 2005. The percent of the sample that is sand (maroon), silt (purple), and clay (yellow) is shown for each sample. Trends displayed indicated that silt and sand represent the largest components of sediments collected in the five reference estuaries.

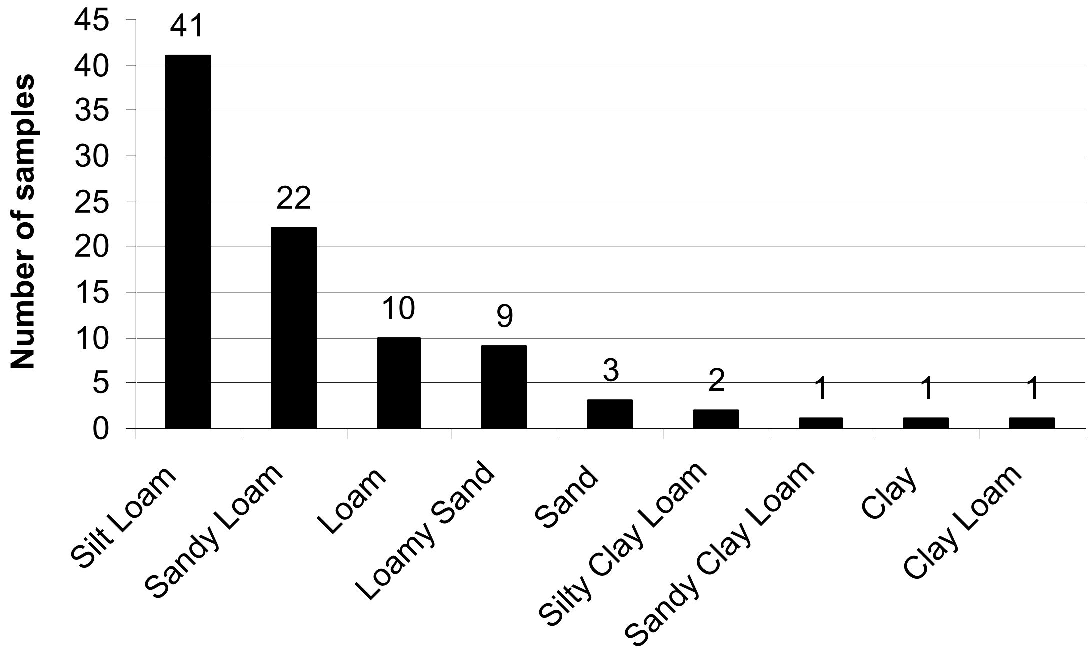

Figure 12. Frequency distribution of sediment texture types collected during field sampling at 90 sites in five south Puget Sound reference estuaries in September 2005. Data labels indicate the number of sites with each sediment texture. Figure 13 indicates the proportion of sand, silt, and clay in each texture.

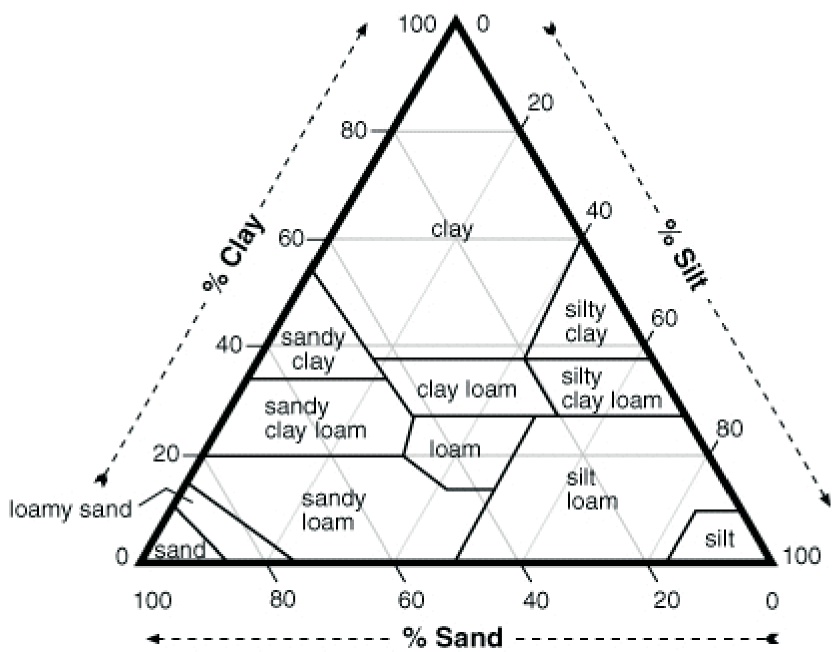

Figure 13. Major sediment texture classes displayed in the texture triangle. Sediment texture classes are defined by the percentages of sand, silt, and clay determined from grain-size/particle-size analysis procedure. The area on the triangle where the three percentage values of sand, silt, and clay meet are the texture class assigned to a particular sample. Texture triangle is from University of Minnesota Extension Service Soil Management Division webpage.

Table 5. Percent frequency of sediment texture classes encountered during field sampling in each of the five reference estuaries and for all sampling points (n=90).

Sediment Texture	**Ellis Cove** sandy loam	**Kennedy Ck** silt loam	**Little Skookum** sandy loam/silt loam	**Mud Bay** silt loam	**Woodard Bay** sandy loam	**Overall** silt loam
% sample points in each texture class						
Clay	0	0	6	0	0	1
Clay loam	0	0	0	5	0	1
Loam	11	0	19	14	11	11
Loamy sand	11	6	6	0	28	10
Sand	17	0	0	0	0	3
Sandy clay	0	0	0	0	0	0
Sandy clay loam	0	6	0	0	0	1
Sandy loam	33	12	31	5	44	24
Silt	0	0	0	0	0	0
Silt loam	28	77	31	71	17	46
Silty clay loam	0	0	6	5	0	2
Silty clay	0	0	0	0	0	0
sample size, n=	18	17	16	21	18	90

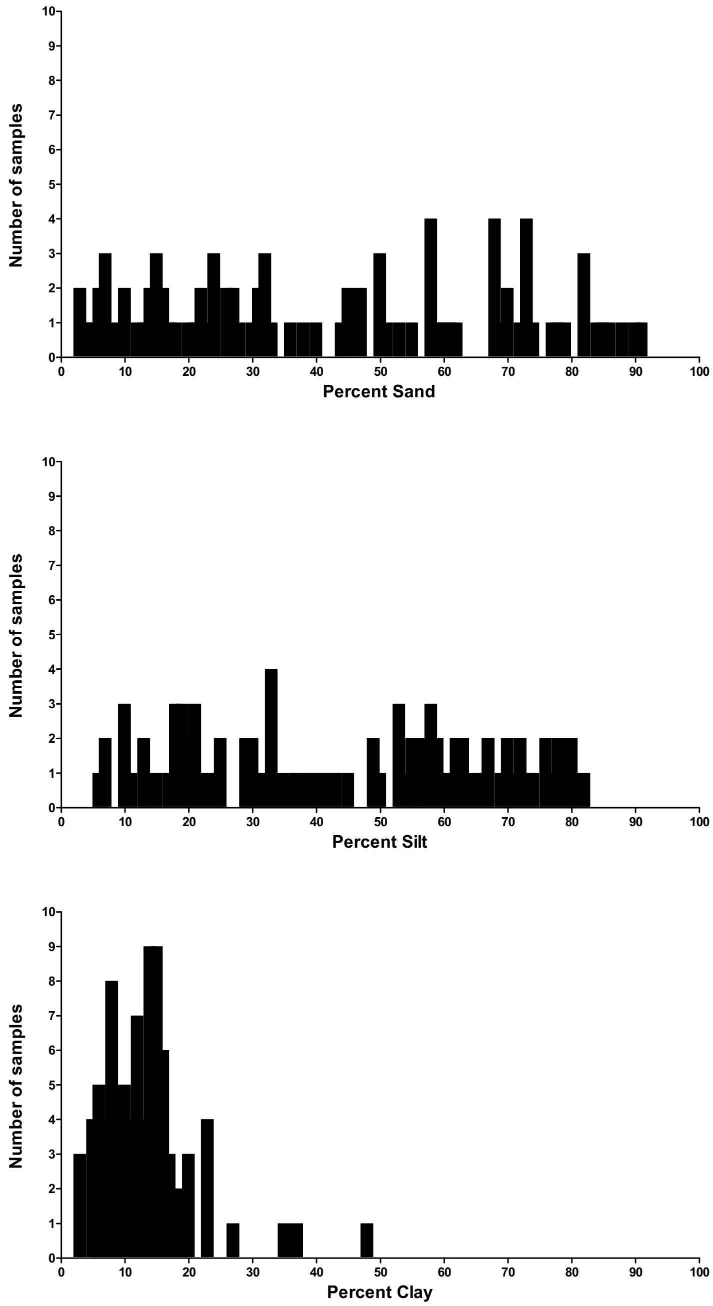

Figure 14. Frequency histograms of percent of sand (upper), silt (middle), and clay (bottom) composition in sediment samples collected at 90 sites in five south Puget Sound reference estuaries in September 2005.

44.0% median value for silt proportion (Table 3). The frequency distributions of sand and silt are similar; both sediment types have frequencies that are relatively platykutric[9] (Figure 14). The greatest proportion of clay sediment was 48.3%, observed at one site, while clay averaged 13.4% throughout all sites (Table 3). The 75th percentile for the clay proportion data was 15.7%. The frequency distribution for clay reflects these numbers and is skewed towards the low end of the scale (Figure 14).

Sediment Organic Matter Content

Organic matter in sediments at the 90 reference estuary sites was relatively low (Figure 15, Table 3). Organic matter comprised 1.9 to 50.1% of our sediment samples. Seventy-five percent of the values were less than 9%, while the average organic matter was 8.4%. Only five sites had values greater than 20% (Figure 15, Table 3).

Bulk Density

Bulk density observed at reference estuary sites ranged from 0.17 to 2.14 gm cm^{-3} (Figure 16, Table 3). The average value for these data is 0.84 gm cm^{-3}, while the median of the bulk density sample is a bit lower, 0.79 gm cm^{-3}. The bulk density data appear to be rather

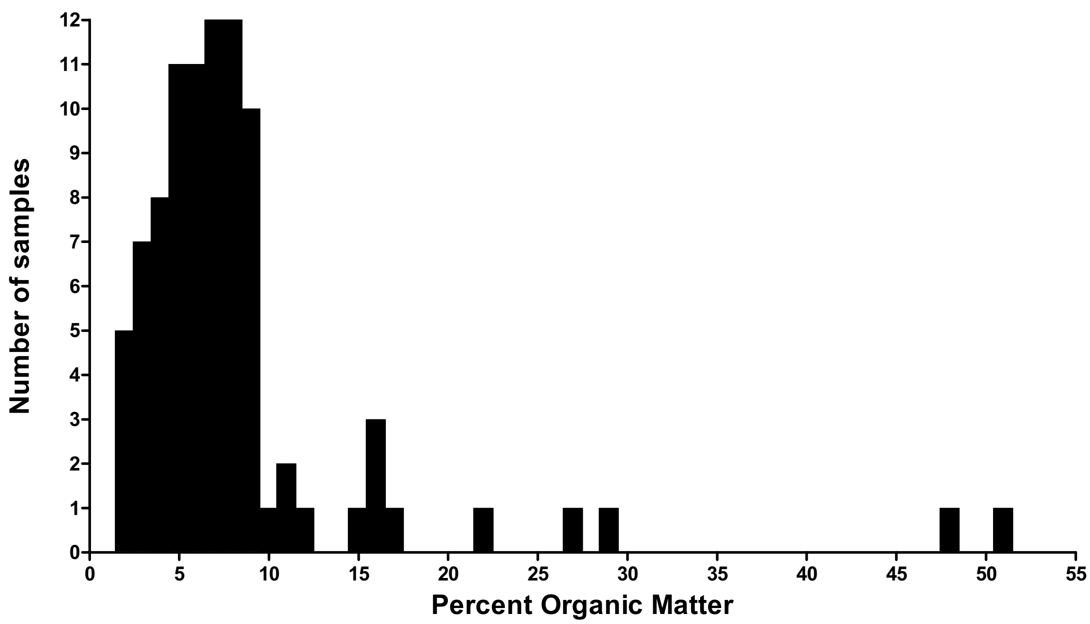

Figure 15. Frequency histogram of percent organic matter in sediment samples collected at 90 sites in five south Puget Sound reference estuaries in September 2005.

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[9]A platykurtic distribution is one in which most of the values share about the same frequency of occurrence. As a result, the curve is very flat, or plateau-like.

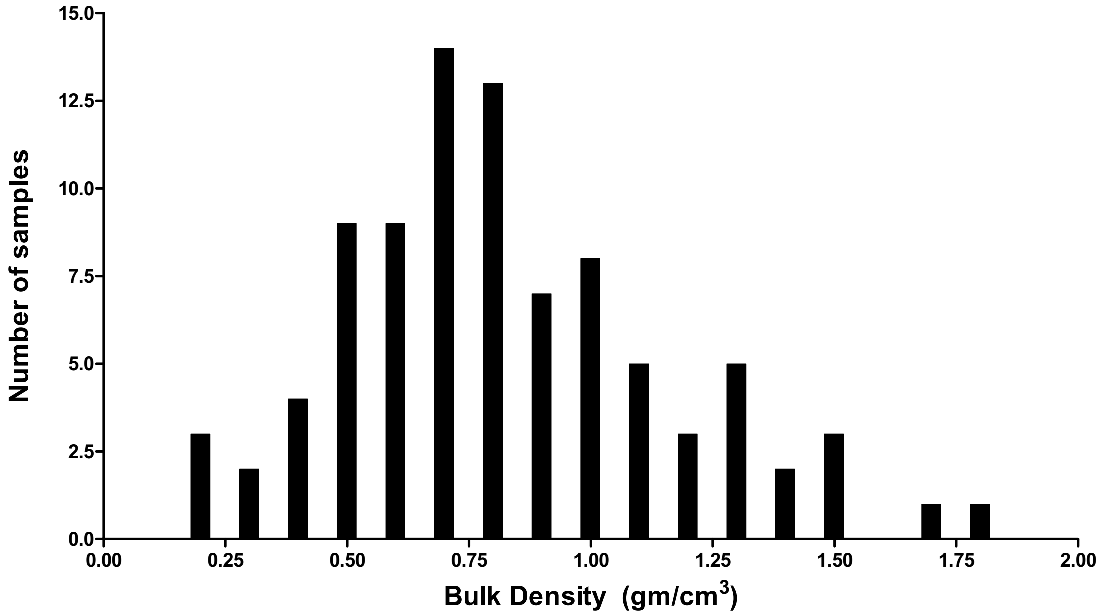

Figure 16. Frequency histogram of bulk density (gm/cm^3) of sediment samples collected at 90 sites in five south Puget Sound reference estuaries in September 2005.

normally-distributed, with a rather high kurtosis (Figure 16). We also found that the finer-textured sediments did in fact have lower bulk densities (Spearman's rho, r^2=-0.778, p<0.001) and that sandier sediments had higher dry bulk densities (Spearman's rho, r^2=0.740, p<0.001).

Vegetative and Sediment Cover Plot Results

The majority of 1 m^2 cover plots sampled contained sediment (sand, mud, or mixed). Several plots contained a layer of diatoms or algal mat upon the sediment. *Ulva* spp., *Enteromorpha* spp., other green algae, and filamentous green algae were also encountered in cover plots, but at a much lower frequency. Twelve of the 90 cover plots sampled contained over 50% marsh vegetation. The species sampled in the reference estuaries included: *Carex lyngbyei*, *Distichlis spicata*, *Atriplex patula*, *Salicornia virginica*, *Puccinellia maritima*, *Juncus* spp., *Potentilla anserina* ssp. *pacifica*, *Jaumea carnosa*, *Triglochin maritimum*, *Zannichellia palustris*, and the wrack/ duff/ dead plant material associated with these marsh areas. These plant species are characteristic of many of Dethier's (1992) estuarine, intertidal and partly enclosed community types, including low, moderate, and high salinity marshes. Figure 4 provides photographic examples of cover types and Table 6 provides the occurrence frequency of each cover type.

Table 6. Vegetation cover classes encountered during field sampling at 90 sites in five southern Puget Sound reference estuaries during September 2005. Table indicates the number of sites out of 90 where the cover type occurred.

	Cover Type	Number of Sites
1	Diatoms	47
2	*Ulva* spp.	9
3	*Distichlis spicata*	8
4	*Carex lyngbyei*	6
5	*Atriplex patula*	5
6	*Salicornia virginica*	5
7	Algal mat	4
8	Other green algae	3
9	*Juncus* spp.	3
10	*Potentilla anserina* ssp. *pacifica*	3
11	*Enteromorpha* spp.	2
12	*Puccinellia maritima*	2
13	*Triglochin maritimum*	2
14	*Jaumea carnosa*	2
15	*Zannichellia palustris*	1

Shells and Invertebrate Collection

We collected shells found atop sediment surface surrounding each of our field sampling sites, if present. Only dead organisms and only those on the surface were collected. Because dead organisms were collected during low tide windows, the presence of a particular species at a sampling site is not necessarily indicative of conditions at that site. Shells and fragments could be transported great distances with each tide because being dead means they are not attached or burrowing into sediment during high tides. We found the following organisms: *Mytilus trossulus*, barnacles, *Crassostrea virginica*, *Saxidomus giganteus* (butter clam), *Tapes japonica* (Japanese littleneck), *Protothaca staminea* (native littleneck), *Mya arenaria* (soft-shelled clam), *Macoma* spp., *Macoma nasuta* (bent-nosed macoma), *Clinocardium nuttallii* (Nuttall's cockle), unknown species of cockles, *Polynices lewisii* (moon snail), *Crepidula fornicata* (slipper snail), *Trivia californica*, and other unknowns and fragments too small or degraded to identify (Table 7).

Table 7. Presence of species of invertebrates observed at five south Puget Sound estuaries during September 2005. Only dead organisms and shells on top of sediment surface were collected. No shells were present at Kennedy Creek sampling sites.

	barnacles	*Clinocardium nuttallii* Nuttall's cockle	uknown cockle spp.	*Crassostrea virginica* Eastern oyster	*Crepidula fornicata* Slipper snail	unknown *Macoma* spp.	*Macoma nasuta* Bent-nosed macoma	*Mya arenaria* Soft shell clam	*Mytilus trossulus* Bay Mussel	*Polinices lewisii* Moon snail	*Protothaca staminea* Native littleneck	*Saxidomus giganteus* Butter clam	*Tapes japonica* Japanese littleneck	*Trivia californica* Sea slug
Mud Bay														
MBB1								x	x					
MBB2				x				x			x			
MBB4	x									x				
MBB6				x	x		x	x	x		x		x	
MBB7								x	x					
MBB8								x						
MBB9	x							x						
MBM1								x	x					
MBM2	x					x	x		x					
MBM4	x							x	x					
MBM6	x								x					
MBR1	x							x	x					
MBR5	x			x								x		
Woodard Bay														
WBB1		x						x	x					
WBB2	x		x		x	x			x					x
WBB3	x				x				x					
WBB4			x				x		x				x	
WBB5					x	x	x		x	x			x	
WBLR1								x			x		x	
WBLR2							x		x		x		x	
WBLR3						x		x			x			
WBLR4						x		x	x					
WBLR5	x	x						x	x					
WBLR6													x	
WBUR4	x								x		x			
WBUR5	x							x	x			x	x	
WBUR6	x					x		x					x	

Table 7 continued. Presence of species of invertebrates observed at five south Puget Sound estuaries during September 2005.

		Clinocardium nuttallii	uknown	*Crassostrea virginica*	*Crepidula fornicata*	unknown	*Macoma nasuta*	*Mya arenaria*	*Mytilus trossulus*	*Polinices lewisii*	*Protothaca staminea*	*Saxidomus giganteus*	*Tapes japonica*	*Trivia californica*
	barnacles	Nuttall's cockle	cockle spp.	Eastern oyster	Slipper snail	*Macoma* spp.	Bent-nosed macoma	Soft shell clam	Bay Mussel	Moon snail	Native littleneck	Butter clam	Japanese littleneck	Sea slug
	Little Skookum													
LSB1	x						x		x		x			
LSB2	x					x								
LSB3								x	x		x			
LSB4	x	x												
LSB5	x							x	x		x			
LSB6						x		x			x			
LSM1	x						x		x		x			
LSM2	x					x	x	x				x		
LSM3														
LSM4		x							x				x	
LSM6							x						x	
LSM8							x						x	
	Ellis Cove													
PPB1	x					x			x		x			
PPB2	x								x		x		x	
PPB3	x								x					
PPB4									x					
PPB5	x							x	x					
PPB6	x					x			x					
PPM1						x	x		x					
PPM2							x	x						
PPM3						x	x	x						
PPM4	x				x		x				x			
PPM5							x				x			
PPM6							x				x			
PPR1	x						x		x					
PPR2	x								x					
PPR3	x								x					
PPR4	x							x	x		x		x	
PPR5	x								x					
PPR6	x								x					

Reference Estuary Multivariate Analysis

Principal Components Analysis (PCA)

Following several iterations where variables were eliminated and data were transformed, we successfully ordinated a 'Site X Environmental Variable' data matrix. The data matrix, handled as described in Chapter 2: Methods, that contained the following seven variables: elevation (in NGVD29 meters + 10), percent organic matter, sediment fractions (percent sand, percent silt, and percent clay), bulk density, and field-measured pore water salinity. We determined that this ordination was successful at grouping similar sites because samples were fairly well distributed along PCA axes 1 and 2 (Figure 17). In addition, when we mapped sediment types associated with each sample point in ordination space, we saw a pattern that grouped sites with similar sediment characteristics. Axis 1 accounted for 61.0% of the information in the original data matrix and axis 2, 18.5% of the information. Together

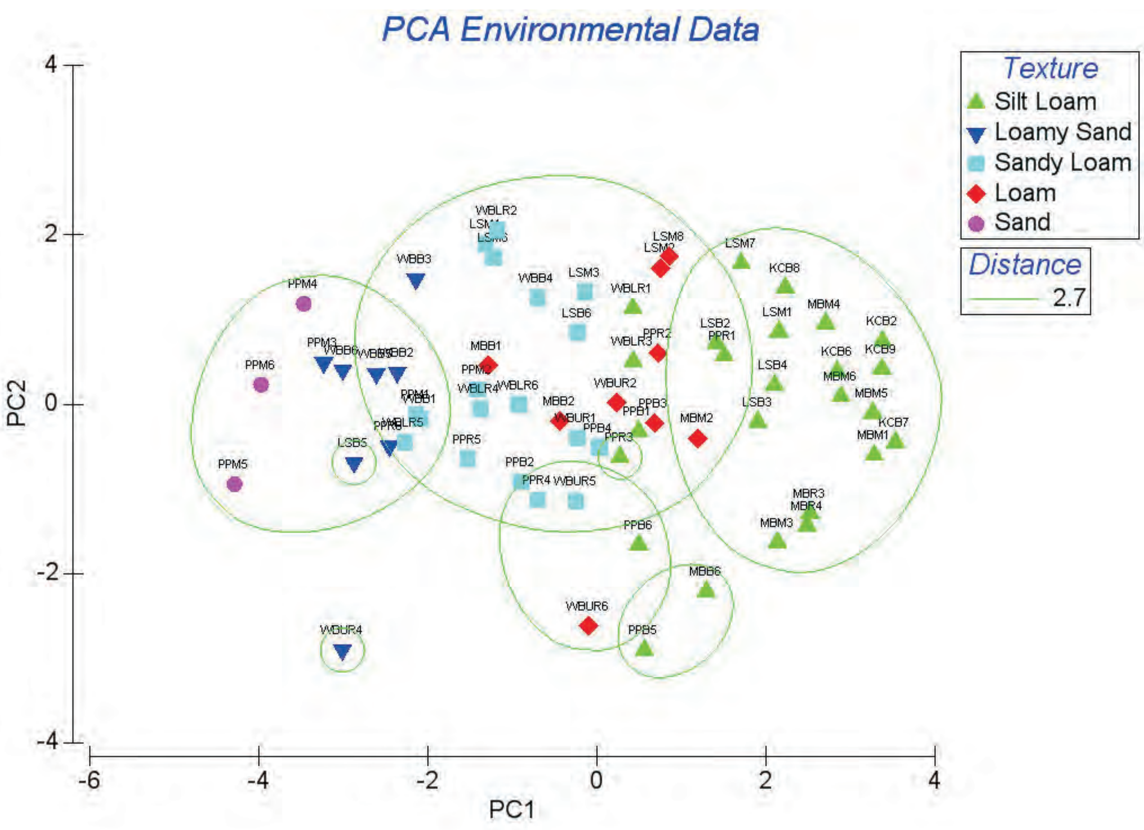

Figure 17. Principle Components Analysis (ordination) of 63 samples from five south Puget Sound reference estuaries during September 2005. Individual points in the graph represent sampling points and are labeled according to estuary: Mud Bay = MB, Little Skookum = LS, Kennedy Creek = KC, Ellis Cove = PP, and Woodard Bay = WB. Green circles represent clusters defined by a distance value of 2.7. PC Axis 1 is negatively correlated to percent sand and bulk density, and positively correlated to percent organic mater and percent silt. PC Axis 2 is positively correlated to field measured pore water salinity and elevation (see text for more details).

axes 1 and 2 accounted for 79.5% of the information in the original data matrix. Table 8 shows the correlation coefficients between the three PCA axes and each of the data matrix variables. We found that percent silt, clay, and organic matter were positively correlated with PC 1 scores and that percent sand and bulk density were negatively correlated to PC 1 scores. PCA axis 2 was most strongly correlated with elevation and salinity. Although this ordination could be used to assign sample sites into groups or habitat bins, we used cluster analysis to derive the groups for the discriminant analysis.

Cluster Analysis

We performed a CLUSTER analysis of the 'Site X Environmental Variable' data matrix to group the 63 sample sites (those with pore water salinity values) into similar groups or 'habitat bins' (Figure 18, Table 9). Following the PCA ordination, we pre-treated the data matrix as described above in Chapter 2: Methods. The CLUSTER analysis made use of all seven variables. We calculated a resemblance matrix based on Euclidean distances from the original data matrix. Euclidean distances, appropriate for environmental data sets, are the distances measured along the shortest path in multidimensional space. We then created a dendrogram based on the distance in multidimensional space of the 63 samples (Figure 18). Ideally, the number of entries in each group would be similar. By selecting a distance value of 2.7 units we were able to group our reference site samples into eight groups based on their similarity, which is the vertical line visible on Figure 18 (Table 9). Larger distance values gave too few groups and smaller values gave too many groups. Notice that there are five main groups of sites with more than eight members and three groups with one or two members.

Table 8. Correlation coefficients between principal components analysis (PCA) axes and each variable from the original data matrix.

		Axis	
Variable	PCA1	PCA2	PCA3
Elevation (NGVD m + 10)	01.06	0.684	-0.719
Percent Organic	0.442	-0.095	-0.065
Percent Sand	-0.450	0.048	-0.001
Percent Silt	0.456	-0.055	0.054
Percent Clay	0.444	-0.008	0.020
Bulk Density	-0.426	0.058	-0.066
Pore water Salinity	0.062	0.717	0.687

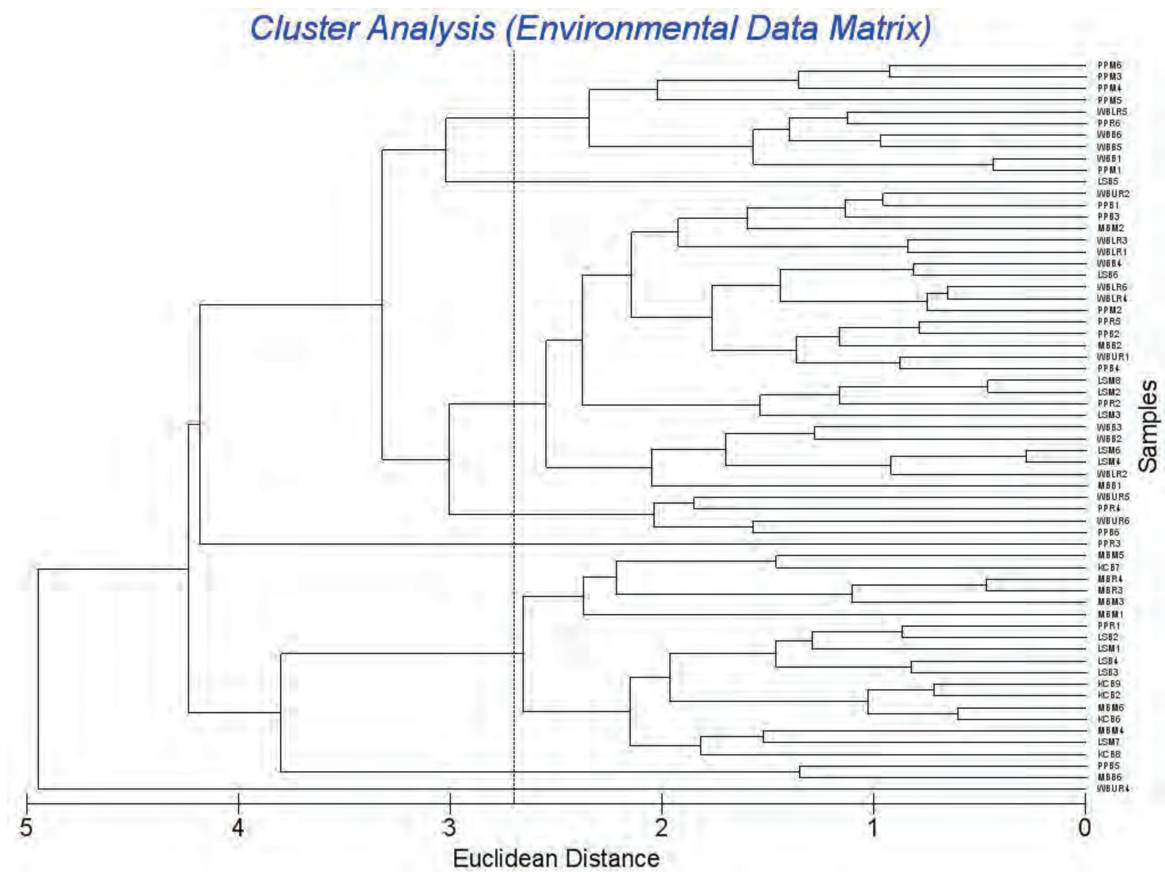

Figure 18. Results of a CLUSTER analysis based on a 'Sampling Site x Environmental Variable' data matrix of eight variables. Similar sites appear close together in the dendrogram. A distance measure of 2.7 was used to assign group membership (see text for more details). These relationships were used to develop 'habitat bins' for the discriminant analysis.

Groupings of sites did not seem to be dependent on position within the reference estuary (e.g., samples taken closer to river mouth or further away) or on individual reference estuaries themselves. That is, groups with more than one member contained samples from multiple reference estuaries and samples taken from multiple positions from within each reference estuary. It was our intention to sample a variety of conditions along the sediment, salinity and elevation gradients in five estuaries. Results of the CLUSTER analysis suggest that we were successful at sampling multiple sites that could be grouped into 'habitat bins' using environmental variables. We felt comfortable moving on to the discriminant analysis using these eight groups.

Discriminant Functions Analysis

Before any discriminant analysis (DA) was done, we evaluated our data to see if they were appropriate for the analysis. We found that the 14 plant cover data sets were not normally distributed, thereby violating one of the primary assumptions of DA. Discriminant

Table 9: Site 'Habitat bins' or groups of sites determined by CLUSTER analysis of a seven variable environmental data matrix. Sites sharing similar characteristics are grouped together. MB sites are from Mud Bay, LS from Little Skookum, KC from Kennedy Creek, PP from Ellis Cove, and WB from Woodard Bay.

Group ID	Site	Group ID	Site	Group ID	Site
1	LSM2	5	MBB6	8	LSB6
	LSM8		PPB5		LSM3
	MBB2				LSM4
	MBM2	6	KCB8		LSM6
	PPB3		LSB2		PPB2
	PPR2		LSB3		PPB4
	WBUR2		LSB4		PPB6
	WBUR6		LSM1		PPM1
			LSM7		PPM2
2	LSB5		PPB1		PPR4
	MBB1		PPR1		PPR5
	PPM3		WBLR1		WBB1
	PPM4		WBLR3		WBB4
	PPM5				WBLR2
	PPM6	7	KCB2		WBLR4
	PPR6		KCB6		WBLR5
	WBB2		KCB7		WBLR6
	WBB3		KCB9		WBUR1
	WBB5		MBM1		WBUR5
	WBB6		MBM4		
			MBM5		
3	WBUR4		MBM6		
			MBM3		
4	PPR3		MBR3		
			MBR4		

analysis, however, is known to be a fairly robust statistical technique; therefore, we proceeded with our analyses using both square root transformed and untransformed data. We ran multiple DA iterations on this data set, trying different groupings and subsets of our data.

In the first run, using eight habitat bins and 14 cover classes from the quadrat data, we found that DA misclassified 54 out of 63 sites. Using the same data sets we tried several analyses using subsets of the data matrix. We varied the data by square root transformation, reduced the number of habitat bins from eight to the five largest, and reducing the number of plant cover classes to those present at three or more sites. Each of these analyses failed to correctly classify more than 15 percent of the sample sites.

Our initial discriminant analysis showed that our habitat bins (Table 9), based on a suite of environmental variables, were not related to the plant cover classes. We then examined the relationships between sediment texture classes for all 90 sites and the plant cover classes. In this case, we used the nine sediment texture classes as our 'habitat bins.' We found that only 47 out of the 90 sites (52.2%) were correctly classified. Subsequent analyses using this data matrix failed to improve upon this result.

Recall, that DA is most effective when there are large differences in the means of each of the groups. We found that the communities did not vary between the 'habitat bins' created from the physical data.

Therefore, we re-examined the data matrix and looked for associations between plant cover classes using simple correlations. Plant cover types that occur together at sample sites will be strongly correlated. Surprisingly, we did not find strong correlations between any of the common cover classes. We did, however, find strong correlation between *Puccinellia maritime* and *Atriplex patula* (correlation coefficient = 0.891), and between *A. patula* and *Juncus* spp. (correlation coefficient = 0.686). Unfortunately, these species were only present at a few of our sample sites. The majority of sample sites were dominated by non-vascular (algal) plant species. We did not find any correlations in the occurrence of diatoms, algal mat, *Ulva* spp., *Enteromorpha* spp., and the other plant cover classes. We did not find any associations between taxonomic groups.

Chapter 4: Discussion

Reference Estuary Study, Biological Conditions Report and the USGS Model

The purpose of the Reference Estuary Study is to develop an idea of what a restored Capitol Lake will look like by examining estuarine habitats at nearby reference estuaries, and identifying the relationships between those habitats and the environmental factors that structure them. Numerous estuarine habitat types occur throughout Puget Sound (Dethier 1990); however, our study, guided by USGS modeling efforts and local expertise, focused on high and low salinity marshes, mud flats, sand flats, and mixed flats – the communities that are most likely to occupy a restored Capitol Lake.

The Biological Conditions Report describes the expected biological conditions in a restored Capitol Lake and identifies the physical and biological uncertainties that may ultimately affect the restoration outcomes. More specifically, in the Biological Conditions Report, we address the impacts of land use and management, climate change, native species recruitment, invasive species, and other human disturbances on any future restoration project; and, the need for active management actions.

We completed the Reference Estuary Study and the Biological Conditions Report concurrently. Our studies relied heavily on the USGS DELFT 3D modeling of sediment texture and salinity changes expected in Capitol Lake under the four restoration scenarios being considered. We interpreted results from our studies along with those from the USGS model in an effort to evaluate the changes that would occur to Capitol Lake under each restoration scenario. In the following sections of this report: we summarize the main findings our studies and the output from the USGS model; we describe whether conditions modeled for Capitol Lake and the Deschutes Estuary exist at the reference estuaries sites; and we identify which reference estuary is most similar to conditions predicted for a restored Deschutes Estuary. We also discuss the biological communities that may be found in the restored Deschutes Estuary and the uncertainties associated with their development. Finally, we conclude by identifying future opportunities and unanswered questions.

Capitol Lake and Reference Estuary Conditions

Characteristics of Capitol Lake

Capitol Lake is located adjacent to downtown Olympia, where the Deschutes River meets Budd Inlet. Historically, Capitol Lake was a tidal estuary. It is now a 260 acre body of water created in 1951 by a dam constructed at 5th Avenue to create a reflecting pool for the State Capitol building. There are several public places that are located within the original estuary boundary (George *et al.* 2006). The dam blocks tide waters from reaching the lake (Figure 1) thereby transforming the estuary and its associated habitats into a freshwater impoundment.

The general orientation of Capitol Lake is north to south. The lake is generally separated into four areas: the North Basin, which is immediately south of the 5th Avenue dam; the Middle Basin, which is between the BNSF Railroad bridge and the I-5 bridge; Percival Cove on the northwest side of the Middle Basin and west of the Deschutes Parkway; and the South Basin, which is southeast of the I-5 bridge where the Deschutes River enters (Figure 1). Capitol Lake is listed as an impaired (303(d) listed) water body for high fecal coliform bacteria concentration and for phosphorus (WDOE 2004a). An in-depth description of Capitol Lake is presented in the Capitol Lake and Reference Estuaries of the Chapter 1: Introduction.

Physical characteristics for Capitol Lake such as bathymetry, sediment texture, salinity, Deschutes River flow and climate were compiled by the USGS to parameterize their model. While some model inputs were taken from literature values (e.g., salinity), others were measured by USGS as part of their study (e.g., bathymetry of Capitol Lake). USGS-surveyed bathymetric data of the lake and Budd Inlet revealed depths ranging from -20 m to 6 m for the Inlet and from -8 m to 6 m for just within Capitol Lake (NGVD29; Figure 19; George *et al.* 2006). Sediments of freshwater Capitol Lake, as it is now, are dominated by silts. The common sediment textures modeled for the lake were silt loam, silt, silty clay loam, and sandy loam, although many other textures are predicted to be present (Table 10a and b, Figures 20 and 21). Water flow data for the Deschutes River were calculated from the USGS gauge at Tumwater, WA.

Characteristics of the five Reference Estuaries

We collected samples from five southern Puget Sound reference estuaries: Little Skookum Inlet, Kennedy Creek of Totten Inlet, Mud Bay/Eld Inlet, Ellis Cove, and Woodard Bay (Figures 7a-e). The intention of our sample collection was not to characterize each of the reference estuaries but to characterize communities and environmental gradients that generally occur within south Sound estuaries. We considered conditions found within the reference estuaries to be representative of what conditions in a restored Capitol Lake could be like. In addition, reference estuaries were not selected to represent pristine conditions, as reference sites are sometimes intended, but simply to represent the range of conditions present in south Sound estuaries. The reference estuaries varied by orientation, size, sediment composition, salinity regimes, depth, and land use/ land cover.

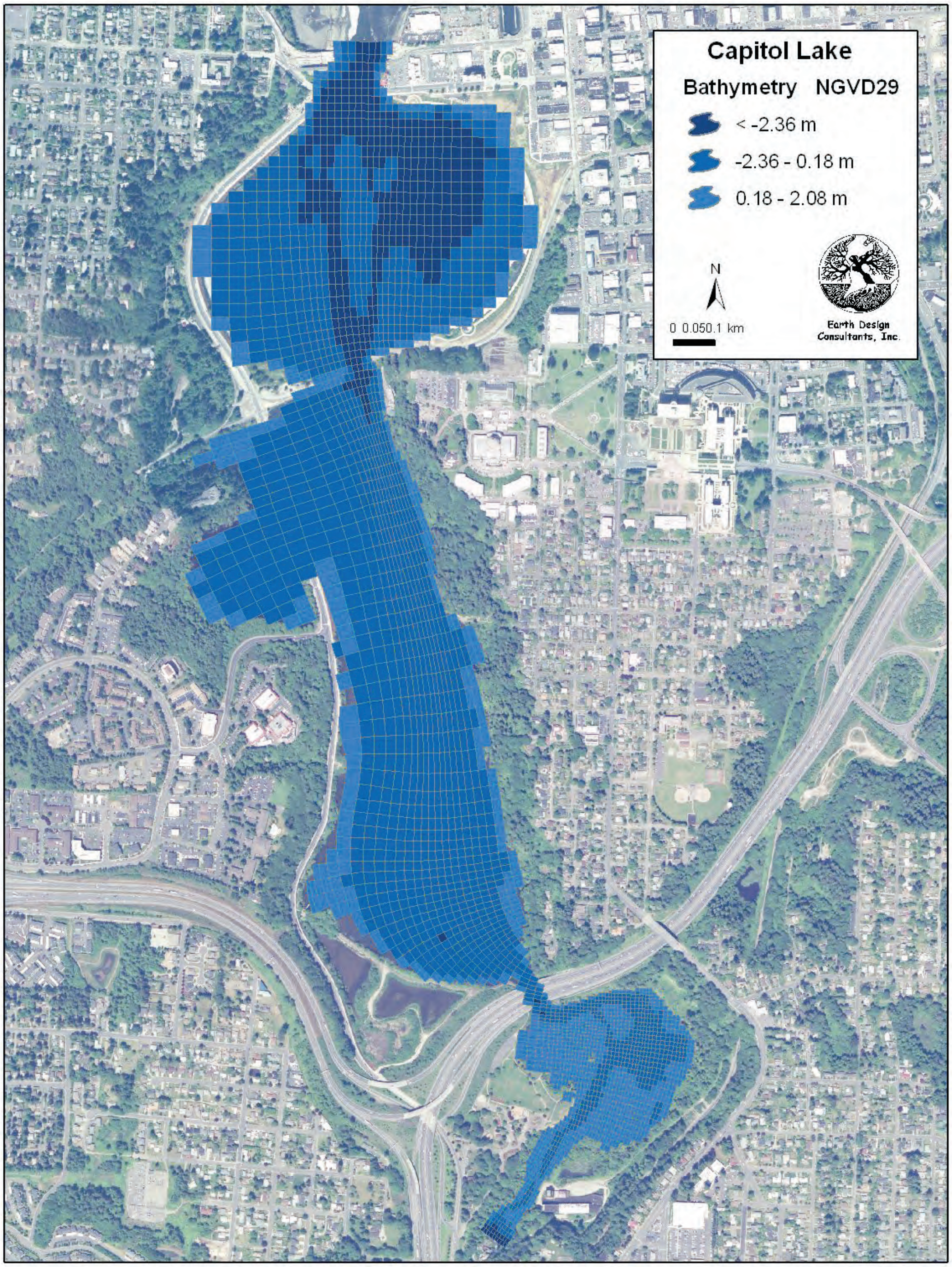

Figure 19. Capitol Lake bathymetry grid displayed in meters using vertical datum NGVD29 using the following categories of: below MLLW (<-2.36 m), between MLLW and MTL (-2.36 to 0.18 m), and between MTL and MHHW (0.18 to 2.08 m). Data source is from USGS (George et al. 2006) sampling within the Lake during 2004 and 2005. Note: Points with elevation higher than 2.08 m (MHHW) are not displayed.

Table 10a. USGS Sediment textures predicted Capitol Lake under A-D restoration scenarios at 500 kg/ m^3 mud bed density based on USGS data (George *et al.* 2006). Sediment texture values are presented as acreage of the lake with each sediment texture, within each elevation category (1=below MLLW, 2=MLLW to MTL, 3=MTL to MHHW, 4=above MHHW) and as the overall percent area of the lake.

A500	**1**	**2**	**3**	**4**	**Total**	**C500**	**1**	**2**	**3**	**4**	**Total**
clay	0.00	4.63	5.25	0.00	0.00		0.00	5.30	5.25	0.00	10.55
clay loam	0.00	0.40	0.39	0.00	0.78		0.00	0.66	0.39	0.00	1.05
loam	1.98	4.26	0.76	0.07	7.07		2.29	3.89	0.74	0.07	6.99
loamy sand	2.87	6.88	3.12	0.00	12.88		2.83	6.68	3.13	0.00	12.64
sand	4.78	12.42	1.81	0.00	19.01		4.83	13.85	1.79	0.00	20.46
sandy clay	0.00	0.00	0.00	0.00	0.00		0.00	0.00	0.00	0.00	0.00
sandy clay loam	0.00	0.00	0.00	0.00	0.00		0.00	0.00	0.00	0.00	0.00
sandy loam	4.17	20.74	6.08	0.00	30.99		4.08	20.30	5.77	0.00	30.15
silt	2.08	32.40	5.24	0.00	39.73		2.32	33.70	5.18	0.00	41.19
silt loam	8.15	68.38	21.76	14.33	112.62		7.80	70.94	22.28	14.43	115.45
silty clay	1.62	11.31	4.19	0.00	17.11		1.62	12.67	4.19	0.00	18.48
silty clay loam	13.57	23.59	6.15	0.00	43.30		13.44	24.43	6.23	0.00	44.10
gravel >50%	0.45	1.33	1.10	0.00	2.88		0.45	1.12	0.92	0.00	2.49
B500	**1**	**2**	**3**	**4**	**Total**	**D500**	**1**	**2**	**3**	**4**	**Total**
clay	0.00	5.38	5.41	0.00	10.79		0.00	4.92	4.62	0.00	9.54
clay loam	0.13	1.04	0.50	0.00	1.67		0.00	1.30	0.00	0.00	1.30
loam	2.50	3.81	0.88	0.07	7.27		0.90	3.88	0.51	0.13	5.42
loamy sand	3.92	9.04	3.05	0.00	16.01		4.66	8.49	2.95	0.00	16.10
sand	3.73	9.99	1.97	0.00	15.69		6.39	11.92	1.86	0.00	20.16
sandy clay	0.00	0.00	0.00	0.00	0.00		0.00	0.00	0.00	0.00	0.00
sandy clay loam	0.00	0.30	0.30	0.00	0.61		0.00	0.00	0.30	0.00	0.30
sandy loam	3.36	24.73	6.12	0.00	34.21		3.72	19.81	6.21	0.00	29.74
silt	4.99	35.87	5.19	0.00	46.04		0.04	34.24	5.33	0.00	39.62
silt loam	7.83	75.40	21.57	14.72	119.52		3.32	58.33	20.66	13.83	96.13
silty clay	0.09	11.08	4.53	0.00	15.70		0.00	7.76	3.08	0.00	10.85
silty clay loam	12.89	16.08	5.17	0.00	34.14		0.52	12.22	5.68	2.59	21.00
gravel >50%	0.23	1.11	1.10	0.00	2.44		0.46	1.21	0.88	0.00	2.55

A500	**B500**	**C500**	**D500**	**overall**
3.3	*3.5*	*3.5*	*3.8*	*3.5*
0.3	*0.5*	*0.3*	*0.5*	*0.4*
2.4	*2.4*	*2.3*	*2.1*	*2.3*
4.3	*5.3*	*4.2*	*6.4*	*5.0*
6.4	*5.2*	*6.7*	*8.0*	*6.6*
0.0	*0.0*	*0.0*	*0.0*	*0.0*
0.0	*0.2*	*0.0*	*0.1*	*0.1*
10.5	*11.2*	*9.9*	*11.8*	*10.9*
13.4	*15.1*	*13.6*	*15.7*	*14.4*
38.0	*39.3*	*38.0*	*38.0*	*38.3*
5.8	*5.2*	*6.1*	*4.3*	*5.3*
14.6	*11.2*	*14.5*	*8.3*	*12.2*
1.0	*0.8*	*0.8*	*1.0*	*0.9*
100%	*100%*	*100%*	*100%*	*100%*

**values in italics are representing the percent area of the Lake with each sediment texture calculated across all elevation categories*

Table 10b. USGS sediment textures predicted for Capitol Lake under A-D restoration scenarios at 1000 kg/m^3 mud bed density based on USGS data (George *et al.* 2006). Sediment texture values are presented as acreage of the lake with each sediment texture, within each elevation category (1=below MLLW, 2=MLLW to MTL, 3=MTL to MHHW, 4=above MHHW) and as the overall percent area of the lake.

A1000	**1**	**2**	**3**	**4**	**Total**	**C1000**	**1**	**2**	**3**	**4**	**Total**
clay	0.00	5.93	5.77	0.00	11.71		0.00	5.30	6.07	0.00	11.37
clay loam	0.00	0.18	0.49	0.00	0.67		0.00	0.18	0.49	0.00	0.67
loam	1.43	5.83	2.56	1.13	10.96		1.27	5.49	2.86	1.13	10.76
loamy sand	4.22	12.60	4.05	0.00	20.87		4.45	12.54	3.58	0.00	20.57
sand	4.36	13.16	2.92	0.00	20.44		4.31	13.44	2.84	0.00	20.59
sandy clay	0.00	0.00	0.37	0.00	0.37		0.00	0.00	0.07	0.00	0.07
sandy clay loam	0.00	0.00	0.00	0.00	0.00		0.00	0.00	0.00	0.00	0.00
sandy loam	4.79	31.82	5.76	0.46	42.83		4.66	31.69	5.96	0.46	42.76
silt	2.46	21.88	3.92	0.00	28.26		0.00	0.00	0.07	0.00	0.07
silt loam	6.74	64.92	20.77	12.80	105.24		2.61	21.13	3.86	0.00	27.60
silty clay	1.23	10.23	2.76	0.00	14.22		6.71	66.22	21.01	12.90	106.83
silty clay loam	14.09	25.63	5.10	0.00	44.83		1.23	10.74	2.78	0.00	14.75
gravel >50%	0.34	1.34	1.37	0.00	3.05		14.09	25.30	5.10	0.00	44.50
B1000	**1**	**2**	**3**	**4**	**Total**	**D1000**	**1**	**2**	**3**	**4**	**Total**
clay	0.00	6.01	6.29	0.00	12.30		0.00	5.93	4.10	0.00	10.03
clay loam	0.00	0.18	0.90	0.00	1.08		0.00	1.67	1.34	0.00	3.01
loam	1.41	5.78	2.14	1.52	10.86		1.08	4.82	1.26	1.52	8.69
loamy sand	4.87	15.59	4.24	0.00	24.70		5.21	14.60	3.98	0.00	23.79
sand	3.27	9.99	3.25	0.00	16.51		6.76	13.79	2.76	0.00	23.30
sandy clay	0.00	0.00	0.00	0.00	0.00		0.00	0.00	0.00	0.00	0.00
sandy clay loam	0.00	0.00	0.31	0.00	0.31		0.00	0.00	0.00	0.00	0.00
sandy loam	4.43	33.93	5.49	0.20	44.06		3.47	30.60	5.82	0.07	39.95
silt	5.14	25.38	3.72	0.00	34.24		0.30	19.77	3.89	0.00	23.96
silt loam	6.92	66.62	20.35	13.07	106.95		2.98	61.64	18.81	12.36	95.78
silty clay	0.33	8.03	2.71	0.00	11.07		0.00	5.81	2.37	0.00	8.18
silty clay loam	13.07	20.48	5.03	0.00	38.57		0.48	14.11	6.53	2.46	23.58
gravel >50%	0.25	1.53	1.42	0.00	3.20		0.28	1.32	1.19	0.00	2.79

A1000	**B1000**	**C1000**	**D1000**	**overall**
3.9	*4.0*	*3.7*	*3.8*	*3.9*
0.2	*0.4*	*0.2*	*1.1*	*0.5*
3.6	*3.6*	*3.5*	*3.3*	*3.5*
6.9	*8.1*	*6.8*	*9.0*	*7.7*
6.7	*5.4*	*6.8*	*8.9*	*7.0*
0.1	*0.0*	*0.0*	*0.0*	*0.0*
0.0	*0.1*	*0.0*	*0.0*	*0.0*
14.1	*14.5*	*14.1*	*15.2*	*14.5*
9.3	*11.3*	*9.1*	*9.1*	*9.7*
34.7	*35.2*	*35.2*	*36.4*	*35.4*
4.7	*3.6*	*4.9*	*3.1*	*4.1*
14.8	*12.7*	*14.7*	*9.0*	*12.8*
1.0	*1.1*	*1.0*	*1.1*	*1.0*
100%	*100%*	*100%*	*100%*	*100%*

**values in italics are representing the percent area of the Lake with each sediment texturecalculated across all elevation categories*

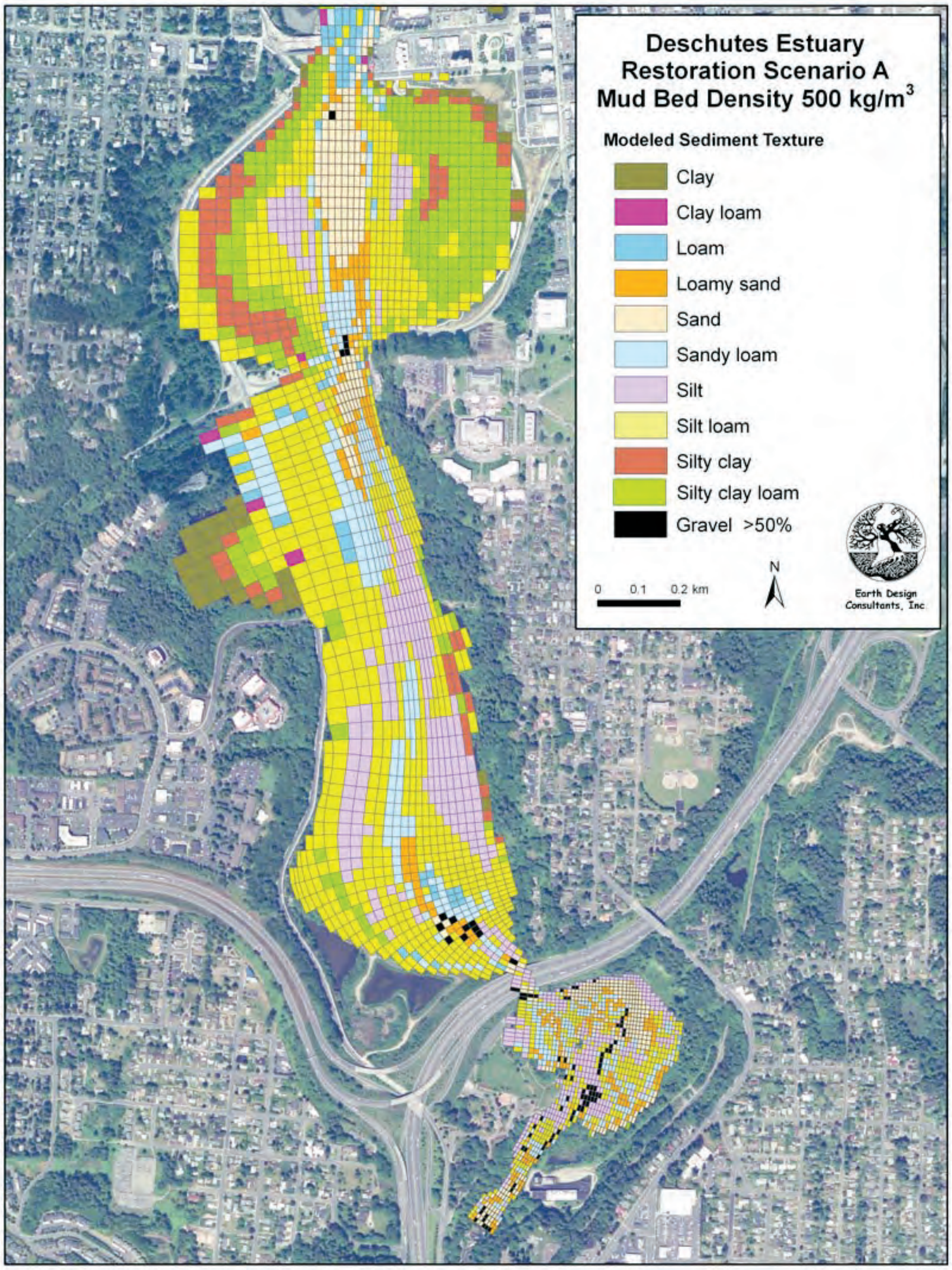

Figure 20. Map of Capitol Lake future sediment textures predicted under restoration scenario A with the lower mud bed density (500 kg/m^3). Restoration scenario A is based upon a 150 m opening between Budd Inlet and Capitol Lake at the 5th Avenue bridge. Sediment data from USGS model were assigned to sediment texture classes. See George *et al.* (2006) and text for further details.

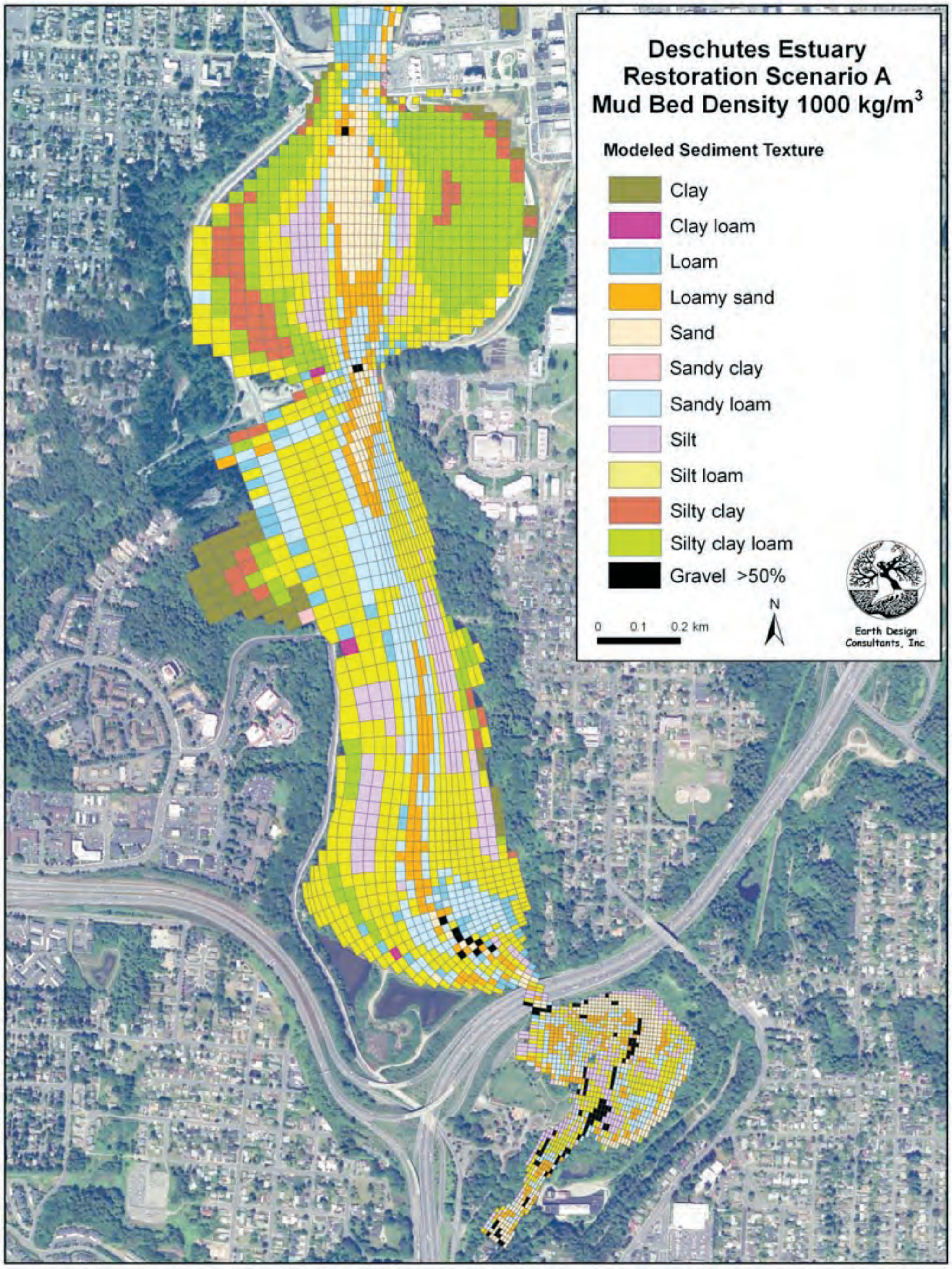

Figure 21. Map of Capitol Lake future sediment textures predicted under restoration scenario A with the higher mud bed density (1000 kg/m^3). Restoration scenario A is based upon a 150 m opening between Budd Inlet and Capitol Lake at the 5th Avenue bridge. Sediment data from USGS model were assigned to sediment texture classes. See George *et al.* (2006) and text for further details.

Little Skookum Bay is the most northwestern reference estuary and is oriented southwest to northeast. Freshwater input into Little Skookum Bay is primarily through Skookum Creek. Little Skookum Inlet drains an area of nearly 19,000 acres in size and the land use is primarily forested (NOAA 2001, Table 4). In Little Skookum Bay, we sampled 16 sites. Elevations at sampling points range from -1.4 to 2.2 m NGVD 29 (Table 3) and pore water salinities range from 6 to 28 psu. The predominant sediment textures are sandy loam and silt loam. Habitats we observed and sampled included mixed sand and mud flats.

Kennedy Creek drains 9,876 acres into Oyster Bay, which eventually enters Totten Inlet (TRPC 2001). We sampled 17 sites in this southwest to northeasterly oriented estuary. The majority of the watershed area is forested (79.6%) and only 1.0% is urban (TRPC 2001). Silt is the predominant sediment type (57.6%; Table 3) and site elevations range from -1.0 to 2.2 m NGVD 29. Pore water salinities range from 14 to 27 psu. Habitats we observed and sampled were mixed sand, mud flats, and high and low marshes.

Perry and McLane Creeks are the major freshwater inputs into the Mud Bay reference estuary. Mud Bay (Eld Inlet) is oriented south to north and the two creeks drain an area of 11,352 acres (4,047 acres Perry and 7,305 acres McLane; TRPC 2001). The majority of the Perry and McLane Creek watersheds is forested (72.8% and 68.8%, respectively) with only 1-2% urban area (TRPC 2001). In Mud Bay, we sampled 21 sites in three distinct areas. The sediments in Mud Bay are primarily silt (59.8%). Elevations of sample sites range from -1.6 to 2.5 m NGVD 29 and measured pore water salinities from 5 to 26 psu (Table 3). The primary habitat type observed and sampled in Mud Bay was mud flat.

Ellis Cove is the smallest reference estuary that we characterized (1,472 acres; TRPC 2001). It is fed by Ellis Creek. The cove is located on northeastern shore of Budd Inlet, just north of Capitol Lake. Nearly half of the watershed is forested (45.7%), and only 5.4% of the Ellis Creek is considered urban (TRPC 2001). We collected data at 18 points in this east to west oriented cove. The primary component of sediments in Ellis Cove is sand (59.6%) with sandy loam textures dominating. Pore water salinities range from 3 to 25 psu and site elevations range from -3.0 to 1.3 m NGVD 29 (Table 3). Habitats we sampled in Ellis Cove were predominantly sand flats.

Woodard Bay is the eastern most reference estuary, located on the western shore of Henderson Inlet. The bay drains Woodard Creek in a southwest to northeasterly direction. The 4,479 ac watershed is 36.4% forested and 17.5% urban (TRPC 2001). We sampled 18 points in this estuary in three sampling areas. Sample site sediments are primarily sand. Pore water salinities range from 4 to 29 psu and elevation of sites ranged from -1.8 to 1.5 m NGVD 29 (Table 3). We most frequently sampled sand flats and sandy channel habitats.

Summary of Main Findings and Conclusions

Although we did not have the USGS model results when the reference estuaries were selected, we were pleased to see that the range of physical conditions predicted for the Capitol Lake restoration scenarios by the USGS DELFT 3D model were present in the reference estuaries we sampled (Table 2). In other words, predicted restoration conditions currently exist within south Sound estuaries. The key variables measured in the reference estuaries and modeled for Capitol Lake are elevation, sediment texture, and salinity. Previous studies have shown these three variables to be important in structuring estuarine communities (Jefferson 1975).

The range of elevations measured in Capitol Lake by USGS during the bathymetry survey was -8 to 6 m NGVD29 (George *et al.* 2006). Although we sampled reference estuary sites during a low tide window in September 2005, our field teams were excluded from the lowest elevation areas by deep water. Consequently, these areas were not sampled from the reference estuaries and their communities and habitats not represented in our study. Elevation, or bathymetry, of our sample sites range from -3.03 to 2.45 m NGVD29. The average elevation for Capitol Lake is 0.4 m, using USGS bathymetry data which is compiled from several sources and includes data from several points (George *et al.* 2006). The average reference estuary elevations are -0.2 m (Table 3). Although we did not sample from some of the deeper areas, we feel that our sampling strategy adequately captured much of the range of physical conditions, and dominant plant and algal communities present in south Sound estuaries. Moreover, since the USGS scenarios were based on the current bathymetry and did not necessarily account for redistribution of sediments within the Capitol Lake basins, it is impossible to determine how important the lack of several deep areas (~-4 m to 8 m) may have been to this study.

Several important distinctions should be considered before comparing the reference estuaries field data to the USGS Model results. First, the model is an approximation of what we believe will happen in a restored estuary. The model is based on data and our understanding of how water flows, and how sediments and salinities behave in estuaries. The model is a simplification of the real-world. A number of assumptions are made in developing and running any model. In the case of Capitol Lake, the USGS Model was operated in both two dimensional (2D) and three dimensional (3D) modes. In real life, estuarine processes occur continuously through time in three dimensions. The 3D model mode takes into account water depth, while the 2D model describes patterns along the bottom surface. The 3D mode is computationally more intensive than the 2D mode, therefore, requiring more time to run. For each restoration scenario, salinity and inundation patterns were modeled using the 3D mode and sediments using the 2D mode. Salinity was modeled for a series of points. Each salinity point represented the salinity within the lower 1/7th of the water column within a pre-defined area of Capitol lake, i.e., a grid-cell[10] (George *et al.* 2006). Salinity was modeled for both low flow (dry bed) conditions and as an annual average. To make the best use of time and resources, the modelers assumed the 2D mode to be adequate for describing sediment processes.

As noted above, the 2D model did <u>not</u> take into account any changes in morphology that may occur over time (i.e., changes in elevation). That is, the same bathymetric grid

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[10]Grid cells are used by modelers to represent an area of uniform conditions. Grid cells are a way to simplfy the model by approximating conditions on a grid cell-by-grid cell basis rather than continuously for every point. See Appendix II.

was used in all 2D model runs of sediment texture. We converted model results into spatial data sets so that restoration scenarios could be compared to each other and with bathymetry. Recall, reference estuary samples were not collected randomly nor collected to be representative of the entire area of each reference estuary. Therefore, we cannot directly compare results from salinity or sediment texture in the reference estuaries to model results for Capitol Lake in terms of area (i.e., acres, hectares, etc.). Instead, we compare model results as area and reference estuaries as frequency (number of sites) of samples.

The modeled near-bed salinity range for Capitol Lake was similar to the range for our pore water salinity samples. We measured a range of 1 to 28 psu from the reference estuaries for those sites where pore water was available (70% of sites). The range predicted for Capitol Lake for both average annual and dry bed conditions was 1 to 30 ppt (Figure 22 - 24). While the reference estuary pore water salinities are not directly comparable to the model-produced near-bed salinities for Capitol Lake, both ranges encompass three salinity classifications of estuarine communities according to Dethier (1992) and based on Cowardin (1979): polyhaline (18-30 ppt), mesohaline (5-18 ppt), and oligohaline (0.5-5 ppt). All of these results have been described in the Salinity section of Chapter 3 and Appendix III and will be discussed in greater detail in the following sections.

Finally, we were excited to see that the sediment textures predicted for Capitol Lake were similar to those sampled within the reference estuaries. In fact, in both the reference estuaries and the modeled Deschutes Estuary/ Capitol Lake, silt loam textures dominate bottom sediments for all model scenarios (Figure 13). Sandy loam sediments are the second most common sediment texture (by frequency of encounter) in the five reference estuaries and were abundant (by area) in Capitol Lake for several of the model runs. Silt and silty clay loam were predicted to be common in a restored Deschutes Estuary but silty clay loam was only sampled at two of 90 reference sites and silt was not encountered during our reference estuary sampling. Therefore, if silt and silty clay loam textures become common in a restored Capitol Lake, additional work may need to be done to characterize the types of communities associated with these textures in south Sound estuaries. Silt loam sediments, the most common in our sampling and predicted for a restored Capitol Lake, are an important factor in the formation of the estuarine communities we sampled.

Elevation/ Inundation

The elevations sampled within the Capitol Lake and surrounding areas by USGS and its cooperators were primarily between MLLW and MSL (78%, -2.36 to 0.18 m NGVD29, Figure 19). Areas above MHHW (>2.08 m using NGVD29 or 4.44 m using MLLW vertical datums[11]), or those considered backshore and intertidal by Dethier (1990), are also abundant in the area of Capitol Lake, including some shoreline upland and surrounding wetland areas. Smaller amounts of the lake are below MLLW (16%) and between MTL and MHHW (24%).

[11]See footnote 5.

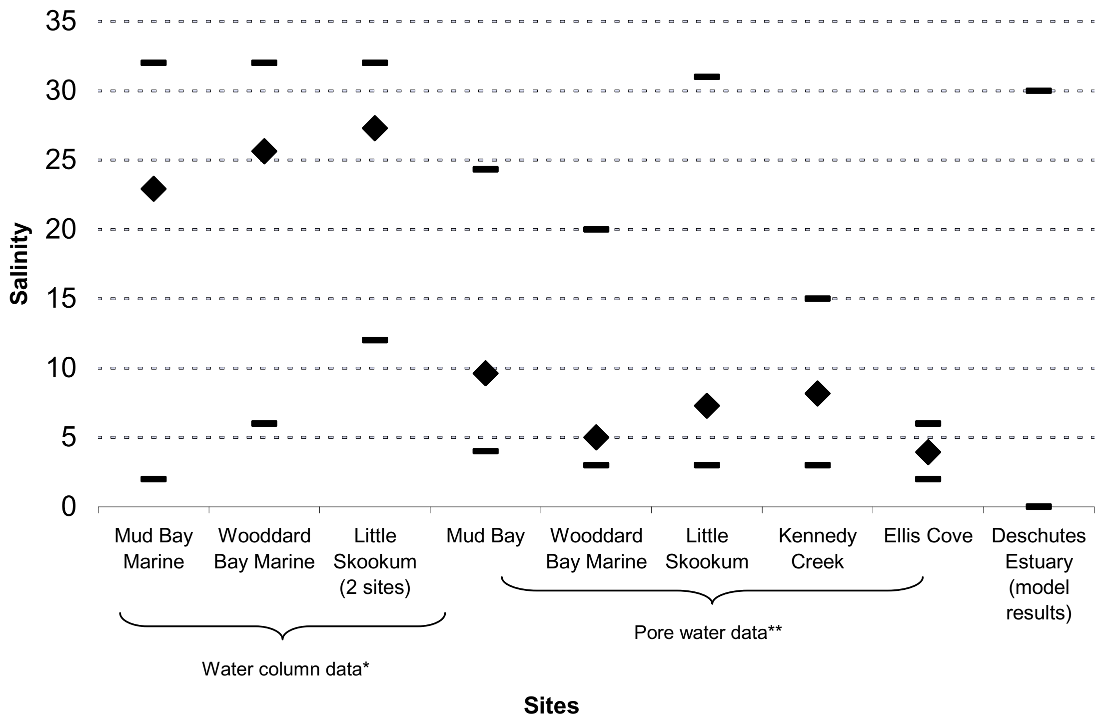

Figure 22. Minimum, maximum, and average (when available) water column and pore water salinity data collected in five south Puget Sound reference estuaries. Deschutes Estuary data presents the range of near-bed salinity (ppt) values predicted for the restored estuary over both annual average and dry bed (low flow) conditions (George *et al.* 2006). See footnotes and report text for further details.

*Data provided by Washington State Department of Health; taken from 1998 (Mud Bay) or 1990 (Woodard Bay and Little Skookum Inlets) through 2005 at various tides during variable times of the year in the water column. Data are in parts per thousand (ppt).

**Data taken in substrate during reference estuary study, September 2005. Data are in practical salinity units (psu).

The range of elevations within the lake was -8 to 6 m. The area where deepest depths occur is in the north basin (Figures 1 and 19) near the dam and this area may be part of the pre-dam channel that existed in the Deschutes Estuary (George *et al.* 2006). This deeper area may develop biological communities that are not represented by our samples collected at the reference estuaries.

Inundation patterns were also described by the USGS DELFT 3D model for the restoration scenarios for Capitol Lake. In all scenarios, inundation occurred throughout the restored estuary, including the North Basin, Percival Cove, and the South Basin. The model showed the Middle Basin to be inundated >50% of the time in all areas, but a channel along its east side generally had an inundation duration closer to 100% of the time (George *et al*. 2006). Although the USGS model is capable of looking at patterns in inundation, no comparable data

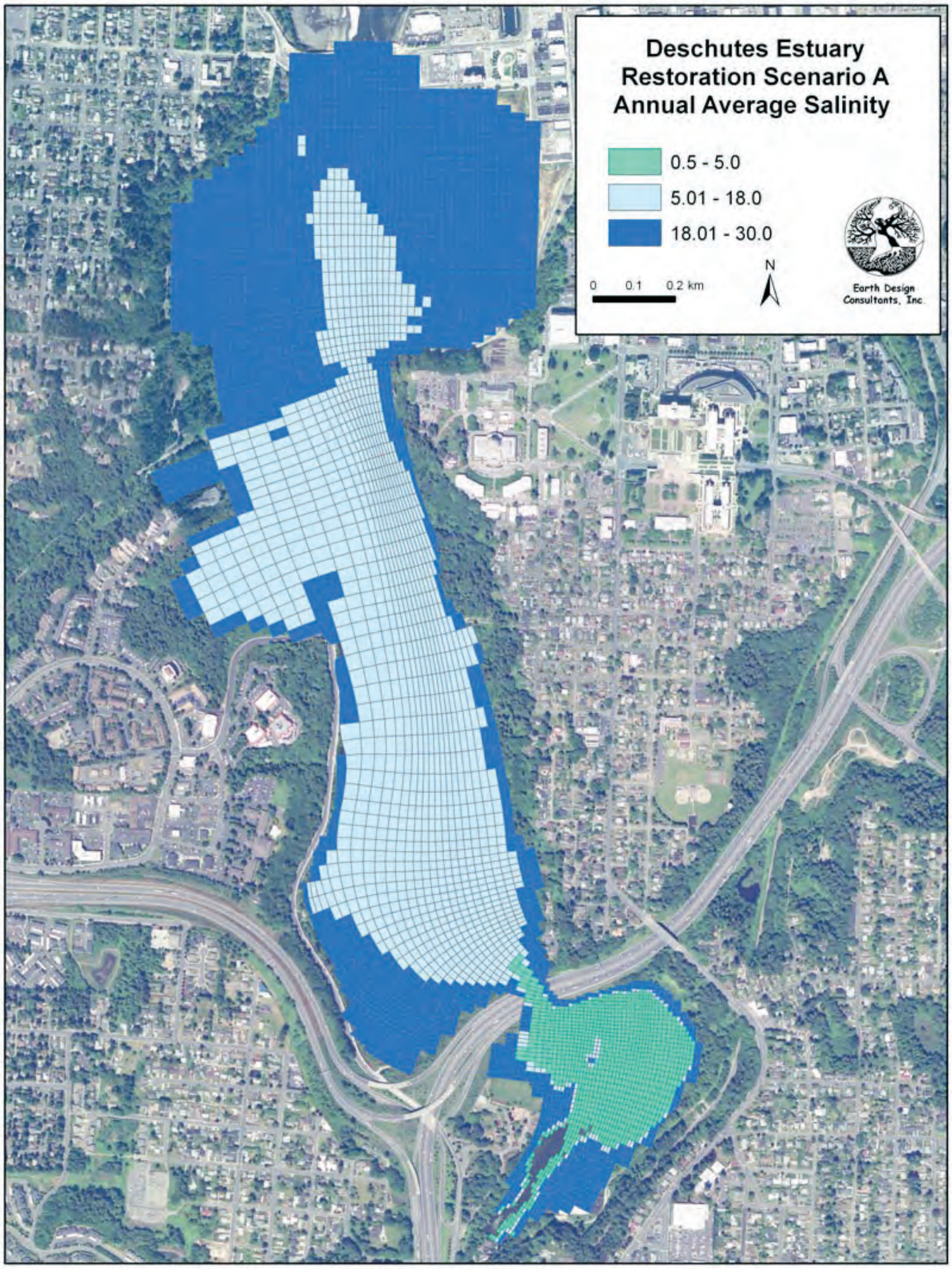

Figure 23. Map of Capitol Lake salinities in oligohaline (0.5-5 ppt), mesohaline (5-18 ppt), and polyhaline (18-30 ppt) categories predicted under restoration scenario A under average annual conditions. Restoration scenario A is based upon a 150 m opening between Budd Inlet and Capitol Lake at the 5th Avenue bridge. See George *et al.* (2006) and text for further details.

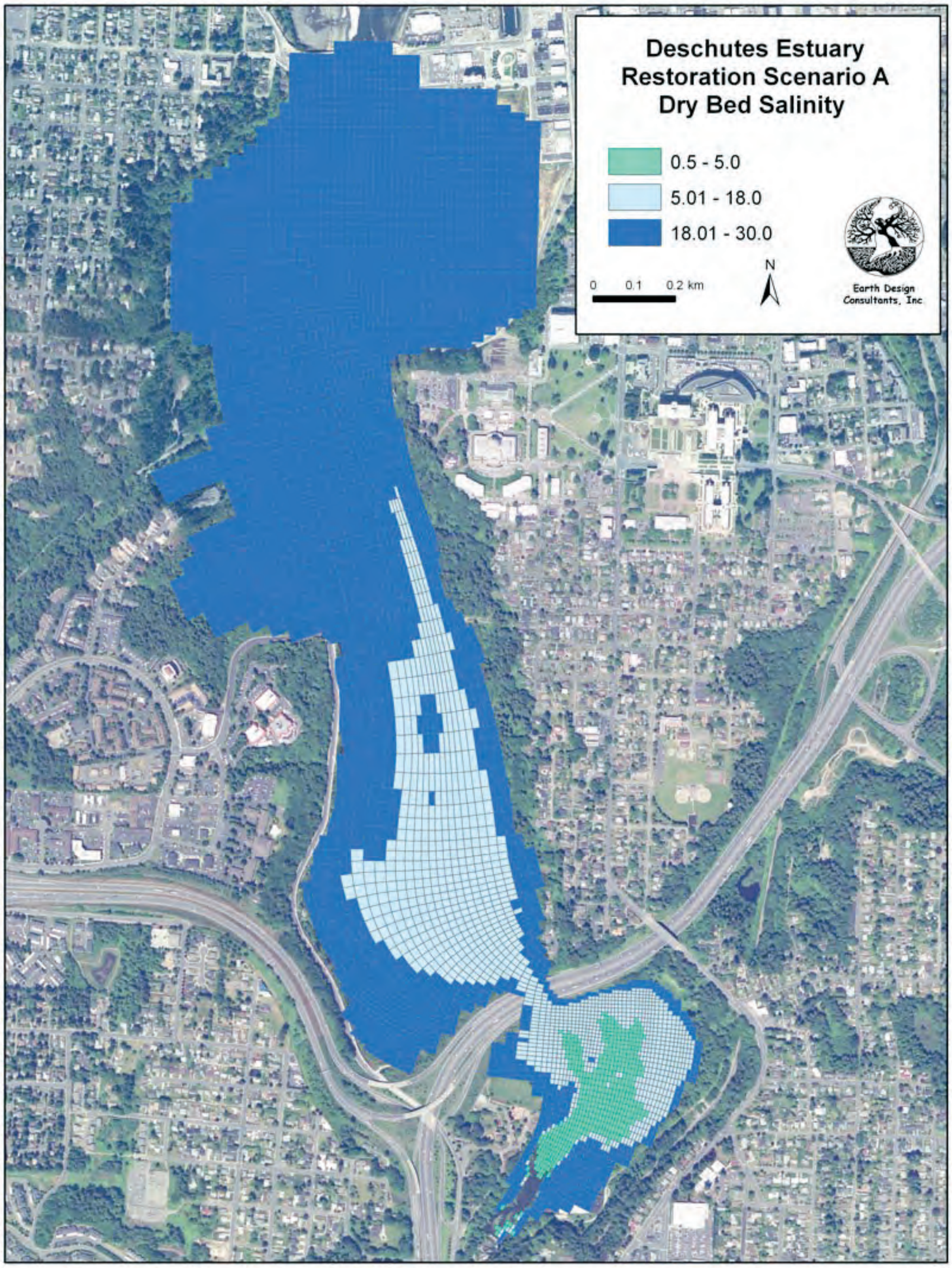

Figure 24. Map of Capitol Lake salinities in oligohaline (0.5-5 ppt), mesohaline (5-18 ppt), and polyhaline (18-30 ppt) categories predicted under restoration scenario A under dry bed (i.e. low flow) conditions. Restoration scenario A is based upon a 150 m opening between Budd Inlet and Capitol Lake at the 5th Avenue bridge. See George *et al.* (2006) and text for further details.

were measured at reference estuaries. Therefore, we rely on elevation, primarily in relation to MLLW, MSL/MTL, and MHHW[12], to describe the importance of patterns in inundation to biological communities.

Salinity

At reference estuaries, we measured pore water salinity while we were at the site during low tides to sample the epibenthic communities. Pore water is commonly measured in estuary studies and strongly affects estuarine communities (e.g., Ewing 1983; Crain *et al.* 2004; Heatwole 2004). We attempted to find the relationship between pore water and surface water salinity, and between pore water salinity and sediment salinity (also measured by our field teams). As mentioned above, due to the low elevation of some sites, we were only able to collect pore water samples from 63 of the 90 sample sites. This affected our analyses. To remedy this situation, we tried to recover salinity measurements from the collected sediment samples and to relate those salinity measurements to pore water salinity. These relationships are summarized in Appendix III: Salinity. Moreover, a direct comparison between reference estuary salinity and modeled salinity was not possible, since modeled conditions reflect near-bed salinities and our measurements were of pore water salinity.

USGS modeled near-bed salinity of the restored Deschutes Estuary revealed mostly mesohaline and polyhaline salinity throughout the estuary (Table 11, Figures 23 and 24). Salinity was modeled for both dry bed conditions, which relates to summer conditions when there is very little freshwater flow, and as an annual average (Table 11). Values presented in the table include both the percent area and the number of acres of the lake/restored estuary that fall into each of the following three salinity categories of oligohaline (0.5 to 5 ppt), mesohaline (5 to 18 ppt), and polyhaline (18 to 30 ppt; Simenstad *et al.* 1991; Dethier 1992). As expected, for all four of the restoration scenarios, salinity values are higher in the dry bed conditions when compared to the average annual values, due to the decrease in freshwater flow during summer that would dilute saline water. Very little area of the restored estuary is modeled to be oligohaline water during both dry bed conditions and for the annual average. Only 3.8 to 4.4% of total area is predicted to be of low salinity waters during dry bed and 8% averaged over the year. During dry bed conditions, 19 to 22% of the total area of Capitol Lake is modeled to be mesohaline waters, whereas the majority of area is predicted to be high salinity, polyhaline water (70 to 77%). In contrast, during the averaged annual conditions, proportions of mesohaline and polyhaline waters are roughly equal (43 to 52% mesohaline, 44 to 48% polyhaline).

For all restoration scenarios, for both annual average and dry (low flow) years, modeled near-bed salinity ranged from 0 to 28 ppt, except for a dry year estimate of scenario D which reached a high of 30 ppt. Estimated near-bed salinity was always highest in the North Basin, which is closer to Budd Inlet/Puget Sound and near-bed salinity was lower next to the mouth of the Deschutes River (Figures 1, 23, 24). In dry years, North Basin was

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[12]See footnote 5.

Table 11. Predam and predicted above-bed salinity conditions for Capitol Lake under four different restoration scenarios. Data are presented in both the percent area of Capitol Lake within each salinity category during dry bed (low flow) conditions and average over an annual cycle, as well as the total area in each salinity category under dry bed and annual conditions. Raw salinity data is from George *et al.* (2006) and based on depth/bathymetric grid provided by George *et al.* (2006).

Restoration scenario	***% area of depth grid*** Dry bed 0.5 - 5 ppt	5 -18 ppt	18-30 ppt	***area in acres*** Dry bed 0.5 - 5 ppt	5 -18 ppt	18-30 ppt
predam	0.0	7.3	92.6	0.6	27.5	349.9
A	3.8	19.4	76.9	14.4	74.2	294.2
B	4.4	22.1	73.4	16.9	84.8	281.0
C	3.8	19.7	76.6	14.4	75.4	293.0
D	4.2	25.0	70.8	14.1	84.1	238.4

Restoration scenario	***% area of depth grid*** Annual Average 0.5 - 5 ppt	5 -18 ppt	18-30 ppt	***area in acres*** Annual Average 0.5 - 5 ppt	5 -18 ppt	18-30 ppt
predam	0.6	39.1	60.3	2.4	145.4	227.8
A	8.2	43.6	48.2	31.5	166.8	184.4
B	8.3	48.1	43.6	31.8	184.1	166.8
C	8.2	43.4	48.2	31.5	166.3	184.6
D	8.7	52.4	38.9	29.4	176.2	130.7

modeled to show polyhaline salinity ranges (20 to 25 ppt), while the Middle Basin, which was more saline in the north, was within the mesohaline salinity category and ranged from 5 to 17 ppt (George *et al.* 2006). South Basin salinities were generally less than 5 ppt and could therefore be classified as oligohaline (George *et al.* 2006).

In the average flow years, near-bed salinity was lower throughout the entire estuary than in the dry years. In these seasons, the North Basin was modeled to show salinity ranges from 15 to 20 ppt, which is between mesohaline and polyhaline categories for estuarine communities. The Middle Basin, which was again more saline in the north, stayed within the mesohaline category and ranged from 5 to 15 ppt (George *et al.* 2006). Again, the South Basin remained quite fresh, with salinities generally less than 5 ppt and again classified as oligohaline (George *et al.* 2006).

Interestingly, a salt wedge is predicted to form under all restoration scenarios except for periods of high river flow. A salt wedge is when a salty bottom layer that is wedge-shaped is separated in a sharp boundary from the upper, less salty layer of water and typically occurs when a river mouth pushes back seawater, controlling circulation. Salt wedges are important biologically because different densities of water can trap food and sediments. Consequently, salt wedges can be areas of increased biological activity.

Reference estuary salinity values ranged from 1 to 28 psu for those points where pore water was measurable (70% of sites) (Table 3). Generally, modeled near-bed salinity range was greater than reference estuary pore water samples and matched more closely water column data provided by Washington State Department of Health (Figures 9 and 22).

Sediments

Sediment texture and transport, both of which are important in structuring estuarine community types (see Sediments in Chapter 1: Introduction and Cluster Analysis in Chapter 3: Results) were modeled in 2D using the DELFT 3D model. Model runs, based on four different sizes of particles (2 um clay, 31 um silt, 200 um sand, and 2000 um gravel), produced descriptions of where sediments would accumulate after one and three years (George *et al.* 2006). The model sediment distributions are really data tables that depict where the four different sizes of particles can be found in the restored estuary under each of four restoration scenarios. The model did not describe ranges of particle sizes as were collected from the reference estuaries. Rather, each of the USGS model runs described one of four particle sizes each representing sand, silt, clay, and gravel. The model was run using two different bed cohesion factors for each of the four restoration alternatives. That gives us four restoration scenarios X two or eight cohesion factors worth of data from which to choose. USGS delivered results as a separate data file for the four particle sizes, for each restoration scenario, and for each cohesion factor (i.e., n= 4X4X2 = 32 data files).

We chose to synthesize this information by using the percent sand, silt, and clay values, also referred to as particle size distribution, to determine sediment texture types (Figure 13). Particle size distribution largely influences soil hydrodynamics (Bishel-Machung *et al.* 1996) and is easily measured with standardized protocols so it can serve as useful comparison measure. Several studies have compared created wetlands, including tidal communities, with reference wetlands on the basis of sediment texture, organic matter content, and bulk density including (Gwin and Kentula 1990; Confer and Niering 1992; Bishel-Machung *et al.* 1996; Craft *et al.* 1999; Craft *et al.* 2002; Goman 2005).

In terms of sediment texture, the four restoration scenarios are quite similar across the Deschutes Estuary and across depths (Figures 20 and 21, Table 10). In all restoration scenarios (A – D) at both bed densities (500 and 1000 kg m^{-3}), silt loam is the most common sediment type, ranging from 37 to 39% of the total area of the Deschutes Estuary (Table 10). Sandy loam, silt and silty clay loam are the next most common sediments, ranging from nine to 15% of the total area of the Deschutes Estuary (Table 10). The only difference in modeled conditions between the two bed densities exists in identifying the second most common texture type, which is silt in the 500 kg m^{-3} density and sandy loam in 1000 kg m^{-3} bed density.

Modeled silt loam is found throughout the estuary, with greater amounts found along the west central areas in North and Middle Basins. In scenarios A – C, silty clay is quite common along both the west and east edges of the North Basin. The deeper channel from

Budd Inlet south into Middle Basin contains loam, sand, loamy sand, silt loam, silt, and silty clay. Notably, this is the area where sand is primarily observed; also, in scenario B the "neck" between North and Middle Basins lacks sand substrate, while it exists in scenarios A and C. In general, Scenario D mimics scenarios A and C, without modeling the east side of the North Basin which would remain as a freshwater impoundment. In all scenarios, the South Basin is quite varied in sediment composition, with gravel, silty clay, silt loam, silt, sandy loam, sand, and loamy sand occurring.

Scenarios A, B and C at 500 and 1000 kg m^{-3} bed densities have the most area and the same total amount of area. The majority of sediments at depth 1 (below MLLW) in runs A, B, and C at 500 kg m^{-3} and A and B at 1000 kg m^{-3} densities are silty clay loam in texture (Table 10), although exact amount varies a bit by scenario. For the rest of the depth categories (MLLW to MTL, MTL to MHHW, and above MHHW) silt loam sediments are predicted to be most common. Scenario C at 1000 kg m^{-3} is a bit different in that sediments in which gravel comprises more than half of the material are most common in areas below MLLW. Silty clay is most common in areas at MLLW and above for model run C (Table 10). In scenario D at both 500 and 1000 kg m^{-3}, areas below MLLW are dominated by sand while areas above MLLW have silt loam, similar to most of the other scenario model runs. More detailed information about textures at each elevation level for each restoration scenario can be found in Table 10.

Overall, all four restoration scenarios predict similar outcomes for Capitol Lake. Varied sediments, dominated by silt loam, sandy loam, silt, and silty clay loam occur. The predicted conditions were represented within the reference estuaries. Silt loam was also most common in the reference estuaries, occurring at over 45% of sampling points. Twenty-five percent of reference estuary sites were sandy loam and the remaining textures predicted for Capitol Lake were not as common or not present at all in samples from the reference estuary sites.

Common Estuarine Biological Communities

One goal of this study was to predict the biological communities and subsequent habitats that could occur in a restored Deschutes Estuary under different restoration scenarios. We studied physical and biological parameters at neighboring estuaries to provide insight into how a restored estuary will look (habitats) and act (function). While habitats can be viewed as the living place of an organism characterized by its physical or biotic properties (Allaby 1994), a community is the biological component of an ecosystem, a group of populations of different interacting species living together in a particular environment (Allaby 1994). In estuaries, communities are structured by sediment type, salinity, elevation, inundation, and other physical properties (see Chapter 1 for further explanation). A proposed classification system for PNW estuaries includes these variables, as well as exposure to wind, waves, and air, and other modifiers (see Dethier 1992). Estuarine habitats and their associated communities are organized along these environmental gradients.

Estuarine, intertidal elevation categories used by Dethier (1992) include backshore, which are areas above mean high water of spring tides (MHWS) or roughly 3.2 m NGVD29[13] in Budd Inlet, and eulittoral, which are areas between extreme low water of spring tides (ELWS) and MHWS or approximately -3.6 m to 3.2 m (Figure 6, USACE 2000). Dethier's subtidal categories include both shallow (areas 15 m or less below MLLW (~-2.4 m NGVD29) and deep, which are those areas deeper than -15 m below MLLW (Figure 6, USACE 2000).

Based on the primary variables and modifiers that structure estuarine communities, several community types are observed in the southern Puget Sound reference estuaries including high and low salinity marshes, mud flats, sand flats, and mixed flats (described below). High salinity marshes are those areas with higher elevations, redox potentials[14] ranging from -100 to 200 mV, salinities in 29 to 40 g kg^{-1} (i.e., ppt) range, and the following plant species: *Atriplex patula, Distichlis spicata, Grindelia integrifolia, Jaumea carnosa, Juncus balticus, Potentilla pacifica, Salicornia virginica,* and *Triglochin maritimum* (Hacker *et al.* 2001; Table 1). From surveys in Puget Sound, Dethier (1992) also associates *Deschampsia caespitosa* with higher salinity marshes. At lower elevations, *Carex lyngbyei, Festuca rubra, Scirpus americanus, Scirpus lacustris, Scirpus maritimus, T. maritimum* (Hacker *et al.* 2001), and *Deschampsia caespitosa, P. pacifica*, and *J. balticus* (Dethier 1992) are typically found (Table 1). Moderate redox potentials (-100 to 100 mV) and salinities ranging from 5 to 15 (i.e., ppt) are associated with low salinity marshes (Hacker *et al.* 2001).

USGS model results have predicted that silty loam sediments, dry season and average annual near-bed salinity ranges of 18 to 30 ppt and 5 to 30 ppt (Table 11), respectively, and elevations falling between MLLW and mean tide level (MTL; -2.36 to 0.18 m NGVD29) will be the prevalent physical parameters in a restored Deschutes Estuary. According to PNW research on estuary classification, function, and ecology (i.e., Dethier 1992; Adamus 2005a and 2005b; Simenstad 1983), these physical parameters will result in a few different community types: mud flats, mixed sand and mud flats, sandy channels, and sand flats (Table 12).

Mud Flats

Mud flats are characterized predominantly by silt and clay sediments that are typically high in organic content but often anaerobic below the surface sediment (Simenstad *et al.* 1991). Organisms expected in mud flat habitats include burrowing crustaceans and polychaetes, mud shrimp, clams (Hacker *et al.* 2001, Simenstad *et al.* 1991, Dethier 1992), and diatoms and algal mats where salinities are higher (Zedler 1980; Underwood *et al.* 1998). Mud flats typically occur in broad expanses over low gradient shorelines, in areas of low wave energy associated with moderate surface salinity (20 to 30 g kg^{-1} [i.e., ppt]) and low redox

[13]See footnote 5.
[14]Redox is a measurement that reflects the balance between oxidation and reduction. Generally, redox values are positive near sediment surfaces where oxygen is present. Negative redox values indicate a reducing environment.

Table 12. Characteristic organisms of Pacific Northwest estuarine natural biological community types arranged by elevation gradient and sediment texture types. All information referenced from Dethier (1992).

Sediment Texture:

Community Type:	Mixed-coarse	Gravel	Sand	Mixed-fine	Mud	Organic
Intertidal, Backshore; Above MHWS			Marsh vegetation, green and red algae, polychaetes, ophiuroids, *Salicornia virginica* (pickleweed), *Jaumea carnosa* (succlent vascular plant)	Transition-zone wetland vascular plants; *Potentilla pacifica*, *Juncus balticus*, *Calamagrostis nutkaensis* (reedgrass), *Picea sitchensis* (Sitka spruce), *Scirpus acutus* (bulrush), *Typha* sp. (cattail)		Moderate-salinity, high marsh, vascular plants; *Deschampsia caespitosa* (hairgrass), *Potentilla pacifica* (silverweed), *Juncus balticus* (rush), *Carex lyngbyei*, *Festuca rubra* (fescue)
Intertidal, Eulittoral; Between MHWS and ELWS	Fucoid and red algae, mussels, barnacles, clams, worms, blennies and clingfish; *Macoma inquinata*, *Protothaca staminea* (clams), *Phoronopsis harmeri* (phoronid worm), *Owenia* and *Mediomastus* (polychaetes)	Vascular plants; sparse salt marsh vegetation; *Glaux maritima* (saltwort), *Salicornia virginica* (pickleweed)	Salt-tolerant or moderate-salinity, low-marsh vascular plants; *Distichlis spicata* (saltgrass); *Salicornia virginica* (pickleweed)	Low-salinity, silt-tolerant vascular plants; *Scirpus maritimus* (saltmarsh bulrush), *Triglochin maritimum* (arrowgrass), *Carex lyngbyei* (slough sedge)		
Subtidal Shallow; Between MLLW and –15m		Burrowing crustaceans and polychaetes, sculpins, flatfishes and other fishes; *Exosphaeroma inornata* (isopod), *Hemipodus* and *Armandia* (polychaetes)	In open areas only: Clams, polychaetes, young flatfishes, salmon, algae; *Gracilaria pacifica* (red alga), *Macoma secta* (clam), *Malacoceros glutaeus* (polychaete)	Channels: Vascular marsh plants, small crustaceans, polychaetes, many fishes		
Subtidal Deep; Deeper than 15 m below MLLW						

potential (-300 to 100 mV; Hacker *et al.* 2001). In Puget Sound, mudflats are commonly found between the vegetated, emergent marsh and MLLW line along channels and delta foreshores of major rivers (Simenstad *et al*. 1991). Birds, fish, and mammals associated with mudflats can be found in Simenstad *et al*. (1991). Low, silty marshes develop on fine-textured sediments, silt, or mud substrate in low energy areas. They are typified by high sedimentation rates, regularly flooded by high tides, drained and flooded by a diffuse pattern of channels, and are covered by clumps of plants which are discontinuous at lower elevations (Adamus 2005a). At high and low tides, mudflats can be a source of food for waterfowl and food and refugia for juvenile fishes (Adamus 2005a).

Mixed Sand and Mud

Mixed sand and mud substrates occur at varying elevations and, of course, salinities. At higher elevations, these habitats form a transition zone up to high marsh areas and are populated with vascular plants and even some trees (Dethier 1992). At lower elevations and low salinities, vascular plants such as *Scirpus maritimus* and *Triglochin maritimum* may also occur. In lower elevation/high salinity areas, microalgae, salt-tolerant plants such as *Salicornia virginica*, and animals such as *Callianassa californica* (ghost shrimp) will likely exist (Dethier 1992). Channels may occur with these mixed substrates and their communities are variable but may include vascular marsh plants, small crustaceans, polychaetes, and fishes (Dethier 1992).

Sandy Channels

Sandy channels generally occur in open, deeper areas where channels form. These open areas are typically inhabited by clams, polychaetes, young flat fish, salmon, and sand-loving algae (Dethier 1992). They are also important for provision of refugia and food for anadromous, resident, and marine fishes (Adamus 2005a) and transport of sediments (Simenstad 1983).

Sand Flats

Sand flats are found along exposed boundaries of mudflats in estuarine river deltas, adjacent to river channels; forming 50 to 100 m benches along moderately exposed, high bank shores of Puget Sound or in moderately exposed embayments without measurable riverine input (Simentstad *et al*. 1991). Sand flats typically occur in higher energy areas than mud flats (Adamus 2005a) where the substrate is predominantly sand and is exposed to sorting from wave and current action (Simenstad *et al*. 1991). Flooded by most high tides, sand flats are covered by scattered vegetation near the tidal edges, with more vegetation farther away from water (Adamus 2005a). Clams, polychaetes, and young fish are typical animals that inhabit sand flats (Dethier 1992). In eulittoral, euhaline areas, salt tolerant plants such as *Salicornia virginica* may occur, while polyhaline areas may also have *Distichlis spicata* in eulittoral depths. Low salinity areas will typically host plants that are less salt-tolerant, including *Scirpus americanus* and *Carex lyngbyei* (Dethier 1992). Birds, fish, and mammals associated with sand flats can be found in Simenstad *et al* (1991).

Dethier (1992) also categorizes communities by exposure but exposure was not characterized at the reference estuaries or by the USGS DELFT 3D model. It is possible to predict, just from observing Capitol Lake, that if restored to an estuary, much of the habitat would be partly enclosed with natural or artificial obstruction reducing circulation, wave action, and/or currents. This type of habitat would likely occur in parts of Middle and South Basins. Some sections, such as Percival Cove, may be largely enclosed with tidal influence blocked by a spit. Partly enclosed estuarine habitats can have sand, silt, or mixed substrate and subsequently their plant communities will reflect this.

Habitat Bins and Biological Communities of the Reference Estuaries

One of the goals of this study was to develop empirical relationships between the biological communities which exist within the reference estuaries and the environmental variables responsible for organizing those communities. Although descriptions of communities have been developed for PNW estuaries (described above), we decided to use environmental data collected during this study to develop 'habitat bins.' The CLUSTER and Principal Components Analysis (see Chapter 3 Results: PCA and CLUSTER Analysis) were successful in grouping sample sites into eight groups (Table 9) based on sediment composition, elevation, and pore water salinity. However, the Discriminant Analysis failed to relate patterns in the biological community data, in this case mainly algae, to the environmentally-derived 'habitat bins.' This was probably due to the wide distribution of algal communities across many of the habitat types sampled and the lack of association between cover types. In other words, the diatoms we encountered were present in most types of the habitat types we sampled.

We returned to the vegetation cover data to see what patterns existed within the biological data. We found that there were no strong associations between the different plant cover classes that we measured except between two salt marsh vascular plant species. In other words, we failed to observe patterns in our plant community data set. Since there was no underlying pattern in the biological data (plant communities) to match up with the environmental data, the Discriminant Analysis failed to empirically relate communities to environmental variables. In addition, our Discriminant Analysis was limited to the 63 sites for which we had complete data sets because pore water data were not available for all 90 sample sites.

Since the non-vascular plants most commonly encountered at the sample sites were not readily identified in the field, we only recorded coarse cover categories for these species. Many of the algal cover classes could be further divided into more detailed cover classes by identifying algae genera or species in the laboratory. It is probable that with a greater number of samples and more detailed community descriptions, underlying patterns could be identified.

In addition, other organisms, such as benthic invertebrates, may have more of an affinity for specific sediment textures and may yield an underlying pattern.

Potential Habitats of a Restored Deschutes Estuary

Although we were unable to empirically relate biological communities with the environmental gradients observed at five south Sound estuaries, the intensive sampling did answer a few important questions. First, we learned that the range of conditions predicted for the restored Deschutes Estuary is well represented in nearby estuaries. Second, we learned that the restored Deschutes Estuary will probably look somewhat like Mud Bay or Kennedy Creek. Thirdly, we learned how underrepresented vegetated salt marshes were in the reference estuaries at the sites we selected. Most of the vegetated salt marshes we sampled fringed reference estuaries at elevations >2 m NGVD29. Therefore, we don't expect the restoration project to produce expansive vegetated salt marshes unless an unanticipated shallowing of the basin occurs: the estuarine communities of a restored Deschutes Estuary will be predominantly intertidal and subtidal sand and mudflats, and some sandy channels in deeper areas. We expect the salinity to range from oligohaline near the river entrance to the basin to polyhaline near the entrance to Budd Inlet. Finally, recognizing that salinity is such an important factor in structuring estuarine communities, we found it difficult to measure salinity in a meaningful way during limited sampling opportunities.

We used the USGS model data to create a graphic of the distribution of potential estuarine habitats based on the sediment transport model and modeled salinities (Figure 25). We found that the majority of the restored Deschutes Estuary will be occupied by meso- and polyhaline intertidal mixed fines-mud flats. Most of the data collected from the reference estuaries were collected from intertidal sand and mixed-fines mud areas so there is good overlap between the data collected and the conditions predicted for the restored Deschutes Estuary.

Overview of Estuarine Functions

Although we can make hypotheses of the physical structure and biological communities of a restored Deschutes Estuary, it is more difficult to determine how the restored estuary will function (Simenstad and Thom 1996). Restoration ecologists warn that function does not always follow form. Important functions of estuarine communities include: denitrification, carbon transformation, nutrient processing, primary production and food web support, sediment deposition and erosion, and habitat for fish and invertebrates. The ever-changing water chemistry in tidal marshes allows for more rapid cycling of some nutrients than in freshwater ecosystems (Adamus 2001). Most estuarine functions are difficult to measure although ongoing research strives to identify wetland function as a manner for classification (e.g., Adamus 2005b). Also, few comprehensive references exist for wetland function specifically in the Puget Sound region. Therefore, for this section we draw upon references from studies elsewhere in the PNW and outside of the region.

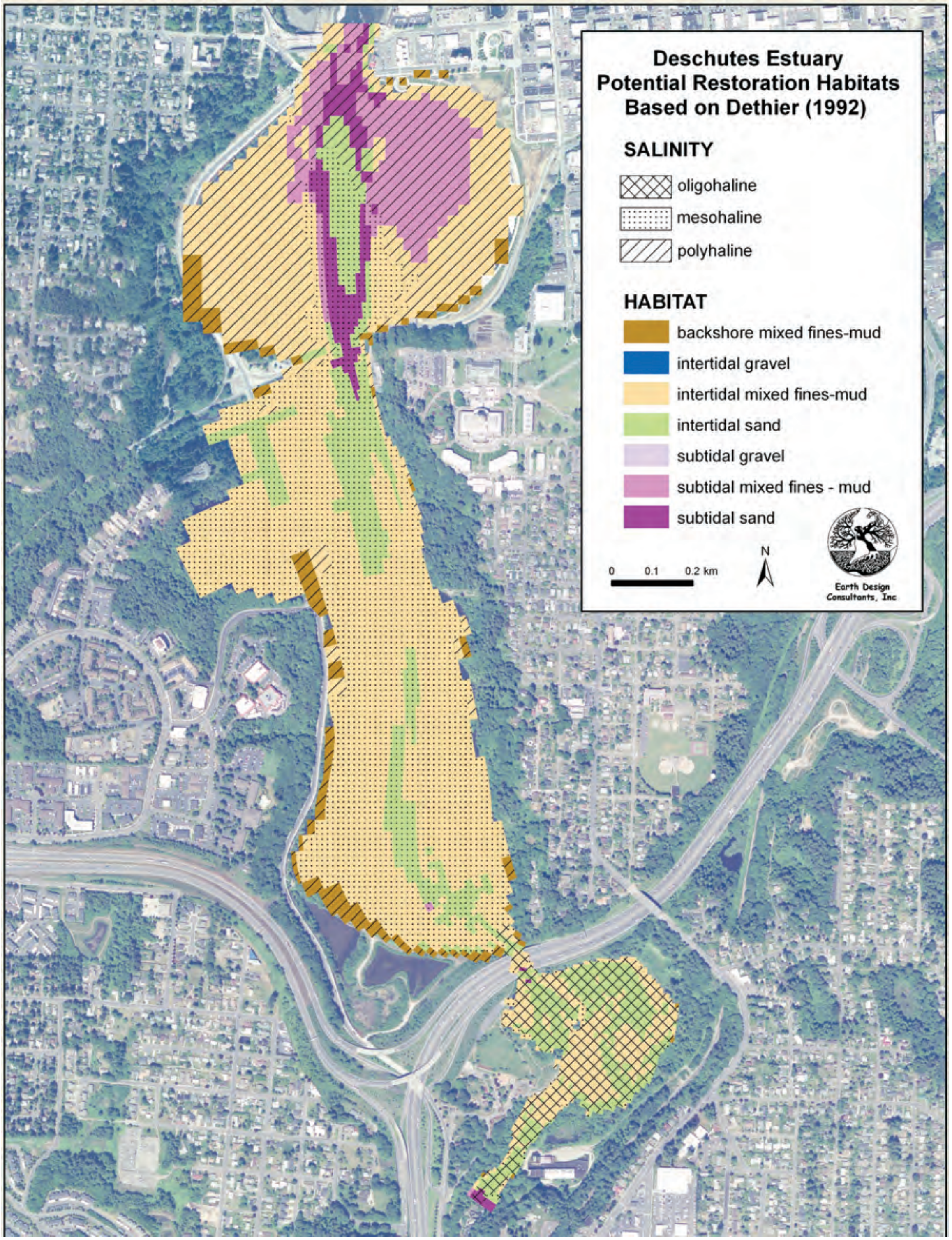

Figure 25. Map of Capitol Lake showing potential habitats predicted under restoration scenario A. Restoration scenario A is based upon a 150 m opening between Budd Inlet and Capitol Lake at the 5th Avenue bridge. Sediment data from USGS model were assigned to sediment texture classes and mapped to intertidal and subtidal depths with predicted salinities for the estuary. Potential habitats are based on Dethier (1992). See George *et al.* (2006) and text for further details.

Nitrogen is an important nutrient. Organisms use nitrogen to build structural materials like exoskeletons and to synthesize enzymes necessary for them to live. Most nitrogen enters the food web from the atmosphere through nitrogen fixation. Many bacterial and some cyanophytes (blue green algae) are capable of fixing atmospheric nitrogen into other forms like ammonia. Ammonia can then be converted by other types of organisms into other nitrogen-containing compounds, like nitrates. Denitrification is the process by which nitrate is converted into nitrogen gas or nitrous oxide, thus released back into the atmosphere. Denitrification generally occurs in anaerobic environments. It completes the nitrogen cycle. In estuaries, denitrification is positively correlated with organic matter (Craft *et al*. 2003). Denitrification occurs primarily through actions of denitrifying bacteria associated with the organic matter. In a restored Deschutes Estuary, we would expect denitrification to be highest in vegetated areas around the periphery of the marsh and in organic-laden sediments. Denitrification is also highest in areas with fresh water input (Adamus 2005a), so areas in South and Middle Basins that are lower in salinity and vegetation may serve this function well. Increased rates of denitrification could be an additional perk of the Deschutes Estuary restoration, as excessively nutrient-rich waters from the watershed, which can negatively affect estuarine food webs, would be subject to the denitrification processes of the restored estuary (Hopkinson Jr and Vallino 1995; McClelland and Valiela 1998).

Carbon transformation is the process by which organic carbon in particulate form is converted by living organisms into carbon dioxide (through cellular respiration) or living matter (through growth or reproduction). Carbon transformation in estuaries can be thought to start with plants, through photosynthesis and respiration. Plants convert atmospheric carbon dioxide into complex organic molecules through the process of photosynthesis. Organic carbon, fixed by plants, then ends up as dissolved or particulate carbon in the environment. Carbon transformation is closely related to primary productivity, which is also very high in marshes (Adamus 2005a). However, the carbon cycle continues beyond photosynthesis and respiration. Carbon enters the food web as plants are consumed by herbivores, and herbivores are consumed by omnivores and waste from metabolic processing within these organisms again occurs as particulate/ dissolved organic carbon. Carbon transformation is generally highest where plant growth is occurring, which we expect to be around the margins of a restored Deschutes Estuary.

Estuaries can also be important areas for phosphorus transformation. Phosphorus, an important nutrient used by organisms to synthesize cell membranes, DNA, and RNA, reaches estuaries through freshwater input and from the ocean. Anthropogenic activities have dramatically increased phosphorus loading from watershed sources (Vollenweider 1968; van Bennekoma and Salomons 1981). Phosphorus can bind to estuarine sediments or be sequestered by organic matter in the water column and sediments (Adamus 2005a). This mainly occurs in more oligohaline areas of marshes. In deeper, more saline waters, phosphorus is adsorbed to fine sediments in a form that tends to be immobilized (unavailable to biota) but transported more freely (Adamus 2005a).

In PNW brackish, intertidal marshes, primary production occurs rapidly as most of aboveground biomass is produced during six weeks in the spring (Ewing 1986). In fact, marshes are thought to be some of the most productive ecosystems in the world (Adamus

2005a). As mentioned earlier, primary productivity (i.e., carbon fixed by plants, the first link in the food web) supports most estuarine fauna, in one form or another. Primary productivity decreases with decreases in elevation due to inundation and increased light attenuation in estuaries. At higher elevations, marsh plants are less able to compete with drought tolerant species and a higher diversity of plant species has been observed in these habitats (Ewing 1983). Benthic macroalgae are also important primary producers in estuaries, and can support other estuarine functions such as the interception of suspended inorganic sediments, reduction of current velocity, maintenance of underlying sediments, and minimization of erosion (Adamus 2001). Algal mats also act to stabilize estuarine sediments and can increase oxygen concentrations at the top of estuarine sediments (Little 2000).

Estuaries are areas of sediment deposition and erosion. Complex physical parameters such as tidal flux, river discharge, salinity, and sediment size combine with biotic factors to hasten and promote these processes (Simenstad 1983; Adamus 2005a). Deposition of sediments generally occurs as channel gradients decrease, velocity slows, and/or water volume decreases (Simenstad 1983; Adamus 2005a). Salinity can act to either promote deposition in well-mixed waters, or allow suspension to continue in stagnant waters (Adamus 2005a). Erosion occurs mainly through changes in current direction and velocity (Simenstad 1983). Other characteristics such as the sediment characteristics (e.g., size, parent material), geological history, and sediment load in river currents also play a part in this process (Simenstad 1983).

Perhaps the most aesthetically pleasing function of estuaries is the provision of habitat for waterfowl, fish, and invertebrates. This function is based on the less-visible functions such as carbon transformation and primary productivity already mentioned but is equally important. Sometimes, the animals themselves provide important functions in estuaries. For example, benthic infauna are relatively stable structures (Simenstad 1983) that can change patterns of erosion and deposition or provide nutrient cycling (e.g., oysters). Waterfowl are valuable to estuarine food webs as transformers and transporters of both terrestrial and aquatic organic matter (Adamus 2005a). Fishes of commercial or recreational importance, such as salmonids and rockfish, can be dependent on estuarine habitat for part of their life cycle. Both resident and migratory bird species use PNW estuaries for foraging and roosting (Simenstad 1983). Although the biodiversity resulting from occurrence of several invertebrate, fish, and bird taxa has value in its own right, culturally, commercially, and recreationally important bird and fish species also add value to estuaries for humans by providing economic support for coastal cities and towns.

Based on the model results and the reference estuary study, we believe that a restored Deschutes Estuary will look most like the areas of Mud Bay with channels similar to Kennedy Creek. As previously mentioned, our conclusions are based on the samples we collected, which were not collected to represent nor characterize the entire reference estuary. The restored Deschutes Estuary will probably have sandier channels and perhaps more mixed sand and mud flats than either of these two reference estuaries. From our sediment sampling, Mud Bay sediments had the highest proportion of silt (60%) and silt loam textures dominated. In the reference estuaries, silt loam textures correspond to moderate percent organic matter (mean 9.4%, st.dev. 4.5), bulk density (mean 0.67 gm cm^{-3}, st.dev. 0.26), and elevation (mean 0.16, st.dev. 0.96 m), with mesohaline salinities (mean 12 psu, st.dev 11.4 psu). The macrotide range (>4 m) of Budd Inlet also suggests that mud flats will predominate community types in the restored Deschutes Estuary (Little 2000). In addition, results of the Budd Inlet Scientific Study (LOTT 1998) indicate that excluding the deeper, dredged areas, significant areas of the East and West bays of Budd Inlet are mud flats. This would suggest a high likelihood of the restored Deschutes Estuary, next to Budd Inlet, would be comprised largely of mud flats.

Mud Bay has limited mesohaline and polyhaline vegetated high marsh areas around the peripheries, with most of the area middle-range elevations with mud or mixed sand and mud substrates (mud flats). These basic community types will be roughly arranged in a restored Deschutes Estuary (Figure 25) with muddy and silty flats along the margins and sandier channels (George *et al.* 2006). These are also the predominant community types we observed at many of the reference estuaries. However, other habitats will certainly exist at the periphery of these communities and some blending between these communities will also occur in a restored Deschutes Estuary.

Key Uncertainties and Factors Affecting Restoration Outcomes

Regardless of modeling, predicting, and pre-restoration efforts, Capitol Lake is a natural system with many influences. Additionally, the restoration of tidal flow to Capitol Lake will introduce varying levels of physical and biological parameters germane to predicted communities. Undoubtedly, processes and community types predicted here may not occur, or may occur in different spaces or proportions than we predict. There are some key uncertainties associated with these predictions – land use and water management, climate change, native and nuisance species recruitment and management, human disturbances, and active management – that we suspect will be important in the development of estuarine communities in a restored Deschutes Estuary. While there are unknowns with these issues, we suggest that adaptive management be strongly enforced to mitigate for these unknowns.

Land Use and Water Management

Compared to the reference estuaries, the Deschutes watershed has more development than most. The effects of higher developed areas generally fall into categories of water management and eutrophication. The first example of this is the extensive bulkheading around Capitol Lake and Budd Inlet (Herrera 2005). Effects of water management also include a reduction in riverine flow due to watershed activities such as irrigation which can change estuarine community composition by allowing high salinity waters to persist in the estuary. In addition, urban areas, with high levels of impervious surfaces, exhibit an increase in overland flow to aquatic areas. Water exits the watershed more quickly over these surfaces, but also at higher velocities, higher peak rates, and higher volumes and with greater likelihood of contaminants than flow through natural surfaces (Hopkinson Jr and Vallino 1995). This can affect estuarine communities by lowering the salinity of a particular area, scouring the benthos, or further reducing water quality.

Increased flows, along with other disturbances in the watershed, also deliver high amounts of organic matter and sediments to aquatic systems. In a review of existing literature from the eastern United States and Europe, Hopkinson and Vallino (1995) report nitrogen delivery from watersheds to be 0.44 g m^{-2} yr^{-1} from forested lands, 0.79 g m^{-2} yr^{-1} from urban lands, and 0.98 g m^{-2} yr^{-1} from agricultural lands. Although decomposition of organic material is a function of estuaries, estuaries can become eutrophic if levels of organics are excessive. Eutrophication can affect estuaries in several ways, including increased primary productivity, nuisance algal blooms, and alteration of the food web (see Eutrophication section in Chapter 1). Also, Budd Inlet was identified by Albertson *et al*. (2002) as exceptionally sensitive to eutrophication. This is likely a problem that will plague restoration planning. Sedimentation also can be disruptive when excessive. Land use activities such as logging, and development have increased sedimentation to estuaries. Sedimentation can change the sediment type in certain habitats and thus have cascading effects on communities. It can also smother benthic and sessile organisms, disrupting estuarine functions such as nutrient cycling and food web support. The effects on a restored Deschutes Estuary from increased sedimentation are difficult to predict.

Another unknown for a restoration of Capitol Lake is the impact that the extensive bulkheads around the lake may have. Herrera (2005) concluded that the elevation of bulkheads in southern Puget Sound inlets can affect spawning habitat and other estuarine functions. In other areas of Puget Sound, the benthos in front of bulkheads were found to have fewer invertebrate prey items for juvenile salmon than natural shorelines (Sobocinski 2003). Sobocinski (2003) also provides a review of literature on this topic for the Puget Sound region.

Climate Change

Climate change is a process that will affect all coastal waters, not just a restored Deschutes Estuary. While the general outcomes of climate change include rises in sea level, warming waters, and an amplification of other disturbances in estuaries (Thom 2001; Scavia *et al.* 2002; Snover *et al.* 2005; see also Climate Change section in Chapter 1: Introduction), it is difficult to predict what will actually occur in Puget Sound estuaries. With rising water levels predicted, an increase in the possibility of flooding during spring tides could occur, along with a change in communities adapted to certain inundation levels. Warming water temperatures could change existing habitats by altering carbon transformations and nutrient cycling, or by favoring species adapted to warmer temperatures; therefore, warming temperatures can be expected to alter estuarine communities and processes. Since the intricacies of how climate change could alter a restored Deschutes Estuary is unknown, managers should aggressively monitor for signs of these changes and investigate what actions can be taken to mitigate these effects.

Native Species Recruitment

Another unknown for a restored Deschutes Estuary is native species recruitment. In fact, Simenstad *et al*. (2005) cite a lack of natural plant and animal propagules in the restored Duwamish River estuary as problematic for estuarine restoration success in that location. In the Duwamish, this absence was mitigated by riparian vegetation plantings. However, keeping native flora and fauna robust requires adaptive management.

Given the expected habitats in a restored Deschutes Estuary, plantings may be considered around the periphery of the estuary and in Percival Cove. For example, along the periphery of the estuary, consider common marsh plants *Typha* spp. in the South Basin, and *C. lyngbyei* in the Middle Basin, Percival Cove, and the less saline parts of the North Basin. Other species we noted in our reference estuaries that may be appropriate for planting in the more saline North Basin periphery are: *J. balticus*, *S. virginica*, and *D. spicata*. Table 1 shows some plant species found in reference estuaries, their preferred habitat characteristics, and matching restored Deschutes Estuary habitats for potential planting. However, from lessons at other restored urban estuaries (e.g., the Duwamish River estuary, see Simenstad *et al*. 2005), plantings as part of restoration activities will likely need management to ensure they do not suffer from the numerous possible disturbances.

Invasive and Nuisance Species

Invasive and nuisance species have also been cited to be problematic for urban estuaries (Simenstad *et al.* 2005). The Canada goose proved to be problematic in the restoration of the urban Duwamish River Estuary (Simenstad *et al.* 2005). In this example, flocks of urbanized, non-migratory Canada geese consumed nearly all of the planted *C. lyngbyei* during the first growing season. This resulted in extensive vegetation protection efforts to keep the geese out of the planted areas. The protected *C. lyngbyei* had higher plant heights than the unprotected vegetation (Simenstad *et al.* 2005).

Of course, the exact extent to which invasive and nuisance species will populate a restored Deschutes Estuary is an unknown outcome of this activity. However, invasive species purple loosestrife and Eurasian watermilfoil, and nuisance species Canada goose and nutria are already present in Capitol Lake. These species could persist in a restored Deschutes Estuary, as they are all cited as adaptable to some levels of saline waters and/or desiccation, or are aggressive herbivores (e.g., geese and nutria). See section on Nonnative and Invasive Species of Chapter 1: Introduction for more information on how these species alter community composition.

Capitol Lake could also be susceptible to invasion by other nonnative species found in Puget Sound estuaries, should it be returned to an estuarine state. These species of concern are cordgrass (*S. alterniflora*), which could colonize mud flats and sand flats in a restored estuary, and two invasive crabs, which are prone to inhabit several estuaries from California to British Columbia. The presence of these in a restored estuary should be monitored for closely, along with other aquatic invasive and nuisance species, so immediate action can be taken if they are discovered.

Cordgrass has the potential to change estuarine habitat structure in a restored Deschutes Estuary, were it to reach this area. While cordgrass has not been observed in southern Puget Sound, it is an aggressive colonizer of intertidal marshes and deserves mention here. Cordgrass has its greatest abundance and highest growth in mudflats and low salinity marshes (Dethier and Hacker 2005) and it can withstand extended periods of submersion (Little 2000); both of these conditions are predicted to occur in a restored Deschutes Estuary. Since fine sediments and low salinity habitats are likely outcomes of Capitol Lake restoration, Capitol Lake would likely be susceptible to cordgrass invasions. Although cordgrass is well-noted for increasing sediment accrual and elevations in estuaries, these processes may not be the primary means of disturbance caused by cordgrass in a restored Capitol Lake. In a recent study in Puget Sound, low salinity mudflat communities invaded by cordgrass suffered reductions in native vascular plant abundance and species richness, and reductions in percent cover and species richness of native macroalgae (Hacker and Dethier 2006). Hacker and Dethier (2006) also found that cordgrass seedling recruitment was dramatically facilitated by already-established cordgrass in low salinity marshes.

Aggressive, adaptive management plans are critical to the suppression, control, and eventual eradication of estuarine nuisance and invasive species. Such adaptive management and monitoring are especially imperative for the control of nonnative species in enhanced estuarine habitats of urban areas, such as Capitol Lake. Washington State has an Aquatic Nuisance Species Management Plan that is aimed at management of nuisance species but also depends on cooperation by private, public, tribal government, and local government agencies (Parrish *et al.* 2003). Federal funding is available for such management through the 1996 National Invasive Species Act.

Human Disturbances

Uncertainties also lie in various human disturbances to urban estuarine restoration sites such as trampling (Erickson *et al.* 2003), disruption of breeding and feeding activities, persistent contaminants, light and noise pollution (Simenstad *et al.* 2005), and shellfish aquaculture. There are public places now within the original Deschutes Estuary borders, so a high level of human disturbance is likely. Persistent contaminants and light and noise pollution are more difficult stressors to decrease in urban settings. Measures that restrict access to tide flats and increase awareness and understanding of estuarine systems could decrease the effects of these stressors.

Other Unknown Outcomes

One matter of this study that we are not able to reconcile through previously conducted field work or literature is the comparison of pore water salinity and near-bed salinities from the reference estuaries and Capitol Lake, respectively (Appendix III). We have made community predictions from known salinities at other communities, but it is possible that the soil salinity of Capitol Lake will be less or more saline than the near-bed salinities. If soil salinities are lower than the modeled above bed salinities, we expect an increase in freshwater vascular plants and algae, especially in the South Basin and southern parts of the Middle Basin. If soil salinities are higher than the modeled near-bed salinities, which could occur during the summer months when riverine flow and rainfall are strictly limited and inundation periods are long due to the low elevation within the lake, community composition will also change. Few plants have been identified in habitats with high soil salinities. Diatoms and algal mats can be successful in these habitats (Zedler 1980; Underwood *et al.* 1998), but vascular plants are unable to cope with high salinities and inundation times.

In addition, it is difficult to characterize the true conditions of both reference estuaries and Capitol Lake using data collected over a very short period. Because of the dynamic nature of estuaries, data should be collected over the long term, such as several representative tidal cycles (Simenstad *et al.* 1991). Also, it is nearly impossible to predict a time-scale for community re-establishment in a restored Deschutes Estuary without a set restoration strategy and management plan, as the resultant communities depend largely on actions taken on those fronts.

We recognize the difference in scale between Capitol Lake and the reference estuaries and do not know how a larger estuary like the Deschutes, with a much larger freshwater input than the reference estuaries, truly compares with the estuaries fed by smaller creeks that we studied. However, the dependence of estuarine communities on salinity, sediment type, and elevation are clearly established through existing literature (see sections on Salinity, Sediment, and Elevation in Chapter 1: Introduction). The results of the USGS DELFT 3D model and our reference estuary study provide us with predictive information on these physical factors for a restored Deschutes Estuary. Therefore, with the noted uncertainties above, we feel our predictions are valid, despite the scale differences between Capitol Lake and our reference estuaries.

However well-planned and managed, urban restoration projects will be influenced by ongoing challenges from anthropogenic disturbances. This may produce unexpected responses. Anthropogenic impacts and other uncertainties associated with predicting communities in a restored Deschutes Estuary can affect community outcomes in several manners. These risks depend largely upon the planning, community involvement, and adaptive management foundations for this project. The urban locale of the restoration and the already extensive development of the watershed and shorelines of Capitol Lake exacerbate the risks associated with the restoration project. With adaptive management activities incorporating local stakeholders and providing a restoration strategy based on the findings of this study and the USGS model study, risks associated with these factors can be limited. It is important to recall that estuarine systems are distinct and highly variable (Paerl 2006); this complexity complicates all predictions of restoration outcomes.

Steps for Success - Active Management

The unknown outcomes for a restored Deschutes Estuary, including land use and water management, climate change, recruitment of native species, limiting nuisance and invasive species, and other human disturbances can be more readily identified and managed through active management of the project. Active management plans can aid in reaching the goals of ecosystem restoration (Dawe *et al.* 2000; Simenstad *et al.* 2005). However, active management includes several steps as part of the restoration activity, some of which come prior to restoration activities. These steps roughly build upon Thom's recommendations for adaptive management (1997; 2000). We have highlighted and outlined the steps below; see Thom 1997 and Thom 2000 for detailed outlines of developing adaptive management planning steps.

- Involve appropriate agencies, governmental regulators, and stakeholders. Agencies and government regulators are critical for passing appropriate regulatory statues and often necessary for financial support. Also, agencies and governments can supply scientists, planners, and data to assist in the subsequent steps. The involvement of stakeholders can assist in creating a better-informed public regarding the functions of estuarine ecosystems (Huppert *et al.* 2003). Stakeholder involvement can also provide volunteer monitoring assistance. Project leads should strive to keep these groups working together, as most projects with agency, government, and stakeholder support persist and are able to garner long term support (e.g., Gog-Le-Hi-Te and Duwamish River restorations) for the project. Also, project managers should work to develop a decision framework (Thom 2000) for working towards restoration success with these groups that facilitates following the management plan (see below).
- Using the network of support built from local groups, set goals for the restoration site. Goal-setting is a foundation for the next steps in the restoration process, as it forms a basis for the decisions that follow.
- Conduct a feasibility study by assessing reference sites and proposed restoration site(s) and analyzing costs. Comprehending the factors, both controlling and disturbing, that underlie the desired system is recommended by Thom *et al*. (Thom *et al.* 2005a; Thom *et al.* 2005b) as an element of successful net ecosystem improvement. Assessing the cost of such a project up-front allows stakeholders and agencies the chance to prepare for and fund large-cost projects, or may garner increased support for lower-cost projects.
- Choose a restoration design to achieve the goals previously set. Design the project with a scientific understanding of the physical processes and disturbances that control the estuary of interest (Thom *et al.* 2005a; Thom *et al.* 2005b).
- Determine areas of uncertainty in reaching the restoration goals and develop management actions to counteract these forces. We suggest that processes that create, maintain, or disturb estuarine communities and function should be factors in the management plan, rather than managing for specific features of the restored site. Work with the established cooperative group to consolidate these management actions into an integrated plan to avoid working cross purpose. Also, we recommend that the project team set thresholds for action for likely disturbances such as invasive plant species, to more easily facilitate their control.
- Apply restoration activities, with regular contact between field crews, engineers, and project owner staff members. Communication between these groups was cited as

important in the Squally Beach restoration, Commencement Bay, WA (Wagoner and Steger 2001). With a set decision framework, unexpected results of the activities can be readily addressed on-site, and with involved groups, if necessary.

- Develop a monitoring plan for the site. The plan should include monitoring the restoration site, shortly after implementation and over the long-term. Given the uncertainties with restoration activities, especially in urban systems, monitoring is critical to success of the project. Monitoring biological communities and/or ecosystem function has often been cited as a method to ensure success of restoration (Thom 1997; Thom 2000; Hood and Hinton 2003; Simenstad *et al.* 2005; Thom *et al.* 2005a; Thom *et al.* 2005b). Monitoring is also an important component of active management (Thom 1997 and 2000), as results from the monitoring can be used to assess whether or not project goals are met and if management action needs to be taken. See Thom and Thomas' guide to developing a monitoring program for estuarine restoration (1996) for an example of a monitoring plan.

Future Work

While this study met its original goals of predicting restoration outcomes for the Deschutes Estuary, it also supplied insight into future opportunities for further investigation for this type of project. For example, identifying benthic organisms from reference estuaries could further define community composition in those estuaries and in a restored Deschutes Estuary. Understanding benthic organisms could complete the expected community composition portion of this study, and "paint" a better picture of what a restored estuary will look like in the Deschutes basin. Invertebrates are key fish and bird prey, and knowing we would be supporting these fauna, especially endangered and culturally-important salmonids, could garner more public support for the project.

Collecting more samples, especially throughout tidal cycles and seasons will also assist in developing predictions of community outcomes. Higher sample sizes during the late summer season could also reduce the uncertainty in multivariate modeling of these communities. Also, since silt and silty loam are substrate types that exist in Capitol Lake, revisiting the reference estuaries to sample those areas more heavily may be prudent. Sampling of specific sediment textures was not focused on because specific textures of sediment are unknown until laboratory work is completed. Also, it would help to have a model that could predict changes in elevation post dam removal and throughout the next few years. At the Gog-Le-Hi-Te restoration site (Simenstad and Thom 1996), constructed channels exhibited a high amount of sediment accretion within the first seven years post-restoration. We predict the community outcomes of a restored Deschutes Estuary based on elevations established with current bathymetry that was assumed to not change with time, but sediment erosion and accretion will likely occur. This will dictate the elevation of the expected communities, an important part of the community structure in estuaries.

Summary

In this study, we use reference estuary conditions and modeled site conditions to predict that a restored Deschutes Estuary, under nearly any of the suggested scenarios, will result in an estuarine setting with high marsh around the periphery, mud and mixed flats at lower elevations, and sandy channels. The results of our reference estuary sampling show that reference estuary conditions represent the range of physical conditions predicted for Capitol Lake restoration scenarios by the USGS DELFT 3D model. Based on the model results and the reference estuary study, we believe that a restored Deschutes Estuary will look most like the areas of Mud Bay with channels similar to Kennedy Creek. Mud flats will be the dominate community types with a large proportion of mixed sand and mud flats (Figure 25). The deeper channel areas will likely be sandy. Mud Bay has limited mesohaline and polyhaline vegetated high marsh areas around the peripheries, with most of the area middle-range elevations with mud or mixed sand and mud substrates (mud flats). We believe that the restored Deschutes Estuary will also have a low proportion of mesohaline and polyhaline vegetated high marshes. These community types are natural and would likely support native estuarine flora and fauna. Some organisms that could be found in these habitats include low-salinity, silt-tolerant vascular plants such as *Scirpus maritimus, Triglochin maritimum*, and *Carex lyngbyei*. Around these communities, other habitats will likely exist and some blending between these communities will also occur in a restored Deschutes Estuary.

Our predictions are largely based on community compositions described in the literature, as analysis of the reference estuary sampling did not establish set communities upon the physical parameters sampled. Although several uncertainties associated with this prediction exist, we believe our prediction is of value to adaptive management, including restoration planning and monitoring, for a restored Deschutes Estuary.

We discovered that predicting restoration outcomes is complicated, especially in an urban setting. Inherent in the definition of ecological restoration is that enhancement activities will create pre-European conditions and provide a thriving, natural ecosystem (Simenstad *et al.* 2005); Aronson and Le Floc'h 1996). Unfortunately, this is not a likely prospect within the constraints caused by anthropogenic disturbances to estuaries. For example, although several habitat restoration projects have been conducted in the Duwamish River Estuary, a history of contaminated substrates leaves enhanced sites as still potentially dangerous to organisms using the sites (Simenstad *et al.* 2005). Even under the best conditions, urban restorations may come to be enhanced or rehabilitated, but never truly restored (Simenstad *et al.* 2005).

While there are no obvious roadblocks uncovered in this study to recreating the Deschutes Estuary, in all restoration activities, ongoing and acute ecological disturbances should be considered before undertaking any restoration project. This is especially important in urban settings, where stressors can be varied and work in a cumulative manner. In the Capitol Lake estuary, excess nutrients, altered hydrologic cycle, urban land use, and invasive species will certainly affect restoration initiatives for this water body. With adaptive management and considerations for the urban setting, nuisance and invasive species and climate change, the removal of the 5th Street dam and restoration of natural flow to Capitol Lake would very likely result in the reestablishment of estuarine communities.

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Footnotes

[1] Appendix I Unit Conversion Table provides conversion factor between metric and U.S. Customary units.

[2] Macrotidal estuaries are those that have a tidal exchange greater than 4m.

[3] Sometimes invasive species can be native species with populations that become unchecked in disturbed communities. For example, Reed Canarygrass (*Phalaris arundinacea*) is generally thought be native to many parts of the U.S.; it has developed the ability to become invasive in some areas.

[4] A comprehensive annotated bibliography was also produced as part of this project: it is available as a separate document.

[5] This project reports elevations referenced to several different vertical datums (e.g., MLLW, NGVD, NAVD, etc.). Generally, we used NGVD29 in this report because the data supplied by USGS were referenced to this vertical datum plane. Elevations can be converted from one reference system to another. Please see http://www.nwd-wc.usace.army.mil/nws/hh/tides/ for more information.

[6] See footnote 5

[7] See footnote 5

[8] This step was necessary because many transformations cannot be calculated for data that have negative values.

[9] A platykurtic distribution is one in which most of the values share about the same frequency of occurrence. As a result, the curve is very flat, or plateau-like.

[10] Grid cells are used by modelers to represent an area of uniform conditions. Grid cells are a way to simplify the model by approximating conditions on a grid cell-by-grid cell basis rather than continuously for every point. See Appendix II.

[11] See footnote 5.

[12] See footnote 5.

[13] See footnote 5.

[14] Redox is a measurement that reflects the balance between oxidation and reduction. Generally, redox values are positive near sediment surfaces where oxygen is present. Negative redox values indicate a reducing environment.

List of Appendices

Appendix I: Conversion Table

Metric to U.S. Customary		
Multiply	**By**	**To Obtain**
millimeters (mm)	0.03937	inches
centimeters (cm)	0.3937	inches
meters (m)	3.281	feet
kilometers (km)	0.6214	statute miles
hectares (ha)	2.471	acres
square meters (m^2)	10.76	square feet
square kilometers (km^2)	0.3861	square miles
liters (l)	0.2642	gallons
cubic meters (m^3)	35.31	cubic feet
cubic meters (m^3)	0.000811	acre-feet
milligrams (mg)	0.00003527	ounces
grams (g)	0.03527	ounces
kilograms (kg)	2.205	pounds
Celsius degrees (^{0}C)	1.8 (^{0}C) + 32	Fahrenheit degrees

U.S. Customary to Metric		
inches (in)	25.4	millimeters
inches (in)	2.54	centimeters
feet (ft)	0.3048	meters
statute miles (mi)	1.609	kilometers
acres (ac)	0.4047	hectares
square feet (ft^2)	0.0929	square meters
square miles (mi^2)	2.59	square kilometers
gallons (gal)	3.785	liters
cubic feet (ft^3)	0.02831	cubic meters
acre-feet	1233	cubic meters
ounces (oz)	28350	milligrams
ounces (oz)	28.35	grams
pounds (lb)	0.4536	kilograms
Fahrenheit degrees (^{0}F)	0.5556 (^{0}F - 32)	Celsius degrees

Appendix II: USGS DELFT 3D Model

The biological and physical results from the Reference Estuary Study are most meaningful when combined with the hydraulic and sediment transport (USGS) model to predict communities associated with restoration activities. Predicting patterns in sediment transport and salinity is critical to the understanding and sustainable management of estuarine resources (Crain *et al*. 2004; Heatwole 2004). Predicting these patterns may also aid in our ability to foresee physical and biological outcomes of restoration activities, e.g., the removal of a tide gate, breaching of a dike, or controlling invasive species.

The hydraulic and sediment transport (DELFT 3D) model is a mathematical and morphological model employed to estimate sediment movement and above bed salinities in a given water body over time, assuming certain scenarios. This type of modeling can be used *in lieu* of costly and time-consuming field studies to predictively map areas of deposition or erosion. The DELFT 3D model combines bed (estuary bottom) level changes with spatial and temporal variations in bed composition (e.g., sand and mud; van Ledden and Wang 2001). Thus, the model presents a method for describing tidal and riverine currents, sediment size, and morphology of an estuary. The following few paragraphs illustrate that this model has been used around the world to describe and predict sediment transport and salinity patterns in tidally influenced ecosystems.

The DELFT 3D model was tested in the Netherlands by van Ledden and Wang (2001) to predict the sedimentation of the Rhine-Meuse estuary after tidal influence to the estuary was strongly reduced for industrial purposes. The results from this application of the model revealed both a sand wave and a mud wave propagating down the main channel of the Rhine-Meuse estuary. The model showed that the sand wave first settled further upstream than the mud wave, but eventually covered the mud layer already on the bed level. These results were verified in the field. The prediction of the mud wave was particularly interesting, as it was not necessarily expected and previously had not been modeled. Thus, the DELFT 3D model was formally introduced as a tool for understanding the morphological changes due to sand and mud movement caused by tidal restriction in estuaries.

The DELFT 3D model has been used since to aid management activities. For example, Lesser *et al.* (2004) used the model to determine whether coastal or riverine processes guide sediment transport in the Columbia River Estuary. Results of the modeling revealed that bed level changes in the upper estuary are mainly dictated by river discharge and floods while deposition and erosion at the estuary mouth are dictated by the relationship between tidal range, wave action, and river discharge. The Columbia River Estuary was found to fluctuate between exporting and importing sand-sized sediment particles.

The DELFT 3D model has also been used to predict salinity patterns. This application, in combination with descriptions of sediment transport, aids in forecasting ecological responses to restoration activities, as salinity has been defined as a gradient for estuarine flora and fauna (Crain, 2004; Heatwole 2004). Bielecka and Kazmierski (2003) reported using the DELFT 3D model to predict salinity of differing layers within the Vistula Lagoon (Russia and Poland). The lagoon, located at the southeast part of the Baltic Sea, is primarily filled and emptied with the tides and saltwater from the sea through a narrow strait. However, because Vistula Lagoon lies both in Russia and Poland, transboundary water quality and water management concerns prompted an investigation of hydrodynamic processes in the Lagoon, specifically relating to salinity. The modeling revealed salinity penetrating most heavily near the mouth of the Lagoon, where velocities are highest. The modeling of salinity in the estuary was accomplished with a relatively small amount of field verification and calibration.

Developing DELFT 3D for Capitol Lake

To develop the DELFT 3D model for Capitol Lake/Deschutes Estuary, USGS scientists compiled existing salinity, sediment, and river discharge data. New bathymetric data were collected during 2004 and 2005 to supplement existing data for the model. USGS chose to run the model for four different restoration scenarios, A – D (Table 1). The specific parameters and assumptions used in the model are outlined in further detail in George *et al.* (George *et al.* 2006) and were highlighted for the Reference Estuary Study to represent low-flow and average flow years. The USGS modeled a fourteen-day spring-neap tidal cycle, which represents conditions that might be observed during the growing season. However, it should be noted that these estimates do not represent the driest or wettest part of the year in Olympia.

The model output can be viewed as a map (computer spatial data set) showing elevation, salinity, and sediment characteristics for each cell of a computer grid representing the 'restored' estuary. This information will be used to develop an understanding of the consequences of each of the restoration scenarios. The USGS model runs on discrete particle sizes, <u>not</u> ranges of particle sizes (i.e., clay represents all fractions in a sample smaller than 2 µm, sand is all fractions between 2 mm – 50 µm) like those produced from the pipette particle size analysis of the reference estuary sediment samples. See the USGS report (George *et al.* 2006) for more details.

Results of the DELFT 3D Model

George *et al.* (2006) reported the following findings based on their model results.

- Variability between restoration scenarios was small for annual mean percent inundation, near-bed salinity, and range of erosion and deposition. There was little to no difference in the wetting and drying behaviors for each of the four restoration scenarios. They concluded that the variables selected to parameterize the model had more of an affect on outcomes than did the restoration scenarios.

- A similar estuary will develop regardless of which restoration scenario is selected.
- The pre-dam condition is more saline (by 3 to 5 ppt) than predicted for each of the restoration scenarios.
- River discharge influences water circulation patterns and salinities.
- The water column in a restored Capitol Lake is expected to range from partially mixed in the Middle Basin to well mixed in the North Basin.
- Capitol Lake is now dominated by silts.
- General erosion and deposition of sediment ranged from 0.5 m to 2.0 m during the three year model run. Erosion was predicted to occur in the main channel and in the South and Middle Basins. Deposition was predicted to occur in the North Basin and Percival Cove.
- In general, the channels were predicted to be sandy and the ‘flanks’ muddy.

Appendix III: Salinity

In Pacific Northwest estuaries, salinity is highly variable in space and time. Salinity values are typically measured in PSU[1] or PPT[2] using several different methods, most commonly with a refractometer or an electronic probe. Values for PPT and PSU are comparable but slightly different because unlike PPT, PSU takes into account temperature. For any given sample, PPT and PSU generally differ by only 0.001 units, which is beyond the precision of most field instruments. Therefore, PSU and PPT are often used interchangeably. Depending on the freshwater inflows and tides, which vary by season, salinity values may range from near 0 to 33 PPT or PSU. For example, based on data provided by Thurston County, in Mud Bay water column salinities ranged from 6 to 32 PPT at a station near some reference estuary sample sites (Figure 22: Comparison of salinities).

Since water column salinity is so variable, large numbers of observations and/ or models are often used to characterize salinity regimes in estuaries. We visited 90 sites in five reference estuaries during a 2005 summer low tide series. We were thus limited in the number and type of observations that we could make at any given sampling location by low tide conditions. Furthermore, the USGS model predicted salinity regimes for different regions within Capitol Lake for each of four restoration scenarios. Those salinity regimes were based on low river flows and on annual averages. Results from either regime would not be comparable to field measurements of water column salinity.

Therefore, with guidance from the CLAMP technical work group, we elected to measure pore water salinity in the field. Pore water salinity is commonly measured in estuary studies because it strongly affects estuarine communities (see Ewing 1983; Crain *et al.* 2004; see Heatwole 2004). Pore water measurements were taken in the field using an electronic probe during low tide from a pit that was at most 50 cm deep for a period of three to five minutes. Unfortunately, about 1/3 of the sites did not have water present on the site during low tide, presumably due to their higher elevation. Therefore, we did not have salinity values for these sites. We found a method used by researchers at Oregon State University (Hacker 2005) whereby pore water salinity values could be measured from sediment samples in the laboratory.

Hacker's protocol is typically used in wetland plant studies where the sediments are too dry to measure salinity in the field. This method is generally performed on wet sediment.

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[1] practical salinity units
[2] parts per thousand

Sediments are then dried so that water content can be measured. Unfortunately, our sediments were too dry to correctly use this protocol. We attempted to extract salt from each sediment sample by adding a known quantity of water and making a measurement with a refractometer. Nevertheless, we felt that these laboratory measured sediment salinities would be related to field measured pore water salinity or at least be used to rank our sample sites. If we were successful, we could use all 90 sample sites in our statistical analysis instead of the 63 sites for which we had pore water salinity measurements.

We used the following protocol. We measured five +/- 0.3 g of sample into a drying tin using our dried sediment samples. Tins with sediment were placed in a drying oven for approximately 24 hours, at a temperature of 124^0 C. Soils were re-weighed after drying and the contents were crushed using mortar and pestle. Contents were then transferred to a 50 ml beaker and 20 ml of distilled water was added. The sample was stirred briefly and set aside. After approximately 30 minutes, two to three drops of water from the sample were placed on the lens of a Vee Gee portable refractometer (model A366ATC) using a pipette and the salinity was determined for each sample. The refractometer was calibrated using distilled water periodically throughout the process. If the salinity value was difficult to determine or seemed out of the norm, the procedure with drops of water on the refractometer was performed a second time. The final portions of the procedure, wetting and refractometer measures, were performed in batches of 10-20 samples to reduce chances for error and to keep settling time close to 30 minutes.

We found that salinities measured using this technique ranged from 2 to 31 units[3]. However, when these values were matched up to field-measured salinity values, we found that they were not correlated. Furthermore, when we compared a list of sites ranked by field and laboratory measured salinity, we found that salinities measured, using the two different methods, gave widely varying results. Therefore, we did not use the laboratory measurements in our analysis.

[3] These values are relative to one another but not to psu or other standard salinity units (e.g., ppt).