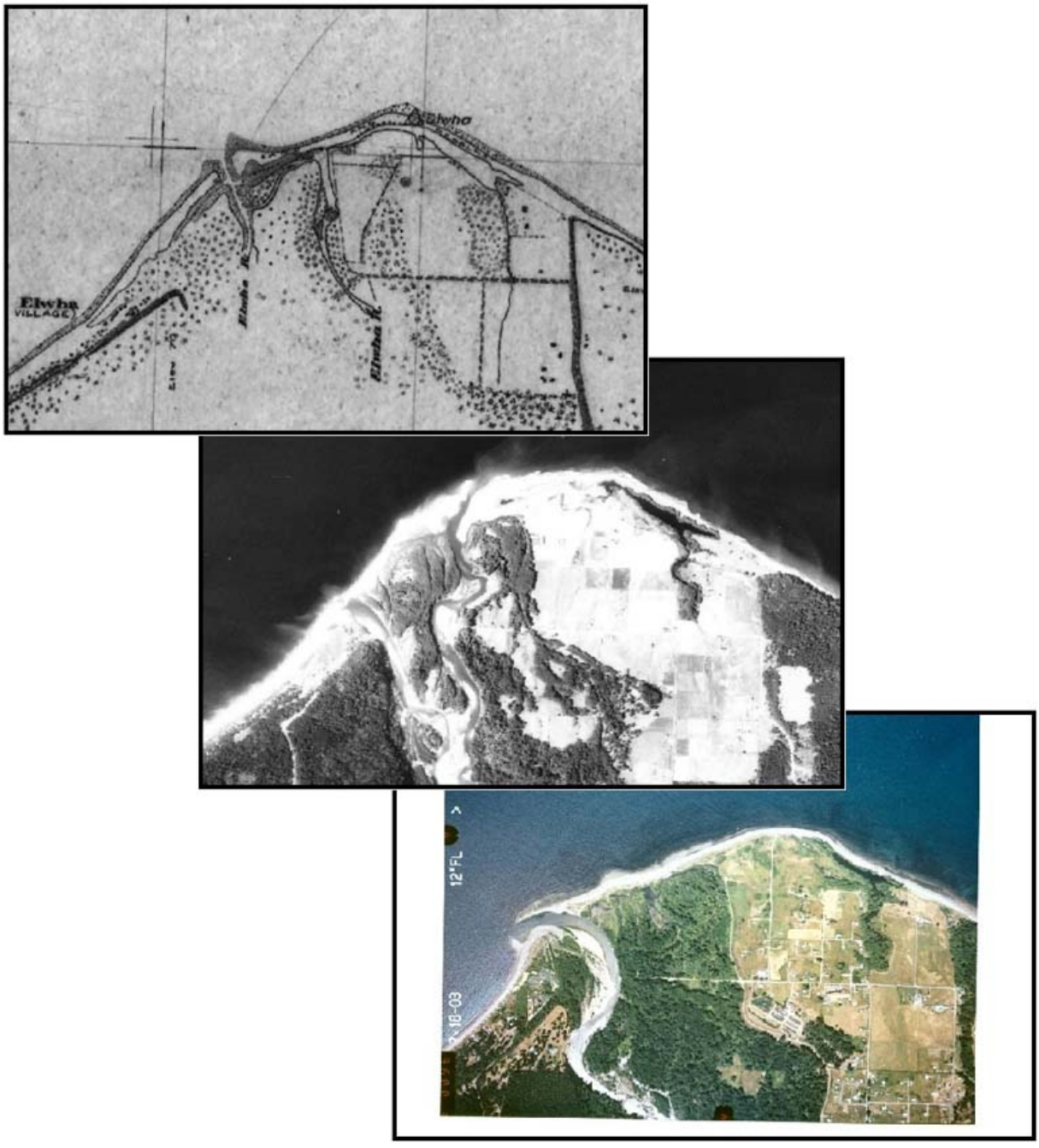
Historical Changes to Estuaries, Spits, and Associated Tidal Wetland Habitats in the Hood Canal and Strait of Juan de Fuca Regions of Washington State



Point No Point Treaty Council **Technical Report 06-1**

PNPTC Technical Report 06-1

Historical Changes to Estuaries, Spits, and Associated Tidal Wetland Habitats in the Hood Canal and Strait of Juan de Fuca Regions of Washington State

Final Report

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ABSTRACT

We used 19th century coastal survey maps and contemporary air photos to assess historical changes in tidal wetland habitats (i.e., marshes, associated channels, and lagoons) associated with stream-delta (defined primarily by fluvial processes) and spit/marsh (defined mainly by longshore sediment processes) habitat complexes in the Strait of Juan de Fuca and Hood Canal regions. We assessed changes in the surface area of tidal wetlands associated with habitat complexes, and in the connectivity of habitats at multiple scales (i.e., local surface water connectivity and landscape scales). We also evaluated how ecological processes responsible for shaping tidal wetland habitats have changed because of human intervention. We provide maps, data summaries, and recommendations to help develop habitat conservation strategies.

We identified 250 habitat complexes (103 stream-deltas and 147 spit/marshes) across the study area, 63 in the Strait, 187 in Hood Canal. The historical size of complexes ranged from < 1 ha to 799 ha (Skokomish River estuary). Changes included an overall decrease in the amount of tidal wetland habitat (marsh, channel, and lagoon) associated with the habitat complexes from 1430 to 1327 ha (7%). Some sub-regions (e.g., Dabob Bay and Central Hood Canal) showed net gains in tidal wetlands, while other sub-regions (e.g., Central Strait, Port Townsend-Oak Bay, Entrance Hood Canal, North Hood Canal) lost considerable tidal wetland habitat. The numbers of spit/marsh complexes that provide surface water connectivity with adjacent waters (i.e., potential accessibility to juvenile salmon) decreased from 77 to 65, and tidal wetland habitat associated with these complexes was reduced from 449 to 351 ha. Therefore, on average, a migrating salmonid would currently encounter a tidally-accessible habitat complex less frequently and the amount of tidal wetland habitat available in these complexes is less today than historically. Also, the overall connectivity of much of the remaining tidal wetland has been impaired since the 19th century.

The most common direct ("footprint") causes of habitat change were attributed to fill associated with transportation infrastructure (including railroads) and residential development. Other important direct causes included urban, industrial, and military-related development, dredging and channelization activities, and diking and revetments. The gains in tidal wetlands observed in some sub-regions were attributed to delta progradation in the larger stream-delta estuaries, where salt marsh now extends seaward of its historic position, the likely combined result of increased sedimentation from watershed land use and river channelization activities. Longshore updrift causes of habitat change were typically less clear because direct causes (e.g., fill) often obscured drift cell-mediated effects on downdrift habitat complexes. To provide an indicator of habitat function, we developed a "Relative Condition" rating for most of the habitat complexes according to surface area changes in tidal wetland and the level of impairment to habitat connectivity within complexes. Overall, 22% of the rated complexes were considered "functional", 30% "moderately impaired", 31% "severely impaired", and 17% "lost". We used the Relative Condition rating to help develop habitat protection and restoration recommendations for individual complexes.

ACKNOWLEDGEMENTS

Many individuals made this project possible. We are particularly grateful to a select few.

Ted Labbe, former Habitat Biologist with the Port Gamble S'Klallam Tribe, initiated this project in 2000-2001 with added support from the Skokomish Tribe and the Hood Canal Salmon Enhancement Group.

Richard Brocksmith, the Habitat Program Director with the Hood Canal Coordinating Council, encouraged the PNPTC to pursue funding through the Washington State Salmon Recovery Funding Board to support the Hood Canal portion of this study. Richard supplied a number of excellent ideas that ultimately benefited the project.

Randy Johnson, a fish and wildlife biologist with the Washington Department of Fish and Wildlife, has been particularly effective at illustrating historical changes in a number of key estuaries in the Hood Canal and Strait regions. In many ways, it was Randy's work that convinced those working in the regions that we needed to further develop the historical nearshore habitat information, as part of formulating salmon habitat conservation strategies in the Strait and Hood Canal.

Brian Collins, Amir Sheikh and colleagues at the UW (Collins group) facilitated the access of archived historical source materials, and with **Jennifer Burke**, helped develop a standard means of geo-referencing the T sheets. The Collins group was instrumental in developing methods for digitizing the T sheets and in the sharing of various ideas in working with historical map and survey source information.

Jeff Shellberg, hydrologist with the Makah Tribe, was generous with his time and showed a sincere interest in the project, particularly in the Western Strait. Jeff provided access to historical air and on-the-ground photographs, and his canoe for a reconnaissance trip in the Hoko River estuary.

Joe Murray, forester with Merrill and Ring, allowed us to access the Pysht River estuary. Joe's own history in the Pysht (about 25 years) was extremely useful in helping us to characterize some of the habitat changes in that estuary.

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Organization of the Report

The main body of the report is in a standard technical document format that includes Introduction, Background, Materials and Methods, Results, Discussion, and Recommendation sections. Appendix A to this report includes data source and sub-regional summary tables, while Appendix B includes specific results and data summaries for sub-regions (e.g., Discovery Bay) and individual habitat complexes (e.g., Salmon/Snow Creek) that occur within these sub-regions. We anticipate that the material found in Appendix B will be particularly valuable for those seeking specific information on the sub-regions and individual habitat complexes.

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INTRODUCTION

In 1999, both Puget Sound Chinook salmon and Hood Canal/Eastern Strait summer chum salmon were listed as "threatened" under the federal Endangered Species Act (ESA) (Federal Register 1999a and 1999b). In response to the listings, assessments of habitat conditions were undertaken to consider potential factors for decline and to help guide salmon recovery planning; e.g., Correa (2002, 2003) and Kuttel (2003). It became apparent in the course of investigating habitat limitations relative to the salmon life histories that little information on the estuarine and nearshore environments was available. This lack of information, coupled with the recognition that, of the Pacific salmon species, Chinook and chum are most dependent on the estuarine environment during the early marine life stage (Healey 1991; Salo 1991), led to the present study.

This study was intitiated to develop a better understanding of the estuarine habitat's status in support of shoreline protection and restoration planning. Our approach was to begin with a historical perspective by evaluating estuarine habitat conditions in the nearshore landscape prior to large-scale alterations of the shoreline that came with the initiation of Euro-American settlement in the 1800s. We thought that in designing measures to protect and restore shoreline estuarine habitats, it would be helpful to know what the estuarine and nearshore landscape "looked like" before major human development, including how specific habitat types were distributed. Also to the extent possible, we wished to identify the physical processes responsible for the shaping of habitats in the nearshore. The existence of detailed historical information, including 19th century maps of the marine shorelines specifying general habitat types, provided the opportunity for making such historical assessments.

Additionally, by comparing historical estuarine and nearshore habitat conditions with current conditions, we could evaluate changes that had occurred over time within specific habitat complexes throughout the study area. Ideally, with this approach, an improved understanding would be had at several levels (region, sub-region and individual habitat complex) of what the historical habitat conditions were, what changes had occurred and why, what habitats were to be protected, and the extent to and means by which some habitats might be restored.

In summary, the purpose of this study is to assess changes, owing to human development since the 1800s, in estuarine and nearshore habitat conditions and related ecosystem processes in Hood Canal and the Strait of Juan de Fuca. This information is meant to inform planning for the protection and restoration of nearshore habitat and the processes that form and maintain these habitats in support of the recovery of ESA listed salmon species.

BACKGROUND

Study Area

The geographical scope of this study extends from the west end of the Strait of Juan de Fuca, east along the Strait, through west Admiralty Inlet, and into Hood Canal, including all of its shorelines all the way to Lynch Cove at the head of Hood Canal (Figure 1). The main focus of the study is the intertidal zone, extending from the low tide line (approximately MLLW) to the upper extent of tidal influence in the estuaries, marshes, and spits along the shore. Particularly with regard to spit shoreforms, we consider modifications along the entire shoreline at the scale of the littoral, or drift cell, due to the importance of sediment sources, transport pathways, and depositional processes in the maintenance of these spits. The estuaries and shorelines of the Hood Canal and Strait of Juan de Fuca were selected as our study area largely because they generally encompass the Hood Canal/Eastern Strait Summer Chum evolutionarily significant unit (ESU) (Federal Register 1999b). Also, the study area includes the western part of the Puget Sound Chinook ESU (Federal Register 1999a), with its western boundary at the Elwha River. We recognize that nearshore habitats west of the Elwha along the Strait may also be important to both chinook and summer chum during the juvenile out-migration to sea phase of their life histories, and therefore were included in the study.

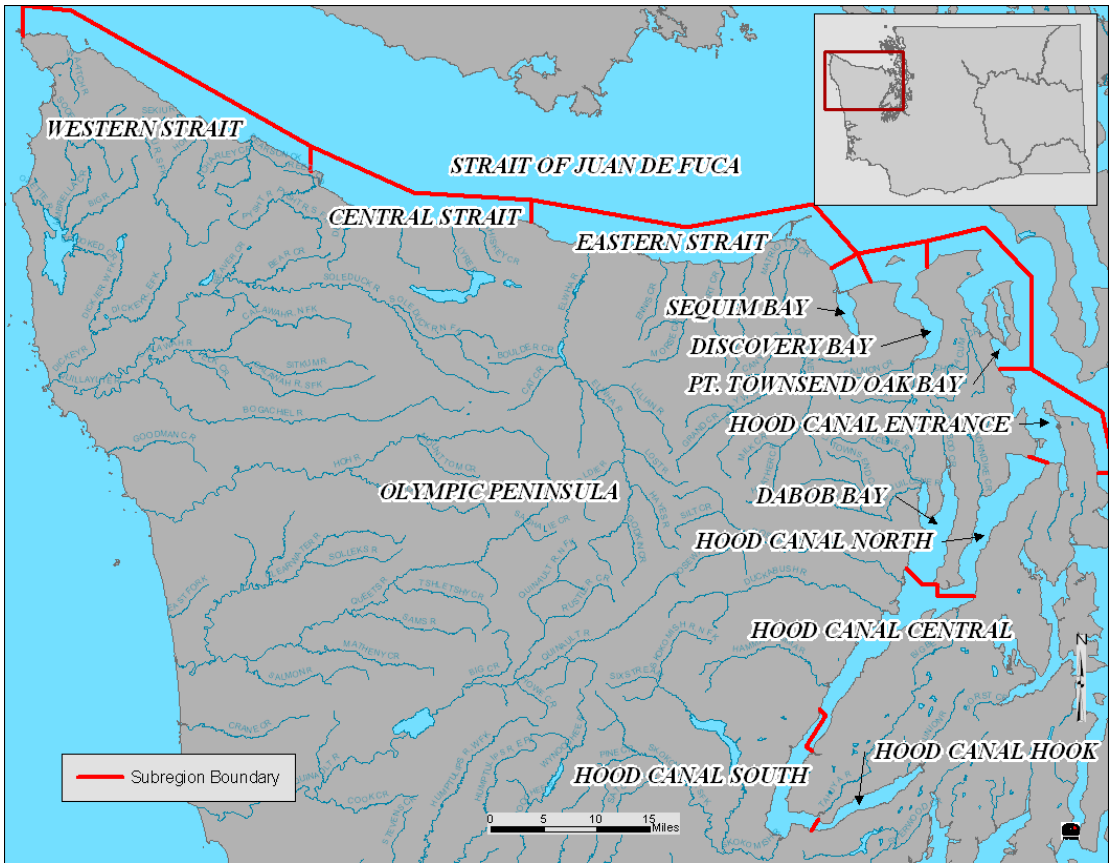

Figure 1. Study area, including sub-regions.

Nearly all of the coastlines in the study area, including the various estuaries and spit features, have been heavily influenced by an alternating series of glacial advances and retreats, the last having left the Puget Sound region about 13,000 years ago (Downing 1983). Following the latest glacial period, the land uplifted in response to alleviation of the weight of the glaciers, and sea level rose due to the increase in volume of water in the oceans owing to a global-scale melting of glaciers. By about 5,000 years ago, both uplift and sea level rise responses slowed and reached their approximate present levels. It was during this past few thousand years that many of the coastal features such as deltas and spits developed the forms we see today (Downing 1983).

There are fundamental differences between the shorelines and nearshore environments in the Strait and Hood Canal. The Strait, with the possible exception of the relatively protected Sequim and Discovery bays, has a strong marine influence compared with the more protected Hood Canal shorelines. Much of the Strait shoreline is exposed to high storm-generated wave action (relative to most areas of Hood Canal) and heavy rainfall characteristically delivers pulses of sediment from drainages to the Strait (Redman et al. 2005). The geology of large stretches of the Strait coastline, mainly west of Freshwater Bay near the Elwha River, is relatively erosion-resistant old marine sediments such as sandstones, whereas the vast majority of eastern Strait and Hood Canal shorelines are composed of glacial material that are typically more susceptible to erosion. These geologic differences translate to generally higher energy beaches with coarse substrates in the western and central Straits compared to the eastern Strait and Hood Canal. Sub-tidal habitats, particularly in the western and central Strait sub-regions, are often dominated by kelp beds (Shaffer 2002), whereas eelgrass beds in the relatively low energy environments of Hood Canal and west Admiralty Inlet often occupy this habitat niche.

Of particular importance to this study, in comparison to Hood Canal, the Strait supports few spit features and other locations of wave-transported sediment deposition. However, a number of "pocket beaches" occur in the western and central Strait (e.g., just east of Neah Bay, Clallam Bay, Crescent Bay), and a number of spits occur in association with larger stream-deltas (e.g., Hoko, Pysht, Clallam rivers, Salt Creek). The two longest spit features in the study area occur in the Eastern Strait sub-region at Ediz Hook near Port Angeles and at the Dungeness Spit.

Hood Canal is a long and narrow fjord with a complex mix of geology, though mainly of glacial origin. Bluffs, low banks, and rocky erosion-resistant shoreforms make up the coastline that is frequently disrupted by rivers and streams that in places have developed broad deltas across the beaches (Redman et al. 2005). Between these estuaries often occur bands of eelgrass that together comprise what are considered important "linkages" or connections between "natal" salmon estuaries and their watersheds and productive rearing habitats along the marine shoreline of Hood Canal (Simenstad 2000).

Estuaries

Estuaries (i.e., semi-enclosed protected inland waters where the mixing of fresh and salt water occurs – to use the definition by Pritchard 1967) are well known as productive environments for salmon (Simenstad et al. 1982). Reference to an estuary can be, in a broad sense, to all of Puget Sound or it can have a narrower focus; for example, applicable to stream-deltas and other protected lagoon and salt marsh areas along the shoreline.

The estuaries or deltas directly associated with watersheds where salmon populations reproduce and progeny spend some time rearing as juveniles (the Dungeness and Skokomish river deltas are examples within the present study area) are important environments for salmon as they transition into less protective, more saline, and perhaps less biologically productive open waters of Hood Canal, the Strait, and eventually the Pacific Ocean. However, emerging research being carried out in many parts of the Puget Sound region suggests that not only these "natal" estuaries, but various tidal marsh systems that are not directly associated with the natal watersheds (e.g., some have termed these "pocket estuaries" – see Beamer et al. 2003) are potentially critical habitats of the estuarine landscape in supporting the early marine life histories of juvenile salmon species (Beamer et al. 2005; Hirschi et al. 2003a; Redman et al. 2005; Bahls 2004). The precise function of these environments and specific habitats for salmon are still being studied, but it is likely that both natal and non-natal estuarine habitats provide protected habitats for the osmoregulatory transition from fresh to salt water, refuge from potential predators, and a rich supply of food (Simenstad et al. 1982; Simenstad and Cordell 2000). This study specifically addresses these natal and non-natal estuaries in Hood Canal and the Strait of Juan de Fuca.

Tidal marshes, a focus of this study, are a significant habitat component of estuaries. However, these marsh systems are only one type of nearshore habitat recognized as important to salmonids. Tidal flats (typically comprised of mud, sand, and/or gravel substrates) are another biologically productive habitat found in estuaries, though this study did not focus on historical changes to these tidal flats. Additional nearshore habitats not included in the study are eelgrass and kelp beds, and rocky shorelines.

Habitat Landscape Perspective

The spatial arrangement of habitats, including the size and shape of habitats, the position of a habitat within a larger landscape context, the composition of adjacent habitat, and the connectivity between habitats are important considerations in describing the nearshore landscape ecology of juvenile salmon (Turner 1989 cited in Beamer et al. 2005). A landscape perspective is helpful when considering salmon in the nearshore for a number of reasons. For one, the creation and maintenance of habitats that salmon depend on are often the result of large-scale processes, such as drift cell and watershed sediment regimes. A second reason is that the physiological and ecological needs of juvenile salmon can change abruptly as the fish move through the nearshore, which likely affects

salmon habitat use. Third, while in the nearshore, juvenile salmon are generally moving from one place to another, and therefore they are not using a specific habitat for long. Another reason for a landscape perspective is that nearshore habitats are inherently dynamic across multiple spatial and temporal scales. Factors such as salinity, temperature, and depth are constantly fluctuating, and channels, for example, might only be accessible at higher tides (Redman et al. 2005). Recent research in the Skagit River delta and surrounding nearshore suggests that the connectivity of estuarine habitats across the landscape affects the abundance of juvenile salmon using these habitats (Beamer et al. 2005). In addition to describing changes in the size and habitat composition of individual estuaries, our study looks at how the connectivity between and within these estuaries has changed since the 1800s.

Related Research

A number of studies have previously examined historical habitat conditions and changes in Puget Sound estuaries (Bortleson et al. 1980; Blomberg et al. 1988; Thom and Hallum 1990; Collins 2005; and Collins and Sheikh 2005). Bortleson et al. (1980) used United States Coast and Geodetic Survey (USCGS) topographic charts ("T sheets") from the 1800s and modern USGS topographic maps to make coarse-scale comparisons in the surface area of tidal wetlands associated with 11 of the larger estuaries in the Puget Sound region, including the Skokomish and Dungeness estuaries of our study area. More recently, Collins and Sheikh (2005) applied a more rigorous methodology in their examination of historical conditions from the middle to late 1800s and habitat changes in the same estuaries that Bortleson et al. (1980) looked at, as well as the numerous smaller tidal marshes throughout the Puget Sound region. By integrating multiple sources, including the historical T sheets and land survey notes and maps, early air photos, soils maps, and other information, in a method of cross-referencing, Collins and Sheikh (2005) improved the reliability of the historical re-construction of habitat conditions. Furthermore, the broader landscape perspective of historical changes taken by Collins and Sheikh (2005) provided a more comprehensive understanding of the pre-development nearshore landscape than had been previously available.

Although Collins and Sheikh (2005) and our study overlap in geographic scope (Collins and Sheikh included the Strait and Hood Canal regions in their study) and our methodologies similarly address reconstruction of historical habitats and their comparison with current day habitats (indeed to increase efficiency and ensure consistency we collaborated on many of the early stages of our respective projects), there are some important distinctions between Collins and Sheikh (2005) and this study. These similarities and differences are addressed in the Discussion section of the report.

A substantial body of information has been gathered in recent years with relevance to watersheds and nearshore salmon habitat in the Strait and Hood Canal regions. A series of "Limiting Factors Analysis" reports, focused on salmon, was conducted by the Washington Conservation Commission (Haring 1999; Smith 2000; Correa 2002 and 2003; and Kuttel 2003), and provides a relatively comprehensive assessment of stream, estuarine, and shoreline habitat conditions for the Strait and Hood Canal areas. Another

significant report is the Summer Chum Salmon Conservation Initiative (WDFW and PNPTT 2000), which was specific to ESA-listed summer chum watersheds and estuaries. Amato (1996) provides an excellent historical perspective (in a narrative fashion) on watershed impacts to salmon (particularly coho) in the Hood Canal region. Among other work that has included the Strait and Hood Canal regions are nearshore and estuarine assessments done by the Puget Sound Action Team (PSAT)/Puget Sound 'Shared Strategy' (see Redman et al. 2005), which targets the recovery of chinook salmon throughout the region. Perhaps the most comprehensive efforts, at least regionally, aimed at building our understanding of salmon use of estuarine and nearshore habitats, including the consideration of historical habitat changes, has occurred in the Skagit River estuary and the surrounding Whidbey Basin areas of Puget Sound (see Beamer et al. 2005) where the focus has been on chinook salmon. In developing our historical study, we intended to complement and build on the existing knowledge.

Native American and Euro-American Uses of the Shoreline

The regions' first human inhabitants, Native Americans, utilized estuaries and stream-delta locations extensively, in large part to take advantage of fishing opportunities afforded by salmon returning to spawn in their natal streams. Both permanent villages and seasonal fishing camps were prevalent at and near the mouths of both Hood Canal and Strait streams. Although the Indians developed elaborate systems for the harvesting of fish at these locations, and village sites were often concentrated at river mouths and along spits, it is thought that physical manipulations to the landscape and shoreline would generally not have significantly impaired hydrology and sediment processes at these locations (Redman et al. 2005).

Euro-American settlement in Hood Canal and the Strait beginning in the mid-late 1800s brought profound alterations to the watersheds and shorelines of the region. Logging and the milling of logs were among the earliest and more defining aspects of early settlement, and several mills became established in the Hood Canal region by the end of the 1850s (Chasan 1981). The trees standing nearest the larger waterways such as big streams and the marine shoreline were often the easiest to access and most efficient to transport once toppled. The larger rivers of the region became conduits for transporting cut logs downriver for awaiting mills or boats. Logjams in rivers were impediments to navigation, log transportation, and dangerous hazards to the settlers attempting to cultivate or graze along streams that would frequently flood. Many of the same locations along the shoreline that were popular and essential to the economies of the Indians became useful in the newly emerging commerce of the Euro-Americans. The lower floodplains and tidal marsh areas became prime locations for agricultural settlement, and in some locations, such as at Seattle and Tacoma, the river delta areas would become major industrial and urban centers. In the 1900s, and particularly after World War II, spit features and other low-lying sediment depositional areas along the shoreline, would become popular locations for developing houses and entire communities, which required the filling of tidal wetlands and alteration of natural drainage patterns and vegetation. Effects of Euro-American developments are the primary focus of this study's assessment of shoreline changes within the last 150 years.

OBJECTIVES

Our study was designed to meet the following specific objectives:

1) To delineate and digitize in a GIS the estuarine, tidal marsh, and spit features present in the early Euro-American settlement period (mid-late 1800s), based primarily on an interpretation of the historical USCS (USCGS) T sheets in Hood Canal and the Strait.
2) To describe the historical (mid-late 1800s) spatial distribution of identified nearshore habitat types within estuarine, tidal marsh and spit features across the Hood Canal and Strait study areas.
3) To delineate from current-day air photos and digitize in a GIS the nearshore habitat types within estuarine, tidal marsh and spit features across the Hood Canal and Strait study area.
4) To describe the major changes that occurred to these habitats through a comparison of historical (i.e., 1800s) map and survey sources with current day (~ 2000-2005) air photos.
5) To consider the potential causes for the changes observed by relating modifications in form (e.g., reduction of tidal marsh and channel features) to changes in fluvial, wave, and tidal processes.
6) Based on the assessment of historical changes (objectives 4 and 5), provide recommendations for habitat protection and restoration.

MATERIALS AND METHODS

As stated generally in the Introduction and reflected in the above listed Objectives, the study approach was to use historical and current information to describe and assess habitat changes in estuaries, spits and associated tidal wetland habitats in the Strait and Hood Canal regions. Historical and current day habitat data were delineated, stored, and analyzed using a geographic information system (GIS). We used an approach and methodologies modeled in large part after that developed by Collins et al. (2003) to re-construct the historical habitat conditions in estuaries and other nearshore habitats.

We began by using 19th century coastal maps to identify stream-delta and spit-marsh habitat complexes throughout the study area; these complexes, as we defined them (see below), provided the focus on estuaries, spits and associated emergent marshes and lagoons at the heart of this study. The historical coastal maps were the primary source for mapping these wetland habitats within the habitat complexes during the middle to late

1800s. We supplemented the historical chart information with General Land Office (GLO) cadastral survey notes and maps, which dated to about the same time period as the historical charts. We also consulted charts from the early 1900s period (~ 1910-1930s), and air photos and USGS maps in many areas for the 1930s to 1970s period where we believed these sources would be particularly useful in our interpretation of historical features and in our assessment of changes during the past 100-150 years. Finally, we used contemporary air photos from the 2000s to map current habitat conditions of the habitat complexes that we compared with the 19th century historical information. Our assessments were first made of the individual habitat complexes; then in a hierarchical fashion, we summarized the information at the sub-regional and regional levels.

Following are detailed descriptions of the materials and methods used in the study. We begin by describing the various sources of information (charts, GLO notes and air photos) and how we used them. Then, after briefly describing the study area sub-regions and how we defined habitat complexes, we discuss how we assessed historical to contemporary habitat changes in the complexes and causes of the habitat changes. For each complex, we also describe our method of assessing current day habitat function relative to historical function using a semi-quantitative "relative condition" rating. Finally, we discuss our approach to ratcheting up the habitat complex results to provide landscape scale assessments.

Historical Information

U.S. Coast Survey Charts ("T sheets")

Surveyors working for the U.S. Coast (and Geodetic) Survey during the latter half of the 19th and early part of the 20th century prepared topographic maps (commonly called "T sheets", the term we will use throughout the rest of this report) that described the intertidal area, tidal marshes, the shoreline and adjacent uplands along coastal areas of the U.S., including Puget Sound, containing Hood Canal and the Strait. The historical T sheets can provide fairly detailed and reasonably accurate characterizations of estuaries, tidal marshes, and spits, though the amount of detail and accuracy varies depending on the geographic region, map scale, the individual surveyor, and other factors (Collins et al. 2003).

Sources of T Sheets: We accessed from the National Archives high-resolution gray scale digital reproductions of the historical T sheets (and accompanying Descriptive Reports where available) from the 1850-1910 period, of the coastline and estuaries for the study area. Because of their parallel study (see Collins and Sheikh 2005) of the entire Puget Sound region, Brian Collins and colleagues at the University of Washington (UW) were essential in helping us obtain the T sheets in a digital format and also in developing the process for georeferencing of the early T sheets (see immediately following sub-section). In exchange, we georeferenced and digitized the T sheets for most of the Strait and Hood Canal areas, which the UW group utilized for their study.

In addition to the early T sheets we also accessed a number of T sheets for parts of our study area for the early 1900s period (approx. 1910-late 1930s). We made photo-reproductions of these T sheets in hardcopy format by visiting the NOAA Library at Sand Point in Seattle, which holds copies of the T sheets on microfilm. We did not attempt to georeference these later T sheets as we did the earlier T sheets (see sub-section immediately below), and instead used them in a descriptive manner in support of our assessment of habitat changes. See Appendix A, Tables 1 and 2, for detailed information on sources of the historical T sheets used for this study.

Georeferencing the T Sheets: We collaborated with the UW in the step involving georeferencing of the T sheets (see Collins and Sheikh 2005 for details describing the georeferencing process). Because the early T sheets were mapped using a datum that is no longer in use, and distortion of the original maps is common with long-term storage of archived hard-copy materials, a process was required to bring the historical maps up to current day standards. Because we were able to access the T sheets in a digital format (as described above), we could easily relate mapped features in a geographic information system (GIS). The first step was to perform a datum shift from the early Puget Sound Datum (PSD) and North American Datum (NAD) to the more contemporary NAD27 and NAD83 references. Datum difference tables in Patton (1999) were consulted to make these datum shifts. An overall datum shift for a given T sheet was calculated by averaging multiple station locations on or near the T sheet. Only station locations that resulted in a residual mean squared error (RMS) less than or equal to 0.003 were used in the datum conversion process. A nearest neighbor resampling method (1 meter) was used in the registration of the T sheets from NAD to NAD27 UTM Zone 10. To check the accuracy of the registration, we compared benchmarks from the T sheets with published benchmarks from the National Geodetic Survey. Only benchmarks that were re-traceable to the original T sheets and had not been relocated (i.e., remounted) since the time of the early T sheets were used for this accuracy assessment. For 1:10,000 scale T sheets, the accuracy was between 2 and 8 meters, and for 1:20,000 scale T sheets, the accuracy is from 6 to 20 meters (Collins and Sheikh 2005).

Identifying Habitat Complexes from T Sheets: The historical T sheets served as the primary source in identifying habitat complexes (see detailed section below on 'Habitat Complexes'). Any distinctive location on the early maps was identified that showed salt marsh or any form of emergent marsh (i.e., salt, brackish, fresh) that was adjacent to the coastline and/or directly associated with a depositional spit or barrier beach, or stream deposits, and likely to be tidally-influenced to some degree. Lagoons or water bodies protected or semi-protected by spit or barrier beach formations were also identified as complexes. We also identified as habitat complexes the locations where low-lying spits or flat depositional features occurred along the coastline where emergent marsh may not have been indicated on the T sheet, but where grassland symbols or protected lagoon or pond features were present. In a few instances we identified habitat complexes from current day air photos (and not the T sheets), where emergent marsh and/or lagoon features occur today. The early T sheets either apparently missed these features or the marsh has formed since the time of the early mapping; these complexes are typically associated with stream-deltas and reflect the accretion of fluvial-deposited sediments.

We also have included a number of additional stream-delta complexes not previously identified by the T sheets that are directly associated with watersheds that are known to support salmon spawning. These stream-deltas are typically small and naturally steep systems that often enter steep beaches where they do not tend to develop large deltaic fans or significant emergent marsh vegetation.

Interpreting Features from the T Sheets: Shalowitz (1964) was consulted for interpreting the symbology found on the T sheets, allowing us to attribute mapped features as we digitized them into the GIS (see Appendix A, Table 3, for a list of the features we mapped). The features from the T sheets that were of foremost importance for purposes of this study were the boundaries and characteristics of tidal marsh (which we took as any emergent marsh that was likely to be tidally-influenced to some degree, including salt and fresh marsh, for example those immediately adjacent to spits or berms), channel and spit features, and the lines or symbols indicating the high and low tide lines (Figure 2). We were also interested in capturing what we termed "lagoon" features (that were likely to be tidally-influenced to some degree) which we considered as enclosed (i.e., ponds or salt pannes) or semi-enclosed by spits (Figure 3). For salt marshes, a reasonably high level of accuracy was typically attained by the T sheet surveyors in the mapped location of the seaward (outer) boundary of marsh because to the T sheet surveyors this generally represented the coastline or the high water line. However, the landward (inner) boundary of salt marsh (or other tidal marsh) was sometimes not mapped as accurately largely because it was of less importance to the surveyors, and access was sometimes difficult in these marsh areas (Shalowitz 1964). We found some evidence in our study area (e.g., Thorndyke, Olympic View Creek, Lynch Cove/Union River, and Skokomish River complexes) that gave us reason to think that the landward (inner) boundary of salt marsh was determined inaccurately in some cases, usually, though not always, mapped in a seaward location of the actual boundary. This may have had consequences for our historical surface area estimates of tidal marsh described below, possibly resulting in under-representing the amounts of marsh in some places (e.g., Lynch Cove/Union River, Skokomish River). In addition, a few locations (e.g., Skokomish River) may have already been diked or developed by the time of the first T sheets, and this would have affected our historical estimates of tidal marsh for these locations.

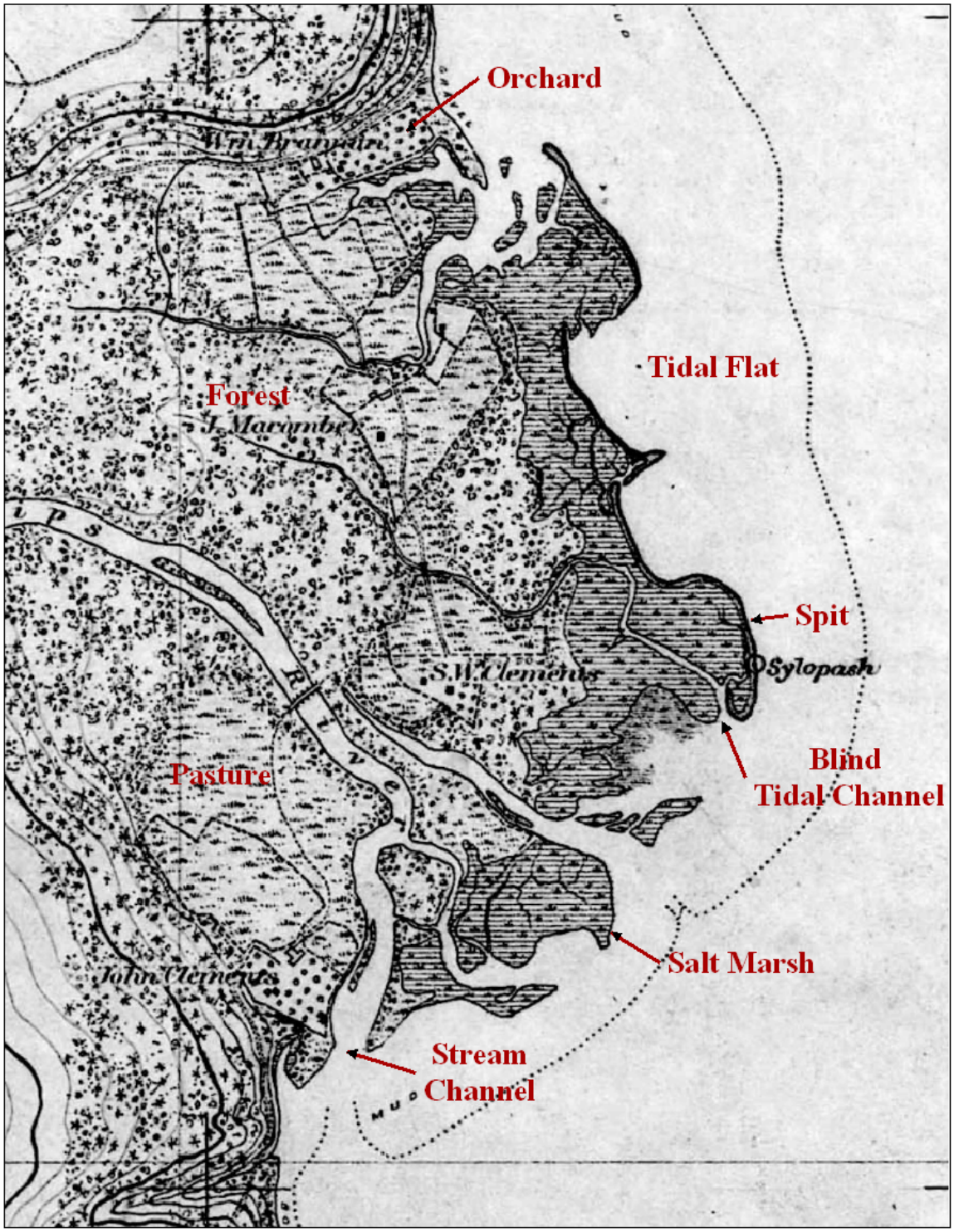

Figure 2. Various features identified from symbology in the early T sheets.

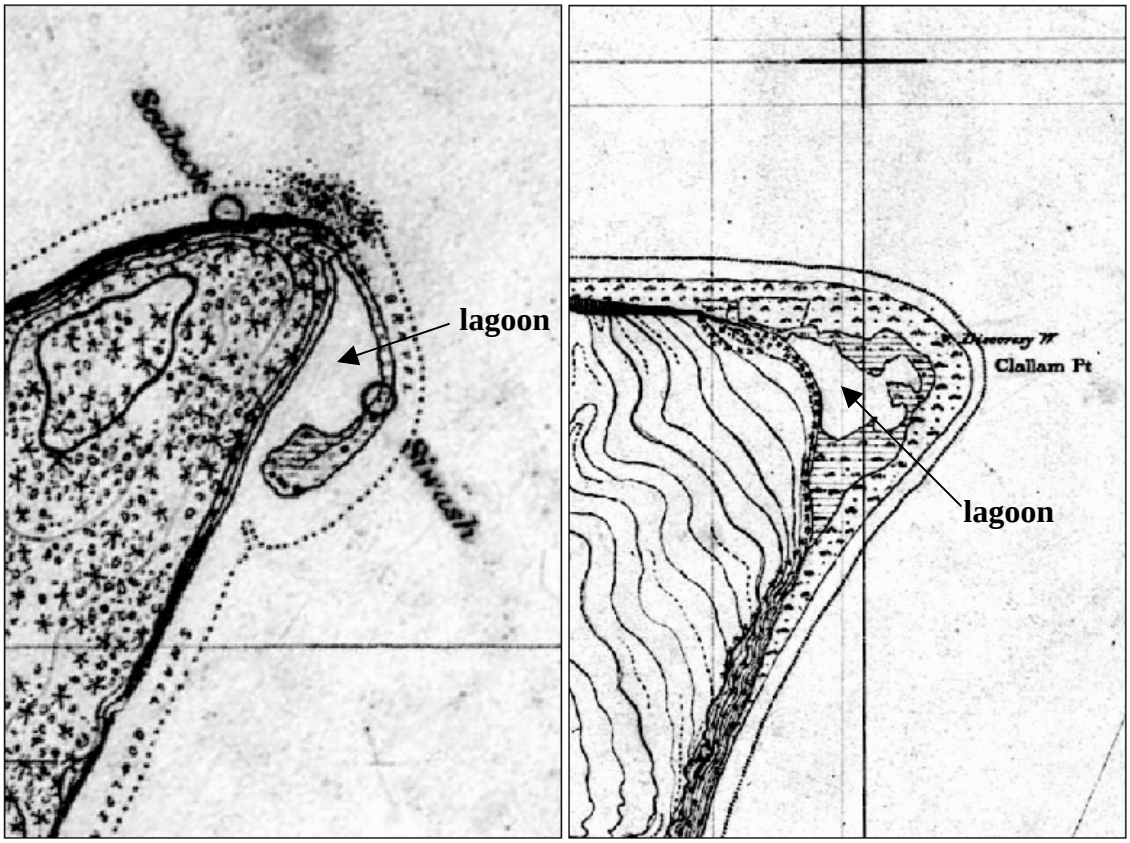

Figure 3. Examples from early T sheets of semi-enclosed (accessible to the tides) and enclosed lagoon habitat features. At left is an example of a semi-enclosed lagoon (Misery Point in the Central Hood Canal sub-region), and, at right, an example of a completely enclosed lagoon (Diamond Point in the Discovery Bay sub-region) that is normally not accessible to the tides (i.e., it does not have surface water connectivity with adjacent nearshore waters). Both of these lagoons were formed in association with the development of a barrier spit.

A distinctive salt marsh type was often indicated on the early T sheets where marsh symbols and continuous horizontal lines (indicative of salt marsh) were placed seaward of the coastline and typically other salt marsh, but no boundary lines were drawn around these marshes. These were considered "submerged marshes" and probably represented marsh in an early stage of development (Shalowitz 1964; Collins and Sheikh 2005). We distinguished these "submerged marsh" patches from other salt marsh or tidal marsh patches, but combined their surface area estimates with the others into total tidal marsh estimates for individual complexes, and in sub-regional and study area totals. We were also interested in delineating tidal channels (including the tidal portion of riverine channels), though we considered channels shown as polygons (with 2 banks) as generally more accurately mapped on the T sheets than channels shown as single lines. We made no comparative estimates of historical and current day channel width or area. Instead, for both historical and current day delineations, we combined the surface area of channel polygons with the associated tidal marsh area when reporting surface area estimates of marshes.

The low tide line drawn on the T sheets [generally the mean lower low water (MLLW)] is not considered a consistently reliable determination as this line was not always surveyed owing to the tide level, and therefore, the line was often interpolated from actual low tide line surveys of nearby locations (Shalowitz 1964). For this reason, we did not use the delineation of this low tide line from the T sheet in making any quantitative comparisons with a current day representation of this line. The hydrographic surveys ("H sheets") that were made at about the same time of the early T sheets would have typically provided more accurate delineations of this low tide line and certainly could be used to make comparisons with the contemporary low tide line (see Jay and Simenstad 1994), though this was not our intent in this study. We did, however, use the MLLW line on the T sheets as an approximation of the low tide line to estimate the historical scale of individual habitat complexes because we wanted to recognize the unvegetated tide flat area (area between high and low tides) as a habitat component within an individual habitat complex (see section below on Habitat Change Analysis).

Digitizing Historical Habitat from T Sheets: Guidelines for digitizing T sheet information into the GIS were developed in coordination with the UW (and are described briefly in Collins and Sheikh 2005). Virtually all features from the T sheets were digitized except topographic lines, because these lines were typically not actually surveyed but rather sketched by eye by the early surveyors (Shalowitz 1964). Lines, points, and polygons were digitized depending on the type of feature digitized (see Appendix A, Table 3), and stored as feature classes in the ArcGIS (v8.3) geodatabase model. All features were digitized at a 1:2,000 scale. When digitizing a line, the center of the line on the T sheet was used during the process. To divide features that were not distinguished by boundary lines on the T sheet, a line was digitized in the area between the two features (e.g., between the end of salt marsh and the beginning forest symbols).

We distinguished four tidal channel types, 1) tidal portion of a mainstem river or stream; 2) distributary channel (secondary to the mainstem river or stream channel); 3) open channel (accessible at both lower and upper ends, but not directly connected with a mainstem river or stream channel such as a distributary channel); and 4) blind channel (accessible only at the lower downstream end).

General Land Office (GLO) Cadastral Surveys

The General Land Office (predecessor of the modern day U.S. Bureau of Land Management) made cadastral surveys of the Kitsap and Olympic peninsula area beginning in the 1850s until the late 1890s. The purpose of the GLO surveys was to provide descriptions of land, vegetation, and hydrologic features (such as streams, rivers, and wetlands) along section lines. They also performed "meander" surveys along the shorelines of navigable portions of rivers and the marine shoreline. The surveyors were mandated to pay particular attention to wetlands because of the 1850 Swamp Lands Act that granted to the states or territories lands determined to be "wet and unfit for cultivation" (White 1991 in Collins and Sheikh 2005). For this reason, they marked where they entered and departed wetlands and included information regarding the depth, frequency of inundation or overflow, and vegetation characteristics of these wetland

features (for more detailed information on the GLO surveys and their use in making historical reconstructions, see Whitney and Decant 2001; Collins et al. 2003; and Collins and Sheikh 2005).

The GLO survey notes and maps were helpful in our assessment of historical conditions because they often preceded the time of the T sheets, and were therefore more likely to have taken place before Euro-American settlement had modified estuaries and shorelines. The GLO surveys also covered inland areas near the shoreline that were not captured particularly well, if at all, by the T sheets. Most importantly, they provided us with a means to cross-reference the information found in the T sheets. For example, the vegetation descriptions provided by the GLO survey in a particular estuary sometimes gave us reason to think that the T sheet delineation of the landward edge of salt marsh may not have been spatially accurate, or that a tidal channel connection occurred at a location that is not particularly clear from interpreting the T sheet. We did not find that the GLO survey notes (or maps) were universally beneficial to our study. Because only section lines and meander surveys along the shorelines were made, the surveyors did not address vast areas in between the section lines. Consequently, many of the small and moderate-sized habitat complexes were missed by the GLO surveys, or the information offered was extremely limited and not particularly useful to us. The GLO surveys were typically most valuable in the larger complexes where there was greater likelihood of multiple section line crossings and intersections and where river channels were meandered. Also, the GLO surveyors were less likely to miss features in these larger complexes simply because the features themselves (e.g., channels, salt marshes) tend to be larger. Consistent with observations reported by Collins and Sheikh (2005), we found that the meander survey notes were often inconsistent in the level of detail, and they provided little to no information along vast stretches of the marine shoreline in our study area. Perhaps one of the strengths of the GLO meander surveys is that they do offer a more comprehensive inventory than that captured by the T sheets of the presence (and width) of streams where they enter the shoreline.

Source of General Land Office Survey Notes/Maps: Most of the GLO survey notes and accompanying map information for our study area was obtained from the Suzzallo Library at the University of Washington where copies are stored on microfiche. However, for much of the Hood Canal area, we used microfiche copies of the GLO survey notes and maps available at the Point No Point Treaty Council (see Appendix A, Table 4).

Digitizing General Land Office Survey Notes Information: We digitized GLO note information from the meander surveys into a GIS with the aid of a tool from ArcView 3.x that allows the creation of point data by including distance and azimuth information taken from the survey notes, and typing in these values in a "drop-down" menu interface. For section line surveys, we used the distance from a given section line intersection that was noted in the survey notes and used the GIS measure tool to locate where a particular feature (i.e., stream, wetland, vegetation type, etc.) occurred along the section line. This gave us a reasonably accurate means of spatially locating GLO survey data and allowed

us to then overlay this information with T sheet and contemporary habitat delineations for further analysis of historical conditions.

For purposes of this study we were interested in general descriptions of vegetation and hydrology (i.e., locations and widths of channels, wetlands, etc.) generally within a distance of a section line (about 1 mile) of Hood Canal and Strait of Juan de Fuca shorelines. We often deviated from this and did not seek GLO information as far inland as one mile if we felt it would not add anything significant to our study; and we also would include areas more than one mile inland mainly where rivers receive considerable upstream tidal influence, a fairly rare occurrence in our study area. Where we identified what appeared to be an obvious disagreement between information found in the T sheets and that described or mapped in the GLO surveys, we made an effort to determine the source of the disagreement. For example, if the GLO survey notes indicated salt marsh in an area that was clearly mapped as upland forest in the T sheet (and the GLO and T sheet surveys were made at about the same time) we were faced with a decision about which of the historical sources was likely the more reliable, and we noted the discrepancy in a narrative of the individual habitat complex (see Appendix B for sub-regional summaries and individual complex narratives).

Early Aerial Photos

Air photos from the period of the late 1930s to about the 1960s were used in a qualitative manner to support the earlier historical information derived from the T sheets and GLO surveys. They also often provided us with an intermediate time-step (or "snapshot") of habitat conditions, that is between the 1800s and the more current period (2000-present). This was often critical to our assessment as it allowed us to examine conditions after initial alterations had been made (perhaps beginning in the late 1800s/early 1900s) but prior to human development in the last several decades (e.g., since about 1960). For example, it is evident that many of the habitat complexes in our study area remained relatively free of direct human modification until well after the 1940s and into the 1960s.

Many of the historical aerial photographs were accessed from the Map Library at Suzzallo Library at the University of Washington in Seattle (a complete list of air photos we used, including source and scale information, is found in Appendix A, Table 5). These aerial photographs were scanned digitally at 200 dpi and used to help qualitatively describe historical changes to the habitat complexes through time.

A series of early air photos from the late 1930s of many parts of our study area had been previously georeferenced by the UW and were available through the Puget Sound River History (PSRH) website (see http://riverhistory.ess.washington.edu/ for information on georeferencing of historical photos). Having historical air photos geo-referenced provided the advantage of being able to overlay historical (i.e., 1800s) and contemporary (i.e., 2000 or more recent) habitat delineations and qualitatively evaluate conditions at an intermediate time period (1930s).

Contemporary Information

Contemporary Aerial Photo Sources and Georeferencing

In developing the current day habitat delineation for the habitat complexes, we used air photos from the late 1990s and 2000s, depending on availability for a particular area (see Appendix A, Table 5, for a complete list of air photo sources used). We attempted to use photo sources that were of comparable scale and/or resolution (when in digital format) such that delineations of different stream-deltas, for example, would be comparable, in terms of the ability to identify features consistently. The most commonly used photo source was the Washington Dept. of Natural Resources (WDNR) 2000 black and white orthophoto series that exists for the Kitsap and Olympic peninsula area. We also used a set of color orthophotos that exist for the Kitsap County shorelines from 2001, and 1999 color orthophotos for the south shore of the "Hook" portion of Hood Canal.

We geo-referenced hard-copy air photos in some areas where we wanted to make use of more recent color photography in interpreting and delineating contemporary habitat conditions. Selected hardcopy color photography from WDNR (2003) were scanned at 200 dpi resolution and georeferenced to Washington State Plane North American Datum of 1983 Feet using the Georeferencing Tool in ArcGIS v8.3. Similarly, we georeferenced more recent (2004-05) color air photos in a few locations where these images were available.

Digitizing Contemporary Habitat from Aerial Photos

The current day habitat features were digitized by interpreting features from existing orthophotos (e.g., WDNR 2000 black and white series) or geo-referenced air photos, and in the same manner as that for the historical T sheets, represented as polygons, lines, and points captured as feature classes in the ESRI ArcGIS (version 8.3) geodatabase model. Lines (to represent habitat boundaries or streams or roads) were digitized at 1:2,000 scale, except when current day air photos were of a particularly fine resolution (<= 1 meter pixel size), in which case feature boundaries were digitized at a 1:1,000 scale. The minimum mapping unit for all linework was 5 ft (~1.5 m), and the minimum mapping unit for all polygons was 10 ft (~3 m) or 625 sq ft in area. A smaller minimum mapping unit was used for those features digitized from the finer scale imagery (e.g., Dosewallips estuary). The digitizing extent was similar to that of the historical extent; however, in some cases an "outer extent" line was created to accommodate the extent of historical mapped features for analysis. No "outer extent" boundary line was digitized if historical mapped features extended beyond the current day shoreline boundary. The 2000-2002 WDOE oblique color air photos (http://apps.ecy.wa.gov/shorephotos/), because of their general high quality and resolution, were used extensively to support the contemporary habitat interpretation in all areas.

We did not attempt to delineate high and low tide lines from air photos except to the extent that we could demarcate an upper extent of estuarine emergent marsh or other wetland within habitat complexes. Otherwise we adopted the WDNR ShoreZone

(WDNR, Nearshore Habitat Program 2001) line that approximates the mean high water line (MHW), and the NOAA (NOAA 2001) mean lower low water (MLLW) for most of the study area. However, we made no attempt to estimate the area of current day tide flat or intertidal beach habitat (for purposes of making comparisons with historical tide flat habitat), primarily because we had little confidence in knowing how comparable the use of the low tide line would be between the historical T sheet surveys and modern day estimates. A more accurate historical estimate of a low tide line (~ MLLW) would likely be derived from early hydrographic surveys ("H sheets") also conducted by the US Coast and Geodetic Survey. However, we obtained but few of the early hydrographic surveys for our study area, and did not pursue estimates of the MLLW for those few hydrographic charts.

Field Reconnaissance and the use of global positioning system (GPS) technology, and on-the-ground photographs were used in the process of current day delineation of habitat features. We prioritized visitations to areas that had features that were difficult to distinguish from aerial photos. Our GPS data combined with on-the-ground photos were used in relatively few instances to help interpret current day features for the digitizing process. In addition to using vertical and oblique air photos, and field checks, in a few key instances (e.g., Skokomish River, Point No Point Marsh, Graysmarsh/Gierin Creek) we consulted the National Wetland Inventory (USFWS, NWI) maps as guidance in the interpretation of wetland or upland vegetation types. These maps were "downloaded" in a georeferenced GIS format for our area from the NWI website, which allowed us to overlay them on contemporary orthophotos or georeferenced air photos. However, we found the NWI maps to be inaccurate or dated in a number of locations (e.g., old dikes areas of the Skokomish estuary that have since breached and reverted to salt marsh again). In only a couple of cases we also consulted high-resolution LiDAR-based topography data available through the Puget Sound LiDAR Consortium to help us interpret elevation and determine whether an area would likely be subject to tidal influence.

We attempted to interpret habitat types in a manner comparable to what the early T sheet surveyors would have interpreted from the landscape. However, following our current habitat delineation, it was realized that we likely interpreted estuarine emergent marsh more generously than the T sheet surveyors in some instances. This appears mainly in cases where upper elevation tidal marsh bounds or transitions into an upland grassland or scrub-shrub vegetation type (see Discussion section below). We did not have a consistent way of correcting for this bias (or alternatively, a T sheet surveyor bias), and chose instead to acknowledge in which complexes this was likely to exist. Overall, this bias might serve to over-estimate in parts of our study area the amount of tidal marsh present today compared with the historical estimates. Seen another way, it could be said that the T sheet surveys represent a conservative (or low end) estimate of tidal marsh relative to our current day estimates. Without this consideration, conclusions about habitat changes could be misleading by simply reading the surface area estimates of historical habitat compared with current day habitat that we provided in our change analysis (see Habitat Change Analysis sub-section below).

Study Regions and Sub-regions

We divided the study area into two regions: Strait of Juan de Fuca and Hood Canal. The regions were then further divided into 12 sub-regions (5 in the Strait and 7 in Hood Canal; See Figure 1 and Table 1) for convenience of analysis and presentation, but also to reflect logical geographic separations across the regions. Within each of these sub-regions individual habitat complexes were identified.

Table 1. Sub-region descriptions in the study area.

Region	Sub-region	Description of Extent
Strait of Juan de Fuca	Western Strait	Cape Flattery to Pillar Point
	Central Strait	Pillar Point to Observatory Point
	Eastern Strait	Observatory Pt. to east of Graysmarsh
	Sequim Bay	east of Graysmarsh to Rocky Point
	Discovery Bay	Rocky Pt. to west of McCurdy Pt.
Hood Canal	Port Townsend/Oak Bay	west of McCurdy Pt. to Olele Pt.
	Hood Canal Entrance	Olele Point to Hood Canal Bridge (both shorelines)
	North Hood Canal	Hood Canal Bridge to west of Oak Head (Toandos Pen.) and Olympic View (Kitsap Pen.)
	Dabob Bay	West of Oak Head to south of Turner Creek
	Central Hood Canal	South of Turner Ck. (Olympic Pen.) to north of Ayock Point; Olympic View to north of Dewatto R. (Kitsap Pen.)
	South Hood Canal	North of Ayock Pt. to east of Dalby Ck (Olympic Pen.); north of Dewatto R. to Sister's Point (Kitsap Pen.)
	Hood Canal Hook	East of Dalby Ck. and Sister's Point to Lynch Cove (Union River)

Habitat Complexes

The focus of our study is to examine historical changes to estuaries, including tidal marshes, lagoons and other nearshore wetlands commonly associated with depositional forms such as stream-deltas and spits. We did not examine quantitative changes to tidal flats (often mud, sand, and/or gravel substrate) associated with these estuaries. Healey (1982), Simenstad et al. (1982), Beamer et al. (2003), and many others have shown that habitats forming in association with estuaries and other tidal marshes provide important functions for juvenile salmonids, particularly in the early marine phase immediately following emigration from their natal river or stream system.

Similar to Collins and Sheikh (2005), we use the term "habitat complex" to describe an assemblage of multiple habitat types that are closely linked in geomorphology and hydrology, with the habitat features tending to show strong interdependence. However, where Collins and Sheikh (2005) identified about 20 different types of tidal marsh habitat complexes in the Puget Sound region, we have combined many of these complex types together, and differentiate just two generalized types of habitat complexes, 1) stream-deltas, and 2) spit/marshes. These two categories are based on what we think are two fundamental physical processes responsible for the formation of nearshore salmon habitat in our study area. The major distinction between the stream-delta and the spit/marsh habitat complexes is in the relative influence of fluvial vs. longshore (primarily wave) sediment deposition. The primary physical process involved in forming stream-deltas is fluvial deposition in development of tidal marsh, distributary channels, and deltaic fans. Longshore wave-generated erosion, transport, and deposition of sediments are typically the most important physical processes involved in the building of spit/marsh complexes. Tidal erosion is a third physical process that can play an important role in both stream-delta and spit/marsh complexes, helping to form tidal channels and lagoon features.

An individual habitat complex is quite often the result of interactions between fluvial and longshore processes, and the decision as to whether to identify a complex as a stream-delta or a spit/marsh complex was sometimes difficult, and subject to our professional judgment. For example, we identified Stavis Creek and Big Beef Creek as stream-deltas (and considered their respective bays as part of these complexes), though significant spit formations occur at the mouth of each bay. In these cases, we felt that the development of estuarine habitat features is the result of stream-deposited sediments and freshwater inputs at least as much as the longshore processes that form the spits. Gierin Creek (Graysmarsh), however, was identified as a spit/marsh complex, despite the presence of a small stream entering the marsh and the fact that the Dungeness River channel once drained to this site (albeit thousands of years ago). In this case, significant longshore sediment supplies and the forming of a spit across the marsh were the primary reasons for identifying the complex as a spit/marsh type. We considered a number of criteria (or attributes) in helping determine the complex type (Table 2).

Table 2. Primary attributes used in distinguishing stream-delta and spit/marsh habitat complex types.

Complex Type	Primary Process	Secondary Process(es)	Spit Formation?	Freshwater Input?	Natal to Salmon?
Stream-delta	fluvial	longshore; tidal	Yes (minor)	Significant	Typical
Spit/marsh	longshore (wave)	fluvial; tidal	Yes (major)	Less important	Atypical

Another challenge was the decision as to whether to consider a site a single complex or two or more separate complexes. A number of examples can be found of this situation in our study area, including Washington Harbor/Gibson Spit (considered as one complex), Big Quilcene/Little Quilcene/Donovan Creek (considered as one complex – "Upper Quilcene Bay"), Tarboo Creek and Long Spit (considered as two separate complexes),

and Dungeness Spit, Cline Spit, and Dungeness River (considered as three separate complexes). Though we acknowledge this to be largely a subjective decision, we applied two primary criteria in helping to make these determinations.

1) Tidal marsh habitat contiguity, and
2) Level of interaction between physical processes.

If tidal marsh habitat were historically (or is currently) contiguous, then we would typically consider this area as a single complex, having no justification for dividing the complex across a common tidal marsh. This was the case with the Upper Quilcene Bay complex (includes the Big and Little Quilcene rivers and Donovan Creek), and the Mission Creeks complex (includes both Little and Big Mission creeks). Another criterion applied is the level of interaction between physical processes occurring in an area. We recognize that this level of interaction between physical processes is, in part, a function of the proximity of habitat features to each other, and the scale of these features in relation to the broader landscape processes. If two processes, such as longshore sediment deposition and fluvial sediment deposition, show relatively weak interaction, then we were more inclined to consider the habitat features resulting from these physical processes to be independent and of separate complexes (e.g., Long Spit and Tarboo Creek). If, on the other hand, we believe there is relatively strong interaction between these two processes, and perhaps a third process (e.g., tidal erosion), then we would likely consider the habitat features resulting from these processes to be part of the same complex (e.g., Big Beef Creek). The potential consequences of identifying a single complex versus multiple complexes might be significant in management decisions. However, we want to stress that one should consider a single complex in the context of its broader landscape surroundings. For example, our decision to split Long Spit and Tarboo Creek results in considering these as two separate moderate-sized complexes that are in close proximity to one another; whereas combining them as one would make for a single large complex that is a considerable distance from any other sizeable complexes.

The T sheets served as the primary source in identifying habitat complexes, though a few complexes were identified using modern day air photos where the T sheets were not particularly detailed. We also identified stream-delta complexes in a number of small stream mouths that are directly associated with watersheds where salmon spawning is documented because we wanted to capture these systems as “natal” to salmon.

Stream Delta Complexes

Stream-delta complexes were identified as being locations of substantial freshwater inputs to the marine shoreline and perhaps more important, where relatively significant localized supplies of stream-derived sediments occur, often expressed in the forming of salt marsh and a deltaic fan. The stream-delta complexes in our study area are most often but not always recognized as natal to salmon, in that they comprise the estuary immediately associated with the watershed where salmon reproduce and the young are born. Stream-delta habitat complexes in the study area can vary tremendously in terms of overall spatial scale, configuration, surrounding landscape, relative influence from

fluvial, wave, and tidal processes, and a number of additional factors. Typical habitat types found in stream-delta complexes include tidal flat, salt and other tidal marsh, channels (riverine, distributary, blind), forested wetlands, and sometimes spit features (grassland or sand) occur in association with stream-delta complexes as well. Examples of stream-delta habitat complexes in the study area are Salt Creek, Dalby Creek, the Pysht, Lyre, Dewatto, and Duckabush rivers (Figure 4).

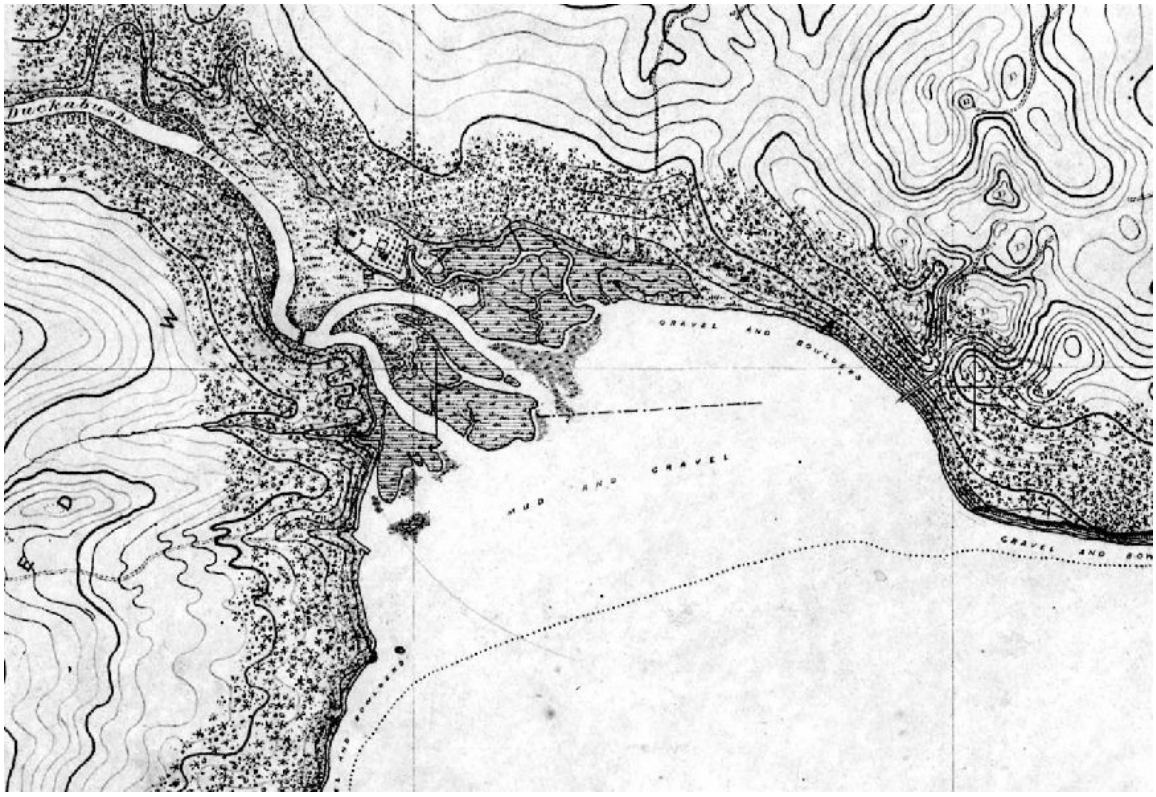

Figure 4. The Duckabush River from the 1883 T sheet (T 1559a) is an example of a stream-delta habitat complex that is clearly dominated by fluvial sediment deposition.

Spit/Marsh Complexes

Spit/marsh complexes were identified where an accretional form is evident, with longshore-derived (primarily wave) sediment deposition being relatively more important than stream-derived sediment deposition. This typically results in the forming of a barrier spit or berm projecting from or along the shore, and often this spit is associated with emergent salt, brackish, and/or fresh marsh vegetation, tidal channels, and/or lagoon features. Freshwater input to spit/marsh complexes is common, either through surface channels or groundwater seepage. Other forms that we identified as spit/marsh complexes, occur at localized topographic depressions (typically glacially scoured), as often seen in the marshes occurring landward of a barrier spit that generally conforms with the adjacent open beach shoreline (e.g., Foulweather Lagoon). Typical habitat features that make up spit/marsh complexes are spits (grassland or sand), salt, fresh, or other marsh, channels, lagoons, forested wetlands, and sometimes tidal flats, particularly

when a freshwater stream contributes sediment and develops sediment deposits across the intertidal zone. Examples of spit/marsh complexes in the study area are Ediz Hook, Point Wilson, Foulweather Lagoon, Kala Point, and Seabeck Spit (Figure 5).

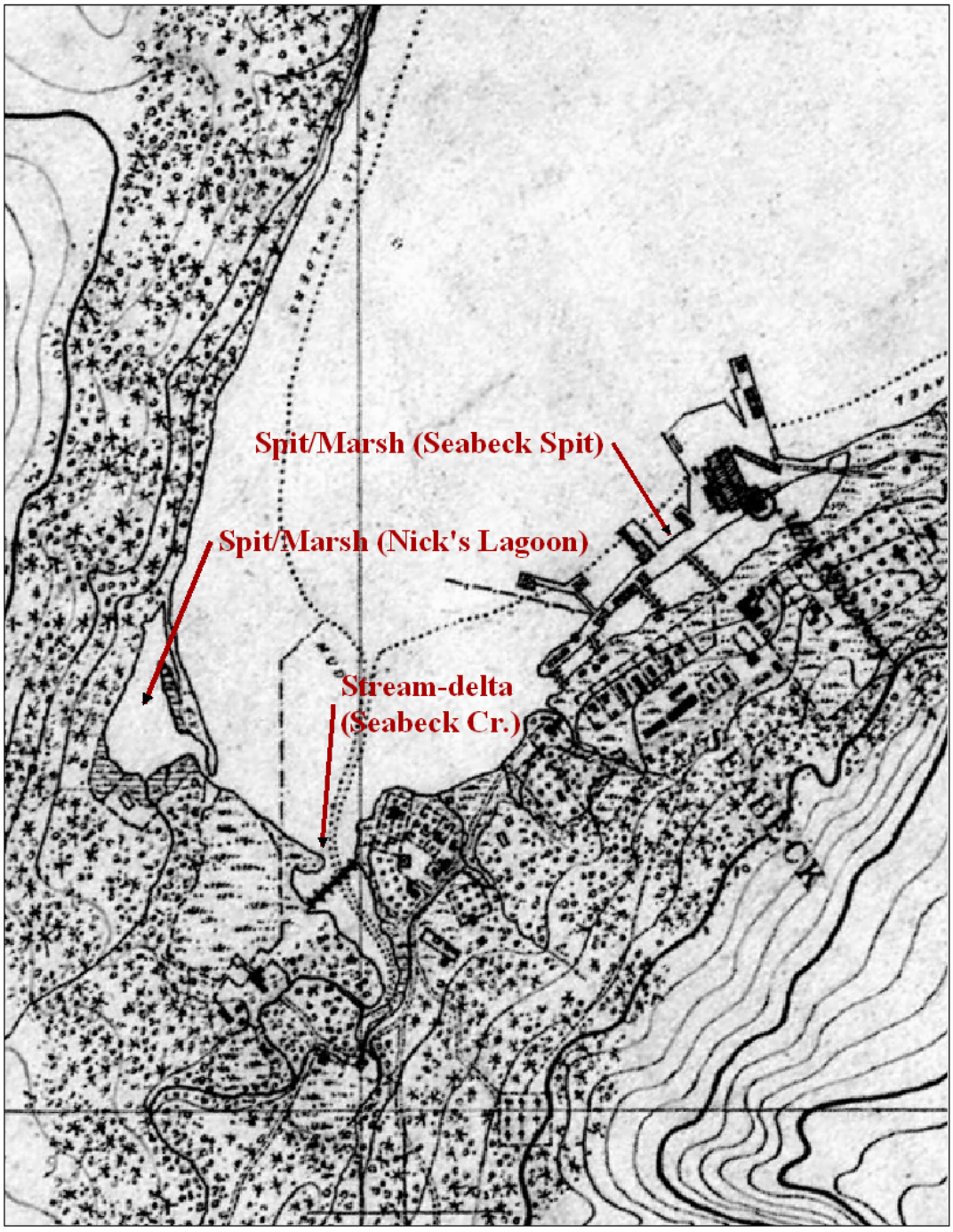

Figure 5. The Seabeck Spit and Nick's Lagoon complexes in the Central Hood Canal sub-region (shown here from the 1884 T sheet [T-1558-1]) are examples of spit/marsh complexes formed primarily from longshore sediment deposition. The Seabeck Creek stream-delta complex occurs between Seabeck Spit and Nick's Lagoon.

The variability among spit/marsh habitat complexes is at least as great as that found among stream-deltas. A factor as fundamental to biological communities as salinity can vary from being at least as saline as adjacent Hood Canal and Strait waters to brackish tidal marshes or primarily fresh marshes that collect streamflow or groundwater seepage. The presence or absence of freshwater can be a critical distinction, as salinity of a spit/marsh complex may determine its relative value to juvenile salmon in terms of providing an osmo-regulatory function transition area during the critical early marine phase of their life history (Simenstad et al. 1982). For each spit/marsh complex identified, we determined which are known to receive freshwater inputs (typically as surface water streams), as opposed to those where we have no documentation or other evidence of freshwater inputs. We realize that groundwater inputs and/or seeps of freshwater may exist in some of these complexes that could certainly affect salinity at the site. However, we currently lack this type of information for most sites and would typically report "unknown" for freshwater inputs in these cases until we have better knowledge of the site.

Spit/marsh habitat complexes can also vary considerably in terms of the degree of surface water connectivity between adjacent salt water and the tidal marsh or lagoon that occurs landward of the spit. Some tidal marshes are capable of maintaining a strong surface water connection (often via a channel feature), while others seem to only rarely make a surface connection with the adjacent salt water, though subterranean exchange of salt water and fresh water may occur through a spit. The degree of surface water connectivity has important implications for salmon by indicating whether a habitat complex was accessible to tides and how a particular complex might serve the needs of juvenile salmonids (Beamer et al 2005). As part of our historical change analysis, we attempted to distinguish which spit/marsh complexes likely had a surface water connection given our historical sources, and which complexes likely did not regularly support surface connectivity. We also described how the degree of surface water connectivity changed over time, and the probable causes for any changes observed. We did not indicate, in any comprehensive manner, the quality of tidal marsh and/or lagoon habitat made available through a surface water connection.

Definition of Tidal Wetlands and Tidal Marshes

The Cowardin system (Cowardin et al. 1979) developed for classifying wetlands identifies four habitat zones that make up many estuaries.

1) Tidal, riverine-forests and wetlands [riverine-tidal (RT)]
2) Emergent, forested-transition scrub shrub [estuarine scrub shrub (ESS)]
3) Estuarine, emergent marshes (EEM)
4) Estuarine (delta) mudflats or tideflats

We incorporated aspects of the Cowardin system in our description of specific habitat types within habitat complexes. The focus of our historical and current day habitat delineations was on zone 3 (EEM), and to a lesser extent on zone 2 (ESS) and zone 4

(estuarine [delta] mudflat or tideflat) wetlands. Because the T sheets typically lacked a good description of the upper estuarine zone 1 (RT), we made no effort to develop a historical re-construction or current day delineation of these upper portions of estuaries. In many of our stream-delta complexes, zones 1 and 2 were naturally limited (compared with other Puget Sound estuaries, e.g., Skagit River) due to the inherent steepness of many of the systems in the Strait and Hood Canal regions.

To be clear, when we refer to "tidal marshes" in our study, we are talking about any emergent marshes that tend to be influenced to some degree by the tides. Usually these are salt and brackish (i.e., diluted by freshwater to some extent) marshes, but they may also include marshes that are typically not connected via surface water with the tides (and may be dominated by fresh marsh vegetation), but may have sub-surface exchange with salt water through spits or berms along the shoreline that have some influence on vegetation characteristics. As mentioned in the above paragraph, however, we made no systematic attempt to delineate riverine tidal (RT) or estuarine scrub-shrub (ESS) wetlands, at least part of which might be considered by some as "tidal marsh". In most respects we consider the tidal marshes as we include them in our study as similar to the estuarine emergent marshes (EEM) as classified by Cowardin et al. (1979).

"Tidal wetlands", for our study, encompass tidal marshes as described above, as well as enclosed and semi-enclosed "lagoons", and the channel features associated with tidal marshes and lagoons. Tidal flats are not included in our definition of "tidal wetlands".

Habitat Connectivity

Connectivity is a term often used in landscape ecology, and when applied in the context of salmon in the nearshore, describes the pathways that fish must travel to access various habitats and the accessibility of habitats at certain tidal elevations (Beamer et al. 2005; Redman et al. 2005). The connectivity of habitats is important to juvenile salmon in the nearshore because the young fish move along a migratory path that requires access to productive feeding areas, protection from predators, and brackish water for osmoregulatory transition (Redman et al. 2005; Beamer et al. 2005). Ease of access to habitats that serve these biological functions likely affects survival in the early marine life stage of salmon.

In addition to assessing changes in the surface area of tidal wetland habitat (see below Habitat Change Analysis), we also evaluated the connectivity of these habitats, and specifically how access to habitats has changed or become altered since the 1800s. We considered three types of connectivity in our study:

1) **Landscape connectivity** describes the distance between individual habitat complexes (see 'Landscape Scale Assessment of Habitat Changes' section below).
2) **Overall complex connectivity** describes the connectivity (or fragmentation) of habitats within an individual complex. We considered the overall connectivity of

individual habitat complexes as a criterion for rating the Relative Condition of a complex (see 'Relative Condition' section below). And,

3) **Surface water connectivity** describes how accessible specific habitats are to the tides (Beamer et al. 2005). We assessed the degree of surface water exchange between channel, marsh, or lagoon habitat associated with individual spit/marsh complexes and their adjacent nearshore waters (see 'Surface Water Connectivity of Spit/Marsh Complexes' section below).

These three scales of connectivity are interrelated in the following ways. The surface water connectivity of a spit/marsh complex influences the overall complex connectivity. For example, if a surface water connection that existed historically has been eliminated by a road and tidegate, then this obviously impairs the overall complex connectivity by disrupting tidal processes and the connectivity between habitats within the spit/marsh complex. This loss of surface water connectivity also affects the broader landscape connectivity (i.e., proximity of habitat complexes to one another) because now the spit/marsh complex is no longer potentially accessible to salmon the way it was historically. Several examples of this exist in the study area (e.g., Beckett Point and Fairmont Marsh in the Discovery Bay sub-region, see Appendix B).

Historical Total Habitat Area Estimates

We used the digitized polygons from the T sheets to provide a historical estimate of the total area of each habitat complex. The overall size of of each complex was obtained by summing the surface area estimates (in hectares) of the intertidal unvegetated area (between mean high water and mean lower low water lines) directly associated with the complex, the salt marsh (or other tidal marsh), and the associated channels, lagoon and spit (vegetated or unvegetated) features digitized from the historical T sheet.

Although generally the representation of the intertidal unvegetated (or tidal flat[2]) area shown in the T sheets was not as reliable as the other habitat features such as spits or marshes (see sub-section above on Interpreting Features from the T Sheets), we believe the tidal flat surface area estimate would provide an adequate historical approximation of that feature. The main purpose of the T sheet delineation of tidal flat surface area was to provide us with a "ballpark" estimate of the historical amount of tidal flat associated with each habitat complex. This area estimate, when combined with the area estimates of the other habitat features, provided a total habitat area estimate for use in describing and comparing the historical habitats within the sub-regions and regions (see below). The lateral boundaries of the tidal flat associated with an individual stream-delta complex were identified where the delta fan ceased to protrude from the shoreline and began to conform to the intertidal corridor along the adjacent open beach shorelines (Figure 6).

[2] "Tidal flat", in our study, generally considers the area between mean high water (MHW) and mean lower low water (MLLW), excluding areas of tidal marsh or protected lagoon. Tidal flat can be comprised of mud, sand, gravel, or coarser substrates.

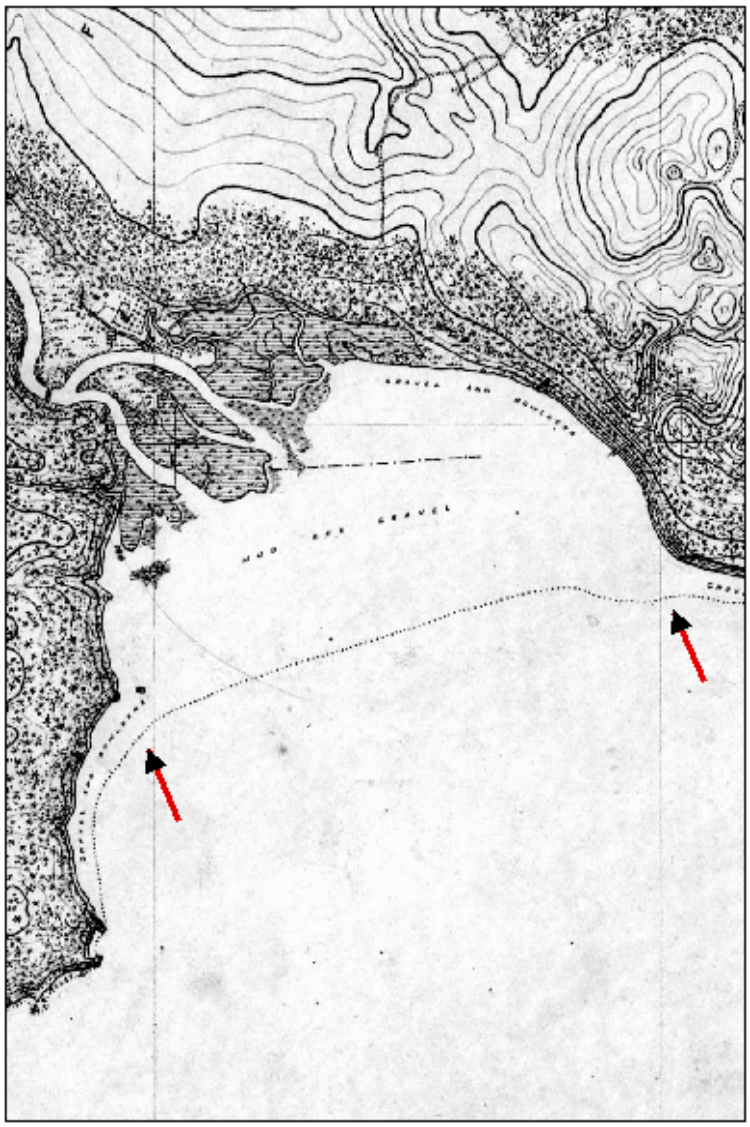

Figure 6. Example of how the lateral boundaries of "tidal flat" were determined for a habitat complex. The red arrows identify where boundaries were drawn perpendicular to the shoreline, indicating the area of tidal flat directly associated with the Duckabush River complex (from 1883 T sheet [T 1559a]). Historical tidal flat estimates were used in combination with estimates of tidal wetland and spit features to provide an estimate of the historical size of habitat complexes (see text).

The T sheet information lacked needed detail to make reliable estimates of the tidal wetland habitat areas (including marshes, associated channels, and lagoons) in the Western, Central, and parts of the Eastern Strait sub-regions. In these instances, we supplemented the T sheet information with estimates derived from current day air photos or other historical sources when these sources were available; for example, GLO notes and Eldridge Morse (in Nesbit 1885) were used for the Pysht River. In using this supplemental information, we felt we successfully estimated most of the historical tidal wetland habitat in the Central and Eastern Strait sub-regions. However, we were not able to make historical estimates for complexes in the Western Strait sub-region.

Habitat Change Analysis

The basic unit of our analysis of habitat changes was the habitat complex, and results of the habitat change analysis at the habitat complex scale were "scaled up" to the sub-regions, regions, and the entire study area.

Habitat Complex Assessment

Our analysis of habitat changes affecting habitat complexes involved both quantitative and qualitative assessments of changes in the amount of habitat available and also in the accessibility and overall connectivity (or fragmentation) of habitat within a complex (see Figure 7 for a diagram that shows the major elements and interrelationships of the habitat changes analysis). We also made a determination as to how changes have taken place (i.e, causative factors) and the ecological processes involved and affected by these changes. Based on quantitative and qualitative changes to habitat associated with individual complexes, we determined the "Relative Condition" of each complex, a rating that indicates current habitat conditions compared with the historical conditions in the complex.

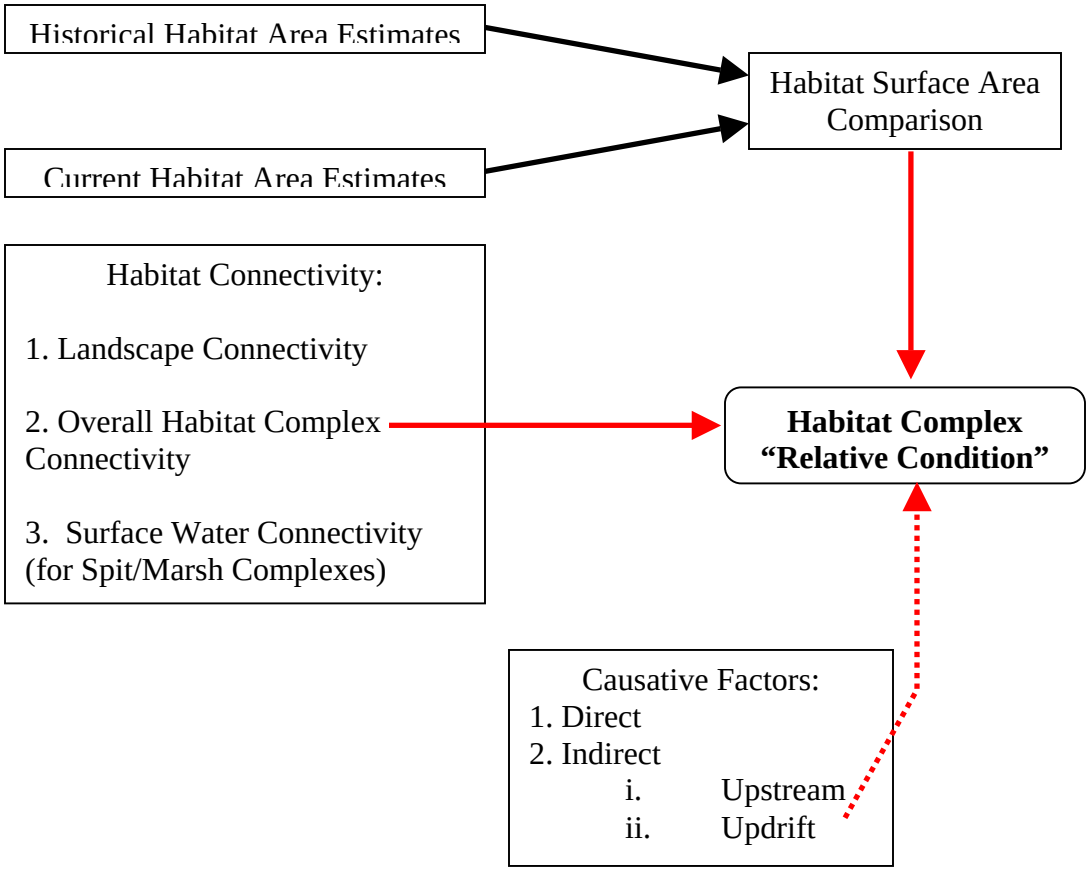

Figure 7. Diagram indicating the major elements and interrelationships of the habitat changes analysis. The dotted red arrow leading from Indirect (both Upstream and Updrift) Causative Factors to the Habitat Complex "Relative Condition", indicates that these causative factors were included in rating the relative condition of complexes. The identification of "indirect" causative factors was typically more subjective than determining the impairment of overall habitat complex connectivity, and making habitat surface area comparisons, which were the main factors considered in rating the relative condition of habitat complexes. See details in text below.

Historical Habitat Areas: The historical habitat area estimates of salt marsh (or other tidal marsh), associated channels, lagoons, and spits (but not the estimates of tidal flats), were used to represent the historical habitat areas for comparison in the habitat change analysis. We used the digitized polygons from the T sheets to make these habitat estimates for each habitat complex.

Contemporary Habitat Areas: Similar to what was done for the historical estimates, we used the digitized polygons from the contemporary air photos to estimate, for each habitat complex, the surface areas of the tidal marsh, and of the associated channels, lagoon and spit features. We did not estimate contemporary tidal flat area because the inaccuracy of

the historical estimate of this feature precluded a reliable historical to contemporary comparison of this habitat feature.

Habitat Surface Area Comparisons: For each individual habitat complex we made a comparison of the surface area (ha) estimates for selected habitat types that were digitized from the T sheet (representing historical conditions) and contemporary air photos (representing current day conditions). Surface area comparisons were made for emergent marsh (i.e., salt, fresh or brackish) and associated tidal channel (including river channel), lagoon and spit features. We also assessed changes in the lengths of spits. Summaries of surface area changes in these habitat types were prepared for each complex.

Surface area comparisons focused on changes in the amount of "tidal wetland" habitat associated with the habitat complexes. We did not include the unvegetated tidal flats (between low and high tide lines) in our description or estimation of contemporary tidal wetland, though we often remarked, using qualitative terms, on the obvious changes or alterations that had affected tidal flats (e.g., dredging and filling that caused conversion to another habitat type) in specific habitat complexes. As previously stated, we made no attempt to compare quantitative changes in the surface area of tidal flat.

Surface Water Connectivity of Spit/Marsh Complexes: In addition to assessing changes in the surface area of various habitat types associated with habitat complexes, we examined how access to habitat has changed or been altered since the 1800s. The accessibility of wetland habitat (marsh, channels, lagoons) from marine waters affects the potential of these habitats to provide direct benefits to juvenile salmon. These benefits, or functions, include the relative protection from predation afforded by spit/marsh systems, a rich food supply, and in cases where freshwater streams or seeps drain to marshes or lagoons, an environment that facilitates the osmoregulatory transition from freshwater to saltwater. Some spit/marsh complexes are accessible on a regular basis, though perhaps only during part of the tidal cycle, and other spit/marsh complexes may have only rarely been accessible at highest tides or in association with storm events (e.g., Point Hudson in the Port Townsend sub-region) and would presumably afford very limited or no direct function for juvenile salmon. We made an assessment of the status of a surface water connection (often via a channel or broad opening through a spit) in all of the spit/marsh complexes in the study area by examining the historical T sheets for evidence of this connectivity and comparing this historical status to its current day status by examining contemporary air photos and/or visiting sites in the field. Although we realize that the degree of surface water connectivity (e.g., depth and width of tidal inlet) between a salt marsh and adjacent nearshore waters can vary from one spit/marsh complex to another and perhaps seasonally within the same complex, we kept our assessment of surface water connectivity simple and considered both the historical and current day status as being either "yes" (i.e., connected), "no" (not connected), or "unknown" (i.e., there was considerable ambiguity in determining whether a regular tidal connection existed or exists today).

Because of the potential for spit/marsh complexes to provide habitat that would facilitate physiological transitions (osmo-regulation) in juvenile salmonids, we also noted, where known (i.e., via a stream, groundwater, or seeps), the presence of freshwater inputs to these complexes. If freshwater inputs are documented (either through the historical T sheet, Wash. Dept. of Natural Resources 1:24,000 scale hydrography layer (WDNR 2005), visibly in air photos, or field verification) we reported "yes" regarding freshwater inputs for that spit/marsh complex. If we could not locate any documentation (through any of the sources mentioned above) of freshwater inputs, we reported "unknown" for freshwater inputs.

Overall Connectivity of Habitat Complexes: Overall habitat complex connectivity describes the extent to which dikes, roads, and other human modifications impair hydrology, tidal exchange, and fragment wetland habitat within a habitat complex. We use overall complex connectivity as a factor in rating the Relative Condition of individual habitat complexes (see Relative Condition section below). Changes in overall connectivity are determined by the extent and position of these roads, dikes, dredging, or other human structures and activities within a habitat complex. This is a subjective decision based on an assessment of likely effect on habitat function. For example, a road placed in the middle or near the mouth of a spit/marsh and affecting access to or function of wetland habitat would be assumed to more greatly affect hydrology, and impair tidal exchange, than a road that occurs near the landward edge of a lagoon or tidal marsh with less effect on available wetland habitat. Thus, overall connectivity in the complex where the road occurs at the mouth or in the middle of the complex would be considered "impaired", whereas overall connectivity in the complex where the road occurs at landward edge of the complex might be considered "unimpaired", other factors being equal (Figure 8).

Figure 8. (At top) 1994 WDOE oblique air photo of Kala Point, a spit/marsh complex in the Port Townsend/Oak Bay sub-region. Although modifications have occurred to the Kala Point complex, they tend to occur near the north base of the spit and do not seem to affect tidal processes. For this reason we would consider overall connectivity to be relatively <u>unimpaired.</u> In contrast, the overall connectivity in the Fairmont Marsh complex (2001 WDOE oblique air photo shown at bottom) in the Discovery Bay sub-region would be considered <u>impaired</u> mainly by a railroad grade built across the historic spit and tidal inlet, disrupting tidal exchange to the marsh and lagoon.

Causes of Habitat Change and Impairment of Ecological Processes: In addition to making various assessments (both quantitative and descriptive) that describe changes in the habitat complexes, we considered and described the likely causes of the changes we observed. Determining the causative factors involved in habitat change gives us an understanding of how habitat-forming processes have been impaired, and which processes would need to be addressed through habitat protection and restoration actions.

We distinguished two general types of human-related impacts, 1) direct, and 2) indirect. Both direct and indirect impacts, or causative factors, affect physical processes and habitat structure and function in habitat complexes. Direct impacts (or what some might term "footprint" or "on-site" impacts) are human actions or structures such as filling, diking, dredging, channelization, and other activities that potentially impair habitat-forming processes and habitats at the habitat complex itself. These actions can directly modify tidal and riverine processes in lower tidal portions of streams and rivers, and these modifications are typically manifested in changes to hydrology, sediment regimes, and vegetation patterns of the habitat complex. Direct impacts that alter or result in the loss of tidal wetland habitat include fill typically associated with residential, agricultural, transportation, urban, industrial, and military-related development. Other direct impacts include dredging and diking of tidal marshes, and channelization of tidally-influenced river and distributary channels.

Indirect impacts are a second major type of human-related impact or mode of habitat change that typically include alterations to hydrology and sediment supply, transport, and deposition patterns in stream-delta complexes, and changes in drift cell sediment processes affecting spit/marsh complexes. In no way do we intend to imply, with our use of the term "indirect", that indirect impacts are any less important than direct impacts. By definition, the source of an indirect impact is off-site, either upstream, or along a marine shoreline updrift of a habitat complex, and we distinguish indirect impacts accordingly. "Upstream" impacts typically involve modifications influencing fluvial processes that affect sediment and hydrology of a stream or river upstream of the stream-delta complex itself (or may similarly affect sediment transport upslope of a spit/tidal marsh), but which clearly or potentially affect the morphology and function of habitat in the complex. For example, a significant upstream diversion of water out of a stream or basin, or land use changes that affect sediment (and hydrology) such as logging or roads, can influence the quantities and timing of water and sediment discharged to the estuary and delta, in turn affecting the amount, type, and spatial distribution of sediment (and where tidal wetland habitat develops). Another type of indirect impact we term "up-drift" occurs when sediment processes are affected at the scale of a marine shoreline drift cell. This is typical with bulkheading, filling, or other marine shoreline development that disrupts the supply, movement, and deposition of sediment, potentially affecting characteristics of spit features in the drift cell; for example, a spit can be de-stabilized, or erode when drift cell sediments reaching the spit are reduced, as is the case at Ediz Hook in the Eastern Strait sub-region of our study area.

In addition to the historical and current day map, survey, and air photo sources we used in evaluating indirect (upstream and updrift) impacts, we also drew on other sources of existing data and studies. One is a series of "Limiting Factors Analysis" reports that were developed and issued between the late 1990s and 2003 for the Strait and Hood Canal regions (Haring 1999, Smith 2000, Correa 2002, Correa 2003, and Kuttel 2003). To help us evaluate potential impairments to drift cell processes that affect spit/marsh complexes in particular, we utilized drift cell information available from the Washington Dept. of Ecology that is based on a number of individual studies (WDOE 2002, based on several masters thesis studies from Western Washington University, and Keuler 1988), and shoreline modifications data collected in the Hood Canal and Eastern Strait region as part of a recently completed inventory and study (Hirschi et al. 2003b). Generally, we considered a complex to have updrift impacts when bulkheading occurs along at least 10% of the length of the contributing drift cell. We applied professional judgment and also considered additional types of modifications to the drift cell in determining indirect impacts, such as the number and location within the drift cell of boat ramps, jetties, docks, and fill protruding below high water. The series of WDOE oblique air photos of the shoreline from the 1970s, 1990s, and 2000-2002 period, currently accessible on the internet (http://apps.ecy.wa.gov/shorephotos/), was very useful to our change analysis.

Relative Condition: To provide a qualitative measure of current day habitat function relative to its historical function, we developed a "Relative Condition" rating for nearly all of the habitat complexes in the study area. This rating is based in general on two criteria, 1) the percent lost habitat (tidal marsh and associated channels, lagoons, spits) when historical and current day estimates are compared, and 2) a determination of historical change in overall connectivity of habitat within a complex (see above description of overall habitat complex connectivity). The percent of lost habitat was typically the primary criteria, though the overall connectivity rating can significantly modify the Relative Condition rating for a habitat complex, but only by "downgrading" the rating. The specific criteria are described in Table 3. Note that habitat complexes that have received insignificant or moderate losses of historical habitat (< 50%), or even gains in habitat, can be downgraded from "Functional" to either "Moderately Impaired" or "Severely Impaired" based on connectivity. If a habitat complex has lost more than 50% of its historical habitat, overall connectivity is not incorporated in rating the Relative Condition; the complex is considered "Severely Impaired" with a habitat loss between 50% and 95 % and "Lost" with a loss greater than 95%. We assumed overall connectivity would be impaired with a habitat loss more than 50%.

In the larger stream-delta complexes such as the Skokomish, Union River/Lynch Cove, Hamma Hamma, Duckabush, Dosewallips, Upper Quilcene Bay (Quilcene Rivers), Dungeness, Elwha, and Pysht river deltas, a decision was made that the percentage lost habitat and overall connectivity criteria were not adequate in capturing the changes in habitat function. Therefore, in these complexes we considered a third factor, watershed impacts, in determining the Relative Condition rating. For example, we believe that the long-term impacts from dams, water diversions, and/or floodplain modifications in the Skokomish, Dungeness and Elwha river deltas have had important negative consequences to their respective estuaries through alterations in water and sediment supply and in the

distribution of sediment across the deltas and, as with overall connectivity, would reduce the Relative Condition rating.

Finally, we chose not to rate the Relative Condition in some smaller complexes, typically very small stream-delta complexes, because the historical and often the current day information describing habitat was lacking in the detail required to warrant making a Relative Condition rating.

Table 3. Decision matrix for determining the Relative Condition of habitat complexes. Watershed impacts also may reduce the Relative Condition rating of the larger stream deltas (see text).

Percent habitat lost since historical	Change in Overall Connectivity	Relative Condition of Habitat Complex
< 25% of historical habitat lost	Unimpaired	Functional
	Impaired	Moderately or Severely Impaired
25-50% of historical habitat lost	Unimpaired	Moderately Impaired
	Impaired	Severely Impaired
50-95% of historical habitat lost	Impaired	Severely Impaired
> 95% of historical habitat lost	Impaired	Lost

The Relative Condition rating was developed to give readers a relatively quick gauge of net changes in habitat function associated with the historical habitat complexes. The strength of this rating system is that it recognizes that providing estimated changes in the surface area of various habitat types does not by itself reveal adequate information about how the habitat complex likely functions today compared with its historical pre-development condition.

Landscape Scale Assessment

In addition to assessing changes at the habitat complex scale (and the watershed and drift cell process scales that affect the complexes), we also assessed broader landscape-level changes such as the distribution (and changes in this distribution) of habitat complexes at sub-region and regional scales, and we examined how the connectivity between habitat complexes had changed.

Landscape Connectivity: The frequency that one encounters habitat complexes along the shoreline is inherently greater in some parts of the study area than in other parts, largely explained by differences in geology, exposure to wave energy, coastal processes, and climate. To consider landscape connectivity within the more direct context of a juvenile salmon that migrates along the shoreline, we describe in the Discussion section below how the distance between specific types of complexes has changed, by considering how tidal access to stream-delta and spit/marsh complexes has changed since the 1800s.

Distribution of Relative Condition Ratings: We used the Relative Condition rating of individual habitat complexes to examine their distribution across the study area and the

sub-regions, looking for "clusters" of habitat complexes that are considered "Lost" or "Severely Impaired" as well as areas where "Functional" and "Moderately Impaired" complexes tend to be concentrated. This was useful in developing our management recommendations as it called out specific sub-regions or areas within sub-regions where estuarine and nearshore habitat conditions and processes have been particularly degraded or impaired, and those areas that have retained relatively functional processes and habitat conditions.

RESULTS

Historical and Contemporary Habitat Data

A core task of this study involved the development of the historical and current habitat data. The data generated in the delineation of historical and current day habitat are represented as polygons, lines, and points, and are stored in a geodatabase format accessed through a GIS software program. These GIS files are available for downloading through the Point No Point Treaty Council website (www.pnptc.org).

Change Analysis at Habitat Complex and Sub-Regional Scales

Detailed results of the habitat change analysis of the individual habitat complexes and sub-regions are presented by sub-region in Appendix B. For each sub-region, there is a summary followed by detailed narratives for all the habitat complexes in the sub-region. We believe these sub-region summaries and narratives are likely to be most useful for habitat protection and recovery planning because they include detailed reporting of the study results and assessments applicable to specific sites where recovery actions may be contemplated. The habitat complex narratives are organized in three sections, 1) a brief description of the complex, including dominant physical processes, 2) a more detailed description of the observed habitat changes, and 3) the rating of relative condition applied to the habitat complex (how relative condition is rated is described in the above Materials and Methods section). Based largely on the results developed for the individual habitat complexes, we below describe the distribution and sizes of the habitat complexes and analyze changes that have occurred across the study area.

Change Analysis at Landscape Scales

Distribution and Sizes of Habitat Complexes

Habitat Complex Distribution: We identified 250 habitat complexes within the study area, 63 in the Strait region, and 187 in Hood Canal. Habitat complexes are distributed unevenly across the study area, with the distance between complexes tending to be much greater in the Strait compared with Hood Canal (Figure 9). Stream-delta complexes dominate the West, Central, and Eastern Strait sub-regions. In fact, no spit/marsh complexes were identified in the Western or Central Strait sub-regions, and just four in the Eastern Strait sub-region. An abrupt shift then occurs as one moves east into the comparatively protected (from wave energy) Sequim Bay, Discovery Bay, and Port

Townsend/Oak Bay sub-regions, where spit/marsh complexes are far more numerous than stream-delta complexes. The relatively low amount of precipitation falling in the watersheds draining to these bays, due to their position within the "rainshadow" of the Olympic Mountains, is the primary explanation accounting for so few stream-delta complexes in these three sub-regions. Through the remainder of the study area, Hood Canal Entrance sub-region and south, we find more equal numbers of stream-delta (67) and spit/marsh (93) complexes.

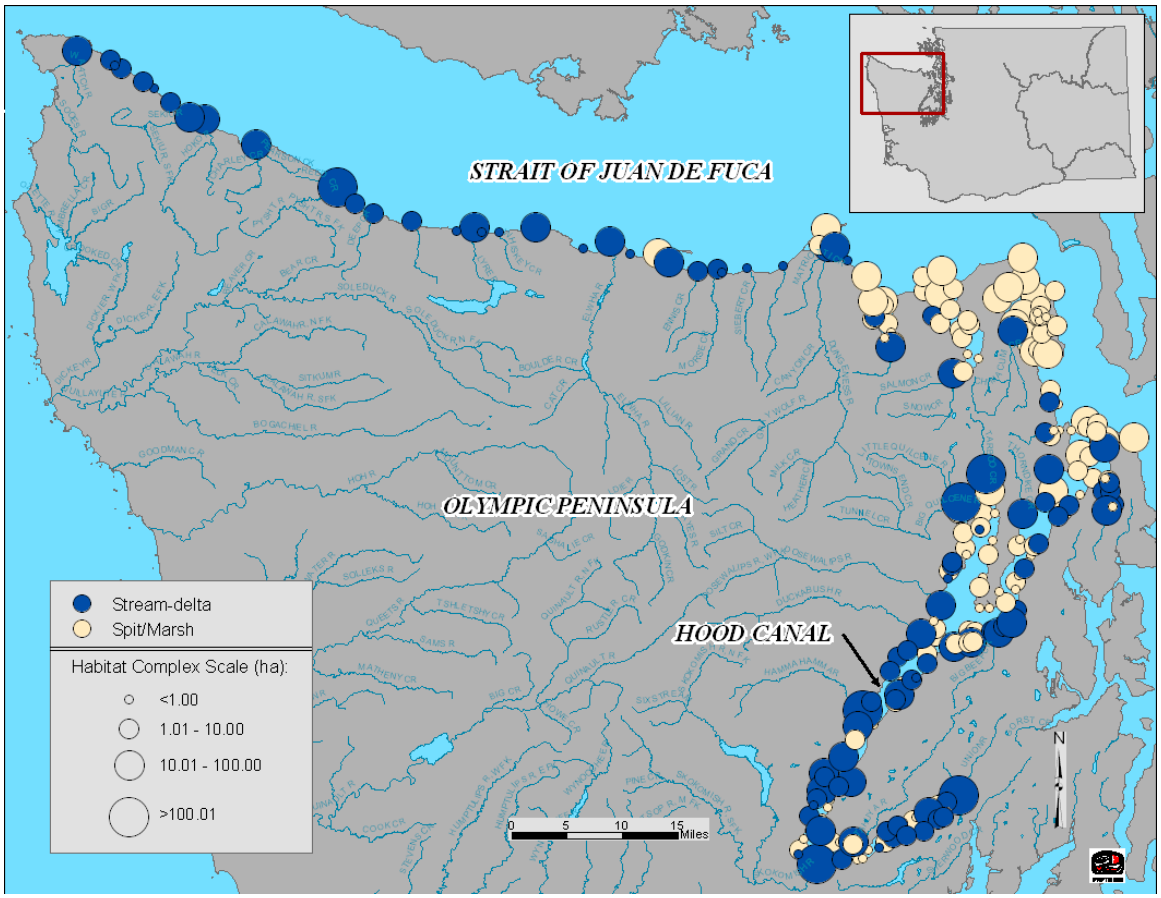

Figure 9. Historical size (by size class) and distribution of stream-delta and spit/marsh habitat complexes in the study area.

Habitat Complex Sizes: The historical size of the habitat complexes (including the surface area of associated tidal flat) in the study area ranges from less than one hectare (75 of the complexes occurred in this size range) to 799 hectares (Skokomish estuary)(Figure 10 and Table 4). Other than the Skokomish, just five additional habitat complexes were greater than 100 hectares (ha) in size (Lynch Cove/Union River, Upper Quilcene Bay [Big/Little Quilcene rivers], Pysht River, Hamma Hamma River, and Tarboo Creek). The Duckabush and Dosewallips stream-delta complexes were historically nearly 100 ha in size as well. Large numbers of habitat complexes occur in the 1 to 10 ha (115 complexes), and 10 to 100 ha (54 complexes) size classes.

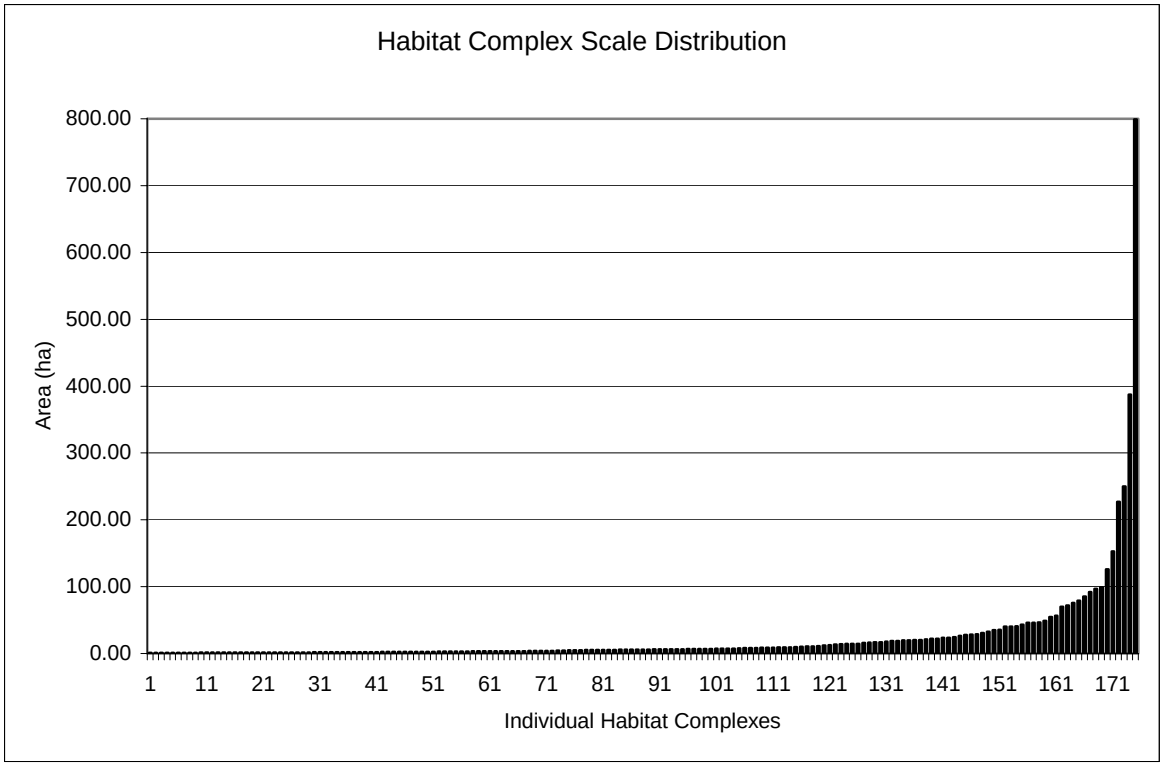

Figure 10. The historical sizes of individual habitat complexes across the study area, in ascending order. The height of an individual bar indicates the size of a complex. Seventy five habitat complexes were less than one hectare in size, and are not shown in this graphic.

Table 4. Historical distribution, types, and sizes of habitat complexes in the study area, by region and sub-region.

Sub-region	Number of Habitat Complexes	Habitat Complex Type		Historical Size of Habitat Complex (ha)	
		Stream-delta	Spit/marsh	Range	Median
Western Strait	10	10	0	< 1 - 23 [1]	4.89
Central Strait	9	9	0	< 1 - 227	7.49
Eastern Strait	16	12	4	< 1 - 92	6.67
Sequim Bay	10	2	8	< 1 - 70	6.17
Discovery Bay	18	2	16	< 1 - 72	1.73
Total Strait	**63**	**35**	**28**	**< 1 - 227**	**5.39**
PT/Oak Bays	27	1	26	< 1 - 56	3.06
H.C. Entrance	30	8	22	< 1 - 46	2.75
N. Hood Canal	24	8	16	< 1 - 47	1.2
Dabob Bay	20	6	14	< 1 - 250	2.55
C. Hood Canal	35	19	16	< 1 - 153	3.44
S. Hood Canal	24	14	10	< 1 - 799	3.24
Hook H.C.	27	12	15	< 1 - 387	1.16
Total Hood Canal	**187**	**68**	**119**	**< 1 - 799**	**2.49**
Total Study Area	**250**	**103**	**147**	**< 1 - 799**	**3.7**

[1] The historical size of habitat complexes in the Western Strait sub-region was derived from tidal flat and tidal portions of river channels. We did not have historical estimates of tidal wetland habitat (i.e., marsh and lagoons) for complexes in the Western Strait because the T sheets typically lacked the necessary detail to obtain these estimates.

Changes in the Numbers of Complexes Supporting Tidal Wetland Habitat

Some habitat complexes that historically provided tidal wetland habitat (i.e., marsh, and/or lagoon) no longer support tidal wetlands, while other complexes that may not have supported tidal wetland habitat historically do provide this habitat today. Of the 250 habitat complexes we identified across the study area, 178 complexes supported tidal wetland habitat according to historical sources; today, 157 complexes support tidal wetland habitat (Table 5). Of those 178 complexes that historically had tidal wetland, 37 no longer provide tidal wetland habitat; however, tidal wetland habitat is present today in 16 complexes, though our historical sources show no indication of these complexes having provided tidal wetland habitat. Because of sediment aggradation that over time would facilitate the establishment of salt marsh, there is good reason to think that in seven (7) of these 16 complexes, tidal marsh has actually grown where it did not in historic times (i.e., 1800s). In the nine (9) other complexes, tidal wetland was probably present historically, though the early T sheets either lacked the detail to map this habitat (4 cases), or the surveyors simply failed to indicate tidal wetland at a given complex (5 cases).[1]

[1] If we apply the reasonable assumption that the historical amount of tidal wetland habitat associated with these nine (9) complexes would have been at least as much as the amount we find at these same nine (9) complexes today, this would result in an increase of 8.56 ha of tidal wetland habitat over our actual historical estimate of 1,430 ha across the study area; we decided not to include this assumption of additional area in our total historical estimate (see following sub-section for area estimates).

Table 5. Changes in the numbers of complexes supporting tidal wetland habitat. Values shown in the 'Current' column represent the number of complexes that today provide tidal wetland habitat (including both the loss and gain in numbers of complexes). Thus, for the study area, the total number of complexes that today provide tidal wetland habitat is 157 calculated as 178 historical – 37 lost + 16 gained (see text).

Sub-Region	Number of Complexes with Tidal Wetland		Change in Number
	Historical	Current	
Western Strait	-*	3	N.A.
Central Strait	2	2	0
Eastern Strait	8	9	+ 1
Sequim Bay	9	8	- 1
Discovery Bay	15	15	0
Total Strait	**34***	**37**	**+ 3**
PT/Oak Bay	24	23	- 1
H.C. Entrance	22	16	- 6
N. Hood Canal	17	12	- 5
C. Hood Canal	30	25	- 5
Dabob Bay	14	13	- 1
S. Hood Canal	18	18	0
Hood Canal Hook	19	13	- 6
Total H.C.	**144**	**120**	**- 24**
Total Study Area	**178***	**157**	**- 21**

* We could not obtain reliable historical estimates of tidal wetland habitat in the Western Strait sub-region because the T sheets in the area lacked the detail to capture salt marsh features. Consequently, we have no historical record of complexes supporting tidal wetland habitat in the Western Strait, though three complexes are known to support this habitat today.

Historical sources indicate that 53 of the 103 stream-delta complexes across the study area supported tidal wetland habitat (just three of these had lagoon habitat only, but no marsh). Today, 55 stream-delta complexes support tidal wetland habitat. Many of the stream-deltas that did not historically have tidal wetland are small steep systems that enter relatively open exposed sections of shoreline where they may develop small deltaic fans. Emergent marsh vegetation was at least historically not likely to develop in many of these relatively high-energy environments, though today marsh has developed in a few smaller stream-deltas where we had no historical record of this marsh (e.g., Seabeck Creek). Several other of these stream-delta complexes are moderate-sized systems along the Strait (e.g., Sekiu, Hoko, Clallam, and Morse Creek), and likely provided a limited amount of tidal marsh and/or lagoon habitat, though we have no reliable way of estimating their historical amounts because the T sheets lacked detail.

Of the 147 spit/marsh complexes, we have record of 125 historically supporting tidal wetland (note: it is likely that an additional 5 spit/marsh complexes supported tidal wetlands though the historical sources apparently failed to indicate the presence of this habitat). Only four of these 125 spit/marsh complexes, however, had lagoon habitat only

and no marsh. Several spit/marsh complexes in the study area can be described from historical maps as low-lying accretional features with upland grassland vegetation, but apparently supporting no tidal wetland habitat. Today, 102 spit/marsh complexes support tidal wetland habitat.

Changes in Tidal Wetland Habitat

Across the study area, the amount of tidal wetland habitat (i.e., marsh, associated channels, and lagoon) has decreased by 7% from 1,430 ha associated with 178 habitat complexes to 1,323 ha associated with 157 habitat complexes today (Table 6).

Changes to tidal wetland habitat were not distributed evenly across the study area. The Strait region has seen tidal wetland habitat reduced from 446 hectares historically to 352 hectares today (21% less), and Hood Canal had 984 hectares historically compared with 971 today (1% decrease). As a result, the proportion of tidal wetland habitat in the study area contributed by the Hood Canal region has increased from 69% historically to 73% today (Table 6). Primarily because of gains in tidal wetland habitat in the Skokomish River complex, the South Hood Canal sub-region now contributes 25% of the total tidal wetland habitat across the study area, up from 19% historically.

Certain sub-regions of the study area have seen substantial quantitative loss in overall tidal wetland, such as the Central Strait (associated with the Pysht River and Salt Creek complexes), Port Townsend-Oak Bay, Hood Canal Entrance, and Hood Canal North sub-regions, and other sub-regions have changed only slightly or even show gains in tidal wetland since historical times (Eastern Strait, Sequim Bay, Discovery Bay, Dabob Bay, Hood Canal Central, Hood Canal South, and Hood Canal Hook sub-regions (Table 6 and Figure 11).

Table 6. Historical changes in the amount (and in the proportion of the total amount) of tidal wetland habitat (i.e., marsh, lagoon, and associated channel), by sub-region and region, for the study area. Values have been rounded to the nearest whole numbers.

Sub-Region	Tidal Wetland (ha)		Change (ha)	Percent Change (%)	% of Hist. Total	% of Cur. Total
	Historical	Current				
Western Strait	-*	4	N.A.	N.A.	N.A.	N.A.
Central Strait	146	73	- 73	- 50	10	6
Eastern Strait	174	164	- 10	- 6	12	12
Sequim Bay	83	74	- 9	- 11	6	6
Discovery Bay	43	37	- 6	- 14	3	3
Total Strait	**446**	**352**	**- 94**	**- 21**	**31**	**27**
PT/Oak Bay	146	95	- 51	- 35	10	7
H.C. Entrance	97	72	- 25	- 26	7	5
N. Hood Canal	103	66	- 37	- 36	7	5
C. Hood Canal	136	173	+ 37	+ 27	10	13
Dabob Bay	111	131	+ 24	+ 22	8	10
S. Hood Canal	270	326	+ 56	+ 21	19	25
Hood Canal Hook	121	108	- 13	- 11	8	8
Total H.C.	**984**	**971**	**- 13**	**- 1**	**69**	**73**
Total Study Area	**1,430**	**1,323**	**- 107**	**- 7**	**100**	**100**

* We could not obtain reliable historical estimates of tidal wetland habitat in the Western Strait sub-region because the T sheets in the area lacked the detail to capture salt marsh features. Consequently, no estimates of change in habitat area were made for the Western Strait sub-region.

Marsh habitat (and associated channels) was historically and remains today the larger component of tidal wetland habitat (the other component being lagoon habitat) across the study area, comprising 81% of the total tidal wetland habitat, both historically and currently. We recorded no lagoon habitat, either historically or currently, in the Western and Central Strait sub-regions, and very little in the Hood Canal Hook sub-region. Sequim Bay is the only sub-region that historically (and currently) had more lagoon habitat than marsh habitat (Figure 11).

The amount of marsh habitat decreased from 1,157 to 1,072 ha (7%), while lagoon habitat decreased from 272 to 251 ha (8%)(Figure 11). Although the amount of marsh habitat was substantially reduced in the Port Townsend/Oak Bay sub-region, the amount of lagoon habitat actually increased slightly from the historical amount. This was driven by shifts in habitat associated with two habitat complexes, Kala Point and Oak Bay Lagoon (see Port Townsend/Oak Bay sub-region in Appendix B). Much of the marsh that was present at Kala Point has been converted to lagoon habitat, and lagoon habitat has actually been created, though not intentionally, at Oak Bay Lagoon by dredging and filling of historical tide flats.

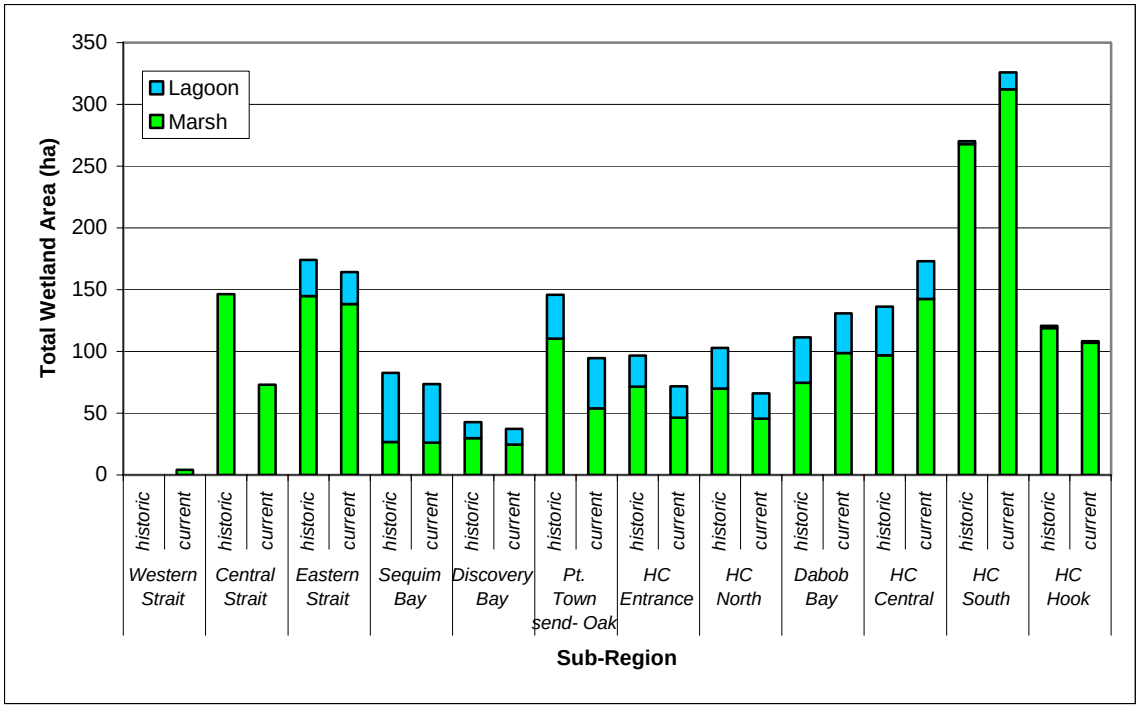

Figure 11. Historical and current amounts of tidal marsh and lagoon habitat associated with stream-delta and spit/marsh complexes by sub-region across the study area. Note: we could not obtain reliable historical estimates of tidal wetland habitat in the Western Strait sub-region because the T sheets in the area lacked the detail to capture salt marsh features. However, using contemporary air photos, we did obtain current day estimates of tidal wetland habitat for the Western Strait sub-region and these estimates are shown here.

Tidal wetland habitat associated with stream-delta complexes increased by 7% from the historical amount (Table 7). However, the degree of historical habitat change differed markedly depending on the historical size of the stream-delta complexes (Table 7 and Figure 12). Stream-delta complexes in the smallest size class (0-1 ha) collectively increased from zero to 0.6 ha since we reported no historical tidal wetland for stream-deltas in this size category. This may be attributed in part to a bias from lack of an accurate characterization of historical tidal wetland in many of the smaller stream-delta complexes, particularly in the Western and Central Strait sub-regions (i.e., the T sheets in those areas simply lacked the detail to capture salt marsh for example). The greatest percentage decrease (39%) in tidal wetland habitat occurs in stream-delta complexes in the 1-10 hectare size class. The larger stream-delta complexes, those in the 10-100 hectare size class and those greater than 100 hectares, showed 14% and 7% increases, respectively, in the amounts of tidal wetland habitat associated with these complexes.

Tidal wetland habitat associated with spit/marsh complexes collectively showed a 28% decrease since historical times (Table 7). Tidal wetlands associated with the smallest size class (0-1 ha) deceased by 19%, while decreases associated with spit/marsh complexes in the 1-10 ha and 10-100 ha size categories were 29% and 28% respectively (Table 7 and Figure 12).

Table 7. Historical changes in tidal wetland habitat associated with stream-delta and spit/marsh complexes by size class. Values in this table were rounded to the nearest whole number.

Stream-delta (size category - hectares)	Number of Historical Complexes	Historical (hectares)	Current (hectares)	Percentage Change (%)
0 - 1	16	0	0.6	N.A.
1 – 10	49	38	23	- 39
10 – 100	32	288	329	+ 14
> 100	6	514	548	+ 7
Total Stream-delta	**103**	**840**	**901**	**+ 7**
Spit/marsh (size category - hectares)	**Number of Historical Complexes**	**Historical (hectares)**	**Current (hectares)**	**Percent Change (%)**
0 - 1	60	16	13	- 19
1 - 10	65	154	109	- 29
10 - 100	22	419	300	- 28
> 100	0	0	0	0
Total Spit/marsh	**147**	**589**	**422**	**- 28**
Total	**250**	**1,429**	**1,323**	**- 7**

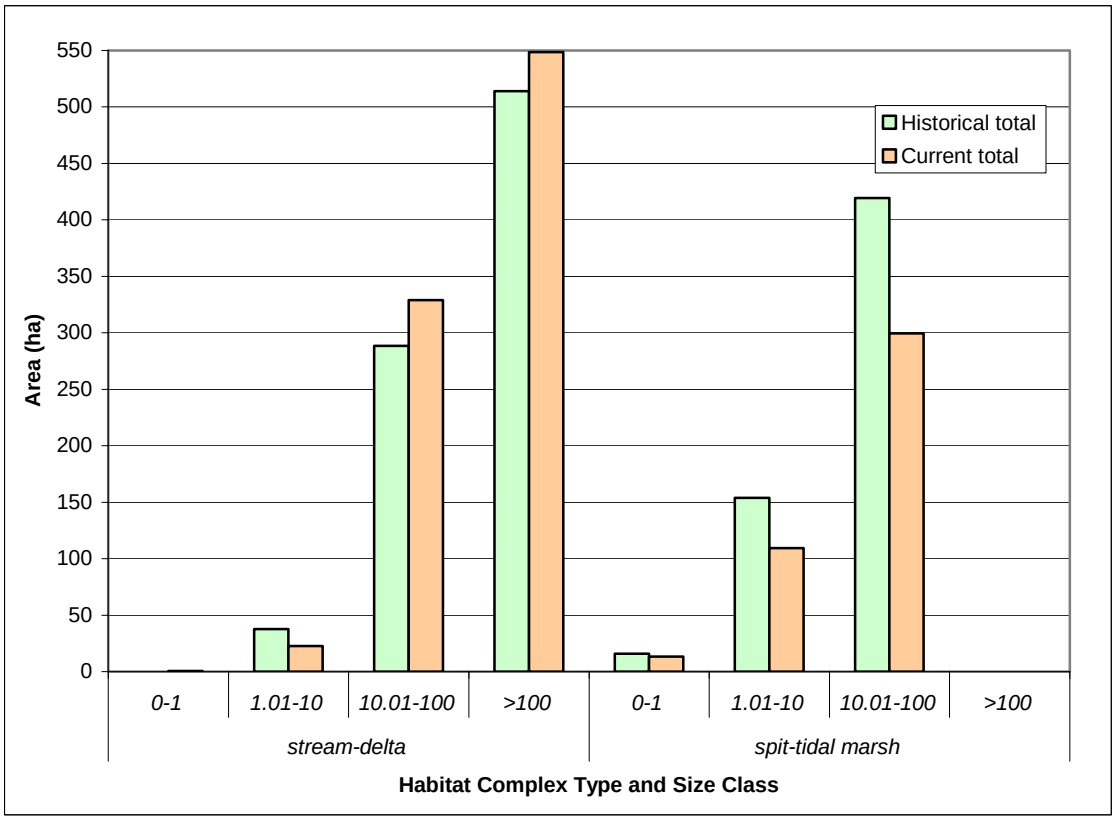

Figure 12. Historical changes to tidal wetland habitat (i.e., marsh, associated channels, and lagoon) by complex type and size class for the study area.

Surface Water Connectivity of Spit/Marsh Complexes:

As part of our analysis of historical changes, we have described how the surface water connectivity of spit/marsh complexes has changed since the 1800s. The concern here is that juvenile salmon gain no direct benefits from the habitats within the spit/marsh complexes unless access is provided though a surface water connection. We also considered whether freshwater inputs are documented at each spit/marsh complex, as the presence of freshwater potentially provides an environment that facilitates osmoregulatory transition from fresh to salt water (Appendix A, Tables 6-17 contains information on surface water connectivity and freshwater inputs for habitat complexes). One important clarification is that we did not evaluate the specific condition of tidal wetland habitat that would be potentially accessed by juvenile salmon. For example, we did not assess whether the geomorphology or water quality would be suitable for salmon in these complexes, which would certainly make for a worthy followup study.

Of the 147 spit/marsh complexes we identified throughout the study area, 77 showed evidence of surface water connectivity with adjacent open waters in the historical record (Figure 13; Figures 14 and 15 display the results of this analysis by sub-region). The historical size of these 77 complexes ranged from less than one hectare (ha) to 91.74 ha (mean of 9.83 ha). The 70 spit/marsh complexes where we did not have historical record of a surface water connection ranged from less than one to 56.48 ha (mean of 3.95 ha). Of the 77 complexes that historically had surface water connectivity, 47 have known freshwater inputs.

Twenty-three of the 77 spit/marsh complexes (30%) that had historic surface water connectivity, today have no apparent, or infrequent surface water connectivity. However, 11 of the 70 complexes that historically did not have surface water connectivity, or where this status was questionable, today show evidence of surface water connectivity. We should note that at least four of these 11 complexes gained surface water connectivity through artificially dredged channels that in 3 instances today provide access to marinas or boat basins (i.e., Violet Point, Cape George, and Point Hudson). Therefore, in total today, 65 spit/marsh complexes have some degree of surface water connectivity with adjacent open waters. Forty-one of these 65 complexes also have known freshwater inputs.

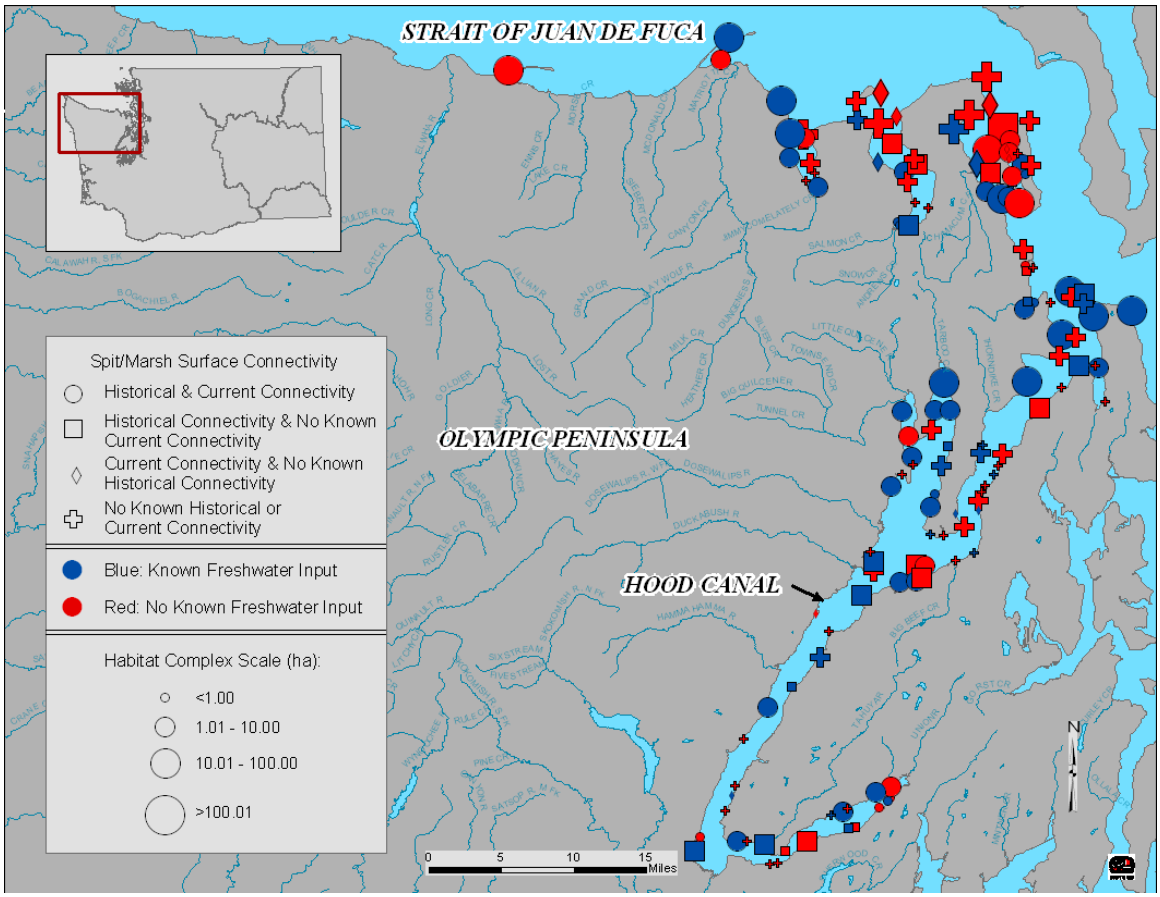

Figure 13. Historical scale, the status of surface water connectivity, and freshwater inputs in spit/marsh complexes in the study area. No spit/marsh complexes occur west of Ediz Hook in the Eastern Strait sub-region. This map is intended for identifying landscape-level patterns in surface water connectivity and freshwater inputs. For details at the sub-regional scales, refer to Appendix B.

Historically across the study area, there were 447 hectares of tidal marsh and lagoon habitat associated with the 77 spit/marsh complexes that showed a surface water connection in the historical record. Today there are 348 hectares of tidal wetland habitat associated with the 65 complexes that now have surface water connectivity.

Surface water connectivity in spit/marsh complexes within some sub-regions of the study area has been more changed than in other sub-regions. For example, the number of spit/marsh complexes with surface water connectivity has been reduced most in the Hood Canal Entrance, Central Hood Canal, and Hood Canal Hook sub-regions (Figure 14), and the greatest decreases (by percentage) in the amount of tidal wetland habitat associated with these spit/marsh complexes has occurred in the Eastern Strait, Hood Canal Entrance, North Hood Canal, South Hood Canal, and Hood Canal Hook sub-regions (Figure 15).

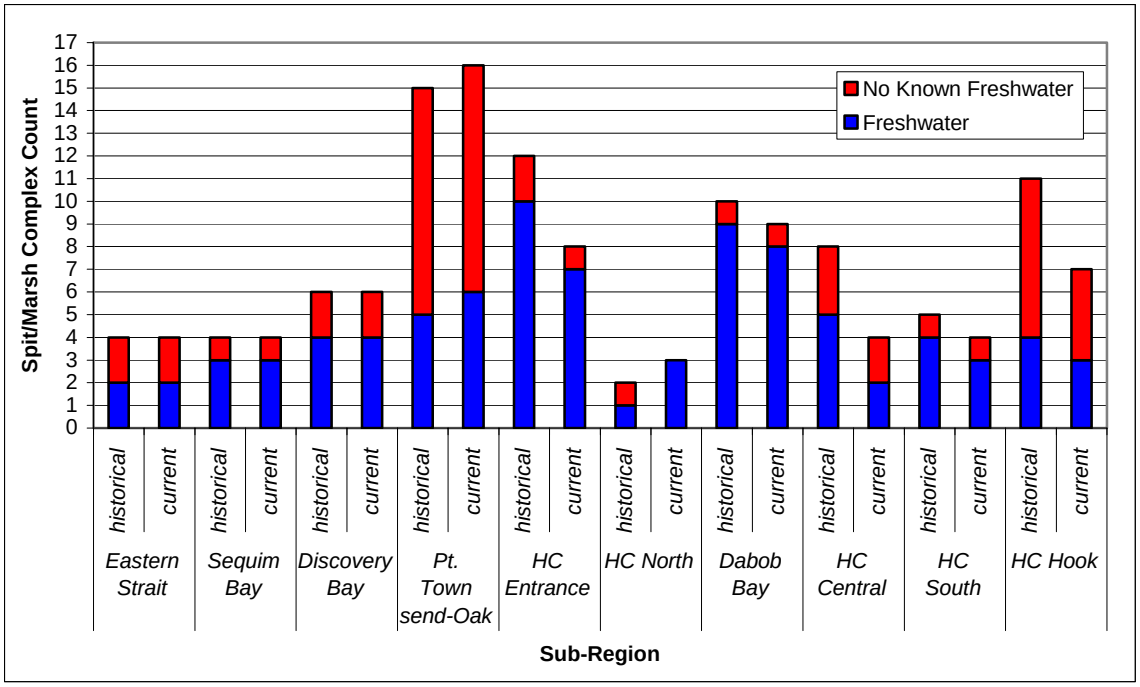

Figure 14. Historical changes in the number of spit/marsh complexes with surface water connectivity and freshwater inputs, by sub-region.

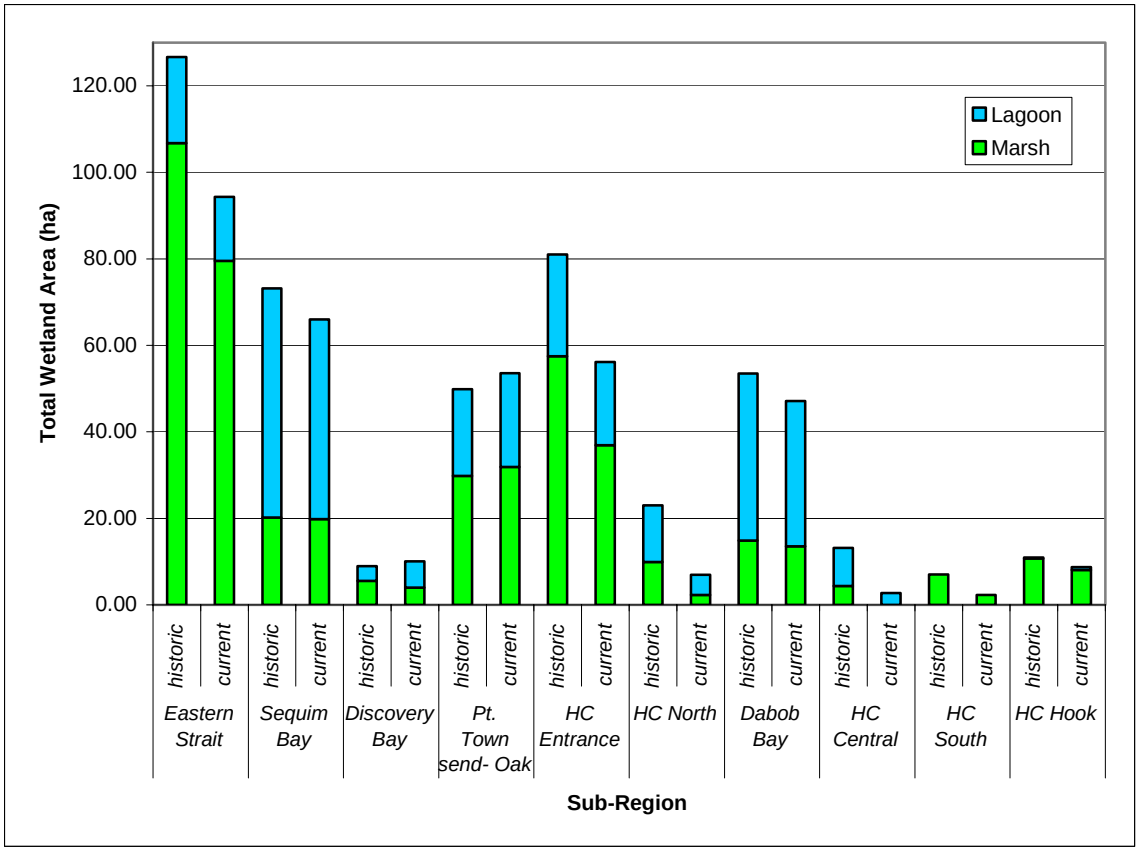

Figure 15. Historical changes, by sub-region, in the amount of tidally-accessible marsh and lagoon habitat associated with spit/marsh complexes. This is based on our observation that 77 spit/marsh complexes historically had surface water connectivity with adjacent nearshore waters compared with 65 spit/marsh complexes that have surface water connectivity today. The Western Strait and Central Strait sub-regions do not have spit/marsh complexes and are not included in the figure.

Causes of Habitat Changes and Impairment of Processes

What follows are the results of an assessment of the major causative factors (impacts) for the habitat changes across the study area. We have considered the land use activities (e.g., residential landfill, transportation, commercial/industrial, etc.) most commonly associated with direct and indirect impacts on habitat complexes, and how these land use activities affect riverine, tidal, and drift cell processes.

Direct Causes of Habitat Change

Across the study area, the most common direct cause of habitat change to complexes is loss and degradation of tidal wetland habitat from landfill associated with transportation; this is the primary cause of habitat change in 101 of the 250 habitat complexes (40%)(see Table 8 for a summary). Important also is residential development, affecting 73 of 250 complexes (29%). Other urban, industrial, military-related, marina and park

developments are responsible for directly causing habitat change in 48 complexes (19%). Also relatively common is dredging, ditching, channelization, or drainage of tidal wetland and riverine-tidal channel habitats, cited in 47 of the 250 complexes (19%). Diking of tidally-influenced river channels or tidal marsh is a relatively uncommon occurrence, noted in just 22 complexes across the study area (9%). Diking (i.e., within the tidal portion of rivers) tends to be limited to the larger stream systems (both in the Strait and Hood Canal) and a few of the relatively large-sized spit/marsh complexes, such as Washington Harbor (Sequim Bay sub-region). Very few moderate or large-sized stream-delta complexes are relatively free of diking, these being Tarboo Creek (Dabob Bay sub-region), Thorndyke Creek (North Hood Canal sub-region), Stavis Creek (Central Hood Canal sub-region), and the Tahuya River (South Hood Canal sub-region). Appendix A, Tables 6 – 17 include summary information on causes of habitat changes (i.e., direct, indirect) for individual habitat complexes, organized by sub-region.

Table 8. Summary of causes of habitat changes across the study area, by sub-region. Direct impacts occur within the habitat complex, while indirect impacts to habitat are impacts that are sourced off-site, either upstream or up-drift along the shoreline. The numbers in each column indicate the number of complexes where different types of direct and indirect impacts were noted as primary or potential causes for habitat changes to habitat complexes. Note: multiple causes of change (within both direct and indirect categories) were identified for several individual complexes (e.g., homes and roads). Superscripts indicate more detailed information that is provided in footnotes below.

Sub-region	No. Comp-lexes	Direct Impacts					Indirect Impacts	
		Homes[1]	Roads[1]	Dikes[1]	Dredge	Other	Upstream	Updrift
Western Strait	10	0	5	0	4	4 [2]	7	4
Central Strait	9	0	4	2	3	4 [3]	7	1
Eastern Strait	16	1	7	6	5	3 [4]	11	7
Sequim Bay	10	0	5	1	1	2 [5]	3	4
Discovery Bay	18	3	10	1	4	2 [6]	11	10
Strait Total	**63**	**4**	**31**	**10**	**17**	**15**	**39**	**26**
Pt Town-send/Oak Bay	27	1	12	0	6	12 [7]	5	18
Hood Canal Entrance	32	13	11	1	6	5 [8]	16	13
North Hood Canal	22	6	8	0	3	7 [9]	7	17
Dabob Bay	20	8	6	2	1	3 [10]	10	4
Central Hood Canal	35	12	16	4	8	1 [11]	18	10
South Hood Canal	24	11	12	3	3	2 [12]	13	11
Hood Canal Hook	27	18	5	2	3	3 [13]	11	22
Hood Canal Total	**187**	**69**	**70**	**12**	**30**	**33**	**80**	**95**
Study Area	**250**	**73**	**101**	**22**	**47**	**48**	**119**	**121**

(1) Homes (i.e., residential development), roads, and dikes all result in the filling of wetlands and spits.

(2) Western Strait "other" includes fill associated with commercial, industrial, and urban land uses.

[3] Central Strait "other" includes fill associated with dredge spoils, logging activity (Pysht), jetty (Whiskey Creek).
[4] Eastern Strait "other" includes fill associated with urban and industrial development mainly around Port Angeles and Lees Creek.
[5] Sequim Bay "other" includes fill associated with a marina at Pitship Point and commercial development at Washington Harbor.
[6] Discovery Bay "other" includes fill associated with marinas at Cape George and Violet Point.
[7] Port Townsend/Oak Bay "other" includes fill associated with urban, industrial, and military-related development.
[8] Entrance Hood Canal "other" includes fill associated with industrial (Teekalet, North Ludlow Spit, Basalt Marsh), hatchery (Little Boston Creek), and a park (Salsbury Point).
[9] North Hood Canal "other" includes fill associated with military-related development, and in at least 2 instances (Devils Hole and Cattail creeks), dam structures at the mouths.
[10] Dabob Bay "other" includes fill associated with military (Zelatched Lagoon), commercial (Whitney Point), and a marina (Indian George Creek).
[11] Central Hood Canal "other" includes fill associated with historical industrial and commercial development at Seabeck Spit.
[12] South Hood Canal "other" includes fill associated with a hatchery (Finch Creek) and a park (Potlatch Marsh).
[13] Hook Hood Canal "other" includes fill associated with parks (Little and Big Mission creeks, Twanoh Creek).

The primary causes of habitat change differ somewhat in the Strait from the Hood Canal region, reflecting in part the distinctive patterns and intensities of (Euro-American) land use and perhaps the differences in the types of habitat complexes that are prevalent in the two regions (much of the Strait, particularly west of the Dungeness Spit, is dominated by stream-delta complexes whereas Hood Canal has a large proportion of spit/marsh complexes). In the Strait, about half (31) of the 63 habitat complexes identified are noted as being impacted directly by landfill associated with transportation (i.e., roads and railroads, Table 8). Dredging, ditching, or riverine-tidal channelization is cited in 17 complexes (27%) as a direct cause of habitat change. Fifteen complexes (24%) are noted for having fill related to urban, industrial, or commercial land use, including several marinas. Ten habitat complexes (16%) have evidence of diking, mainly an occurrence in the larger stream-delta complexes. Residential development is noted as directly impacting just four (6%) of the 63 habitat complexes in the Strait region.

In the Hood Canal region, 69 of the 187 habitat complexes (37%) have been directly impacted by fill related to residential land use (Table 8). At least as important in Hood Canal is transportation-related landfill (auto and railroads), which directly affects 70 complexes (note: many of the same habitat complexes are impacted by transportation and residential or other urban land uses, and many complexes had multiple types of direct and indirect impacts cited).

Urban, industrial, and military-related development, including several parks and marinas, are a direct cause of habitat change in 33 of the 187 habitat complexes (18%, Table 8) in the Hood Canal region. Dredging, ditching, and other channelization activities are noted in 30 Hood Canal complexes (16%), and these activities often have especially important consequences for tidal wetland habitat where they do occur. Considerably more rare

(than even in the Strait) is diking, which was cited in just 12 complexes (6%) in the Hood Canal region. Much as in the Strait, diking in Hood Canal habitat complexes is, with few exceptions, restricted to many of the larger stream-delta complexes.

The direct causes of habitat changes are similar in many respects in stream-delta and spit/marsh complexes, though some direct causes are more important than others in their effects on the two habitat complex types. For example, residential land use and fill is a primary cause of habitat change in at least 44 of the 147 spit/marsh complexes (30%) across the study area. Low-lying spit/marsh complexes are popular locations for residential and other urban-related development, particularly in the Hood Canal and Discovery Bay sub-regions. Nowhere is this pattern more evident than in the Hood Canal Hook sub-region where at least 12 of the 15 spit/marsh complexes are directly impacted by residential development. In the Port Townsend/Oak Bay sub-region, many of the 26 spit/marsh complexes are directly impacted by urban, industrial, and military-related land uses.

Residential development appears considerably less important as a direct cause of habitat change in stream-delta complexes, where it is noted in 14 of the 103 complexes (14%). Transportation, however, is widespread in affecting stream-delta complexes, cited in at least 50 (49%) stream-deltas distributed across the study area. Dredging and channelization of riverine-tidal and tidal marsh habitat is indicated in 17 of the 103 stream-delta complexes (17%), and diking was noted in 13 complexes as a direct cause of habitat change. All of the stream-delta complexes where diking has been observed are relatively large in size, the smallest being Lilliwaup Creek (South Hood Canal sub-region).

Of the 103 stream-delta complexes across the study area, 17 (17%) have no apparent direct impacts. Most of these stream-deltas are small in size, the most notable exceptions being Thorndyke (North Hood Canal sub-region) and Seabeck (Central Hood Canal sub-region) creeks. Only 11 of the stream-deltas (11%) having no or few direct impacts also have minimal indirect (upstream and updrift) impacts, the largest being Thorndyke Creek.

Twenty-five of the 147 spit/marsh complexes (17%) across the study area have little to no indication of direct impact on tidal wetland habitat, the largest of these complexes by far being Bywater Bay (Entrance Hood Canal sub-region) and Long Spit (Dabob Bay sub-region). However, just 16 of these spit/marsh complexes (11%) have no known direct or indirect impacts.

Of the 40 habitat complexes in the study area that we consider “lost” based on the elimination of their historical tidal wetland habitat (see section on Relative Condition), all are directly impacted by filling. Half (20) of these complexes have been filled for residential development, ten for urban, industrial, park, and other developments, and five because of military-related development.

Indirect Causes of Habitat Change

Indirect causes of habitat change were frequently noted across the study area (Table 8). Indirect causes were observed as upstream sources alone in 63 of the 250 complexes (25%); 60 complexes (24%) were noted as being at risk of up-drift indirect causes of habitat change; and an additional 55 habitat complexes (22%) had both upstream and up-drift causes of change to tidal wetland habitat. We did not attribute indirect causes of habitat change in 70 complexes across the study area. As with direct causes of habitat change, the importance of indirect causes of change differs between the Strait and Hood Canal regions. Upstream causes alone (that is up-drift was not noted) were observed in 19 of the 63 complexes (30%) in the Strait, compared with 44 (24%) of the 185 complexes in Hood Canal. Updrift causes alone is cited in just 7 (11%) Strait complexes, compared with 53 (29%) complexes in Hood Canal. Both up-drift and upstream causes were noted in 20 complexes (32%) in the Strait, and in 35 complexes in the Hood Canal region (19%).

Delta progradation is common among many of the larger stream-delta complexes in the study area (i.e., Skokomish, Hamma Hamma, Duckabush, Dosewallips, Big Quilcene, Snow/Salmon Creek, Dungeness, and Jimmycomelately Creek). The progradation, which typically results in the growth of salt marsh seaward of its location in the 1800s, is a natural occurrence, but appears accelerated by man-made actions such as riverine and estuarine channelization, diking, and an increase in sediment yield from the watersheds, often related to past and present land use activities, particularly logging and road building. We return to the subject of progradation and its consequences on salmon habitat in the Discussion section below.

One apparent "indirect" cause of habitat change was observed in a number of spit/marsh complexes in the study area, where an abundance of drift logs now occupy lagoon and marsh habitats, though we saw no evidence in the historical record of the presence of drift logs covering large areas of marsh and lagoon. We certainly do not wish to imply that woody debris material was absent in marshes and lagoons in historical times, as most certainly it was present, and probably in large concentrations in some locations. Nor do we intend to convey woody debris as a negative attribute in nearshore habitats, as woody debris in stream channels, spits, beaches, and along shoreline areas, is known to provide geomorphic complexity and likely benefits the formation of habitat for various plant and animal communities. However, in a recent study by MacLennan (2005) of two tidal marshes in northern Puget Sound, the source of driftwood to the marshes was predominantly cut wood from log transport and storage operations, and the wood was transported to these marsh systems as a result of escape from rafts during heavy storm events. The presence of drift logs that cover large areas in these complexes may have important implications on hydrology and changes in vegetation patterns over time, which would require consideration in any conservation measures taken at these complexes. Drift logs can change localized topography, vegetation, and hydrology of tidal marshes by creating islands or entire areas of upland habitat that displace former wetland habitat. Though certainly woody debris accumulated in massive amounts in natural catchments during historic, pre-industrial times, we do not know if these locations had similar levels

of accumulated wood in historic times to the levels we see today. Also, it may be fair to question how wood was moved into and around lagoons and marshes historically compared with today. Historically, there were likely far more pieces of very large wood including branches and rootwads that conceivably would have become trapped along spits or near the tidal inlets of lagoons. Far fewer of these types of very large and complex wood pieces are available today, and the vast majority of the wood is now smaller and missing branches and rootwads. It is assumed that these comparatively small and less complex wood pieces more readily float into lagoons and marshes and become trapped and build up over time.

As mentioned above, we did not attribute direct causes of change in 42 habitat complexes. However, some of these complexes are at risk of indirect causes of habitat change (either upstream or up-drift). Eight of these complexes are potentially at risk of upstream causes for habitat change, and six additional complexes have up-drift causes indicated as potential agents of habitat change to the complex. Both upstream and up-drift causes for change were indicated in three other habitat complexes. Therefore, direct or indirect causes of habitat change were not found in just 24 habitat complexes across the study area (~10% of the complexes).

Relative Condition of Habitat Complexes

A Relative Condition rating was assigned to 233 (93%) of the 250 habitat complexes in the study area; seventeen complexes were not rated because we either lacked adequate historical or current information to make an assessment, or we lacked a sufficient understanding of the changes that have occurred at the complex. All of these un-rated complexes were relatively small in size (< 10 hectares), and many were stream-delta complexes that appeared not to have had historical tidal wetland habitat (marsh and lagoon), nor to have current day wetland habitat, so that a comparison was not possible or relevant. Details on rating the Relative Condition (including the level of impairment in overall habitat connectivity) of individual complexes are provided in Tables 6 – 17 of Appendix A, and in the sub-regional summaries and habitat complex narratives in Appendix B.

Including only the habitat complexes that were rated, 52% of the complexes are either considered “functional” or “moderately impaired”, and 48% are either “severely impaired” or “lost” (Figure 16). Stream-delta and spit/marsh complex types were similar in the breakdown of Relative Condition ratings, except that the relative proportions of “lost” and “severely impaired” were substantially different. Five percent of the 92 rated stream-delta complexes were rated “lost” and 42% were rated “severely impaired” (Figure 17). Among the 141 rated spit/marsh complexes, 25% were rated “lost”, with 25% rated “severely impaired” (Figure 18).

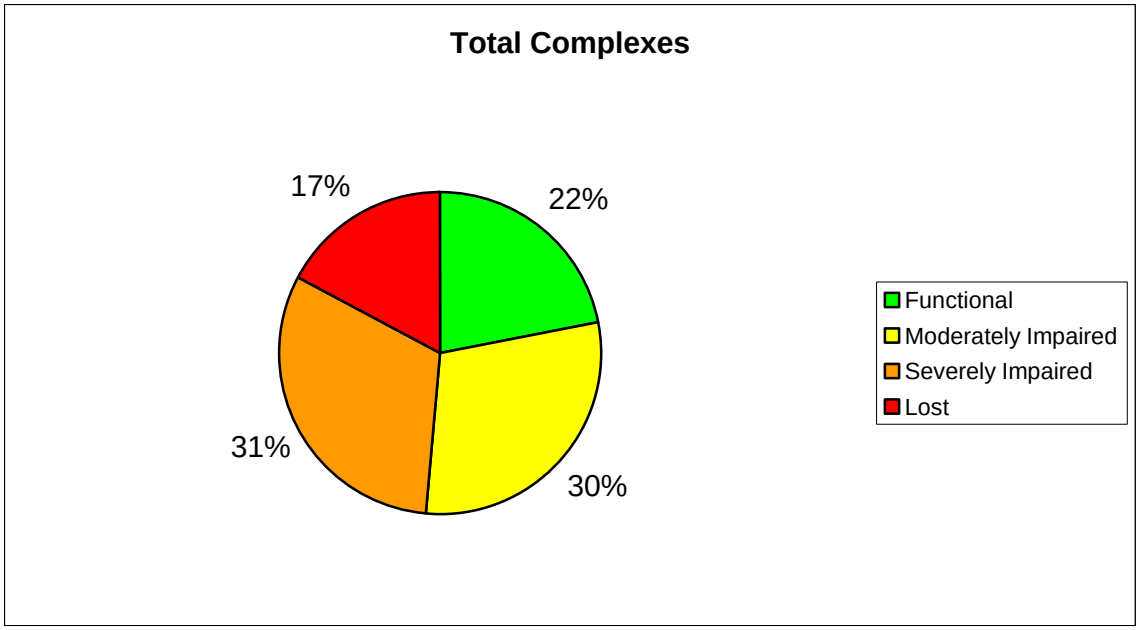

Figure 16. Relative Condition of the 233 rated (17 complexes were unrated) habitat complexes for the study area, by percentage of complexes within the four categories of Relative Condition.

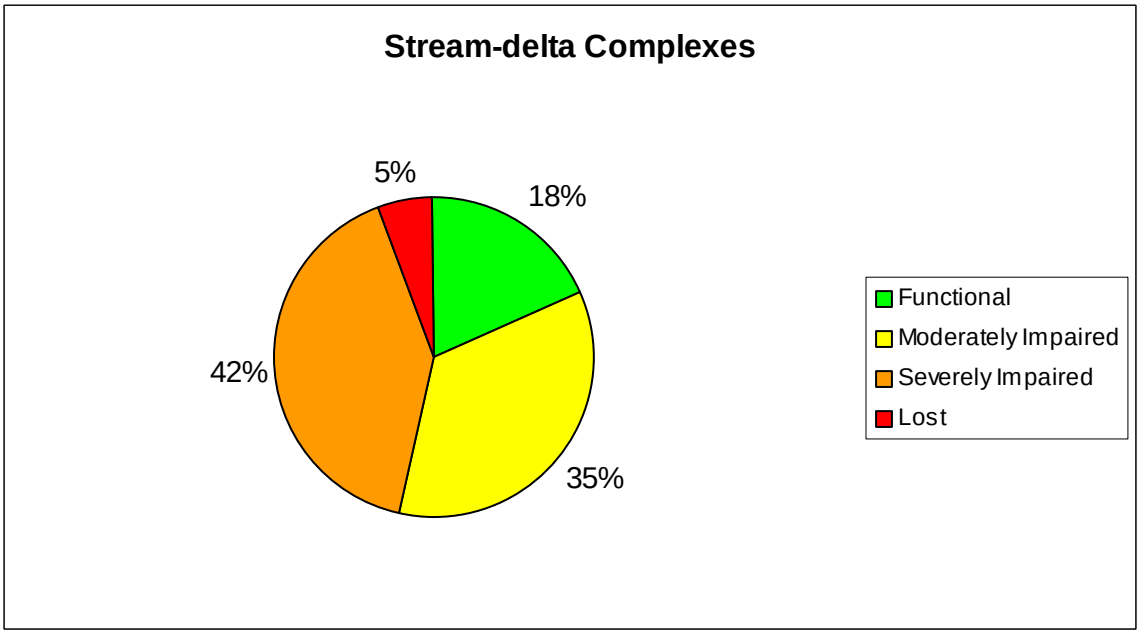

Figure 17. Relative Condition of the 92 rated stream-delta habitat complexes for the study area, by percentage of complexes within the four categories of Relative Condition. Eleven stream-delta complexes (11% of 103) were not rated for Relative Condition.

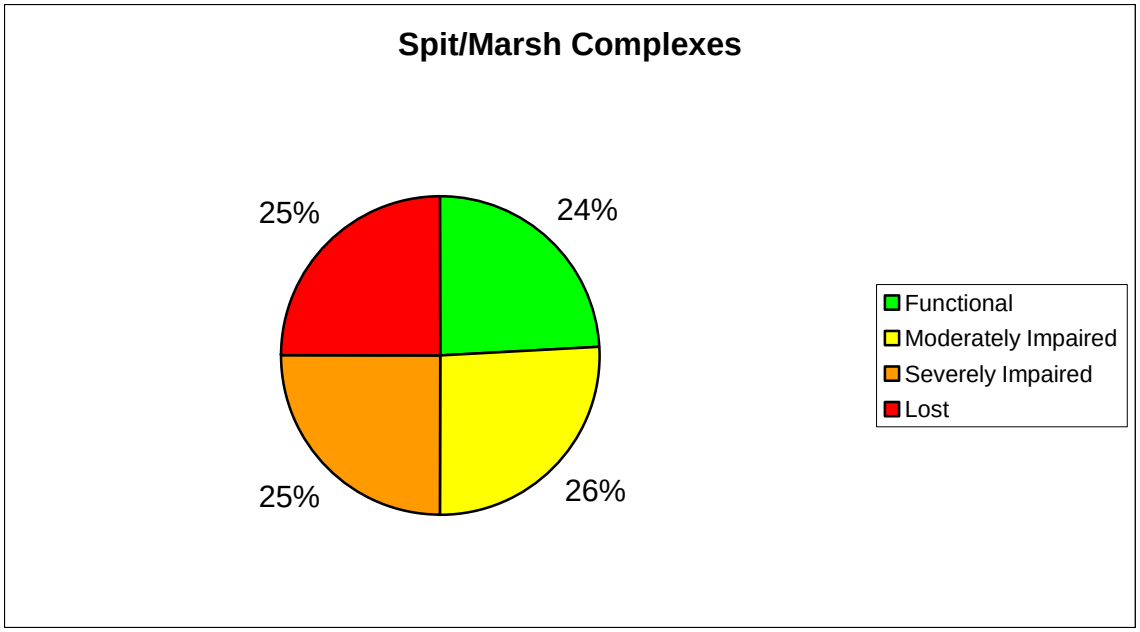

Figure 18. Relative Condition of the 141 rated spit/marsh habitat complexes for the study area, by percentage of complexes within the four categories of Relative Condition. Six (4%) of the 147 spit/marsh complexes were not rated for Relative Condition.

The distribution of Relative Condition ratings varies according to size class of habitat complexes (Figure 19 and Table 9). Of the 12 stream-delta complexes that were assigned a Relative Condition within the < 1 hectare size class, none were rated "lost", six "severely impaired", one "moderately impaired", and five "functional". Four additional small stream-deltas across the study area were not rated for Relative Condition.

About half (22 of 42) of the rated stream-delta complexes in the 1-10 hectare size class are either "severely impaired" or "lost" (four of these are "lost"). Fourteen of the 42 stream-deltas in this size class were rated "moderately impaired", and five "functional". Seven of the 49 stream-delta complexes in the 1-10 ha size class were not rated. Of the 32 stream-deltas in the 10-100 hectare size class, just one (Hawks Hole Creek) is considered "lost", 11 are "severely impaired", 14 "moderately impaired", and 6 "functional". Among the six largest complexes in the study area, all of which are stream-delta complexes, just one is considered "functional" (Tarboo Creek), two "moderately impaired" (Upper Quilcene Bay and Lynch Cove/Union River complexes), and three "severely impaired" (Skokomish, Hamma Hamma, and Pysht river complexes).

Of the 55 rated spit/marsh complexes (4 were unrated) that are in the smallest size class (< 1 ha), 20 (36%) are considered "lost", 6 were rated "severely impaired", 16 "moderately impaired", and 13 "functional". Of the 64 rated spit/marsh complexes (2 were unrated) in the 1-10 ha size class, 13 of these are "lost", 18 rated "severely impaired", 17 are "moderately impaired" and 16 are considered "functional". Of the 22 largest spit/marsh complexes in the study area (all in the 10-100 ha size class), 2 are "lost" (Point Hudson/Port Townsend and Driftwood Key), and 11 complexes are

considered “severely impaired”. Four of these largest spit/marsh complexes were rated “moderately impaired” and five “functional” (Dungeness Spit, Bywater Bay, Long Spit [in Dabob Bay], Foulweather Marsh, and Kala Point).

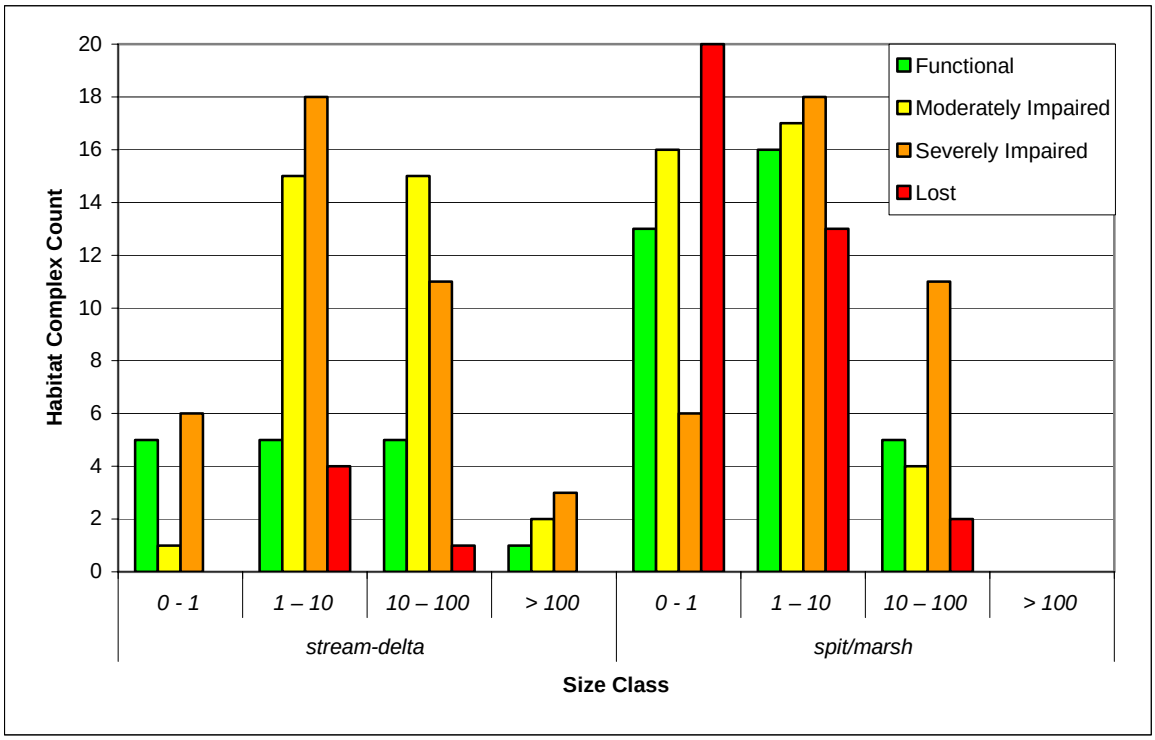

Figure 19. Relative condition of habitat complexes according to complex type and size class.

Table 9. Relative Condition of habitat complexes by size class.

Relative Condition/Size Class	Stream-Delta Complexes				Spit/Marsh Complexes			
	0-1	1-10	10-100	>100	0-1	1-10	10-100	>100
Functional	5	5	5	1	13	16	5	0
Moderately Impaired	1	15	15	2	16	17	4	0
Severely Impaired	6	18	11	3	6	18	11	0
Lost	0	4	1	0	20	13	2	0
Unrated	4	7	0	0	4	2	0	0
Totals	16	49	32	6	59	66	22	0

When we examine how Relative Condition of habitat complexes varied across the study area, we see differences between the Strait and Hood Canal regions, and by sub-region (Figure 20). Clusters of “lost” and “severely impaired” complexes occur in some parts of the study area, and other areas are characterized as having groupings of “functional” and “moderately impaired” complexes. A relatively large concentration of habitat complexes are rated either “lost” or “severely impaired” along the northeast coastline of Hood Canal (Kitsap Peninsula side), the Hood Canal Hook sub-region, southwest Hood Canal, and the Port Townsend Bay areas. Similarly, there are clusters of mainly “functional” and

"moderately impaired" complexes found in the upper Dabob Bay/Tarboo Bay area, south Sequim Bay, in the drift cell contributing to the Dungeness Spit in the Strait, the east shorelines of the Toandos Peninsula and Indian Island, and around Dewatto Bay. We return to this subject and its implications for juvenile salmonids migrating along the shoreline in the Discussion section below.

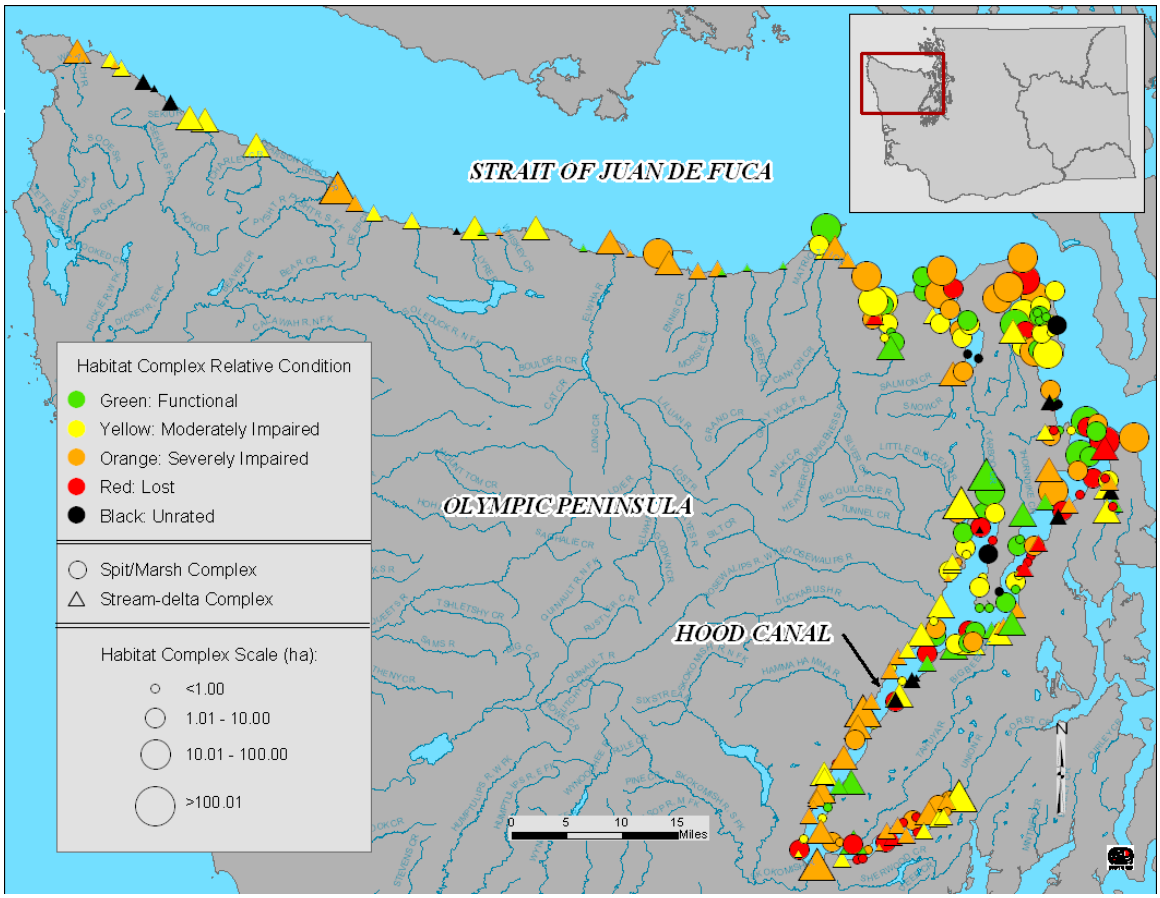

Figure 20. Relative condition of habitat complexes across the study area. The intent of this map is to identify landscape-level patterns in Relative Condition. For more details at the scale of sub-regions, refer to Appendix B.

DISCUSSION

Habitat Conditions at the Time of Early Surveys

The T sheets and GLO survey notes and maps were used in this study to approximate the extent and description of habitat features prior to alterations resulting from Euro-American settlement and industrial activity. However, it is well known that at the time of the earliest surveys (~1850s-1880s), settlement and commerce activities had already begun to change the character of landscapes, and in some instances, directly modify the watersheds, estuaries, and shorelines across much of the study area. For example, notes uncovered from the 1800s GLO surveys of the watersheds and coastline along the Strait

and Hood Canal repeatedly refer to forest fires and early logging activity affecting the forest conditions.

These fires, whether natural or human-caused (e.g., Native Americans in parts of the study area are known to have used fire to clear areas [Boyd 1999]), would have influenced forest conditions in much of the area at the time of early settlement, and potentially carried both negative and positive consequences for anyone who decided to settle in the area. For example, the General Description of Township 30 North, Range 5 West (in the eastern Strait sub-region) from 1862 suggests the importance of fire in the area, and how recent and frequent forest fires actually had facilitated settlement of the land. Interestingly, the ravines and riparian corridors through which the streams flowed in the township had been largely spared by the fires.

> … Each quarter section contains a large proportion of tillable land, easily cleared, most of the timber having been burnt off. There is a dense undergrowth, almost impenetrable but easily cleared… The annual fires which must have swept the surface for many successive seasons have in a great measure anticipated the labor of the settler in clearing the land of its heavy forests for cultivation while the ravines and gulches which lead into the water courses still afford an abundant supply of green fir, cedar, hemlock, alder and maple for all domestic purposes (Henry and House 1862).

Eldridge Morse (in Nesbit 1885) described the sawmills of Hood Canal as the "farmer's markets" of the area. Like much of Puget Sound, early logging activity in Hood Canal and in the Strait was typically concentrated along the shoreline and larger rivers due to the close proximity of water for easy transport of cut logs to the numerous sawmills that were springing into operation by the mid-1850s in Hood Canal (Chasan 1981; Amato 1996). There are numerous descriptions in the 1800s GLO notes, particularly in areas of Hood Canal, of logged off areas at or very near the marine shoreline. The T sheets, most notably from the 1883-84 period in Hood Canal, indicate dozens of logging camps, log chutes, and log dumps placed along the shoreline. The log chutes (or flumes) were used to quickly transport cut logs from typically steep upland areas to the adjacent water below. To enable boats and logs to travel on the larger rivers in the Hood Canal and Strait regions, of which there are relatively few compared with other parts of Puget Sound, there was a keen interest in clearing the channel beds of snags and drift logs that presented hazards and inefficiencies to navigation and log transport (Morse in Nesbit 1885; Collins et al. 2003).

Of direct significance to this study was the early modification to estuaries, tidal marshes, and spits across the study area. Due in great part to the difficult work required in clearing densely forested areas for settlement and cultivation, the tidal marshes were often considered prime locations for these early settlement activities. One reference from an early account of agricultural use of these marshes reads "… Puget Sound tide marsh is the *best* (italics are original) land in the world, and the river bottoms next" (Morse in Nesbit 1885). The T sheets capture some of the use by early settlers of these shorelines

and particularly in the tidal marshes where there is extensive evidence of the conversion of presumably former forested areas adjacent to marshes into pastures, orchards, and other agricultural plots. Also, there is some indication that upper tidal marsh areas were being used for pasture [as mentioned by Eldridge Morse (in Nesbit 1885)]. Fencing was very common, and limited attempts at diking were already evident as shown in the T sheets of our study area. Eldridge Morse (as described in Nesbit [1885]) provided perhaps the earliest comprehensive accounts and estimations of the extent of tidal marshes and their early diking in the Puget Sound area during the early-mid 1880s. In the Strait and Hood Canal regions, the Dungeness River was the only tidal marsh that had notable diking in 1884, where Captain E. H. McAlmond had diked off 60-70 acres for hay use. Although Morse indicated that the tidal marshes of the Hood Canal region were free of diking at the time, nearly all of the marshes were used for pasture to raise livestock. Only the Point No Point marsh (not in Hood Canal proper, but included in our study area) was described as having a few acres diked. Still, estuaries, tidal marshes and lagoons became popular locations for the storage of logs due to their often protective nature, and many of the stream-deltas and spit/marsh complexes identified in the Strait and Hood Canal were used for log storage by the late 1800s and early 1900s.

Study Sources of Error

Other than the potential error generated from the process of georectification of the historical T sheets (covered in the Materials and Methods section above), the following is a discussion of potential sources of error found in our study.

Historical Sources

One potential source of error is in how the historical T sheets (or other historical information that we used) represented habitat features on maps, or characterized them in field notes such as the GLO surveys, that would lead us to in turn potentially misrepresent the spatial extent or character of historical habitat condition. There are indications suggesting for several habitat complexes that the T sheets estimated the landward (inner) extent of salt marsh conservatively (by delineating the boundary somewhat seaward of its actual location at the time of survey; see Shalowitz 1964 and Collins and Sheikh 2005). We noted these instances when they were evident by comparing the T sheet boundary information with that of the GLO notes (if available), early air photos, or more contemporary air photos. Instead of modifying the T sheet boundary and attempting to correct for these apparent mapping inaccuracies [as Collins and Sheikh (2005) attempted in their study that included the Strait and Hood Canal], we indicated that our historical estimates of tidal marsh were probably conservative in the particular complexes affected in this way.

As mentioned previously, the T sheets of the Western and Central Strait sub-regions in particular did not indicate salt marsh; this was probably due in large part to the scale, typically 1:20,000, that limited the amount of detail that could be shown. However, with few exceptions, the complexes in these sub-regions were probably naturally limiting in the amounts of salt marsh present. Except for the Pysht River and Salt Creek complexes,

where we relied on other sources in addition to the T sheets [such as Eldridge Morse (in Nesbit 1885), or GLO survey notes] in estimating historical amounts of tidal marsh, we were unable to make any historical estimates for tidal marsh in other complexes, including the Hoko and Clallam rivers, and Morse Creek, all of which support limited marsh habitat today. Because of this, our overall estimate of estuarine emergent marsh (tidal marsh) for the entire study area is probably conservative (i.e., we more than likely produced an underestimation of historical marsh rather than an overestimation).

Mapping inconsistencies were evident in the early T sheets. For example, the amount of salt marsh associated with a habitat complex sometimes differed as shown in two different T sheets from roughly the same time period. These were relatively rare occasions in our study, but where they did occur we had to consider a number of factors in deciding which T sheet probably provided the more accurate representation, including consultation with GLO notes (if they existed), contemporary air photos, topographic data, and rational thought. In the case of the Miller Creek complex (South Hood Canal sub-region), both T sheets (T-1560a and T-1560b) indicated similar patch sizes of salt marsh, though one of the T sheets also showed an additional smaller patch of "submerged" marsh that was not bounded by dark lines as was customary with salt marsh. In making our estimates of salt marsh for the Miller Creek complex, we chose the T sheet that did not indicate the submerged marsh, giving us perhaps a low-end estimate of historical salt marsh at the site. At another site (Olympic View Creek in the North Hood Canal sub-region), we chose estimates from one T sheet over another because it was clear, by consulting a contemporary LiDAR-based topographic map, that one of the T sheets had shown salt marsh in a location that was not topographically possible, whereas the other T sheet had indicated a more realistic and limited representation of the extent of salt marsh at the site.

Current Habitat Delineations

There is also potential inaccuracy in our current delineation of tidal wetland habitat. This is particularly evident in our salt marsh delineations that may have been relatively generous (i.e., included a larger surface area) in comparison with those from the early T sheets (see immediately above and also Materials and Methods section of this report). This is because we included transitional areas involving upland grassland/emergent wetland or scrub-shrub wetland/emergent wetland areas as "salt marsh", whereas T sheet surveyors may have been inclined to map such areas as upland "grassland" or simply indicate wooded marsh or forest. The complexes potentially affected in this way are those where these transitional vegetation zones are particularly broad rather than those where emergent marsh abruptly transitions into an upland forest type.

Comparisons with Other Studies

Because of overlap in geographic scope, and similarities in the use of historical and contemporary sources in our study and that of Collins and Sheikh (2005), it makes sense to compare the approach and results of that study with ours. Apart from distinctions in how "habitat complexes" were identified and defined, there are important differences in

the estimates of historical and current day tidal wetland habitat reported by Collins and Sheikh (2005) and in our study. These differences can be explained by slight though important variations in the habitat types considered, and in the sources (both historical and current) emphasized to make the habitat delineations. First of all, Collins and Sheikh (2005) included estuarine emergent marsh (EEM), estuarine scrub-shrub (ESS), and riverine tidal (RT) wetland habitats (following on the Cowardin et al. [1979] wetland classification) as their main categories of "tidal wetland". Of these three wetland types, we mapped only EEM, and as described below, we sometimes arrived at this delineation in a somewhat different way than Collins and Sheikh (2005) might have. We made no effort to provide historical estimates of ESS or ETT wetlands as was done by Collins and Sheikh (2005) because we relied almost solely on the T sheets for delineating historical habitat conditions, and the T sheets typically lacked an accurate characterization of both ESS and RT wetland types (these wetland types typically occur in a zone that is on the upstream margin of the T sheets). Also, ESS and RT wetland types were naturally limited in areal extent in most of our study area. For example, Collins and Sheikh (2005) reported that of the historical amount of tidal wetland in the Hood Canal region, about 10% of it was ESS, and 5% was RT (the balance of 85% being EEM), most of the ESS and RT wetland types occurring in the Skokomish estuary. Collins and Sheikh (2005) were able to augment historical habitat information derived from the T sheets using the GLO survey notes and/or maps, as well as early air photos to make adjustments to the T sheet delineations. Because these other sources typically better characterized ESS and RT wetland types than did the T sheets, this allowed them to delineate EES and RT wetland types separately from the EEM wetland type. We generally did not incorporate these additional historical sources in a quantitative way or make adjustments to our historical habitat delineations based on them; rather we chose to use them in a qualitative manner to check on the reliability of the T sheet information.

In addition to EEM, we mapped another category of tidal wetland habitat - lagoons (enclosed and semi-enclosed) - that it appears Collins and Sheikh (2005) may not have always included in their estimates of tidal wetland. They apparently mapped "lagoons" only when they were directly associated with estuarine emergent marsh habitats (Brian Collins, personal communication), whereas we included as lagoons bodies of water associated with spits even if emergent marsh was absent from the complex. Finally, we also included in our overall estimates of "tidal wetland" habitat (both historical and current day), the surface area of what we considered the tidal extent of river channels, whereas Collins and Sheikh (2005) did not include this area in their tidal wetland estimates. As a consequence of these differences, the Collins and Sheikh (2005) estimate for historical EEM tends to be slightly greater than our estimate (~ 3% for Hood Canal). This likely is largely because the T sheets that we relied on in some places (e.g., Skokomish, Lynch Cove/Union River) showed the landward (i.e., inner) boundary of salt marsh in a location seaward of the actual boundary as indicated by the GLO survey and/or early air photos. Also, it appears that a few salt marshes may have already received some diking by the time of the first T sheets (again, possibly the Skokomish) that would have affected how the T sheet surveyors drew salt marsh boundaries.

There were also some differences in the use of contemporary sources of information used to delineate current day habitat conditions. Although both Collins and Sheikh (2005) and our study relied primarily on air photos (both vertical and Wash. Dept. of Ecology oblique photos) to delineate current day tidal wetland habitat, the studies diverge somewhat in that Collins and Sheikh (2005) also employed high-resolution LiDAR-based topography (where available) or the 10 meter digital elevation model (DEM) to make subtle distinctions in elevation that would have consequences for vegetation. They also used the National Wetland Inventory (NWI) wetland maps (which are typically based on the interpretation of relatively coarse-scale air photos from the 1970s-80s period) to help them make habitat delineations in areas that were particularly challenging to delineate using air photos. We consulted the NWI maps and LiDAR topography in few instances [e.g., Skokomish River (NWI), Graysmarsh (NWI), and Olympic View Creek (LiDAR)] but our use served only as guidance in helping interpret vegetation and hydrology patterns that we were seeing from the contemporary air photos, or where we suspected the T sheets inaccurately mapped salt marsh.

Another way that our current day habitat delineations and that of Collins and Sheikh (2005) may have differed is that we included as EEM, areas of salt marsh and other tidally-influenced emergent marsh that had been diked in the past (and may still be partially diked today), but are now reverting back to salt marsh. Probably the best example of this is in the Skokomish estuary where dikes that are no longer maintained have been breaching since the 1990s and marsh and other wetland types, including what we categorized as lagoons, are developing behind these diked areas. These areas were categorized as "upland" according to the NWI maps (mainly because the NWI maps pre-date the breaching of the Skokomish dikes), and Collins and Sheikh (2005) therefore may not have included these as estuarine emergent marsh (EEM). This probably explains in part why our current day estimates for EEM are considerably greater (7-25%) for Hood Canal than that reported by Collins and Sheikh (2005).

Finally, one other distinction between Collins and Sheikh (2005) and our study is that we were able to evaluate the possible causes of habitat changes on a more comprehensive and detailed level (i.e., scale of individual habitat complexes) whereas Collins and Sheikh (2005) were not afforded the time to examine the specific causes of the habitat changes observed. Also our study frames a discussion around habitat management and conservation considerations at the scale of the individual habitat complex and at broader landscape levels, and in this way is meant to offer another tool to help prioritize habitat protection and restoration actions.

Two other studies bear comparative reference in the context of our study. One truly unique report was an inventory of tidal marshes made of the Puget Sound region in the 1880s that allows for an interesting comparison with the estimates we derived from the T sheets in our study area. Eldridge Morse (reported in Nesbit 1885) estimated that about 2,000 acres (809 hectares) of tidal marsh occurred in Hood Canal, including Port Gamble and Port Townsend bays, a figure remarkably close to our own estimate of 1,952 acres (790 hectares) of the same area (2.4% difference).

A recent report, prepared as part of the PSAT/Shared Strategy (Redman et al. 2005), included an assessment of "pocket estuaries" across Puget Sound. The authors developed a scoring system that is in many ways similar to our "relative condition" rating. Using the most recent series (2000-2002) of WDOE oblique air photos, Redman et al. evaluated freshwater inputs, the presence of human stressors (e.g., shoreline modifications), and additional factors that lead to the scoring of pocket estuaries as either "properly functioning", "at risk", or "not properly functioning" depending on whether a pocket estuary provided for salmon functions of food production, refuge from predators and osmoregulation. A critical piece of information lacking from their assessment, they acknowledged, was historical conditions that would have enabled them to compare the current day function of these pocket estuaries to their function prior to development in the 1800s. Our rating of "relative condtion" of habitat complexes is based on differences between historical and contemporary conditions.

Landscape Changes in Tidal Wetland Habitat

Although the cumulative changes to tidal wetland habitat that we reported across the study area might be considered modest (total 7% reduction, Table 6 in the Results section above), some sub-regions, and many individual complexes have been changed substantially. Indeed, some complexes have been lost altogether. Furthermore, the quantitative loss or gain of habitat by itself does not describe how the connectivity within and between habitat complexes has changed, or how the quality or function of habitat has been altered. This point is illustrated when we compare the changes in habitat surface area associated with the eleven stream-delta complexes that historically had greater than 20 ha of tidal wetland habitat with habitat changes associated with the 239 other complexes across the study area. These eleven stream-delta complexes accounted for 47.5% of the total amount of historical tidal wetland habitat in the study area (Figure 21), and today the same complexes account for about 56% of the total tidal wetland. Collectively these eleven complexes showed a 9% gain in tidal wetland, while tidal wetland habitat associated with the remaining 239 complexes together has decreased by 22% (Figure 22).

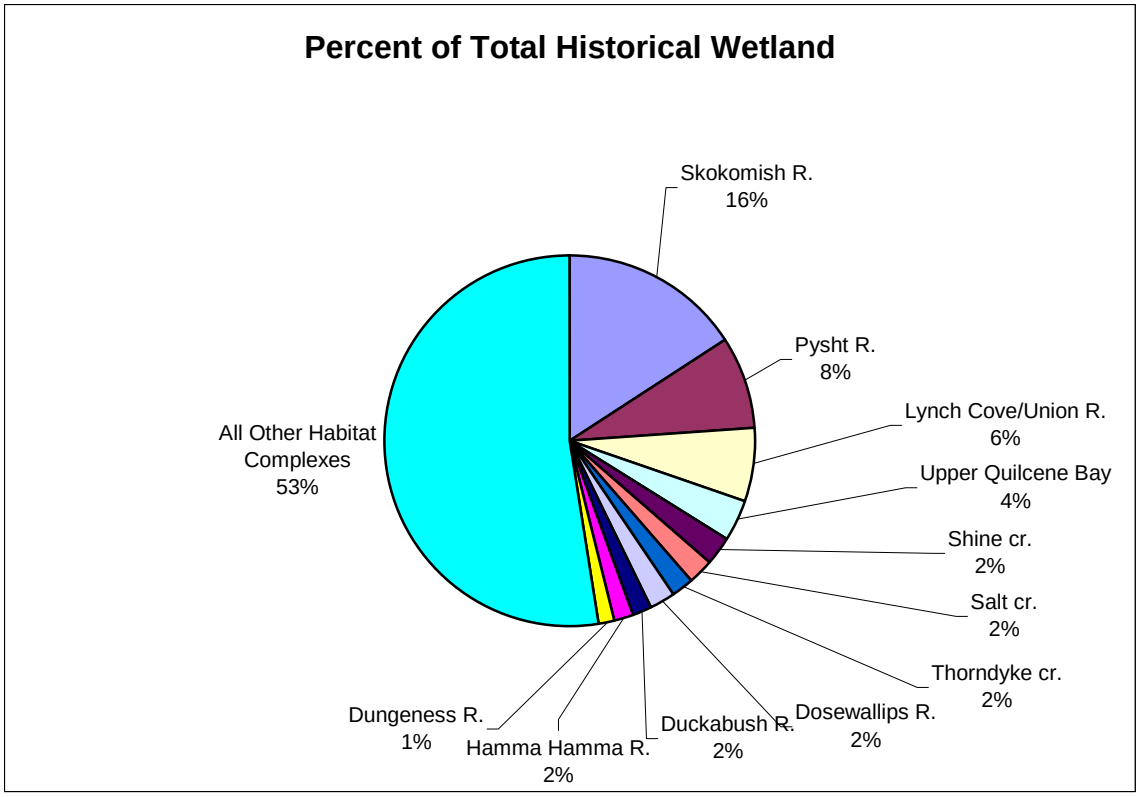

Figure 21. Historical amounts of tidal wetland habitat (i.e., marsh, associated channels, and lagoons) associated with the 11 stream-delta complexes that supported the most tidal wetland habitat, compared with tidal wetland habitat associated with the remaining 239 habitat complexes across the Strait and Hood Canal study area.

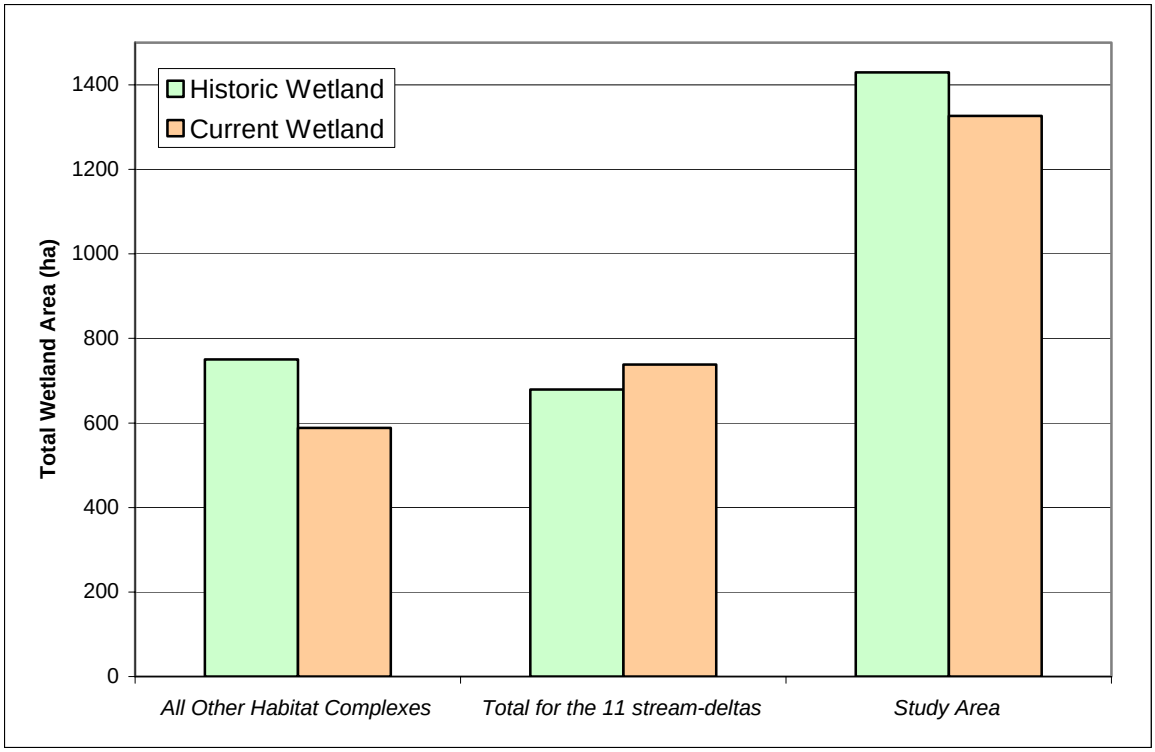

Figure 22. Historical changes in the surface area (ha) of tidal wetland habitat associated with the 11 largest stream-deltas (as defined in the text above) compared with changes associated with the remaining 239 habitat complexes.

The primary reason for the gains seen in many of these larger 11 stream-delta complexes (Figure 23) is that their deltas have prograded and salt marsh now grows a considerable distance seaward of the historical extent. For example, the observed gains in tidal marsh habitat in two sub-regions in particular – Dabob Bay and Central Hood Canal (Figure 11 in the Results section above) – can be attributed to delta progradation in the largest stream-delta systems, including Upper Quilcene Bay (Big Quilcene and Little Quilcene river deltas), and the Dosewallips, Duckabush, and Hamma Hamma river deltas (Figure 23). It appears this seaward advance in salt marsh has typically offset or more than compensated for the losses of salt marsh from diking and filling (e.g., Highway 101) that have taken place in other parts of these estuaries. At the same time, however, the seaward advance in salt marsh has displaced former tidal flat habitat, a habitat type for which we were not able to make quantitative estimates of historical changes for the study area. We want to emphasize that the potential degree of historical loss of tidal flat habitat associated with delta progradation in these larger stream-deltas should not be seen as trivial because of the value of tidal flats as productive salmonid habitat. For this reason, one of the recommendations we make at the end of this report is that future historical assessments quantify the historical changes to tidal flat and unvegetated intertidal habitat using historical bathymetric data derived from the hydrographic charts ("H sheets"). Such an assessment would more clearly define surface area changes caused by filling and seaward advance of the low tide line (e.g., through the process of sediment progradation) in historical tidal flat areas.

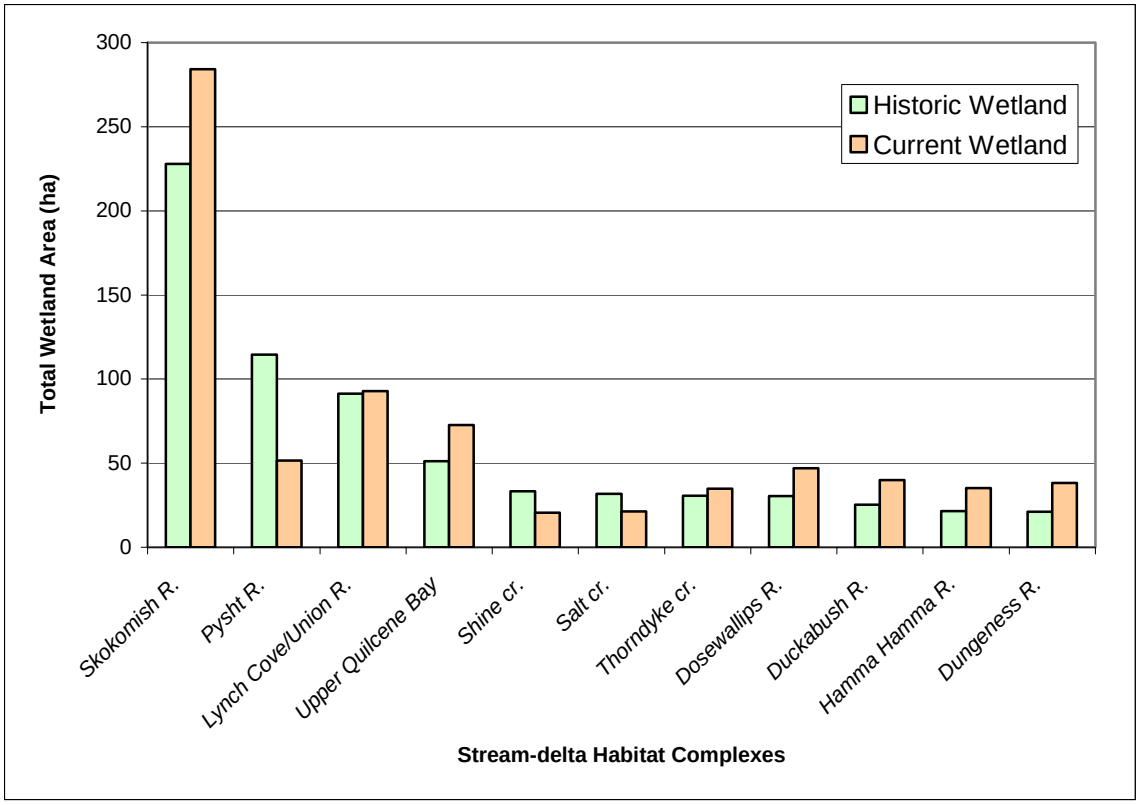

Figure 23. Habitat changes associated with the 11 stream-delta complexes that historically had more than 20 ha of tidal wetland habitat.

The causes of the delta progradation might vary somewhat from complex to complex, though presumably they are related to the filling, channelization and diking of floodplain and estuarine reaches, and also possibly increased sediment yield associated with watershed land use (e.g., logging, road construction). These actions have modified the way sediment and large woody debris are distributed across the estuary, usually restricting the distribution of riverine sediments across the estuaries, and in some instances, decreasing tidal prism, which reduces the efficiency with which sediment is moved through the deltas with tides and floods. The area where sediment can deposit is thus confined, and in extreme cases the delta protrudes out in a tongue shape (e.g., Upper Quilcene Bay associated with the Big and Little Quilcene rivers in the Dabob Bay sub-region). The consequence of this delta progradation on salmon habitat is that the overall habitat connectivity within these estuaries has become impaired. In some instances, channel and salt marsh habitat, though it may still exist, has become isolated from riverine processes and less accessible to juvenile salmon that might emigrate from the river (e.g., Hamma Hamma and Duckabush rivers in the Central Hood Canal sub-region). Many of the smaller stream-delta complexes in the study area have also been affected by delta progradation, and presumably for the same reasons (i.e., increased watershed sediment yield and floodplain/estuary channelization and diking). In short, the overall connectivity of estuarine habitats in these larger systems, not to mention many other complexes throughout the study area, has been impaired by diking, channelization, loss of large wood, and in the Dosewallips, Duckabush, and Hamma Hamma (to draw on our

examples from above), the presence of the Highway 101 causeway (see details in narrative summaries of Appendix B).

Salt marsh habitats in many of our study's larger (as well as smaller) stream-delta complexes have also been affected in yet other ways by diking, road causeways and other fill (that act as dikes). In the Skagit River delta, Hood (2004) found that the widths of tidal channels in salt marshes located ***seaward*** of dikes was reduced substantially in comparison with tidal channel widths in undiked "reference" marshes. He attributed this to a decrease in tidal prism caused by dikes located even in the upper landward portions of these marshes. The dikes reduce tidal energy causing the accretion of sediment in the channels over time, and they consequently become narrower. Therefore, not only do the dikes directly impact the area behind them (that have now become excluded from the tides) but they apparently can significantly affect the adjacent habitat even in the areas that are still accessible to the tides. The ecological implications of reducing tidal channel widths can be critical for juvenile salmon species (e.g., chinook and chum) that favor these relatively protective and productive estuarine habitats. Unfortunately in our study we were not able to examine historical changes in specific tidal channel habitats to see if diking of salt marsh has affected the seaward areas of marshes and channels in this way. The point we wish to make from this is that estimates of surface area changes in habitat, though perhaps useful as an indicator, are quite often not adequate in themselves in describing habitat changes in that they do not wholly represent modifications in the quality or function of salmon habitat. In fact, using the areal estimates of salt marsh alone can mislead one into thinking that habitat conditions are perhaps more suitable now than in historical times when actually habitat function may be considerably impaired and less suited to salmon. Though we did not make quantitative assessments (other than surface area) to describe changes in habitat quality or function associated with habitat complexes, we did use the Relative Condition rating as a qualitative means of indicating this change in function. Indeed, we gave consideration to overall habitat connectivity [including the "indirect" diking effects as described above from Hood (2004)] as well as watershed impacts on processes in the Relative Condition rating as applied to complexes affected in these ways.

Habitat Connectivity and its Relevance to Salmon

The value of habitat to salmon depends on the capacity of a habitat to support salmon and the opportunity the fish have to use that habitat (Redman et al. 2005). The capacity or quality of habitat refers to attributes such as prey production or refuge afforded by geomorphic features (such as a barrier spit), whereas opportunity refers to the ability of a juvenile salmon to actually gain access to and benefit from the habitat capacity. For example, the tidal elevation and geomorphic features can "dictate both the extent of fish access into habitats and the interface along which they feed," refugia from predation, and the "proximity to deepwater habitats" (Simenstad 2000 and Simenstad and Cordell 2000, cited in Redman et al. 2005).

In the Skagit River delta area of Puget Sound, researchers in recent years have used the term "pocket estuary" (Beamer et al. 2003) to describe an estuary that meets specific

environmental and ecological conditions that serve juvenile salmon (i.e., food production, foraging, refuge from predation, osmoregulation), particularly chinook, though they may apply in many respects to other salmonid species as well (Redman et al. 2005; Beamer et al. 2003; Hirschi et al. 2003a). Pocket estuaries are typically "small sub-estuaries that form behind spit or barrier beach landforms at submerged, tectonically, or glacially-derived valleys or at small creek deltas." They support relatively protected (from wave action) tidal lagoon, salt marsh and channel habitats, and local freshwater sources (either surface or groundwater) lower salinity during some part of the year, typically winter and spring (Beamer et al. 2003). Many of the spit/marsh complexes and stream-delta complexes (particularly those that provide marsh or lagoon habitats) that we have identified in the Strait and Hood Canal as part of this study, fit this definition of "pocket estuary" (Beamer et al. 2003; Redman et al. 2005).

We were interested in knowing how tidal accessibility to salt marsh, channel, and lagoon habitats (collectively termed "tidal wetlands" in our study) has changed since the 1800s, not just at individual habitat complexes but across broader landscape scales as well (i.e., sub-regional and regional). That is, we wanted to know how the distance between tidally-accessible habitat complexes has changed. In addition, we were interested in changes in the quality of the habitat (as indicated by the Relative Condition of the complexes) that juvenile salmon could potentially access. To make this assessment we compared the historical and current day numbers of complexes (both stream-delta and spit/marsh) that provided tidally-accessible wetland habitat. We also compared the historical and current amounts of tidal wetland habitat associated with these tidally-accessible complexes. For this particular analysis, we were not interested in considering stream-delta complexes that have never provided salt marsh or lagoon habitats, nor were we interested in considering spit/marsh complexes that have never been accessible to the tides (except perhaps rarely). Our intent was to focus on the changes in complexes that are most likely to provide a suite of functions for juvenile salmon (including refuge from predation, food production and foraging, and osmoregulation).

Across the study area, we identified 123 habitat complexes (53 stream-deltas and 70 spit/marshes) that historically provided tidally-accessible habitat, and 1,289 ha of marsh, lagoon and associated channel habitat (Table 10 and Figure 24). Nine spit/marsh complexes no longer maintain a surface water connection with nearshore waters; however, nine other spit/marsh complexes now show a surface water connection where our historical sources do not clearly indicate such a connection. Among these complexes are a few that include marinas or dredged out channels that today artificially allow for tidal access (e.g., Violet Point on Protection Island, Discovery Bay sub-region). Four additional complexes are now considered "lost" (according to our Relative Condition rating) and provide very little or no tidal wetland habitat.

Table 10. Historical changes in the numbers of habitat complexes that provided tidally-accessible wetland habitat (i.e., marsh, lagoon), and the amounts of tidal wetland habitat associated with these complexes throughout the study area.

Sub-region	Number of Complexes			Tidally-Accessible Wetlands (ha)		
	Historical	Current	Change	Historical	Current	% Change
Western Strait	-[1]	3	N.A.	-	4	N.A.
Central Strait	2	2	0	146	73	-50
Eastern Strait	8[2]	9	+1	174	164	-6
Sequim Bay	6	5	-1	79	71	-10
Discovery Bay	8	7	-1	23	21	-9
PT/Oak Bay	15	17	+2	56	59	+5
HC Entrance	13	10	-3	84	55	-35
North HC	8[3]	6	-2	95	62	-35
Dabob Bay	11	12	+1	109	130	+19
Central HC	23	19	-4	133	170	+28
South HC	14	15	+1	269	325	+21
HC Hook	15	12	-3	119	108	-9
Study Area	**123[4]**	**117**	**-6**	**1,289[5]**	**1,242[5]**	**-4**

[1] T sheets in this sub-region did not indicate tidal wetlands (e.g., salt marsh) due to coarseness in scale (1:20,000) and limited amount of wetlands that occur in the area. Therefore, we could not make a valid comparison between historical and current habitat estimates.

[2] The T sheet for the Morse Creek habitat complex did not indicate tidal wetland and we therefore had no reliable historical estimate.

[3] The T sheet did not indicate the presence of two spit/marsh complexes in the North Hood Canal sub-region that provide tidally-accessible wetland today.

[4] If we assume that the three stream-delta complexes in the Western Strait, Morse Creek in the Eastern Strait, and the two spit/marsh complexes in the North Hood Canal sub-region all provided tidally-accessible wetland habitat (i.e., marsh and/or lagoon) historically (though we have no documentation that they did provide this habitat primarily because of coarse and/or poorly detailed historic maps) as they do today, this would result in a total of 129 habitat complexes (instead of the reported 123). This assumption would also result in historical amounts greater than the 1,289 ha of tidally-accessible wetland habitat that we have reported in the table above.

[5] Because of rounding to whole numbers, the total amounts of tidal wetland habitat shown are slightly different than the sum of the values in the above rows.

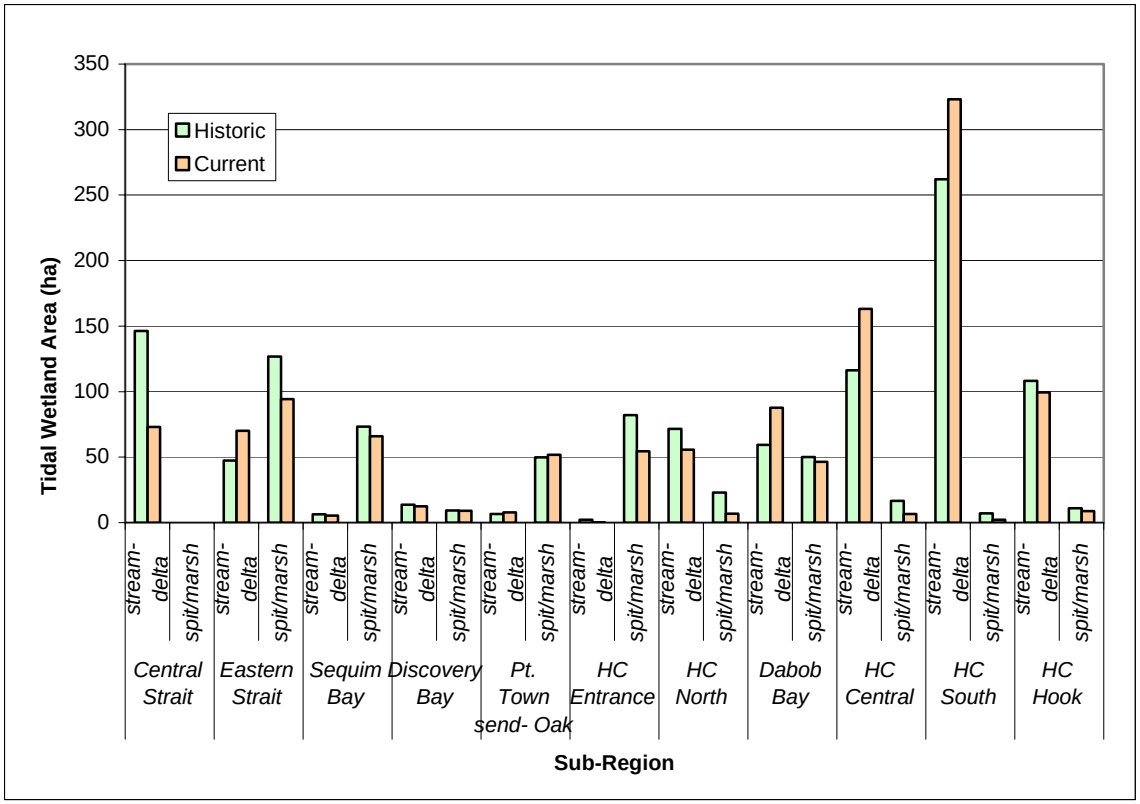

Figure 24. Historical changes in the amounts of tidally-accessible wetland habitat associated with stream-delta and spit/marsh complexes, by sub-region. Note: we did not make historical estimates of tidal wetland habitat in the Western Strait sub-region because the T sheets lacked the detail needed to make an assessment of tidal wetland, making an assessment of changes in tidal wetland habitat for the Western Strait sub-region invalid. Though we lacked detailed T sheet information for the Central Strait sub-region as well, we were able to supplement the T sheet information with other sources (i.e., GLO notes and Eldridge Morse [in Nesbit 1885]) to provide historical estimates.

We should mention that we have no historical record of tidal wetland associated with 13 complexes that today support tidal wetland habitat (e.g., Sekiu, Hoko, Clallam, and Elwha rivers, Seabeck and Spencer creeks). Tidal wetland habitat was likely present at some of these complexes, but the T sheets were too coarse in scale and lacked the detail to show salt marsh. In other complexes, it is probable that salt marsh has developed where it did not exist historically. If we had no reliable historical record of tidal wetland then this complex was not included in the 123 complexes listed above in Table 10 (i.e., the 13 complexes were not included). We realize that this creates a potential bias in the result of this particular analysis in that less severe losses of habitat complexes and tidal wetland habitat may be represented than has actually occurred.

Considering changes in the status of surface water connectivity in many complexes, and the loss of habitat complexes, today there are 117 habitat complexes (55 stream-delta and 62 spit/marsh complexes) that currently provide tidally-accessible wetland (compared

with 123 historically)(see Table 10 above). A total of 1,242 ha of tidal wetland habitat (compared with 1,289 ha historically; 4% decrease) are associated with these 117 complexes. Of these 117 complexes, four (3%) are considered "lost", and 40 (34%) are considered "severely impaired" according to our Relative Condition rating, and the amount of tidal wetland habitat associated with these 40 complexes has been reduced from 417 ha to 284 ha (32%). Therefore, in total, 72 habitat complexes today provide tidally-accessible wetland habitat and were rated as either "functional" (30 complexes) or "moderately impaired" (42 complexes; one of these complexes was not rated for Relative Condition). This constitutes a 41% reduction from the 123 historical complexes.

Putting this in the context of migrating juvenile salmon along the shoreline, there are fewer complexes (and less habitat associated with those complexes) along the shoreline today that provide tidal wetland habitat and connectivity to this habitat than during the 1800s. Furthermore, many of the complexes that still provide habitat and connectivity today we have rated "severely impaired". Some areas along the shoreline have been impacted more severely than others, with the north part of the Kitsap Peninsula (especially south of the Hood Canal Bridge), the southwest shore of Hood Canal, and the Hood Canal Hook sub-region being areas where relatively high concentrations of complexes that historically provided surface water connectivity and tidal wetland habitat have been "lost" and/or their surface water connectivity has become lost or reduced. Many other complexes in these areas are considered "severely impaired" (Figure 25). Though we do not consider any of the complexes represented in the Strait (west of Sequim Bay) as "lost", a high proportion of the complexes are considered "severely impaired" in that area. These areas are not providing the habitat conditions for juvenile salmon or the accessibility to wetland habitats that were present historically. However, other parts of the study area include clusters of complexes that retain surface water connectivity and habitat conditions that are considered "functional" or "moderately impaired". These include the Tarboo Bay area within Dabob Bay (including Tarboo Creek, Long Spit, and Broad Spit complexes), and portions of the middle-Kitsap Peninsula and along Indian and Marrowstone islands.

In sum, the results of our study indicate a reduction in tidal wetland habitats and a loss or impairment in the connectivity of these habitats across landscape (i.e., sub-regional and larger) and local scales (i.e., within individual habitat complexes). Beamer et al. (2005) have shown that the connectivity of estuarine habitats in and around the Skagit River delta influences the abundance of juvenile chinook salmon in these various habitats, including "pocket estuaries". They use these observations to suggest that increasing habitat connectivity should be a part of a restoration strategy that addresses chinook recovery in the Skagit area. We have no direct evidence of how the abundance of chinook or other juvenile salmon species relates with the connectivity of nearshore habitats in the Hood Canal and Strait regions. However, it is likely that the proximity of "pocket estuaries" and other nearshore habitats to natal estuaries is an important factor determining juvenile salmon use of these habitats in the Strait and Hood Canal.

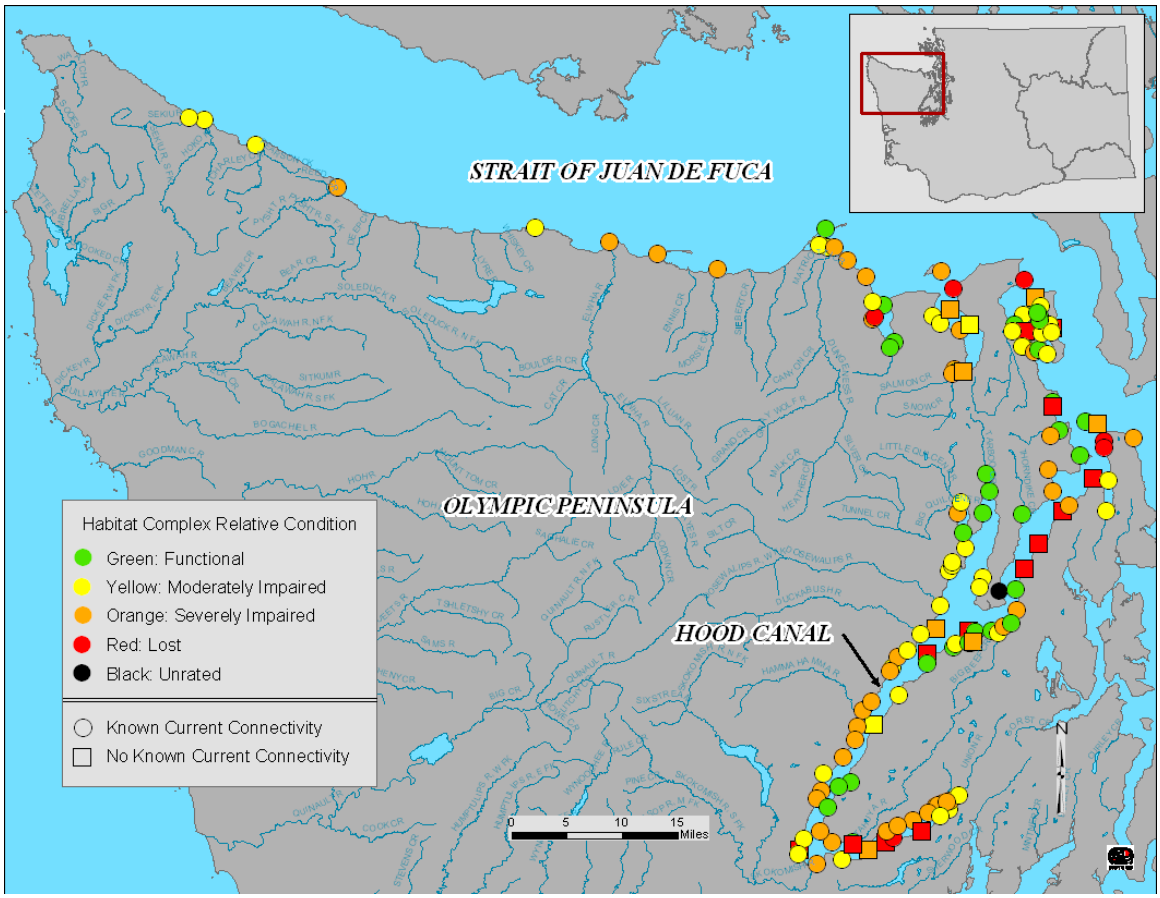

Figure 25. Relative condition and changes in the status of surface water connectivity in habitat complexes (both stream-delta and spit/marsh types) that historically and currently have provided surface water connectivity and tidal wetland habitat (i.e., marshes, channels, lagoons). Notice particular parts of the study area where there are concentrations of complexes that have lost their historical surface water connectivity and most complexes are either "lost" or "severely impaired" (e.g., Hood Canal Hook sub-region), and other parts where there are clusters of mainly "functional" or "moderately impaired" complexes, and surface water connectivity has been maintained (Tarboo Bay part of Dabob Bay sub-region).

RECOMMENDATIONS

Habitat Protection and Restoration Recommendations

A considerable effort has been made in recent years to develop habitat recovery strategies and action plans for salmon in the Hood Canal and Strait of Juan de Fuca regions. The North Olympic Peninsula Lead Entity (NOPLE) and Hood Canal Coordinating Council (HCCC) have each developed conservation strategies and project lists for the Strait and north Washington coast (NOPLE; http://noplegroup.org/NOPLE/pages/nearshore.htm), and the Hood Canal/eastern Strait (HCCC; see HCCC 2004) regions to address

implementation of salmon habitat recovery actions. These strategies drew heavily on recommendations from a series of limiting factors analysis (LFA) reports completed for the Strait and Hood Canal regions (see Haring 1999, Smith 2000, Correa 2002, Correa 2003, and Kuttel 2003). In addition, recovery plans have been drafted for ESA-listed Hood Canal/Eastern Strait summer chum (HCCC 2005), and for Chinook salmon in Hood Canal, Dungeness, and Elwha rivers (Shared Strategy Development Committee 2005; http://www.sharedsalmonstrategy.org/plan/). These recovery plans include specific actions, including habitat protection and restoration, intended to help recover the listed populations. We encourage the reader to consult these documents.

Similar to the priorities and actions outlined in the above documents, our habitat conservation recommendations are aimed at salmon recovery. However, by addressing habitat-forming processes, it is expected that many other organisms, and ecosystems as a whole, should benefit from the recommended actions if implemented at appropriate scales and in concert with adequately protective land use policies.

We provide habitat conservation recommendations for individual complexes and at the sub-regional scale (refer to the 'Management Recommendations' section of the individual sub-regional summaries in Appendix B). In addition, we provide summary tables (see Tables 18 – 31 in Appendix A) that organize the habitat complexes according to a number of factors that we think those interested in conservation would want to consider in making habitat protection and restoration decisions. These factors include:

1) The historical amount of tidal wetland habitat associated with individual habitat complexes,
2) Historical changes in the surface area of tidal wetland habitat,
3) Impairment in the connectivity of habitats (including the loss or reduction in surface water connectivity of spit/marsh complexes), and
4) The status of freshwater inputs to these complexes.

These factors help describe how the individual habitat complexes potentially function for juvenile salmonids in terms of supporting productive feeding areas, refuge from predation, and osmoregulation. We encourage readers to also consider additional factors, including the extent of indirect impacts (i.e., impairment of watershed and drift cell processes) affecting the function of habitat complexes.

Our habitat conservation recommendations are directed at addressing the physical processes involved in forming and maintaining habitats associated with stream-delta and spit/marsh complexes; for example, a recommendation may address restoration of tidal processes through the removal of a dike located in a spit/marsh complex where habitat is influenced primarily by tidal energy. We have recommended removal of bulkheads or other shoreline modification structures where wave processes influence the recruitment of sediment to down-drift barrier spit and associated wetland habitats. Similarly, our recommendations have addressed primarily fluvial processes by removal of bank armoring and levees that impair floodplain and riparian function along a river. We also stress the importance of maintaining and re-establishing connectivity (when it has

become impaired or lost) at multiple scales, including surface water connectivity (particularly affecting spit/marsh complexes), overall habitat connectivity within habitat complexes, and the connectivity (or proximity) of habitat complexes to one another.

Prioritizing Complexes

We recommend using the Relative Condition ratings (which incorporates the percent of historical habitat loss and the overall habitat connectivity within the complex), and the history of surface water connectivity (i.e., local scale connectivity) of the individual habitat complexes, to help prioritize habitat complexes for protection and restoration actions, as shown in the prioritization strategy shown in Table 11. In general, we recommend habitat protection priority be given to complexes that we rated "functional", and where surface water connectivity occurred historically and still occurs today (also see sub-section below describing "Reference" complexes). For spit/marsh complexes, this latter provision generally gives priority to spit/marshes that historically had surface water connectivity over spit/marshes that have never shown evidence of surface water connectivity. For stream-delta complexes, it tends to favor protection to complexes that support tidal marsh or lagoon habitats (collectively referred here as 'tidal wetlands') over those that never did support these tidal wetlands. In prioritizing habitat complexes for restoration we generally recommend those rated as either "moderately impaired" or "severely impaired" be considered the favorable candidates. Generally, all other factors being equal, the larger-sized complexes would be considered of higher priority for protection and restoration actions over smaller complexes.

Table 11. Protection and Restoration Priorities and targeted complexes for the Strait and Hood Canal study area[1].

Protection/Restoration Priority and Strategy	Description of Strategy	Targeted Complexes[2]
Protection (P)	Primarily protection; typically minimal restoration required	"Functional" stream-delta and spit/marshes that have surface water connectivity
Restoration (R1)	Primarily restoration, addressing habitat loss and overall habitat connectivity. Protection may be component of strategy.	"Moderately" and "Severely impaired" stream-delta and spit/marshes that have surface water connectivity
Restoration (R2)	Primarily restoration, with particular focus on habitat connectivity. Protection may be component of strategy.	"Moderately" and "Severely impaired" spit/marshes that have lost surface water connectivity

[1] One level of prioritizing complexes is shown for protection actions that meet the criteria for shown targeted complexes. Two levels in descending order of priority are shown for restoration actions that meet the criteria for targeted complexes.

[2] Complexes that fall outside of the "targeted" scenario described in the table may also be considered. For example, a complex rated "lost" according to the Relative Condition might be given restoration priority upon consideration of a number of factors not applied here. Similarly, it might be reasoned that a spit/marsh complex that has never provided tidal access for salmonids might be granted protection or restoration priority based on other criteria, such as its value in a broader landscape or ecosystem context (see text that follows).

Though generally we would recommend a lower priority for protection and restoration actions of stream-delta complexes that have never supported tidal wetland habitat, and spit/marsh complexes that have apparently never exhibited surface water connectivity with adjacent open waters, important exceptions occur. For example, the Hoko and Clallam river estuaries in the Western Strait sub-region, and the Elwha River estuary in the Eastern Strait sub-region, even historically probably supported only limited tidal wetland habitat (i.e., tidal marsh, channel, and lagoon features), yet their estuarine channel and lagoon habitats are likely critical for salmonids that are born in their watersheds. Smaller stream-deltas in Hood Canal that have local importance for salmonids also may be given a higher priority status. Also, spit/marsh complexes that may never or rarely provide tidal access for juvenile salmonids (e.g., Point Wilson, Foulweather Lagoon) might be regarded as quite important in how they function in the broader ecological context (e.g., in support of trophic interaction such as forage fish spawning, adjacent eelgrass beds, shellfish, or water quality benefits) at local or even regional scales. Though salmon recovery may be a secondary, or less direct, objective in the protection and restoration of such complexes, there may be other compelling reasons to consider conservation actions.

Similarly, habitat complexes that we consider "lost" in our Relative Condition rating generally would not be favorable candidates for restoration except perhaps if an opportunity exists to readily acquire properties or develop conservation strategies with

existing willing landowners. Generally, we would recommend restoration to "lost" complexes that historically had surface water connectivity (in the case of spit/marsh complexes). Good examples of this might be at Potlatch Marsh (South Hood Canal sub-region) and Twanoh Creek (Hood Canal Hook sub-region), both of which are owned by Washington State Parks, and the Devil's Hole and Cattail creek complexes that occur on the Bangor Naval Base on the Kitsap Peninsula, both in the North Hood Canal sub-region.

Additional Comments

With restoration, the protection of habitat is implied. In fact, in order to restore habitat-forming processes and habitat structure in many complexes, it may be necessary to acquire properties, work with existing landowners, and/or implement adequately protective land use policies and regulations. Generally, in complexes where we identify protection, little to no major habitat restoration would be expected at the complex site itself, though measures to restore drift cell or watershed processes might be necessary to maintain long-term habitat function. We stress that the most beneficial restoration actions, likely to have long-term success, are those directed at the causes of habitat alteration, rather than measures that treat the symptoms of habitat change. For example, instead of removing prograded deltaic sediment deposits (a symptom), it would be prudent to first address the upstream causes of sediment accretion that led to the progradation (i.e., increased sediment supply in the watershed, and loss of riverine-floodplain connectivity).

For spit/marsh complexes that historically showed surface water connectivity, we evaluated the level of drift cell impairment that influences the forming of these habitat complexes. We did this evaluation in the context of the Relative Condition rating that we applied to the complexes to help those potentially interested in restoration quickly gauge whether drift cells that affect the complexes are relatively "intact", "impaired", or "severely impaired". For example, if one were interested in possible restoration project opportunities involving Pitship Marsh (located just south of Pitship Point in Sequim Bay) he or she would find that drift cell function is relatively "impaired" and so would need to take this into account with any restoration measures being considered at the site. Similarly, if one were considering restoration of Long Spit (at the northwest end of Marrowstone Island), he or she would want to know that drift cell processes affecting this complex are currently considered "intact", that is up-drift of the complex itself. This kind of information bears upon the likelihood for success of restoration actions taken at the site and should influence decision-making. For example, one might want to remove fill along a spit to restore connectivity to a historically connected lagoon and salt marsh. However, if the drift cell influencing the sediment dynamics at this spit/marsh complex is bulkheaded along 50% of its length, or other potential disruptions to sediment processes are evident, then the likelihood for success of this project might be low compared with a similar project proposal where drift cell impairment is considered minimal.

One factor that may prove to have profound implications for stream-delta and spit/marsh complexes that we did not take into account is the risk to tidal wetland habitat from sea

level rise given global climate change projections (see Snover et al. 2005). Habitat complexes that occur immediately adjacent to steep topography or where encroachment from human infrastructure or fill has taken place, would likely be at greater risk of habitat loss through erosion and inundation of wetlands than complexes that are adjacent to relatively flat topography and those relatively free of human encroachment. Of course, sea level rise could have important implications on coastal erosion and sediment processes that might at least partially offset the erosion or inundation of down-drift spit and marsh features. Therefore, spits and marshes associated with drift cells that are heavily armored by bulkheads, for example, might be particularly vulnerable to erosion under sea-level rise projections (Beamer et al. 2005). Thus, we encourage restoration practitioners and long-term planners to seriously consider the implications of sea-level rise in their development of policies/regulations and restoration strategies and plans.

Additional factors would of course need to be integrated into final decisions regarding conservation actions, such as how habitats function for salmon and other organisms (e.g., whether a habitat complex serves as a 'natal' salmon estuary), and the broader landscape context of the habitat complex (e.g., what is its proximity to other important habitats such as eelgrass and kelp beds, or other complexes), costs and technical challenges involved in restoration, and the certainty of success in sustaining the goals of the restoration project.

"Reference" Complexes

Based on the results of our analysis of the habitat complexes (Appendix B), we have identified several "reference" complexes, both stream-delta and spit/marsh, where we consider habitat conditions and the processes that shaped and maintain these habitats to be functional (Table 12). These complexes might serve as guides or models for restoration actions involving similar complexes. All of the examples we discuss below have surface water connectivity, and are thus potentially accessible to juvenile salmon. A number of additional spit/marsh complexes that lack surface water connectivity and small stream-deltas that have never supported tidal marsh habitat might also be considered reference complexes.

Table 12. "Reference" habitat complexes in the Strait and Hood Canal regions.

Habitat Complex	Complex Type	Sub-Region
Dungeness Spit	Spit/marsh	Eastern Strait
Paradise Cove	Spit/marsh	Sequim Bay
South Indian Lagoon	Spit/marsh	Port Townsend/Oak Bay
Fawkes Spit	Spit/marsh	Port Townsend/Oak Bay
Bywater Bay	Spit/marsh	Hood Canal Entrance
Foulweather Marsh	Spit/marsh	Hood Canal Entrance
Thorndyke Creek	Stream-delta	Hood Canal North
Long Spit	Spit/marsh	Dabob Bay
Fisherman's Point	Spit/marsh	Dabob Bay
Tarboo Creek	Stream-delta	Dabob Bay
Nick's Lagoon	Spit/marsh	Hood Canal Central
Misery Point	Spit/marsh	Hood Canal Central
Stavis Creek (and Bay)	Stream-delta	Hood Canal Central
Dewatto River	Stream-delta	Hood Canal South
Tahuya River	Stream-delta	Hood Canal South

We find few reference complexes in the Strait, although there are certainly stretches of shoreline that appear relatively unaltered (the exception being that coastal forest and watershed conditions have often been degraded over the past 100+ years by logging and road construction activity). The Dungeness Spit complex is remarkable in that its geomorphology and tidal wetland habitats closely resemble the characteristics seen in early coastal maps. Perhaps it is no coincidence that the drift cell processes that influence the Dungeness Spit to the west are largely intact, with little to no bluff armoring or other shoreline modifications (see the Eastern Strait sub-region in Appendix B).

We could not identify any reference spit/marsh habitat complexes (that historically had surface water connectivity) in either the Hood Canal South or Hook sub-regions, probably reflecting the fact that transportation corridors and residential development occurs along the majority of the shoreline in these two sub-regions and affects nearly all of the complexes.

A few additional stream-delta complexes across the study area could also serve as reference complexes, though they have been impacted by human development. These include Thorndyke, Tarboo, Stavis creeks (and bay) and the Dewatto and Tahuya rivers. All of these watersheds have been subjected to logging, road construction, and/or agricultural land uses that have affected hydrology, sediment, and large wood processes to varying degrees, with impacts on their respective estuaries. Residential development now poses a potential risk to watershed processes in some of these watersheds. Though we think none of the relatively large stream-delta complexes could serve as reference complexes in whole, there are portions of some larger systems that we should call out as possible reference areas. These include the western part of the Skokomish estuary (although this area has also been affected by a road bed and some fill, and it is not directly associated with the Skokomish River), portions of the Union River/Lynch Cove and Dosewallips estuaries, and the South Sequim Bay habitat complex

(Jimmycomelately/Dean Creek estuaries), where a significant multi-year restoration project has recently been completed. Restoration projects of this scale are extremely valuable as potential references for additional restoration actions taken elsewhere.

Regulatory/Policy Recommendations

The regulatory and policy recommendations we want to emphasize are broad-scale protection to longshore sediment processes (sediment supply, transport, and deposition pathways) and marine riparian functions, and to provide for floodplain connectivity and associated riparian functions, particularly in lower riverine corridors. Given the current regulatory protections provided on wetlands, we think the most beneficial additional habitat protections would address sediment processes (i.e., erosion, transport, and deposition) in drift cells that ultimately affect the stability of down-drift spit features (i.e., spit/marsh complexes). In watersheds, we stress the importance of protecting hydrologic and sediment regimes within natural ranges that would be beneficial to stream-deltas and estuaries. Put simply, regulatory mechanisms must provide adequate protections to marine and freshwater riparian, floodplain, and sediment processes, including sediment and large wood sources, pathways, and deposition zones (i.e., estuaries and spits).

Recommendations for Future Study

Having completed this study, we recognize a number of areas where we feel further assessment would provide additional valuable information in developing our understanding of estuarine and shoreline changes and in formulating conservation strategies affecting nearshore salmon habitat.

Time-series Analysis of Historical Changes

More intensive time-series examinations of drift cell, watershed, and habitat complex changes would help to clarify linkages between land use development and habitat changes. This type of assessment might be most effective in specific watershed(s) or drift cell(s) where adequate information exists, and would be particularly useful in the context of considering habitat conservation alternatives at these scales. Example areas that might benefit from such high-resolution time series analysis would be the shoreline north of the Hood Canal Bridge, the Elwha littoral cell affecting Ediz Hook, and the Hamma Hamma and Quilcene watersheds and estuaries. An example of a time-series analysis would be to examine the potential for shoreline armoring or other modifications to disrupt drift cell sediment delivery, transport, and deposition, ultimately affecting spit stability.

One could attempt to identify historical changes to drift cell function since early settlement time by coupling historical sources such as the T sheets, GLO notes, and early air and ground photos, with current day characterization of sediment source, transport, and depositional reaches along shorelines (see recommendation immediately below for ‘Historical Changes to Drift Cell Processes’). Similarly, this would be important when looking at watershed sediment supply, transport, and deposition, or changes in hydrology

and the impacts on stream-delta characteristics. These last were linkages that, because of the scope of the present study, we could merely surmise are important in affecting the habitat changes we observed at a habitat complex scale.

We recommend that any additional more in-depth historical investigations consider additional forms of historical information such as oral interviews with tribal and non-tribal elders, and old on-the-ground photographs. Also, specific locations might benefit from more exhaustive gathering and examination of air photos, soils studies, and other documentation.

Historical Changes to Drift Cell Processes

We strongly recommend an assessment of historical changes in drift cell processes, with an emphasis on sediment source areas of the shoreline. When T sheet information (that shows bluffs and spits) is combined with additional historical information, such as from early air and ground photos, descriptive reports, and perhaps GLO survey notes, we can evaluate changes to sediment source areas along the shoreline. King County recently completed such an assessment (Johannessen et al. 2005), and is hoping to use it in development of shoreline restoration alternatives. We could use this type of an assessment in the Strait and Hood Canal regions as a means to consider restoration, and also to more effectively manage land use development along the marine shoreline.

Historical Changes to Tidal Flats and Bathymetry

An assessment of historical changes in bathymetry would be useful, particularly at a number of stream-deltas where progradation of sediments has occurred, the likely result of river channelization and increased watershed sedimentation. Recall that we were unable to assess changes in the low water line because we relied on T sheets that lacked consistently accurate representations of this line. The early hydrography charts ("H sheets"), also produced by the U.S. Coast and Geodetic Survey, could be used to more accurately derive the historical low water line as well as other bathymetric data, and thus allow for a comparison with the contemporary bathymetry. Detailed studies of historical changes in bathymetry might be valuable in a number of locations in our study area, particularly at major river deltas such as that carried out by Jay and Simenstad (1994) in the Skokomish River delta, and also in the more protected embayments and harbors such as at Quilcene Bay, Lynch Cove, Clallam Bay, and Port Townsend Bay. This approach would give us a better understanding of changes in tidal flat and other unvegetated intertidal habitats that are critical shallow water habitats for juvenile salmon.

Diking Effects on Estuarine Habitat Function

A detailed assessment of changes in the function of salt marsh and other tidal wetland habitats in the Strait and Hood Canal areas would give us a more direct understanding of historical changes to estuarine habitats. Our assessment focused on quantitative changes in surface area, and made some assessment of disruption of connectivity between habitats. However, we did not examine in detail how diking, for example, has altered

tidal processes (e.g., affecting channel widths that has direct implications on salmon habitat) in specific habitat complexes, such as in the Skokomish, Lynch Cove/Union River, and other complexes that have been diked. Hood (2004) provides a model study of how this type of assessment was carried out in a Puget Sound estuary (Skagit River).

Historical Changes to Marine Riparian Corridors

Another aspect of the nearshore that is largely missing from our study is an inventory and assessment of historical changes to marine shoreline vegetation patterns. A recent review on the subject suggests that marine riparian vegetation may be critical in the support of food organisms for salmonids that migrate along the shoreline (see Brennan and Culverwell 2005). An assessment of historical changes in marine riparian vegetation could be made using historical sources such as the GLO survey notes and the same T sheets we used for the current study. Knowledge of the extent of change to marine riparian vegetation, along with a growing understanding of the ecological functions provided by marine riparian vegetation, might prove useful to local governments that are charged with developing and implementing land use policies and regulations that directly affect the character of the marine shoreline.

Juvenile Salmon Use of Nearshore Habitats

Another recommendation for future work is to examine how juvenile salmonids are currently using the various estuarine and nearshore habitats available in the Strait and Hood Canal regions, and to insert a historical perspective of the relationships between juvenile salmon and nearshore habitat that we have gained with completion of this study. Several efforts have been underway in recent years that are monitoring juvenile salmonid use of the nearshore, including the Hood Canal and Strait (e.g., Hirschi et al. 2003a; Bahls 2004). Redman et al. (2005) highlights some of the hypotheses regarding juvenile salmon use of the nearshore that require further work.

The present study focuses on historical changes in estuarine and other tidal wetland habitats that are generally known to provide habitat for juvenile salmonids. However, we still lack a good understanding of what habitat structures (e.g., channel sizes) and environmental factors (e.g., salinity) are particularly important for juvenile salmon, and what specific functions these habitats serve for salmon. We recommend an examination into how juvenile salmon use various nearshore habitats across the Strait and Hood Canal, beginning with a synthesis of existing information from Hirschi et al. (2003a), Bahls (2003), and others working in the region. We could then use this existing (and any newly developed) data in the context of the knowledge gained from our present historical changes study to build our understanding of salmon use of nearshore habitats that would give us an added focus in considering nearshore habitat conservation measures.

SUMMARY

The following recaps the most important findings of our study.

Habitat Complexes:

- Based on the relative influences of fluvial, wave, and tidal processes, we classified two generalized "habitat complex" types, 1) stream-deltas (primarily fluvial and tidal energies), and 2) spit/marshes (primarily wave and tidal energies).
- We identified 250 historical habitat complexes across the study area, 63 in the Strait, 187 in Hood Canal; 103 are stream-deltas and 147 are spit/marshes.
- The historical size of habitat complexes ranged from < 1 ha (76 complexes) to 799 ha (Skokomish River estuary). Other than the Skokomish, only five other complexes were historically larger than 100 ha, and just one of these occurs in the Strait (Pysht River estuary).

Habitat Changes:

- Historical changes included an overall decrease in tidal wetland habitat (marsh, channel, and lagoon) from 1430 to 1323 ha (7%) since the earliest survey maps (~1850-1900). Some sub-regions had net gains (e.g., Dabob Bay, Central Hood Canal, and South Hood Canal) while other sub-regions lost considerable tidal wetland habitat (e.g., Central Strait, Port Townsend-Oak Bay, Hood Canal Entrance, and North Hood Canal).
- Cumulative changes to stream-delta complexes showed a 7% gain in tidal wetland habitat, much of this probably the result of delta progradation and growth of tidal marsh associated with increased sedimentation from watershed activities and estuarine and floodplain channelization. The smallest sized stream-delta complexes (i.e., those historically less than 1 ha) showed a net gain in tidal wetland habitat over historical time. Stream-delta complexes in the 1-10 ha size category collectively lost 39% of their historical tidal wetlands. Stream-deltas in the 10-100 and > 100 ha size classes showed a 14% and 7% gain in tidal wetland habitat, respectively.
- Cumulative changes to spit/marsh complexes included a 28% loss in tidal wetland habitat. The smallest spit/marsh complexes (< 1 ha) collectively showed a decrease in tidal wetlands of 19%, and spit/marsh complexes in the 1-10 ha and the 10-100 ha size classes had tidal wetland habitat decreased by 29% and 28%, respectively.
- The number of tidally-accessible spit/marsh complexes (generally considered "non-natal" to salmon) decreased from 77 historically to 65 complexes today (16% reduction); associated tidal wetland habitat also decreased from 447 to 348 ha (22% loss). At least four of the currently connected spit/marsh complexes are maintained as artificial entrances to marinas.

Causal Factors for Habitat Change:

- We attributed both direct and indirect causal factors for the habitat changes observed. Direct causes (or impacts) are "footprint" effects such as landfill of former wetlands, whereas indirect causes were sourced off the site of the habitat complex itself with symptoms evident at the habitat complex. Indirect causes were categorized as either 1) upstream (i.e., watershed), or 2) up-drift, in the case of drift cell effects. The relative importance of these causes varied somewhat by region (Strait vs. Hood Canal) and sub-region, as well as by complex type (stream-delta vs. spit/marsh), and complex size.
- Overall, the most common direct causes of habitat change were attributed to fill associated with transportation (including railroads) infrastructure, and residential development. Other important direct causes included urban, industrial, and military-related development, dredging and channelization activities, and diking and revetments.
- A common indirect cause of habitat change to stream-delta complexes appeared to be increased sedimentation from watersheds and floodplain disconnection that resulted in delta progradation and development of emergent marsh seaward of its historical extent. However, identifying the effect of increased sedimentation from upstream watersheds may be challenging where the stream-delta and/or estuary has been diked and channelized, since both the watershed and the lower channel/estuary actions might result in changes to delta sedimentation patterns. Also, though progradation often led to a net gain in salt marsh vegetation, it appeared to come at the expense of overall habitat connectivity within the complex, and possibly an overall displacement of tidal flat habitat.
- Similar to watersheds and stream-deltas as described above, the influence of updrift modifications on habitat complexes is often obscured by direct changes to those complexes. For example, the effects of updrift bulkheading on a spit/marsh complex might be difficult to observe where the spit/marsh has been heavily modified by road construction and filling. Perhaps the most evident instance of up-drift impact was at Ediz Hook in the Strait where up-drift littoral and fluvial (i.e., Elwha River) sources of sediment were greatly reduced over the past 80-100 years by a buried pipeline along the toe of updrift historical bluffs along the marine shoreline and the presence of the Elwha River dams, both trapping historical sources of sediment that fed the extensive spit (i.e., Ediz Hook).

Relative Condition of Habitat Complexes:

- The Relative Condition rating of habitat complexes was based on estimates of quantitative historical habitat change, and the level of impairment to overall habitat connectivity (as opposed to just surface water connectivity as examined in spit/marsh complexes). The Relative Condition ratings were in four categories: "functional", "moderately inpaired", "severely impaired" and "lost". We did not assign a Relative Condition rating to17 of the 250 habitat complexes because we either lacked adequate historical habitat information for the complex, or we felt we could not sufficiently characterize the changes to the complex.

- Relative Condition varied geographically (i.e., by sub-region) and according to habitat complex type (stream-delta vs. spit/marsh) and complex size. Overall, for the rated complexes, 22% were rated "functional", 30% "moderately impaired", 31% "severely impaired", and 17% "lost". For stream-deltas, 18% were rated "functional", 35% "moderately impaired", 42% were rated severely impaired, and 5% lost. For spit/marshes, 24% were rated functional, 26% moderately impaired, 25% severely impaired, and 25% lost.
- Because of the loss of historical complexes (generally by landfill), the average distance between complexes (as well as tidally-accessible complexes) along the shoreline across the study area has grown. However, this pattern varies geographically, as some parts of the study area still retain mainly "functional" or "moderately impaired" complexes, that maintain surface water connectivity, and other parts have concentrations of "lost" and "severely impaired" complexes, where surface water connectivity has been eliminated.

Recommendations:

- In making habitat protection and restoration recommendations for habitat complexes, based on the findings of our study, we considered changes in surface area of tidal wetland habitat, the level of impairment in the connectivity of habitats (including the loss or reduction in surface water connectivity of spit/marsh complexes), and the overall scale of habitat complexes. We encourage readers to also consider the extent of indirect impacts (i.e., impairment of watershed and drift cell processes) affecting the function of habitat complexes in their conservation decisions. Conservation recommendations emphasize the protection and recovery of habitat-forming processes that affect the extent and overall connectivity of tidal wetland habitat associated with habitat complexes identified across the study area (recommendations are provided in Appendix B sub-regional reports).
- Among our recommendations for future study are testing current assumptions of how salmonids use various nearshore habitats, with particular emphasis on tidally-accessible marsh, channel, and lagoon habitat; other recommendations are to improve our understanding of drift cell processes (particularly sediment source areas, i.e., feeder bluffs) prior to Euro-American settlement, and the historical impairment of these processes; perform historical and contemporary mapping of tide flats, and assess changes to tide flat habitat and the bathymetry of other shallow water habitats that were not a focus of our study; characterize historical changes in marine shoreline vegetation across appropriate scales; and examine changes in salt marsh and estuarine channel habitats resulting from diking and filling (including "indirect" diking effects on tidal prism).

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