

Historical reconstruction, classification, and change analysis of
Puget Sound tidal marshes

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Introduction

Scope

This report presents the results of an investigation into the historical nearshore environment of the Puget Sound region. Our geographic scope includes the marine shoreline in Washington State inland of Cape Flattery, inclusive of the south coast of the Strait of Juan de Fuca, Hood Canal, Puget Sound proper, the San Juan Islands, and the mainland coast north to Canada. This geographic extent is the same as the “Puget Sound Nearshore” defined by the Puget Sound Nearshore Ecosystem Restoration Project (PSNERP).

The largest portion of this project’s scope was to create digital data, with a secondary goal of regional analysis. We georeferenced 125, gray-scale scanned originals of US Coast & Geodetic Survey (USC&GS) topographic sheets (T-sheets) that encompass the Puget Sound Nearshore. We digitized the T-sheets and then edge-mapped them to create a Geographic Information Systems (GIS) geodatabase with continuous coverage of the entire Puget Sound shoreline. We coordinated methods and data development with the Point No Point Treaty Council, which is undertaking a related study of changes to the nearshore of the Hood Canal, western Admiralty Inlet, and the Strait of Juan de Fuca. We then used this data to reconstruct the historical nearshore environment, by making use of a number of other sources that supplemented and cross-referenced the T-sheets, including records of the federal land survey, following a methodology developed over several years (Collins et al. 2003). In order to compare the historical and current conditions of the nearshore environment, we created a geodatabase of current conditions by digitizing from recent aerial photographs, supplemented with existing digital data. This report accompanies this digital data.

We concentrated on one facet of the nearshore environment, tidal wetlands. Our study supplements and expands on an inventory made 120 years ago (Nesbit 1885) of the condition of Puget Sound's tidal wetlands at the time of Euro-American settlement. Specifically, we created a spatially explicit digital database, useful for making a variety of analyses, to provide the starting point for more detailed site-level investigations, and to guide restoration efforts. We used additional cross-referencing sources to add descriptive and quantitative detail. We used our reconstruction to create a landform and process based classification of tidal wetlands for structuring an historical description and to compare it with comparable mapping of the current condition of Puget Sound's nearshore, and present a brief summary analysis here. Additional analysis of our data would supplement our regional quantitative summary with additional information including more detail on the nature and causes of change to wetlands.

Other analyses that could be made with our digital data, in addition to the focus on tidal wetlands reported on here, include using the T-sheets to extend an earlier study of change to kelp distribution (Thom and Hallum 1990) back another 20-60 years prior to the inventory by Rigg (1915) and by providing a cross-referencing source to Rigg's examination. The data could also provide a base level for analysis of some types of change that might have occurred in the last century and a half to erosional and accretionary patterns of the region's shoreforms. The data includes ecological and land use data useful for various other types of analyses.

Definitions

We use the widely adopted Cowardin et al. (1979) system for classifying wetlands. We use "estuarine" (intertidal) and "riverine tidal" (tidally-influenced freshwater) wetlands together to refer to "tidal wetlands." We also mention briefly the palustrine wetlands that were found

historically within the floodplains of river valleys where the river itself was tidally influenced, but only indirectly affected the floodplain wetlands, not by regular tidal influence, but by altering the flooding regime. We include these wetlands along with tidal wetlands to encompass “nearshore wetlands.”

We use the term “nearshore” as defined by PSNERP:

“[The Puget Sound Nearshore] generally extends from the top of shoreline bluffs to the depth offshore where light penetrating the Sound’s water falls below a level supporting plant growth, and upstream in estuaries to the head of tidal influence. It includes bluffs, beaches, mudflats, kelp and eelgrass beds, salt marshes, gravel spits and estuaries.”

Structure of the Report

The report consists of three sections. The first summarizes methods used to reconstruct historical conditions. The second presents a classification or typology for tidal wetlands in the Puget Sound region. The third presents a description of the historical tidal wetlands based on our reconstruction of mid-late 19th century conditions, and structured by the classification, concluding with a brief comparison to current conditions.

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Chapter 1: Methods used to reconstruct tidal wetlands in the Puget Sound region prior to Euro-American-settlement (mid- 19th century)

Abstract

To understand the historical amount, distribution and functions of tidal marshes in the Puget Sound region, we reconstructed nearshore environments in the Puget Sound region representative of the time of earliest Euro-American settlement. To achieve comprehensive spatial coverage, we first created a geospatial database using Geographic Information Systems (GIS) by registering, interpreting, and digitizing topographic sheets (T-sheets) surveyed by the US Coast & Geodetic Survey (USC&GS) mostly in the period between 1850 and 1890. This source does not predate all conversion to agricultural and other land uses, and in most of the larger river deltas the T-sheets do not extend far enough inland to include the entire nearshore. For these reasons, and because it is desirable to augment and cross check the T-sheet information even where there had not yet been land use change, we supplemented the T-sheets with a number of other sources and methods to recreate the pre-settlement condition. These additional sources include the field notes and plat maps from the General Land Office survey, other early maps and aerial photographs, early text sources, and recent data including high-resolution digital elevation models.

Introduction

Statement of the problem

Anthropogenic transformation of Puget Sound's nearshore environment since Euro-American settlement in the mid 19th century includes the conversion of tidal wetlands (inclusive of

estuarine and tidal freshwater environments) to other land uses. Conversion in many parts of the region was early and extensive, and consequently the native condition of the nearshore environment is poorly known. Specifically, knowledge of the character and occurrence of larger tidal wetlands prior to settlement is limited to pre-settlement reconstructions, and to field investigations of remaining pristine wetlands. As a result, understanding of the historical type, amount, and distribution of tidal wetlands is fragmentary.

In an effort to create a regionally inclusive and spatially explicit database of the historical condition of regional tidal wetlands, we used a variety of archival sources and a GIS. To achieve spatially comprehensive coverage, we began by creating a geospatial digital database from topographic sheets (T-sheets) surveyed by the US Coast & Geodetic Survey (USC&GS) between the early 1850s and early 1890s. This several decade period does not predate all conversion to agricultural and other land uses; in a number of areas, especially larger river estuaries, wetland conversion was already widespread. In addition, in most of the larger river estuaries, the topographic mapping did not extend far enough inland to encompass the entire nearshore. Finally, it is also desirable to augment and cross check the T-sheet information even where there had been no land use conversion. For these reasons, we then supplemented the T-sheets with a number of other sources to reconstruct the pre-settlement condition. These sources include the federal land surveys made in the period of 1850-1880, soil surveys, 1930s aerial photographs, other early maps, and text sources. We were also able to cross-reference our estimates of pre-settlement tidal marsh with an 1884 inventory of pre-settlement conditions (Nesbit 1885).

Previous approaches to the retrospective study of tidal wetlands in Puget Sound

Snohomish resident Eldridge Morse made the first published retrospective inventory of tidal wetlands in the greater Puget Sound area, for an 1885 federal survey of tidal marshes (Nesbit 1885). Although by Morse's estimate 38% of tidal marsh had already been converted to agricultural or urban land uses, most of this was within the decade preceding his assessment, making it possible for him to make his reconstruction from a combination of field observations, map sources, and field interviews.

More recently, a federal study of eleven Puget Sound area river deltas published in 1980 (Bortleson et al. 1980) used hand-registered T-sheets and early US Geological Survey (USGS) topographic maps to estimate the extent of marsh that remained undiked at the time of the T-sheet surveys and in some rivers to estimate marsh extent prior to the T-sheet surveys. More recent investigations of individual rivers have drawn on maps created in the 1980 study (e.g., Burg 1984; Blomberg et al. 1988). Thom and Hallum (1990) summarized and synthesized the 1980 study, National Wetlands Inventory (NWI) mapping, and Morse's inventory (1885) to develop an estimate of tidal wetland area change.

More recently, we reported on reconstructions of the historical environments of several river estuaries in northern Puget Sound, showing the efficacy of combining T-sheets with other data sources for mapping and characterizing pre-settlement riverine and estuarine environments (Collins et al. 2003).

Digitization of US Coast & Geodetic Survey topographic sheets

The USC&GS topographic sheets were our primary data source. We obtained high-resolution gray-scale scans of original maps from the National Archives. We also obtained electronic copies of the available descriptive reports that surveyors wrote to accompany each sheet. Most sheets do not use a datum that is in current use; most have graticules marking latitude and longitude in the early local Puget Sound Datum and a second set of graticules that were added later to update to the North American Datum (NAD). To shift to a current datum from the earlier NAD, we calculated X and Y values from published tables from the resurvey of station locations between NAD and NAD27 (Patton 1999). We determined an overall datum shift for each T-sheet by averaging the shift from a number of stations in or near the T-sheet area. In converting to a modern datum, in general RMS (root mean square) values were 0.003 or below, and points that produced RMS errors above 0.003 were discarded through an iterative process. We used a polynomial transformation to rectify each T-sheet into UTM Zone 10 NAD27 projection. To provide an independent check on the accuracy of the registration process (i.e., not the accuracy of the original survey itself), benchmarks located on the T-sheets were compared to published National Geodetic Survey benchmarks that were retraceable to the time of the surveyed T-sheet. The accuracy assessment only made use of benchmarks which it could be established with a high degree of certainty existed at the time of the original T-sheet survey and had not subsequently been remounted. Values ranged from 2 to 8 meters on 1:10,000 scale T-sheets, and from 6 to 20 meters on 1:20,000 scale T-sheets. These values compare favorably to those reported in the literature (Daniels and Huxford 2001).

We digitized on-screen at an average scale of 1:1,500. We generally digitized everything on a sheet, except for a few sheets where the information extended farther inland, primarily in the San Juan Islands. In those cases we digitized information within 500 m inland of the nearshore. We did not digitize topographic lines, which the surveyors sketched by eye (Shalowitz 1964). We attempted to interpret and digitize the maps keeping as closely as possible to the topographer's intent, including by attributing our coverages using the surveyors' categories and with a minimum of translation into modern terms. To understand the conventions of surveyors at that time, we made use of the extensive research by Shalowitz (1964), symbology legends published during that period, and documentation provided by individual surveyors within their descriptive reports for individual sheets. There were subtle variations in symbology and conventions through time and between surveyors, making it necessary to interpret sheets within those contexts. While the maps we used represented the work of 18 chief surveyors, just three of them surveyed 75% of the sheets we used, and one surveyor (J. J. Gilbert) made 36% of them. Only one surveyor, E. Ellicott, who mapped 9% of the sheets we used, and worked primarily in the southern Puget Sound, used symbology that varied significantly from the others.

We summarize here the elements of T-sheets most relevant to the interpretation of tidal wetlands [for systematic discussion of the analysis and interpretation of topographic surveys, see Shalowitz (1964)]. Surveyors paid close attention to the outer (seaward) boundary of marsh, because they used it to denote the shoreline rather than attempting to locate the actual mean high water line (Shalowitz 1964). The outer boundary was drawn with a solid line when the outer edge of marsh could be clearly identified in the field. If the boundary was unclear, surveyors could omit a line, but this was uncommon in this region. On Puget Sound sheets, topographers commonly made use of a symbol identified in published legends as "submerged marsh." The

submerged marsh symbol was drawn outside (seaward) of the line that was drawn to indicate the outer edge of marsh; the submerged marsh symbol was also drawn without a defined outer limit. We have taken the topographer's use of the submerged marsh symbol in Puget Sound to represent marsh in an early stage of development and distinguish it from estuarine emergent marsh in our composite, interpreted historical coverage by coding it as "low estuarine emergent marsh."

The line marking the landward edge of marsh was intended to represent the landward-most penetration of the tide (Shalowitz 1964). However, depending on accessibility, topographers paid less attention to the landward boundary, tended to generalize, or not to draw a definite line at all (Shalowitz 1964). We found that the landward boundary in many cases was drawn short of (seaward of) the boundary indicated by the General Land Office survey and other sources. In some cases, the marsh symbol stopped and the forest symbol started on reaching what other sources confirmed as estuarine scrub-shrub wetland (also referred to as "spruce marsh"). This is not universally true, and the topographers in some cases made use of hybrid symbols to indicate spruce marsh.

The topographers used two other symbols for marsh, defined in published legends as "fresh marsh" and "wooded marsh." We have taken "fresh marsh" to generally represent emergent or scrub-shrub vegetation, and "wooded marsh" to represent scrub-shrub or forested, and both to encompass either or both riverine-tidal and palustrine wetlands.

After digitizing the individual T-sheets, we then edge-matched the digital data to create a single continuous geodatabase feature class that covered the entire study area. Most internal inconsistencies in the T-sheets became evident at this stage. We found the sheets in general to be

accurate and internally consistent when compared to digital orthophotos and digital elevation models (DEMs), with two exceptions. Some of the maps lose accuracy positionally (and sometimes in their content), with distance inland. This occurred in a few of the river deltas; we did not make adjustments for these inconsistencies, because we had other sources to augment or supplant the T-sheets for creating an interpreted pre-historical geodatabase. The digitized T-sheets should be used with this possible inaccuracy in mind. The second case is where discrete sections of shoreline were obviously shifted, probably reflecting surveying error. In nine of these locations, we manually shifted the data by making visual best fit with digital aerial photography. The areas where we made adjustments are coded in the geodatabase, including the distance and general direction of the shift we made.

For the reasons previously given, we then augmented and modified this geodatabase using other sources, to develop an understanding of the likely condition of the landscape a few decades prior to the Coast Survey. However, the composite digital T-sheet geodatabase in itself provides an immense amount of information in addition to that used to make this inventory of tidal wetlands, and it is an important record of the natural and cultural landscape in the second half of the 20th century in the Puget Sound region.

Interpreting conditions prior to land uses

General Land Office records

Similar to the T-sheets and second in importance to them for mapping nearshore conditions, maps and field notes from the General Land Office (GLO) cadastral survey systematically cover the Puget Sound area. They were an important supplement to the T-sheets because they extended

farther inland, and because they were generally made prior to the USC&GS topographic surveys when there had been much less land conversion. They also provide different sorts of information than the T-sheets that is not replicated by any other source.

Most of the lowland of Puget Sound was surveyed between the late 1850s and late 1870s. We integrated into the GIS scans of original plat maps from this period supplied by the US Bureau of Land Management by georeferencing the maps' section corners and quarter corners to current Washington Department of Natural Resources (WDNR) data. We also obtained copies of the field notes from which the plat maps were drawn. The notes provide a record of all the lines surveyed, which includes section lines as well as "meander" lines along navigable rivers and the marine shoreline.

The land surveyors were instructed to record in their field notes land and water features they encountered, including major changes to the plant community, streams and marshes, and the width of all "water objects." Springs, lakes and ponds and their depths, the timber and undergrowth, bottomlands, visual signs of seasonal water inundation, and improvements were also to be noted along section lines. This information is not equally complete in the notebooks of different surveyors, nor consistently transferred to the plat maps. Nonetheless it was an important resource in our mapping, interpretation, and descriptions of wetlands. We also used the surveyors' bearing tree records to characterize species frequency, diameters, and spacing as an aid for interpreting land cover. For example, bearing tree records were invaluable in delineating estuarine scrub-shrub wetlands from estuarine emergent wetlands. While the surveyors recognized the difference between the two wetlands ("spruce marsh" compared to "tide prairie"), their line notes do not always record the transition, whereas their bearing tree records provide

inferential information at every section corner and quarter corner, and unlike some other observations, bearing trees were recorded universally throughout the survey.

The land surveyors' attention to wetlands was motivated by their mandate to identify "swamp and overflowed" lands that were considered "unfit for cultivation." The 1850 Swamp Lands Act extended to Oregon in 1860, and granted lands "wet and unfit for cultivation" to the states or territories (White 1991). The surveyors were charged with recording the points at which they entered such lands documenting the "distinctive character of the land" including "whether it was a swamp or marsh, or otherwise subject to inundation to an extent that, without artificial means, would render it unfit for cultivation;" we have not found their definitions of "marsh" or "swamp." The surveyors were also charged with noting the depth of inundation and its frequency.

We made use of land survey records mostly in the larger estuaries, because the survey grid is coarse relative to the scale of smaller coastal wetlands: for the most part, the survey followed section lines on a one-mile grid, and the banks of navigable streams and coastlines. The survey was conducted at a finer scale on Indian Reservations where survey lines were at 1/4 mile rather than 1 mile spacing. We made a pilot evaluation of the efficacy of the surveyors' coastal meander notes for characterizing the coastline generally, by plotting the shoreline meander notes in 44 townships and eight representative parts of the Puget Sound shoreline. We found that surveyors were inconsistent in noting features along the shoreline and made no observations at all in 10 of the 44 townships. In the townships where surveyors recorded descriptive information, it did not add significantly to the information already available on the T-sheets. An exception is

that the annotated shoreline meander notes provide a more thorough accounting of coastal creeks than the T-sheets, and are the only source of information on coastal creek widths.

Additional sources

Additional sources of information from the second half of the 19th century and first decade of the 20th century include maps from early investigations by the Army Corps of Engineers, the first US Geological Survey topographic maps, federal land use and soils mapping, and detailed field records made by county assessors. We georeferenced a number of these maps to supplement the earlier coastal and cadastral surveys. Among the contemporary text sources we consulted are the field reports of Army Engineers published in the Annual Reports to the Chief of Engineers (Chief of Engineers 1880—), which include important observations on estuaries and estuarine rivers; settlers' journals; newspapers, and the previously mentioned federal survey of tidal marshes (Nesbit 1885).

Although not taken until a half-century after the T-sheets, the earliest aerial photography made in the 1930s are still very useful because in many areas land and tideland was not converted to agricultural or industrial uses until the middle of the 20th century. Additionally, where land had already been converted by the 1930s, the photos are still revealing because they show relict patches of wetland, relict tidal channels, and the remnants of shallow water bodies. For every major river estuary, we scanned and orthorectified photographs from between 1931 and 1941.

We used a variety of recent information for inferential or corroborating purposes. We used high-resolution digital elevation models, in much of Puget Sound from lidar imagery made

within the last few years by the Puget Sound Lidar Consortium. The DEMs can reveal tidal (and other) channels hidden by vegetation, and can help in extrapolating features the boundaries of which are partially elevation controlled. Among other more recent sources of data, we used hydric soils mapping in the National Soil Survey Geographic (SSURGO) online database, wetland mapping from the National Wetlands Inventory (NWI), and peat mapped by Rigg (1958) and on published geologic maps.

Mapping methods in common situations

Delineating the landward limit of marsh in developed areas. A considerable amount of tidal marsh had been converted to agriculture in several of the larger river estuaries and in a number of mid- and small-sized tidal marsh complexes prior to the Coast Survey's visit, particularly the higher, landward marshes. In these cases we used the land survey to help delineate the landward limit of tidal marsh. Useful observations and data within the survey line notes include notation of entering and leaving "tide prairie" or "spruce marsh" (or tidelands described using other terms), and the bearing tree notes. Many of the plat maps would also show at least fragmentary lines marking the landward limit of saltmarsh. We also used the presence of relict tidal channels visible on the 1930s (and more recent) aerial photographs and on lidar DEMs as indicators for delineating the pre-diking landward limit of tidal marsh. Secondary, corroborating information included soils mapping, NWI mapping, and elevation from DEMs. We placed more weight on data that represented direct observations (e.g., the GLO notes or early USGS topographic maps) over inferential information (e.g., soils or NWI mapping or elevation) and were generally able to use the latter to supplement the former.

It was common practice in the first decades of settlement to use saltmarsh as pasturage, or to mow it for “salt hay;” and one settler on the Nisqually delta planted non-native plants in undiked saltmarsh (Nesbit 1885). The practice of pasturing marsh was widespread; about the marshes from Port Townsend, Port Gamble and Hood Canal, Eldridge Morse wrote “None of this is diked or cultivated, but nearly all is utilized for pasturage in connection with other lands” (p. 85 in Nesbit, 1885). The T-sheets show many small coastal patches symbolized as grassland, sometimes enclosed by fences and sometimes not. The early land use practices sometimes made it challenging to determine the presence and extent of saltmarsh. In some cases, later maps and photographs showed that these areas previously mapped as grasslands had later reverted to saltmarsh. In many other cases, we could confirm that the patches in question were just above the local upper elevation limit of saltmarsh. In several small marshes where we couldn’t tell we did not map it as saltmarsh. This was particularly common in the very small patches of marsh that form behind a sand berm or beach in coves in the San Juan Islands.

Small patches symbolized as grassland with associated ditches and dikes were interpreted as having originally been saltmarsh if they were at an elevation below the local, upper limit of saltmarsh, later maps showed they had reverted to marsh, or because written documentation confirmed they had originally been marsh. For example, Morse’s notes often gave the amount of saltmarsh individuals had diked, and it was possible in some cases to match the settler’s name from Morse’s account to the settler’s name annotated on the T-sheets. In a few cases small patches of marsh were present at the margins of urban development, making it impossible to determine the original marsh extent. For all these reasons, the *number* of marshes or complexes of marsh that we identified is a minimum, but the area of marsh is not greatly underestimated

because most of these locations where we lacked time to investigate the pre-land use condition were small.

Distinguishing types of marsh. On the larger river deltas where a large portion of saltmarsh had been diked and converted to agriculture (primarily the Duwamish, Stillaguamish, Skagit, and Lummi rivers), it was necessary to infer a boundary between emergent and scrub-shrub vegetation. Where there had been limited or no land conversion, there was still the need to cross-check the T-sheet information because surveyors were not consistent in separately symbolizing scrub-shrub and emergent marsh. As indicated above, the land survey notes and bearing tree records were the most important source for drawing this boundary, the latter indicated not only the presence or absence of trees, but also their spacing, species and diameter.

We used several sources in delineating estuarine from tidal freshwater and palustrine wetlands in the larger river deltas. The T-sheet symbology distinguished saltmarsh from freshwater marsh, but often ambiguously so especially on smaller features, and in the large river estuaries the coastal survey did not extend inland far enough to encompass the freshwater tidal marsh. An exception is the Snohomish River estuary, where the survey extended much of the way inland through the freshwater marsh, and the topographer modified the standard symbology to show variations in land cover that generally matched those indicated by the land survey notes. The land survey notes generally recorded the difference between estuarine, tidal freshwater, and non-tidal freshwater wetlands, and species differences appeared in the bearing tree notes between estuarine and freshwater marsh. Their notes would also, in some estuaries, include observations on the depth and frequency of tidal inundation, or the depth of standing water on the date of their visit. Some surveyors were less diligent in noting these features, but records in the largest river

estuaries are generally very good. In a separate document, we have included and highlighted observations on hydrology in descriptive narratives for individual features. Supplemental sources useful for delineating differences in marsh vegetation and hydrology include aerial photographs from the 1930s, which often showed remnants of not-yet drained wetlands, and tidal channels or relict tidal channels. On the Lummi and Nooksack river deltas, symbology on the earliest US Geological Survey topography maps provided corroboration of the land survey notes. For smaller wetlands that have not been substantially altered since the early surveys, we also consulted the NWI database to corroborate or clarify the wetland hydrology.

Stream channels. The accuracy and reliability of stream and tidal channels varied between map sources and with the type and size of the channel. Comparing channels large enough to be shown as polygons on T-sheets with the location of relict channels on aerial photographs indicated their general accuracy near to the shoreline, which generally diminished with distance inland. When cross-referenced to photography and elevation, larger (polygon) channels on the plat maps were reliable if those channels were large enough to have been meandered. Otherwise, their accuracy was only dependable where section lines crossed them.

Streams small enough to be depicted with lines were less accurate than streams represented as polygons on both sources. Coast Survey charts in other western North America regions sometimes mapped tidal creeks in great detail and with considerable accuracy, for example in the San Francisco Bay estuary (Grossinger 1995) and the Columbia River estuary (based on our examination of T-sheets of that area). We have not found that to be the case in Puget Sound, although practice appears to have varied between surveyors. Most drew small tidal channels with varying fidelity to their location, as checked by comparison to relict channels. One surveyor

(Ellicott) drew tidal channels schematically; his small channels on a map of the Puyallup River saltmarsh don't resemble the plan view of typical tidal channels and are not substantiated by relict channel networks. Channels on the land survey plats were unreliable in their own way; surveyors noted the presence and size of non-navigable channels when their section line transects crossed them, and otherwise sketched the channel location between section line crossings. Where possible we supplemented both sources with evidence for relict channel locations from the early topographic maps and aerial photographs and from the topography revealed by the lidar DEM.

Saltponds and lagoons. Puget Sound area T-sheets did not use different symbols for freshwater ponds, tidal lagoons, or saltmarsh ponds (salt pannes). Where possible we made use of text sources to distinguish the hydrology of saltponds, including the descriptive reports accompanying the T-sheets, the cadastral survey notes, and other descriptions such as those contained in the Army Engineers' Annual Reports and in Nesbit et al. (1885). We mapped as saltponds the very small water bodies in saltmarshes shown on T-sheets. Because many saltponds appear to persist for many decades unchanged, we could sometimes use aerial photographs to confirm the interpretation.

Data structure

Attributes for our composite historical GIS layer for a "land cover/land use" field include the wetland type (e.g. estuarine emergent; riverine tidal forested), and the vegetation zone in which channels are found (e. g, within one of the wetland types or within non-tidal freshwater). A "channel type" field indicates whether a channel is a blind tidal creek, or a distributary, tributary, slough, or mainstem. A "source" field lists the sources we drew on for the individual line or polygon.

For larger or more complicated wetlands, we created feature identification numbers for the purpose of referencing these areas to narrative descriptions we created for them. The narrative descriptions include the information from the sources we consulted for that feature, including transcriptions of the relevant GLO field notes, and discussion of the logic and assumptions that went into an interpretation.

Lines and polygons representing wetlands, channels, and water bodies are also coded with a “wetland complex” identification number and a three-letter code for one of 20 typical wetland types that we identified and organized into a classification scheme (see Chapter 2). To organize the analysis at the largest scale, we also assigned data to one of ten sub-basins we created within the study area, as described in the following chapter.

Methods used to map the current nearshore condition

We mapped the current condition of Puget Sound’s nearshore wetlands primarily from Washington Department of Natural Resources (WDNR) digital aerial photography from 1998 and 2000 having a 3-ft pixel resolution, and locally with higher resolution photography available for parts of east Central Puget Sound. We consulted the digital NWI layer at each complex, and deferred to the NWI when there was a question of interpretation or extent. At each site we also consulted the lidar DEM, and oblique shoreline photographs from the WDNR.

We used these sources to modify the shoreline from WDNR’s Shorezone coverage in the historical complex areas. Outside these areas we did not modify the Shorezone line. We found the oblique photographs to be essential for delineating the shoreline, which would not have been possible to do accurately from vertical aerial photographs alone. We based our line coverage of

channels on the WDNR digital hydrology layer, modifying and augmenting it within the wetland complexes by mapping from aerial photographs.

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Chapter 2: A landform-based classification for tidal wetlands in Puget Sound

Abstract

A landform-based classification of nearshore wetlands in Puget Sound has been developed to structure a regional historical wetland inventory and an historical change analysis, and for developing strategies for wetland restoration in the Puget Sound region. To account for historical wetland loss, change, and degradation, the classification was constructed from an inventory of tidal wetlands reconstructed for the mid-19th century, before widespread Euro-American settlement. The inventory includes 621 discrete assemblages, or “complexes,” of wetlands. These historical tidal wetland complexes were described by geomorphic, hydrologic, and oceanographic variables: relative salinity (marine, estuarine, and tidal-freshwater); dominant energy input (wave, stream, and tidal); coastal geometry (embayed, unembayed, and accretionary); and geomorphic history. The regional geomorphic history includes the thick Pleistocene glacial sedimentary deposits that fill the lowland, and the pervasive patterning of the surface topography by glacial erosion; post-glacial coastal submergence or emergence; Holocene stream responses to changing relative sea levels; extensive Holocene volcanic deposition, and recent tectonics. Describing historical tidal wetlands with these variables results in 20 typical complexes. Some of the types tend to cluster regionally in part because geomorphic variables covary regionally. The various complex types have characteristic habitats, structures, and sizes. They also have characteristic susceptibilities to environmental and anthropogenic change, and thus can be used to generate hypotheses for testing in a regional change analysis.

Introduction

Statement of the problem

Tidal wetlands in Puget Sound have been a focal point in the Puget Sound region (Figure 2-1) as long as human inhabitation; tidal wetland habitats and resources were critically important for indigenous peoples. Tide marshes were also one of the first environments occupied and modified by Euro-American settlers, who typically diked and drained tidal marshes for agriculture, starting in the 1850s, and later, in some areas, for urban development. This extensive landscape change has converted, or modified the function of, the majority of tidal wetlands (Chapter 3 of this report provides an assessment of historical change). The biological function and habitats of tidal wetlands, and their restoration, are of increasing interest to the Puget Sound region's inhabitants.

To provide a basis for analyzing historical origins, functions, and distributions of tidal wetlands, we reconstructed the historical condition of these modified environments using a variety of archival and recent sources (see Chapter 1 of this report, and Collins et al. 2003); Chapter 3 of this report presents the historical inventory. A regional, process-based classification scheme is a useful tool for structuring such an inventory, and can help answer questions about the historical condition, such as: What different types of tidal wetlands exist, and existed, and what processes created them? What size and structure characterized the different types? How common were different tidal wetlands types, how were they distributed, and what factors controlled their distribution? Additionally, a classification can structure an analysis of tidal wetland change from pre-Euro-American contact to the present. Such a change analysis can in

turn point to the opportunities for restoration, and help answer such questions relevant to restoration as: What anthropogenic and natural influences are particular wetland types most sensitive to, and why? What critical processes are important to restore in different settings, and what are the preconditions and likelihoods of success?

While there have been some previous descriptions of tidal wetlands in the Puget Sound region, none provide a landform and process based classification in a comprehensive regional or historical treatment. In the absence of an existing classification, one can be created, based on the historical inventory of nearshore wetlands. The classification described in this chapter was shaped by specific objectives and constraints: It needed to (1) be based on physical processes, and to encompass the entire Puget Sound region; (2) describe features that can be discerned from historical sources and compared to modern data; (3) imply biologically meaningful distinctions; and (4) be compatible with existing classification schemes currently used or being developed for Puget Sound.

Existing tidal wetland and coastal landform classifications in Puget Sound

It is desirable for a regional classification of tidal wetlands to be consistent with existing classification schemes developed in the Puget Sound region. We focus specifically on regional landform-based classifications of wetlands and regional landform classifications. We did not consider fine-scaled hierarchical coastal habitat classifications (e.g. Dethier 1990), community descriptions (e.g. Simenstad 1983), or geomorphic classifications focused primarily on landforms lacking tidal wetlands (e.g., beaches or bluffs).

Kunze (1984) identified nineteen representative coastal wetlands in the Puget Sound area for

potential inclusion in Washington's proposed Estuarine Sanctuary system. She identified five different systems into which she placed these nineteen sites: (1) A "coastal lagoon" is a "body of water or tideland with limited access to the open ocean or estuarine waters;" (2) a "coastal embayment" was defined as a "body of water or tidelands partially enclosed by land but with an unimpaired connection with open marine or estuarine waters;" (3) "tidal river" wetlands are estuarine systems along the tidal reaches and mouths of streams and rivers;" (4) "bay shore" sites are "wetlands with limited channeled freshwater influence and with no restrictions to marine influences;" and (5) "coastal spits" are ridges or embankments of sediment which may or may not be attached to the land at one or both ends."

Beamer et al. (2003) took a landform approach to characterizing small estuaries in the Whidbey Basin of northern Puget Sound. They classified estuaries into: (1) landforms enclosed by spits or barrier beaches, associated with fjords, stream mouths, tectonic valleys, tidal floodplains, and lagoons; (2) drowned stream mouths; and (3) stream mouths. They use the term "pocket estuary" to refer to these environments collectively. In an ecological and hydrological study of three small reference estuaries in central Puget Sound, Fetherston et al. (2001) had previously used the term "pocket estuary" to refer to "a topographic embayment set within a high relief coastline."

Downing (1983) described several depositional landforms in Puget Sound's coastal zone. He defined a river delta as the form that results "where a stream or river discharges sediment to an estuary or coastal area faster than it is removed by marine processes." "Tidal flats" develop "in partially enclosed or protected waters where there is low wave energy and a supply of sediment from tidal currents or a nearby river." He defined a spit as a "narrow ridge of sand and gravel,

exposed at high water, that extends from shore into deep water.” He includes spits that are relatively straight, resulting from unidirectional waves, and spits having an inward curve resulting from the addition of waves from a secondary direction. He defines a tombolo as a “spit that connects an island with the adjacent shore,” and a cusped foreland as “large triangular or cusp-like sedimentary deposits along the shore” that vary in scale from hundreds of meters to kilometers.

Shipman (in prep.) is developing a geomorphologically based typology for Puget Sound nearshore environments. He defines eight “shore types” organized within four “systems,” all of which include categories that are relevant to tidal wetlands: (1) A “rocky shorelines” system includes “rocky shore” and “pocket beach;” (2) a “beach shorelines” system includes “bluff” and “barrier beach” shore types; (3) a “large delta” system includes “estuarine deltas,” created by riverine deposition in coastal embayments; and (4) a “coastal embayments” system includes “estuary,” “lagoon,” and “other low energy bay shore” types. Shipman groups the geomorphic settings of estuaries into drowned stream valleys, glacial depressions, and projecting barriers; he classifies lagoons as open or closed, and their geomorphic settings as drowned stream valleys, glacial depressions, and projecting barriers.

Approach

From the historical reconstruction we identified several types of inter-related controls on the creation of tidal wetlands (Figure 2-2): (1) the geologic history, including bedrock structures and glacial sedimentation and erosion, coastal submergence or emergence; (2) post-glacial fluvial response to glaciation including within-region variability in relative sea level change resulting

from sea level rise and isostatic rebound, and the fluvial response to these changes; (3) episodic and chronic Holocene modifications, including volcanic sedimentation, local and regional tectonism, and ongoing coastal erosion and deposition; and (4) the dominant energetic input (i.e., fluvial, tidal, or wave). These give rise to primary characteristics that we used to describe and classify wetlands: (1) the coastal geometry (whether embayed, unembayed, or accretionary); (2) the relative salinity (nearshore marine, estuarine, or tidal freshwater); and (3) the topography (whether glacially sculpted, bedrock-influenced, or from post-glacial fluvial incision). We also considered separately from the other environments the estuaries of large rivers that drain the Cascades and Olympics into the Puget Sound region. Many of the formative factors and resulting characteristics co-vary spatially, causing a number of complex types to cluster. We defined 20 types of tidal wetland complexes, which in turn are grouped hierarchically (Table 2-1).

In the absence of a standard nomenclature for landforms in Puget Sound, we define how we used several terms for nearshore landforms and environments. We use “spit” as defined by Downing (1983): a “narrow ridge of sand and gravel, exposed at high water;” his definition continues “... that extends from shore into deep water,” but we did not consider a requirement for the depth of water at the spit terminus. Downing’s definition includes spits that are relatively straight, resulting from unidirectional waves, and spits having an inward curve resulting from the addition of waves from a secondary direction. We also follow Downing (1983) definitions of “tombolo” as a “spit that connects an island with the adjacent shore,” and of “cusate foreland” as a “large triangular or cusp-like sedimentary deposit along the shore” that vary in scale from hundred of meters to kilometers. We use “closed lagoon” for nearshore waterbodies separated from marine water by a barrier, and “open lagoon” for those connected to saltwater by a channel,

or separated by a partial barrier extending across at least 80% of the water body's width (e.g., Bird 2003).

It is also necessary to define terms expressing relative salinity. "Estuary" can be applied to water bodies at multiple scales. We use "estuary" to refer to an embayed, semi-enclosed body of water, diluted with freshwater, freely exchanging with marine water, and roughly coincident with the intertidal zone within an embayment in the shoreline. We use "nearshore marine" to refer to Puget Sound waters beyond embayed estuaries. We have not used the term "pocket estuary" because it was broadly defined in its first uses, and in current usage is defined even more broadly to encompass any smaller estuary not associated with a large river.

The regional geologic context for nearshore habitats

The legacies of Pleistocene glaciation pervasively influence the types, distribution and sizes of tidal wetlands in the Puget Sound region, beginning with the several-hundred-meter-thick layer of glacial deposits that constitutes the "great lowland fill" (Booth 1994). These sediments fill the Puget Lowland, extending northward to the San Juan Islands (Figure 2-1). In the San Juan Island region, including the mainland coast between the Samish and Nooksack rivers, bedrock outcroppings interrupt the glacial fill in an east-west trending, 30-km wide swath of the lowland. A fill of glacial sediment again dominates the lowland nearshore north of the Nooksack River within the Fraser Lowland. These glacial deposits influence nearshore wetlands primarily in three ways. Eroding bluffs and banks of glacial outwash and till contribute generous amounts of sand for nearshore transport and to build accretionary landforms. Second, sub- and pro-glacial processes sculpted the glacial surface, resulting, where the surface topography intersects the

coastline, in variously shaped embayments. Finally, estuarine embayments have also been created by the post-glacial fluvial incision of glacial sediments.

The glacial legacy also takes the form of post-glacial changes in relative sea level resulting from eustatic sea level rise and isostatic adjustment. While post-glacial sea level rose, the land surface also rose from isostatic rebound, but differentially, ranging from a negligible amount in Olympia (Figure 2-1) to about 200 m in the northern Puget Lowland. As a result, coastal embayments in the southern half of the Sound region were drowned by rising sea levels, whereas coastal landforms in the north part of the Sound region reflect land emergence; early Holocene sea shores at a number of embayments on Whidbey Island are indicated as a series of steps on the land surface rising from the shoreline (Kovanen and Slaymaker 2004). The “hinge” between these two contrasting responses in the south and north (coastal submergence versus emergence) is roughly at the latitude of Seattle.

Lahars from three Cascade Range volcanoes created or greatly expanded at least five of the seven major river estuaries on the east side of Puget Sound. Mt. Rainier lahars contributed to the filling of the Nisqually embayment and building of the Nisqually delta and estuary. A series of Mt. Rainier lahars beginning 5.7 kaBP (thousands of years before present) and as recently as 2.2, 1.6, and 1.1 kaBP extended the Puyallup and Duwamish valleys 25 and 50 km seaward, respectively, to their present locations (Dragovich et al. 1994; Zehfuss et al. 2003). Lahars from a 12.5 kaBP eruptive episode of Glacier Peak likely traveled to the mouth of the Stillaguamish River (Beget, 1982). At least one lahar in a 5.5 kaBP Glacier Peak eruptive period (Beget, 1982) reached the mouth of the Skagit River, creating an immense delta into the Whidbey Basin, prograding 25 km beyond the Skagit River valley and creating an immense delta into Skagit,

Padilla, and Samish bays (Dragovich et al. 2000). In an eruptive period about 5.9 kaBP, a lahar from Mt. Baker traveled at least 35 km down the Nooksack River to the Sumas River (Kovanen et al., 2001) and likely contributed to the progradation of the Nooksack-Lummi rivers delta.

Vertical tectonic movements along a series of east-west trending faults have also played a role in shaping nearshore environments locally. For example, about 1.1 kaBP, several meters of vertical movement on the Seattle Fault (Bucknam et al. 1992) appears to have caused uplift, and consequent incision and narrowing, of the Duwamish River estuary (Collins, unpublished data). Around the same time, there was at least 1 m of earthquake-induced subsidence in the Nisqually River delta, and possibly up to 3 m to the south at Skookum Inlet (Sherrod 2001). Tectonics also exerts a region-scale influence on nearshore environments in the Puget Sound region. Warping of the North American plate as it collides with the offshore Juan de Fuca plate causes differential vertical movements throughout Puget Sound. As a result, the modern rate of sea-level rise in southern Puget Sound is roughly twice that in northern Puget Sound (Canning 2002).

The regional oceanographic context for nearshore habitats

Many of the variables that generate different nearshore wetlands are specific to, or relatively more dominant in, different parts of the Puget Sound region, making it useful to define oceanographic sub-basins for reference in a wetland inventory and classification. We defined ten sub-basins, based in part on the oceanographic basins defined by Burns (1990).

South Sound. The South Sound (coincident with the “southern basin” of Burns, 1990) is the system of inlets and islands south of the Tacoma Narrows (Figure 2-1). Numerous embayments create the greatest length of shoreline of any sub-basin. South of the Tacoma Narrows, the main

basin of Puget Sound splits into two large arms, Case and Carr inlets. Case Inlet, in turn, splits into a number of narrow “finger inlets.” Case and Carr inlets and the smaller finger inlets all end in (and are, themselves) broad, linear depressions created by glacial drainage. In much of the South Sound, wind fetch is small, and tidal range relatively great, commonly creating a dominance of tidal energy over wave energy. The upland and shore bluffs are almost entirely characterized by glacial sediments. This glacial fill directly and indirectly influences nearly all topography. Subglacial drainage ways have subsequently been drowned by a rising relative sea level. The drowned drainages that comprise the finger inlets are very low in gradient and give rise to tideflats that extend 3-4 km from inlet head. Seawater also floods other, smaller or more localized depressions created by glacial erosion, and often lacking a significant stream. During lower sea levels earlier in the Holocene, many coastal streams incised to the Sound’s lower base level, creating post-glacial fluvial valleys, which were subsequently drowned or partially drowned by rising sea levels. The Nisqually River, the only major river system in the South Sound, emerges from a post-glacial valley only three miles from the shoreline onto the broad but short glacial valley that contains the river’s estuary.

Central Sound. Coincident with Burns’ “Central Basin,” its eastern shoreline is relatively straight and featureless, consisting nearly entirely of high bluffs in glacial sediments, broken only by Elliott Bay and Commencement Bay, the embayments associated with the Duwamish and Puyallup rivers, respectively. Both of these river estuaries are in broad, low-gradient troughs created by subglacial fluvial erosion (Booth, 1994), and subsequently filled by sediments from Mt. Rainier lahars and flooded by rising sea level. (These troughs eroded by sub-glacial fluvial erosion are distinguished from previously-mentioned glacial drainages by being much larger, and

by containing a major river draining the Cascade Range, or in the case of the Skokomish River, the Olympic Mountains.) The eastern shoreline between these two bays is characterized by a number of streams in steep, narrow ravines, and several cusped forelands. The channel splits around Vashon Island to the south, and around Bainbridge Island in the north; the system of inlets west of Bainbridge Island comprise the “Western Inlets” of Burns (1990).

Western Inlets. Shallow inlets to the west of Bainbridge Island, created by shallow flooding of a series of glacial drainage ways, include Dyes Inlet, Sinclair Inlet, Port Orchard, and Liberty Bay. This inlet system connects at the north to the Central Sound basin through Agate Passage at Port Madison, and opens to the Central Basin at the south end through Rich Passage at the south end of Bainbridge Island. The Western Inlets are topographically similar to the South Sound. The basin has no major rivers.

Whidbey Basin. The Whidbey Basin (Burns 1990) encompasses the waters to the east of Whidbey Island, including Skagit Bay, Saratoga Passage, Port Susan, and part of Possession Sound. It includes the deltas of the Skagit, Stillaguamish, and Snohomish rivers. Outside these three river valleys, much of the shoreline is high bluffs of glacial sediment, interrupted by embayments or accretionary landforms. Embayments are characteristically shallow and arcuate in form. Their arcuate shape may relate to the circumstances of their origin. The embayments appear to be localized by linear glacial depressions, where shore processes operated during progressive exposure of the land surface during isostatic emergence of the land relative to sea level. Relatively high wind energy in much of the Whidbey Basin has given rise to numerous accretionary landforms. The basin also has three major rivers. The Snohomish River is formed in a wide glacial trough having a low gradient; the river is influenced by the tides as far as 27 km

upstream. The Skagit and Samish river deltas were both created by immense sediment deposition from mid-Holocene eruptions of Glacier Peak; the Skagit delta coalesces with that of the Stillaguamish, which was likely at least augmented by Glacier Peak sediments. Historically the estuarine and tidal-freshwater wetlands in the Skagit-Samish system accounted for more than two-fifths of tidal wetland area in the Puget Sound region. The mid-Holocene volcanogenic progradation of the Skagit delta closed off the north end of the Whidbey Basin; as a result the Whidbey Basin's northern connection to Puget Sound is limited to narrow passages of Deception Pass and the Swinomish Slough.

Hood Canal. The shoreline of Hood Canal is the least complicated of the regions. Hood Canal fills a long, linear NE-SW trending trough eroded at the ice margin. At the south end, the Skokomish River valley, draining the southeast Olympic Mountains, is a broad glacially-eroded valley similar to the major sub-glacial troughs on the east side of the Sound. Five major rivers draining the eastern Olympics (Hamma Hamma, Duckabush, Dosewallips, and Quilcene) enter Hood Canal as short, steep fan-deltas in narrow valleys, confined in their upper reaches by steep bedrock valleys. Their estuaries are also moderately topographically confined by bedrock valley sides and glacial terraces. At its southern end, Hood Canal attaches to a shallower ENE-WSW trending trough that ends in a drowned glacial drainage, similar to those formed in the South Sound's finger inlets creating the Union River-Lynch Cove estuary.

Admiralty Inlet. The Admiralty Inlet basin connects Puget Sound to the Strait of Juan de Fuca. It extends from Point Partridge on Whidbey Island's outer coast to the island's southern tip (Burns 1990). The western coast of Whidbey Island in Admiralty Inlet has high bluffs, and a strong wave environment that generates a number of large accretionary landforms and embayed barrier

estuaries. The western shoreline has steep bluffs and includes two embayments at Port Townsend and Kilisut Harbor associated with Marrowstone and Indian islands. Relatively small streams are tributary to the Inlet.

Eastern Strait of Juan de Fuca. The nearshore of the eastern Strait of Juan de Fuca is similar to Admiralty Inlet in being dominated by bluffs and steep slopes of glacial sediments and having a high wave energy environment, except for two embayments—Sequim and Discovery bays—and in the lee of two very large recurved spits, the Dungeness and Ediz spits. This region also includes the high-wave-energy outer, northern coast of Whidbey Island, north of Point Partridge. The more exposed shorelines have both accretionary and embayed barrier beaches, estuaries, and lagoons. The Dungeness and Elwha rivers both have steep estuaries on alluvial fans emerging from the northern Olympic Mountains, less confined than the steep fan-deltas on Hood Canal.

Western Strait of Juan de Fuca. Roughly west of the Elwha River, the north coast of the Olympic Peninsula is a rocky shoreline with shallowly embayed rocky coves. Several rivers draining the north Olympic Peninsula foothills create small estuaries within these shallow coves, most notably along the Pysht River and Salt Creek. Wave and current energy is high, but the limited sediment available along the rocky shorelines limits formation of accretionary landforms.

San Juan Islands and the North Coast. This province encompasses the bedrock terrane that interrupts the glacial fill of the Puget Lowland to the south and the Fraser Lowland to the north. The nearshore is characterized by rocky shorelines interrupted by rocky coves. Many of the coves are commonly a few times longer than they are broad, often reflecting the bedrock stratigraphy and structure.

Fraser Lowland/Southern Strait of Georgia. Low bluffs of glacial sediment characterize the coastline north from the Nooksack-Lummi rivers to the Canadian border and including Point Roberts. The Nooksack-Lummi river delta is inset below the general elevation of the glacial fill, and emerges from the Nooksack River valley, which flows in a glacial meltwater channel.

Summary of criteria used in creating wetland complexes

Several distinctions were important in defining wetland complex types and assigning individual complexes to a type (Table 2-1); Table 2-2 provides a generalized key that uses those distinctions to assign wetland complexes to a type. Estuaries of large rivers were treated separately. Coastal geometry separates accretionary landforms from unembayed coasts from coastal embayments. Glacial sediments are distinguished from bedrock terrane. Estuaries in glacial terrain are distinguished by being within fluvially incised post-glacial valleys, submerged glacially sculpted topography, or emergent glacially sculpted topography. The resulting groupings of complexes reflect differences in the dominance of tidal, wave, and stream energy, the relative potential for fluvial sedimentation, and salinity. The 20 complexes (Table 2-1) fall within a hierarchy of groupings, and are described individually in the following section.

Descriptions of Wetland Complexes

Twenty different wetland types fall into four major groups: (1) Nearshore marine accretionary landforms (including cusped forelands, spits, tombolos, and coastal barrier marshes); (2) Unembayed coastal environments (including small coastal fringing marshes and coastal stream mouth estuaries); (3) embayed estuaries, marshes and lagoons (exclusive of the

major rivers draining the Cascades and Olympics); and (4) major river estuaries, which include in some cases extensive tidal freshwater floodplains (Table 2-1).

Nearshore-marine accretionary landforms

These wetland complexes are associated with landforms created and maintained by longshore transport, and that extend outward from the generalized plane of the shoreline. The wetlands generally lack significant freshwater influence.

(1) *Cusate forelands* [NCF]

A cusate foreland is a triangular, accretionary shoreform, typically bounded on both sides by a barrier beach or berm, a landform designation used locally and globally (Downing 1983; Bird 2000). On T-sheets in Puget Sound, the barrier is commonly symbolized as sand, sand and gravel, grassland, or by no symbol. A few features were depicted as saltmarsh not bounded by a different symbol, presumably because the barrier was small or subtle. All of these latter forelands lacking a mapped barrier are in the lower-wave-energy areas of the Sound; examples include Quarters Point and Stretch Point.

Most cusate forelands had saltmarsh mapped within the interior. The features had between 0.03 and 102 hectares of tidal marsh, and a median size of 1.5 hectares (Figure 2-3). Of the 84 that we mapped that had tidal marsh, two-fifths had lagoons within their interior, including 26 lacking a channeled connection with marine water, 13 having a channeled connection, and 5 with an open connection. A smaller percent included a channeled freshwater influx; seven had a channel large enough to be mapped as a blue line on USGS topographic maps, another nine had

channels not shown on USGS topographic maps but appearing on WDNR digital hydrology data or on the T-sheet. [For brevity, channels shown on USGS topographic maps are referred to as “blue-line” channels and those not appearing on the topographic maps but on the sources mentioned above are referred to as “non-blue-line” channels. Together these are referred to as “mapped” channels.]

Wetlands in cusped forelands lacking a marine connection or a freshwater connection include Point Julia and Marrowstone Point. Examples of features having a marine connection and no freshwater connection include West Point, Becket Point, Kala Point, and Kayak Point. Features having freshwater influx and no mapped marine connection include Thompson Spit (Strait of Juan de Fuca) and Aycock Point; features having a mapped marine connection and freshwater connection include Lone Tree Point and Lagoon Point.

(2) *Nearshore marine coastal spits* [NSP]

These features occur along open shorelines and are distinguished from spits associated with estuaries. The spits typically included saltmarsh on their shoreward side, or were shown on T-sheets entirely as saltmarsh. The tidal marsh area on individual spits ranged from 0.06 to 52 hectares and the median was 0.6 hectares (Figure 2-3).

(3) *Nearshore marine tombolos* [NTO]

In the Puget Sound area, tombolos typically consist of a barrier of sand, or grassland on sand, often with saltmarsh, and sometimes a lagoon. The largest numbers are in the San Juan Islands, which include many small islets and rocks. Of the 17 that had tidal marsh, nine had a lagoon

(seven with a channeled connection to marine water, and two without a channeled connection), and two created an estuary. Tidal marsh area ranged from 0.08 to 8.6 hectares and the median was 1.9 hectares (Figure 2-3).

(4) *Coastal barrier marshes and lagoons* [NBM]

These features consist of marshes, lagoons with marsh, or lagoons only, behind barriers formed on unembayed coastline. The largest numbers of these features were on Whidbey and Camano islands (Figure 2-4). The tidal marshes ranged in size from 0.1 to 39 hectares, with a median size of 2.5 hectares (Figure 2-3). One feature had a freshwater influx mapped as a blue-line stream, and an additional five features had non-blue-line streams. These features are distinguished from barrier marshes within embayments by having been constructed beyond the general plane of the shoreline, and also differ in their relative absence of freshwater input compared to embayed barrier features.

Unembayed coasts

This second of four major groupings include numerous very small marshes that fringe open shorelines, and also marshes and lagoons associated with the unembayed mouths of steep coastal streams.

Small unembayed coastal marshes

(5) *Small coastal marshes* [NCM] and (6) *Small coastal marshes with small barriers* [NCM/B]

Historically Puget Sound had a large number of small saltmarshes fringing lower-energy

shorelines and elongate in the along-shore direction; on higher energy shorelines these small saltmarshes were mapped with narrow barriers (Figure 2-4). The marshes large enough for Coast Survey topographers to map ranged in size from 0.02 hectares to 12 hectares, and had a median size of 0.3 hectares. The marshes included in this category generally lacked freshwater input; only four had associated blue-line creeks, and non-blue-line creeks fed another twenty-five. They are distinguished from the large accretionary landforms described in the previous major grouping by not extending outward of the general line of the coast, and by being very small. A minority included small lagoons, fifteen of which had no mapped channeled connection to marine water and six having a channel. Some of these features, generally in higher-energy environments, had narrow barriers, and were essentially the same size as those lacking a narrow barrier, ranging between 0.05 and 14.5 hectares with a median of 0.3 hectares.

Unembayed stream mouths

(7) *Coastal stream-mouth estuaries* [ESM] and (8) *Coastal stream-mouth estuaries with small deltas* [ESM/D]

These small estuarine wetlands form at the mouths of small, generally steep coastal streams. Marshes or small lagoons form in the sedimentary flat at the river mouth within the bounds of the stream's shallowly incised valley. A minority had a mapped barrier; fourteen had a full barrier and 10 a partial barrier. The complexes in this type probably encompassed a range of salinities; symbology on the T-sheets was primarily recognizable as "saltmarsh," but also appeared to include "wooded marsh" and "fresh marsh" symbols. A few complexes had small lagoons; five had lagoons without a mapped, channeled connection to marine water, and two had

a mapped channel. The wetlands ranged in size from 0.03 to 3.4 hectares and the median size was 0.48 hectares. This complex excludes stream mouths that included a delta extending beyond the general line of the shoreline into nearshore marine waters (see below).

Those coastal stream mouth estuaries having small deltas were given a separate category. In all but one case the marsh symbology was interpretable as saltmarsh. Eight had partial barriers. Two had lagoons having channeled connection to marine water and one lacked a channeled connection. They were larger than wetlands in coastal stream mouths lacking deltas, ranging in size from 0.21 to 3.3 hectares with a median of 0.9 hectares.

Embayed estuaries, marshes, and lagoons

Embayed estuaries exclude the thirteen major rivers that drain the Cascades and Olympics, which are treated separately in part because of their large freshwater influx and large watershed area, and in several cases because of the very large size and complexity of the major river estuaries. Embayed estuaries have been divided into seven complex types within glacial terrain, and two complex types in bedrock terrain (Table 2-1). Within glacial terrain, there are three further subgroupings, reflecting different glacial topography and post-glacial histories of emergence or submergence, as described below.

Embayments in drowned, post-glacially incised stream valleys

The two wetland complexes in this sub-grouping are within valleys that incised into the Puget Lowland's glacial fill when relative sea level was lower in the early Holocene, then

subsequently flooded by rising sea level. These features are almost entirely in the southern half of the Sound, roughly south of Seattle.

(9) *Stream estuarine in drowned steep, v-shaped, narrow inlets* [EIV]

These wetlands are within narrow (typically less than 100 m wide) steep-sided estuarine inlets. In all but three, a spit or spits separates the inlet from nearshore marine waters. All features having this morphology were included in this category, and the additional three lacking the barrier spit but having tidal marsh were also included. Tidal marsh typically formed on the bayward side of the spit or spits, and at the bayhead, associated with the freshwater channel mouth. Tidal marshes ranged in size from 0.05 hectare to 3.6 hectares; the median size was 0.5 hectares. Most of these features are not named on published maps; among those that are named are Thompson Spit (Carr Inlet), Whiteman Cove (Case Inlet), and Glen Cove (Case Inlet).

(10) *Stream estuaries in long, narrow, incised floodplain valleys* [EIF]

Estuaries in this grouping are similar to the drowned v-shaped narrow inlets in their origin, having incised through the glacial fill and subsequently been partially inundated by rising sea level, but have important differences from those features. These features form in longer, broader, floodplain valleys incised by larger streams and small rivers. While the valleys were incised after deglaciation to lower mid-Holocene sea levels, the drainages in many cases partially exploit glacially sculpted surface topography. Nearly all of these features drain the central Kitsap Peninsula, typically into the Hood Canal drainage, where streams draining the glacial upland have larger drainage areas than the smaller, shorter coastal creeks that created the incised “v”

shaped valleys. The relief is greater, and thus the rivers have incised farther inland. The valleys have floodplains 100-500 m wide.

The stream mouth and associated tidal wetlands are at the ends of inlets 1.5-1.8 km long. Tidal marsh was associated with the bay-head stream and fringed the embayment sides. The bay-head streams are relatively low gradient, tide-dominated and funnel-shaped; some estuaries include small distributary and blind tidal streams. Wetlands in all of these features were mapped as saltmarsh on T-sheets. Marsh area ranged from 0.16 to 19.1 hectares and the median was 1.7 hectares. Examples include Anderson Creek, Dewatto Creek, Tahuya River, Rendsland Creek (all, Kitsap Peninsula, Hood Canal), and Eagle Creek and Liliwaup Creek (Olympic Peninsula, Hood Canal). In a few cases a spit forms a partial barrier at the entrance of the drowned valley; examples of the latter are Big Beef Creek, Stavis Creek (Kitsap Peninsula, Hood Canal), Minter Creek, Vaughn Creek, and Fletcher Bay (Puget Sound).

Embayments in drowned glacial topography

Like the previous two, the two complexes in this grouping are in glacial terrane and are drowned features. However, in contrast to the previous two complexes, which are located in valleys created by post-glacial fluvial incision, the two complexes in this grouping are formed in topography created during glaciation. Both are primarily in the southern part of the Puget Sound region but are not exclusive to the southern Sound.

(11) *Stream estuaries in drowned glacial drainages* [EGD]

A dominant surface topographic feature of the Puget Lowland is the network of subglacial

and proglacial drainage ways carved into the lowland fill. (As indicated previously, the largest of these drainage ways having large rivers comprise a separate complex type.) Prominent examples include the narrow “finger inlets” at the southern end of the South Sound and the Western Inlets. Sea level rise flooded or partially flooded these drainage ways, creating long, low-gradient inlets. Most of these features lack barriers; of the 20 included here, 16 have no barrier and five have a partial barrier. The inlets extend upland as broad-floored glacial drainage ways. All but one of the complexes in this category has a stream entering the inlet head; 18 of the 20 are blue-line streams. Commonly, the creek or small river at the head of the inlet is a funnel-shaped tidal channel. The amount of tidal marsh ranged in size from 1.1 to 106 hectares with a median size of 14.6 hectares. Tidal marsh is commonly associated with the stream entry and fringing the embayment’s shoreline; examples include Mud Bay at the end of Eld Inlet, Oyster Bay at the end of Totten Inlet, Henderson Inlet, Lynch Cove at the end of Hood Canal, and Hammersley Inlet. Complexes having a partial barrier include Olalla Bay, Tarboo Bay, and Burley Lagoon.

(12) *Drowned linear glacial topography* [EGT]

These environments are similar to the previous type in that they form in the drowned, linear topography created by subglacial or proglacial erosion. They differ in two respects. The wetlands placed into this complex are generally in linear topography that is more local and does not extend for as great a distance as the drowned glacial drainages (EGD). They also differ in generally having less freshwater inflow than the glacial drainage environments. More than half lacked barriers; eighteen had a partial barrier and four a full barrier. The largest proportion (18) had non-blue-line streams, another 16 had blue-line streams, and the remainder had no mapped

freshwater-channeled input. The size of mapped saltmarshes ranged from 0.12 to 31.5 hectares, with a median of 1.9 hectares.

Barrier estuaries, marshes, and lagoons within arcuate embayments in emergent glacial terrain

The three closely related complexes in this grouping are within essentially the same landform. They are separated into those having an estuarine body and marsh behind a partial barrier, those having marsh behind a full barrier, and those having a large lagoon behind a full barrier. The landform is a long-radius, arcuate embayment about 1-3 km wide, enclosed or semi-enclosed by a barrier. As described previously, the embayments appear to have resulted from the post-glacial emergence of the glacial fill, in interaction with shore erosion and in the context of linear glacial topography on the fill surface. These features occur primarily in the high wave-energy environments in the Admiralty Inlet and Whidbey Basin areas, and secondarily in the northern Central Sound basin and the northern part of Hood Canal. All are north of Seattle. Individual features had more marsh on average than all other types except for the estuaries of major rivers in glacial troughs or in the greater Skagit River delta, and accounted for more area in aggregate than other types except for the two large-river estuary types; and taken together they accounted for three times more marsh than the next largest type.

(13) *Barrier estuaries in arcuate embayments* [EBE]

This complex consists of an estuary, and associated saltmarsh, formed behind a partial barrier seaward of a broad (1-3 km wide) arcuate embayment. More southern examples include Ten Mile Point (in the town of Edmonds), Doe-kag-wats estuary (on Kitsap Peninsula), and Smith Cove (Elliott Bay). More northern examples include Cultus Bay and Deer Lagoon on Whidbey

Island and Thorndyke Bay in the Hood Canal. These features generally had more freshwater input than the other two types described below. Twelve had blue-line streams, four had non-blue-line streams, and two had no mapped stream inflows. The minimum and maximum amounts of saltmarsh in this type were 0.4 hectares and 179.2 hectares; the median size was 22.1 hectares. The amount of marsh in individual complexes in this category and the category described after this (“barrier marshes in arcuate embayments”) were third in the Puget Sound region only to the Skagit-Stillaguamish delta system and the river estuaries in glacial troughs.

(14) *Barrier marsh in arcuate embayments* [EBM]

These features are similar to those in the previous type, except that a full barrier encloses tidal marsh. Most marshes have less freshwater input than the type described above (EBE); there was little or no mapped freshwater influx: nine lacked a mapped freshwater channel, three had a non-blue-line channel, and three a blue-line channel. Examples include Livingston Bay (Camano Island), Crescent Harbor (Whidbey Island), and Glen Cove (in town of Port Townsend). Saltmarshes ranged in size between 1.2 and 100.2 hectares, with a median size of 20.79 hectares.

(15) *Barrier lagoons in arcuate embayments* [EBL]

These features are large lagoons formed behind full barriers. All form in the northern part of the Puget Sound area in high wave-energy environments. One feature had saltmarsh associated with it, and five had associated “fresh marsh” or “wooded marsh.” Two had no mapped freshwater channel inflow, four had a non-blue-line freshwater channel, and two had bluewater channel sources. Examples include Crocket Lake, Lake Hancock, and Cranberry Lake (all on the west shore of Whidbey Island) and Kah Tai Lagoon in Port Townsend. The tidal marsh area

ranged from 5.7 to 58.6 hectares, with a median of 44.8 hectares. The lagoons could be much larger. Crocket Lake historically was 240 hectares; it was drained with a ditch, and diked for hay and pasturage, reducing it to a lagoon a third its original size (Nesbit 1885) prior to the 1870 visit by the Coast Survey.

Embayments in bedrock terrane

The environments represented by the two types included in this grouping are characteristic of the east-west trending band of bedrock terrain that forms the San Juan Islands, Fidalgo Island, and the Chuckanut Drive area of the mainland (between the Samish and Nooksack rivers) and that separates the glacial sediment dominated Puget and Fraser Lowlands. The complex type also encompasses estuarine wetlands on the bedrock shoreline of the western Strait of Juan de Fuca.

(16) *Estuarine barrier marsh/lagoon complexes in rocky coves* [ERC]

The San Juan Islands include numerous inlets with rocky shorelines. They are commonly elongate, several times longer than wide, with gently arcuate heads. They generally are separated from marine water by a narrow beach berm. Landward of the berm, about two-thirds of the mapped features have saltmarsh, about one-fourth had fresh marsh, and one-third had lagoons. All of the lagoons had a channeled connection with saltwater. The size of these habitats is in almost all cases small, ranging between 0.06 and 6.0 hectares, with a median of 0.69 hectares. They lack large amounts of freshwater influx; about two-thirds lacked a mapped channel, one-fourth had blue-line streams, and the remainder had non-blue-line streams. Coves having marsh or lagoons with mapped freshwater inflow almost always have a mapped connection to saltwater. Many of these environments had been settled and cultivated prior to the 1880s Coast Survey

work, obscuring their original condition.

(17) River estuaries in rocky coves and coasts [ERE]

This grouping includes the river estuaries at the mouths of rivers draining to the Strait of Juan de Fuca from the Olympic Mountains foothills in the western part of the Olympic Peninsula's north coast. Examples include the estuaries of Salt Creek and the Pysht River. Similar to the other complex in this grouping, described above, these environments form behind beach-berms within embayments in a rocky shore; the embayments are shallower than those in the preceding (ERC) category, but differ primarily by being the estuary of a small river with significant freshwater component, and include tidal marsh with tidal channels.

Estuaries of major rivers

This fourth and last grouping is exclusive to the estuaries of rivers draining the Cascade Range and Olympic Mountains. The separate grouping of these complexes is warranted because of their connectivity to extensive freshwater habitats, their very large amount of freshwater influx, the distinctive hydrologic regimes reflecting mountainous headwater environments, and in some cases, the very large size of the estuaries.

(18) *River deltas and tidal freshwater floodplains in major glacial troughs* [ERG]

This complex includes the estuarine and tidal-freshwater estuaries of the Lummi, Nooksack, Snohomish, Duwamish, Puyallup, and Nisqually rivers draining the Cascade Range, and the Skokomish River draining the southeast Olympic Mountains. These river estuaries have formed within broad (2-5 km wide), low gradient (0.0001 - 0.001) valleys created by sub-glacial fluvial

erosion. Most of these river estuaries include extensive estuarine wetlands having a well-developed network of tidal and distributary channels. The Duwamish is the narrowest of the valleys, and had the least amount of estuarine marsh. Landward of the estuarine marsh were tidal freshwater marshes, in some cases extensive, and freshwater tidal channels. Tidal influence in the Snohomish River estuary extended the farthest upstream, 27 kilometers, and the Snohomish valley had the most extensive riverine-tidal wetlands of the rivers in this grouping. Excepting the Skagit-Stillaguamish delta complex, the estuaries in this complex generally had more tidal marsh than estuaries in other complexes.

(19) *The greater Samish-Skagit-Stillaguamish river delta* [ESK]

Largely as a result of one or more mid-Holocene eruptive episodes of Glacier Peak (Dragovich et al. 2000), the Skagit River built a vast delta into the Whidbey Basin, including that part drained by the Samish River, the network of small streams that historically drained to Padilla Bay, and the Skagit Bay. Previous to this eruptive episode, stratigraphic evidence indicates the delta front was near Sedro-Woolley, confined by the mountainsides of the Skagit River valley. The Stillaguamish River has built a similar, steeper, and less extensive delta into the Whidbey Basin, beyond the confines of the Stillaguamish River valley. This delta also resulted at least in part from eruptions of Glacier Peak. The Skagit and Stillaguamish River deltas coalesce, forming a single landform connected to Port Susan, Skagit Bay, Padilla Bay, and Samish Bay.

This complex differs from most of the river valleys in glacial troughs (ERGs) in extending beyond the confines of the river valleys, making them more subject to wave energy than the

other deltas. The Samish-Skagit-Stillaguamish fan included a considerable amount of estuarine marsh, including estuarine scrub-shrub wetland, referred to historically as “spruce marsh” (e.g. Nesbit, 1885), adjacent to the estuarine emergent marsh, particularly extensive on the Skagit River part of the delta. Tidal freshwater marshes were extensive, less so in the steeper Stillaguamish River valley. The wetlands in this complex type accounted for just more than half of the Puget Sound region’s tidal marsh (see Chapter 3).

(20) *Estuarine river fan/deltas of the east and north Olympics* [ERF]

These six rivers, draining the Olympic Mountains to the east into Hood Canal and to the north into the Strait of Juan de Fuca, have relatively steep fan-deltas. The Hamma Hamma, Duckabush, and Dosewallips river deltas are confined by valley walls; the Quilcene, Elwha, and especially the Dungeness have less confined fans, but all are steep and historically tidal marshes extended at most a few kilometers upvalley. The Elwha River’s high wave energy environment on the Juan de Fuca Strait coast precluded the development of a significant amount of saltmarsh, although we lacked sufficient information to quantify the amount. While located in this same high-energy environment as the Elwha, the Dungeness River is partially protected by the Dungeness Spit. The Dungeness River throughout the course of the Holocene has successively occupied different locations, leaving a legacy of at least three estuaries in addition to the modern estuary, along the coast from Dungeness Spit to Washington Harbor at the entrance to Sequim Bay (see Collins 2005 for detail).

Summary and Discussion

Consistency with existing coastal classifications in Puget Sound

How well does the proposed classification map onto the “Geomorphic typology for Puget Sound shorelines” under development by Shipman (in prep.)? The two systems have different purposes and classify different things, on the one hand shoreforms, and on the other hand the settings in which tidal marshes occur, but they both identify characteristic physical settings, so it should be possible to make correspondences between the two (Table 2-3). Some of the complexes correspond reasonably well to one of the shore types; the large river complexes could be mapped to Shipman’s “Estuarine deltas” shore type, the estuaries in rocky coves could be mapped to the “Pocket beach” shore type, seven of the complexes could be mapped to the “Barrier beach” shore type, and the six complexes in glacial terrane fit in one of the three “Coastal embayment” shore types. Several complexes do not fit well into any one of the Shipman Types. The setting of stream mouth estuaries on unembayed coasts without or with deltas (ESM and ESM/D, respectively) is hillsides that drain to unembayed shoreline; “bluffs” are the closest Shipman Type. Small coastal marshes on unembayed coasts (NSM) also tend to occur at the base of hillslopes on unembayed coasts, and secondarily at the base of bluffs in low energy environments. Some complexes could fit in more than one Type.

Regional distribution

Because some of the factors influencing the formation of tidal wetlands vary systematically between and within basins, and because some of the factors co-vary, most of the complexes cluster in particular sub-areas within the Puget Sound region (Figure 2-4). Regional geologic factors control the location of the major river estuaries. The Skagit-Stillaguamish delta system (ESK) reflects in large part the influence of volcanic sedimentation from Glacier Peak. Rivers in glacial troughs (ERG) are localized by the glacial dynamics that created the system of troughs.

The steep fan/delta estuaries are localized by their steep and rapid emergence from the Olympic Mountains. The other complexes cluster in several ways that are apparent in Figure 2-4, listed in a roughly south-to-north direction:

(1) Submerged post-glacial incised valleys (EIV) cluster south of Seattle. The wider, longer floodplain valleys (EIF) are on the somewhat higher-relief Kitsap Peninsula, where stream drainage areas are larger because of the absence of large river networks.

(2) Small coastal marshes (NCM) cluster in the South Sound and Western Inlets basins, which include lower energy environments. Most of the complexes outside these two basins are in moderate energy environments and have small barriers (NCM/B).

(3) Complexes in submerged glacial topography cluster in the southern part of the study area, generally south of Seattle. Stream estuaries in drowned glacial drainages (EGD) are localized by the pattern of channels created by glaciation. The interaction of the local orientation of linear glacial topography, elevation, and coastline orientation, locally control the occurrence of linear glacial topography (EGT).

(4) Coastal stream mouth estuaries (ESM) are localized by steep coastal streams along unembayed coastlines.

(5) Barrier estuaries in arcuate embayments in emergent glacial terrane (EBE, EBL, EBM) cluster in high-energy parts of the Admiralty Inlet, Whidbey Basin, northern Central Sound, and eastern Strait of Juan de Fuca basins, which is also north of Seattle, where crustal depression and post-glacial rebound were greater.

(6) Estuaries in bedrock terrane are concentrated in the San Juan Islands and North Coast basin and the western Strait of Juan de Fuca. The estuarine barrier beach/marsh/lagoons in rocky coves (ERC) cluster in the San Juan Islands which have few large streams, and the estuarine river mouths in rocky coves (ERE) concentrate on the western Strait of Juan de Fuca where rivers drain the north Olympic Peninsula foothills.

Susceptibilities to anthropogenic and natural change

Because each complex type represents a specific environment resulting from a characteristic combination of physical factors, each should have a unique set of sensitivities to changes in marine or fluvial conditions, or to anthropogenic stressors. For example, small coastal wetlands generally lacking barriers—including complexes NCM and ESM/D—are expected to be vulnerable to erosion by increased marine wave energy. Coastal accretionary landforms—including complexes NCF, NTO, NSP, and NBM—as well as the small coastal wetlands generally lacking barriers, could be sensitive to changes in the coastal sediment budget such as a diminished sediment supply due to bank armoring.

Smaller wetlands subject to levels of fluvial energy that are large relative to their size—including complexes ESM, ESM/D, EIV, EGD—could be sensitive to filling by fluvial sediment, especially where sediment loads have been augmented by the effects of urbanization. Coastal road building could restrict or redirect the supply of sediment and water to small deltaic marshes with fluvial inputs, including complexes EGD and ERF. Rapid estuarine progradation could result from increased sediment supplies in low-gradient fluvial estuaries, such as complexes EIF, EGD, ERG, and ERS.

A number of tidal wetland complexes provide attractive sites for urban development. For example, barrier beaches associated with barrier estuaries, marshes, and lagoons in arcuate embayments (EBE, EBM, and EBL), or with spits or cusped forelands (NSP and NCF) are attractive sites for housing, roads, and associated bank hardening. Some cusped forelands are small enough that their interiors are readily filled and developed. Wetlands in a number of complexes are susceptible to diking and draining, particularly estuarine scrub-shrub and riverine-tidal wetlands in larger river valleys; distributary channels and tidal channels in deltaic environments (e.g. EGD, ERG, and ESK) are subject to being closed by dikes to freshwater and marine water, which can locally starve marshes of sediment. Different tidal wetlands should also be expected to have differing sensitivities to the more rapid sea level rise that is forecast to result from global climate change. For example, estuaries in drowned topography are susceptible to sea level rise, especially those lacking significant fluvial input of sediment, and those in the southern Puget Sound region where regional warping of the North American tectonic plate augments relative sea level rise. Potential vulnerabilities of different complexes can generate hypotheses for testing in an analysis of historical change.

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Table 2-1. Nearshore wetland classification used to inventory historical and modern wetlands.

(1) Nearshore-marine accretionary landforms

- ***Cuspate forelands (NCF)***
- ***Tomboles (NTO)***
- ***Coastal spits (NSP)***
- ***Coastal barrier marshes (NBM)***

(2) Unembayed coasts

Small unembayed coastal marshes

- ***Small coastal fringing marshes (NCM)***
- ***Small coastal fringing marshes with narrow barriers (NCM/B)***

Unembayed stream-mouth estuaries

- ***Coastal stream mouth estuaries (ESM)***
- ***Coastal stream mouth estuaries with delta (ESM/D)***

(3) Embayed estuaries

Estuaries in glacial terrain

Submerged valleys from post-glacial incised incision

- ***Stream estuaries in drowned steep, narrow creek inlets (EIV)***
- ***Stream estuaries in drowned incised floodplain valleys (EIF)***

Submerged glacial topography

- ***Stream estuaries in drowned glacial drainages (EGD)***
- ***Drowned linear glacial topography (EGT)***

Barrier estuaries associated with emergent glacial topography

- ***Barrier estuaries in arcuate embayments (EBE)***
- ***Barrier lagoons in arcuate embayments (EBL)***
- ***Barrier marshes in arcuate embayments (EBM)***

Estuaries in bedrock terrain

- ***Estuarine barrier marsh/lagoon in rocky coves (ERC)***
- ***Estuarine river mouths in rocky coves (ERE)***

(4) Large river estuaries

- ***River estuaries and tidal freshwater floodplains in glacial troughs (ERG)***
- ***River fan/delta estuaries (ERF)***
- ***The greater Skagit-Stillaguamish rivers delta (ESK)***

Table 2-2. An example key for assigning wetland complexes to one of 20 types.

1.	Estuary of a major river (If NO, continue to 2)	
	1a. Glacial trough	(ERG)
	1b. Steep fan delta	(ERF)
	1c. Part of Samish-Skagit-Stillaguamish delta system.	(ESK)
2.	Embayed (If NO, go to 6)	
3.	Glacial or bedrock terrain (If GLACIAL, continue to 4)	
	3a. Marsh or lagoon, small or no stream, beach in arcuate rocky cove	(ERC)
	3b. River in arcuate rocky cove	(ERE)
	3c. Otherwise, continue to 4	
4.	Postglacial fluvial erosion (If NO, continue to 5)	
	4a. Narrow V-shaped valley	(EIV)
	4b. Wider floodplain valley	(EIF)
5.	Wetland created by glacial topography (If NO, continue to 6)	
	5a. Linear depression	
	5a-i. Stream estuary in glacial drainage	(EGD)
	5a-ii. Drowned glacial topography	(EGT)
	5b. Barrier estuary in arcuate embayment	
	5b-i. Partial barrier	(EBE)
	5b-ii. Full barrier	
	5b-ii.1 Large central lagoon	(EBL)
	5b-ii.2. Primarily marsh	(EBM)
6.	Unembayed (If CONVEX ACCRETIONARY, continue to 7)	
	6a. Mouth of steep unembayed stream	
	6a-i. No delta	(ESM)
	6a-ii. Small delta	(ESM/D)
	6b. Coastal fringing marsh	
	6b-i. No barrier	(NCM)
	6b-ii. Barrier	(NCM/B)
7.	Accretionary landforms	
	7a. Connecting two land masses (tombolo)	(NTO)
	7b. Attached to land at one end (spit)	(NSP)
	7c. Cuspate (cuspate foreland)	(NCF)
	7d. Nearshore barrier marsh	(NBM)

Table 2-3. Relation of the classification system presented in this report to the geomorphic typology under development by Shipman (in prep.). Complex acronyms are as defined in Table 1. Complex acronyms in italics are poor fits to the Shipman Type to which they are assigned, but fit no other Type better. Those complexes that fit in more than one Shipman Type are in parentheses.

SHIPMAN CLASSIFICATION			THIS PROJECT
SYSTEM	SHORE TYPE	SETTING	WETLAND COMPLEX
Rocky Shorelines	Rocky shores	Bedrock, little sediment	—
	Pocket beaches	Isolated between resistant headlands	ERE, ERC
Beach shorelines	Bluffs	Erosion into elevated upland surface	<i>ESM, ESM/D, NSM</i>
	Barrier beaches	Coastal deposition	NCF, NTO, NSP, NBM, EBM, EBE, (EBL)
Large deltas	Estuarine deltas	Riverine deposition in coastal embayment	ERG, ERF, ERS
Coastal embayments	Estuaries	Drowned stream valleys, glacial depressions	EIV, EIF, EGD, (EGT)
	Lagoons	Drowned stream valleys, glacial depressions, projecting barriers	(EBL)
	Low energy bay shores	Heads of bays	(EGT)

Figure Captions

Figure 2-1. Sub-basins and major rivers of the Puget Sound region.

Figure 2-2. Factors that create different types of tidal wetlands and some defining characteristics.

Figure 2-3. Areas of historical wetland complexes. Two complex types, river estuaries in glacial troughs (ERG) and the Samish-Skagit-Stillaguamish deltas (ESK) are excluded from the figure because of the great size of complexes in these types. Two values for the “EBE” type, 179 ha and 145 ha, are not shown. Numbers are sample size. Each box encloses 50% of the data. Horizontal line within box represents median. The lines extending from the top and bottom of boxes indicate minimum and maximum values, excepting outlier values (circles) greater than the inner quartile plus 1.5 times the inner two quartiles.

Figure 2-4. Historical distribution of complex types. Acronyms are defined in Table 1.

Figure 2-1

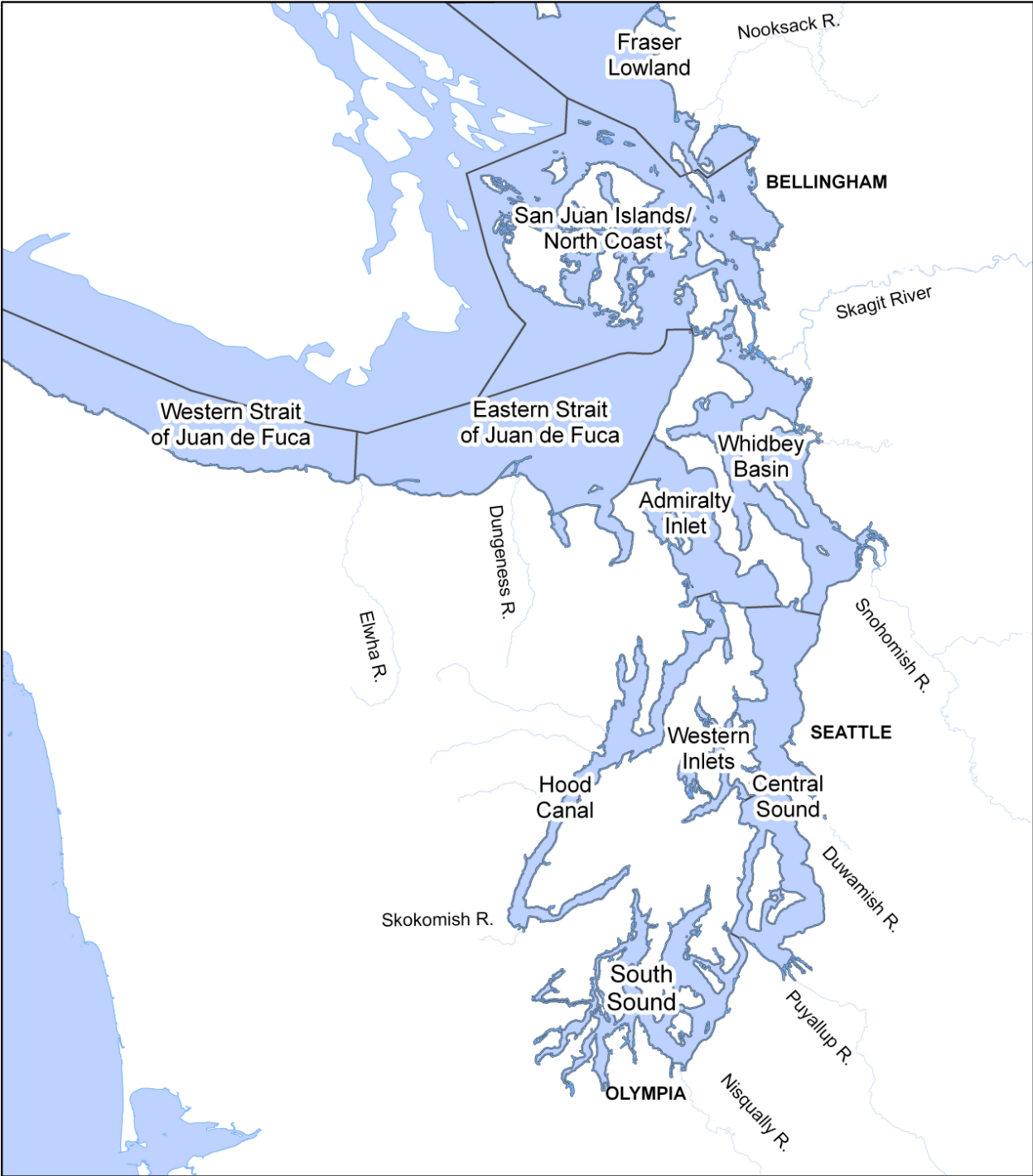


Figure 2-2

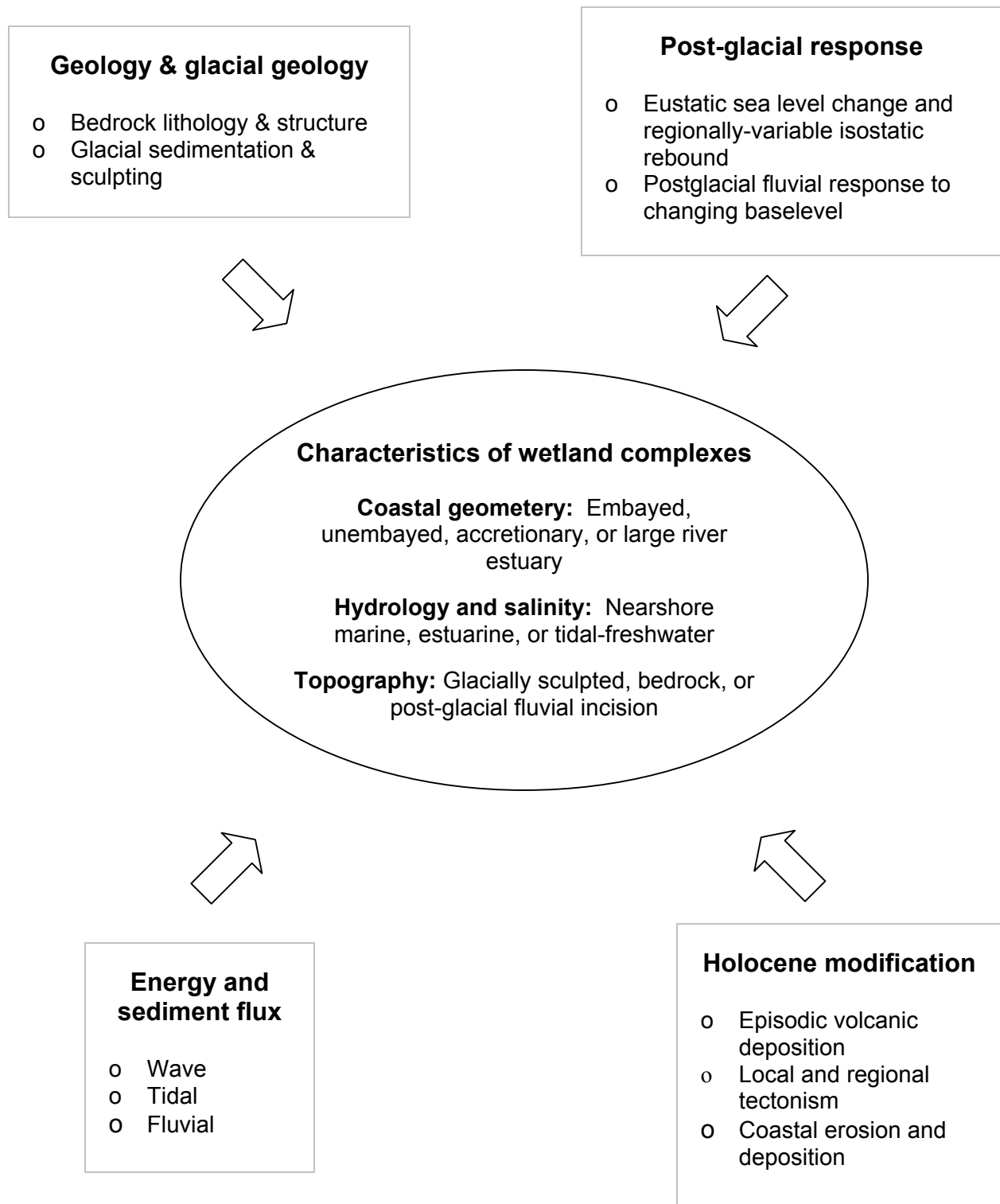


Figure 2-3

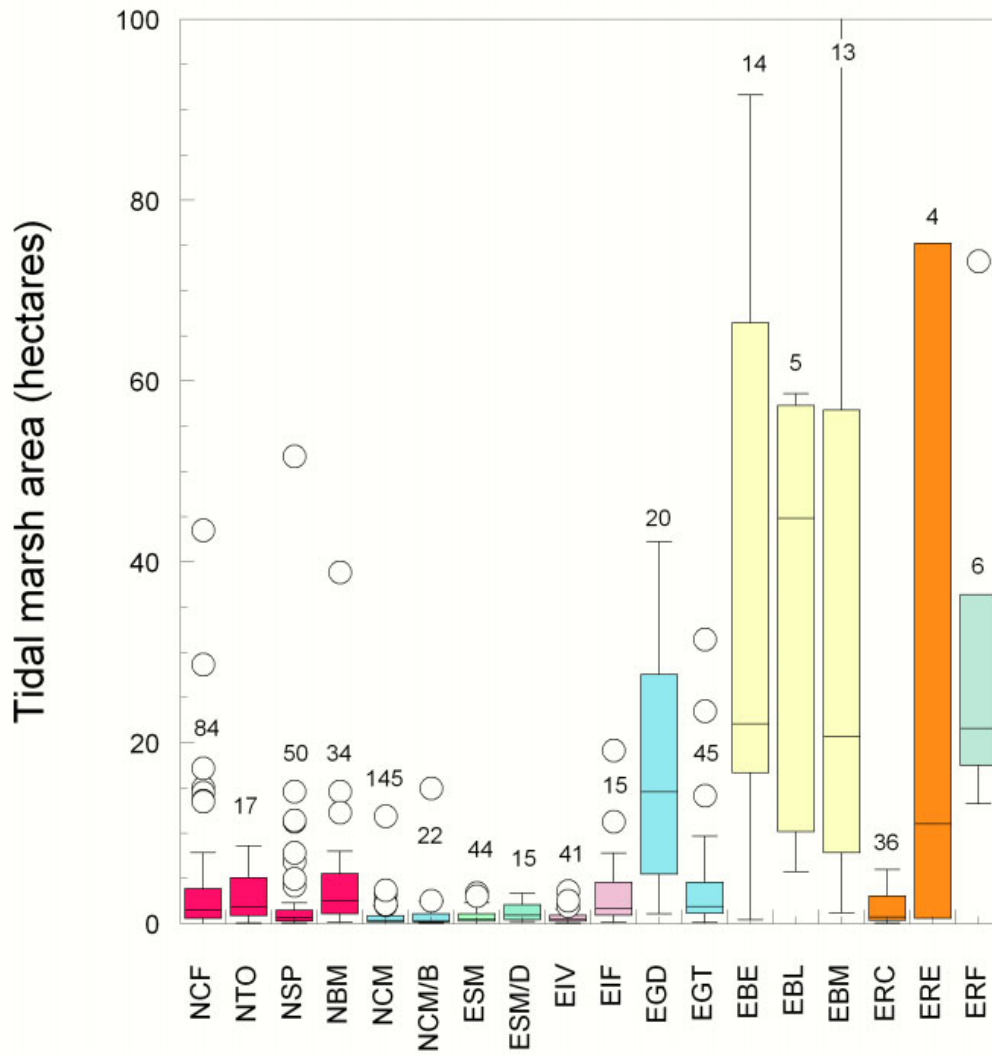


Figure 2-4

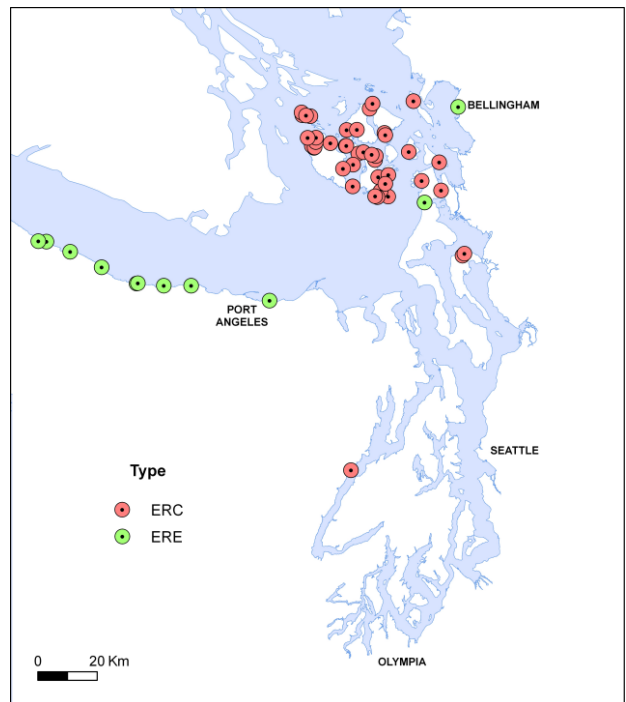
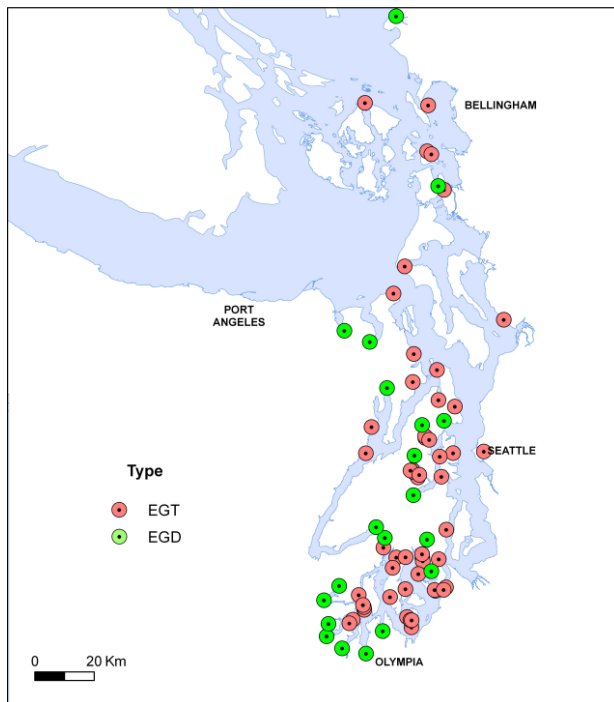
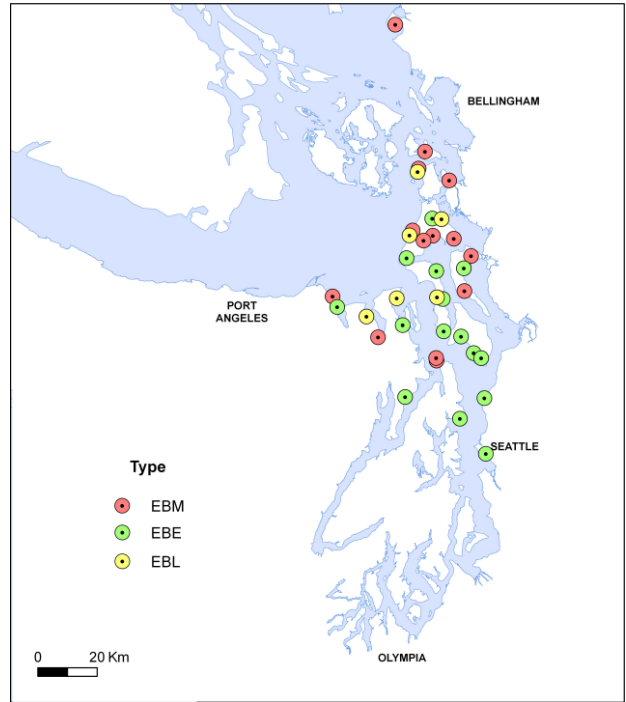
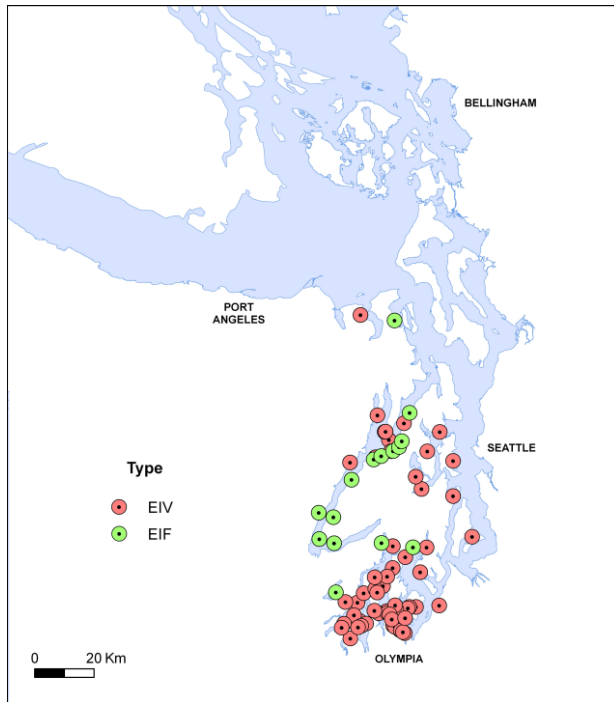
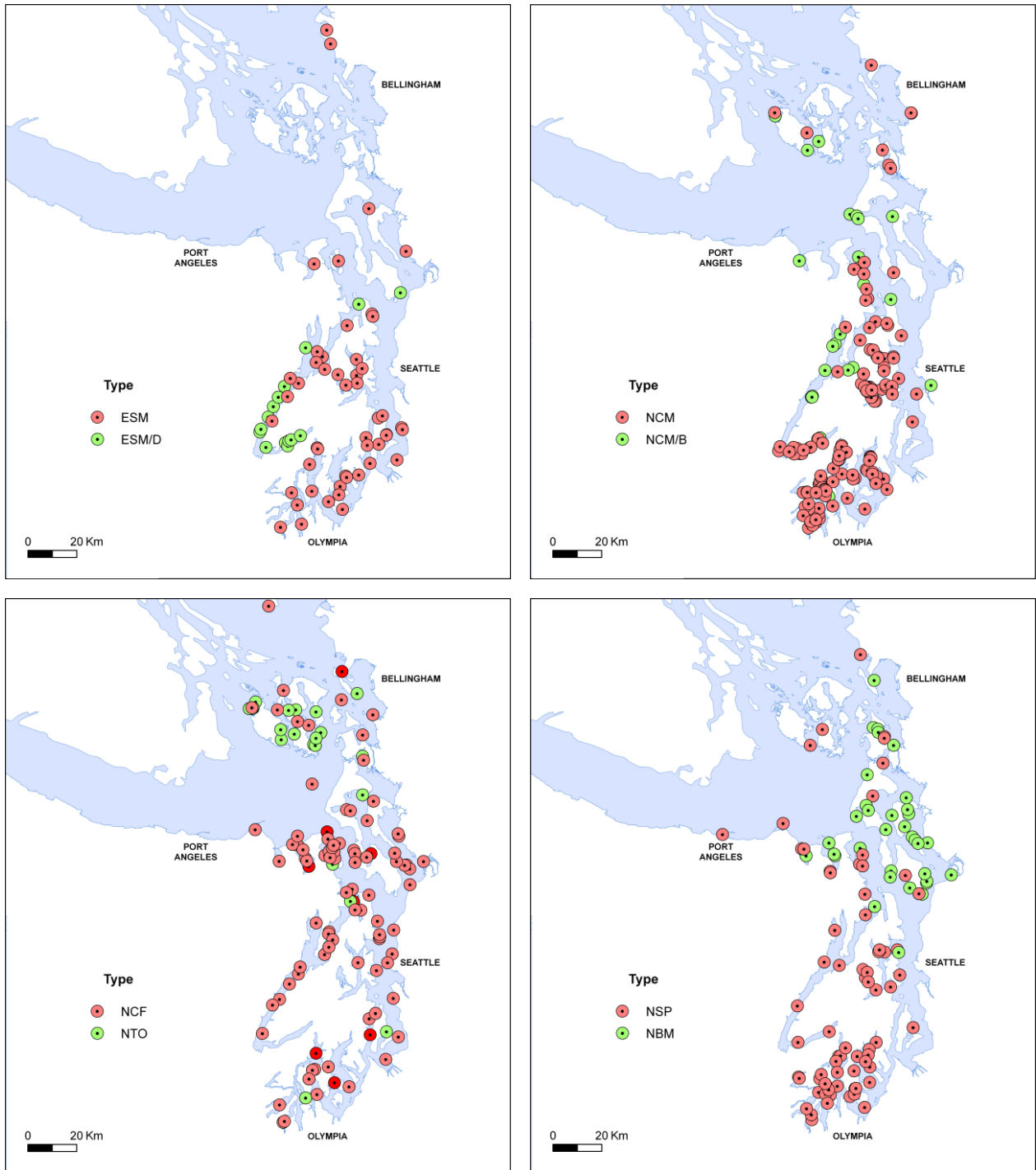


Figure 2-4



Chapter 3: Tidal wetlands in the Puget Sound region prior to Euro-American-settlement (mid- 19th century) compared to current conditions

Abstract

The historical amount, distribution and functions of tidal marshes in the Puget Sound region were reconstructed for nearshore environments in the Puget Sound region representative of the time of earliest Euro-American settlement. We identified 29,500 hectares of tidal wetland including 12,000 hectares of estuarine emergent marsh, 6,000 hectares of estuarine scrub-shrub wetland, and 11,500 hectares of tidal-freshwater wetlands. The estuaries of large rivers accounted for 90% of this total. The Skagit River alone accounted for 37% of the total, and the Snohomish River estuary an additional 22%, when combined with the nearby Samish and Stillaguamish river estuaries; these four adjacent rivers accounted for 74% of the total. The steep, narrow fan-delta estuaries draining the Olympic Mountains to Hood Canal and the Strait of Juan de Fuca accounted for only 1% of the total area of tidal marsh around Puget Sound. Outside these river valleys, wetlands associated with accretionary landforms and with barrier estuaries in arcuate embayments associated with emergent glacial terrain, more abundant in high wave energy environments of the northern study area, accounted for 3% and 4% of the region's tidal marsh, respectively. Drowned glacial drainages accounted for the largest portion of tidal marsh in the southern Sound, which is characterized by lower energy environments and a rising post-glacial sea level. The effects of Pleistocene glacial erosion and sedimentation, Holocene volcanic deposition, and the ongoing effects of wave and current energy are the primary controls on the relative sizes and spatial distribution of wetlands. An 1884 inventory of pre-settlement tide

marsh agrees with our total estimate within 1-2%. Tidal wetlands are now about 17-19% of their historical extent, including wetlands created since the historical reference condition. Both the number and sizes of wetlands have diminished. About half of current tidal marsh is concentrated in the greater Skagit River delta area, proportionately nearly as much as historically. In contrast, rivers in glacial troughs account for a smaller portion of the total than they did historically, reflecting the substantial loss in area from the Lummi, Duwamish, and Puyallup river estuaries. Other wetland types in aggregate have experienced a smaller relative decline. Some wetland types have lost much more than others, notably the large barrier marshes in arcuate embayments in the north Sound. Change was not uniform spatially; of the different sub-basins, the northern Sound and Central Sound sub-basins have the least of their historical wetland area remaining proportionally, and the Hood Canal, South Sound and West Strait sub-basins have proportionally the most remaining tidal wetland.

Introduction

Statement of the problem

There is at present an incomplete understanding of the historical amount, types, distribution, and sizes of tidal marshes that existed in Puget Sound prior to the land use transformation that began with Euro-American settlement in the mid 19th century. Such information would provide insight into the structure and function of wetlands in environments for which there are few or no analogs, and would contribute to the basis for quantifying lost biological productivity from tidal wetland conversion in determining restoration targets for endangered species. Spatially explicit information would also provide a template for guiding wetland restoration in parts of the

nearshore environment that have been most transformed. In addition, there has been no comprehensive accounting of the amounts and causes of change to the region's tidal wetlands. To characterize historical wetlands and to compare their abundance and distribution to the present, we reconstructed historical environments using primarily archival sources with a Geographic Information Systems (GIS), and for comparison created a comparable GIS map of current conditions.

Approach to reconstructing historical conditions

To make an inventory of historical tidal wetlands, we reconstructed the Puget Sound region's native nearshore environment using a GIS and a number of methods and sources, primarily historical; methods are described in Chapter 1 of this report. Briefly, to achieve spatially comprehensive coverage, we began by creating a geospatial digital database from topographic sheets (T-sheets) surveyed by the US Coast & Geodetic Survey (USC&GS) in the period between 1850 and 1900. We supplemented these maps with a number of other sources because there had already been a great deal of land conversion by the time of the USC&GS work, the T-sheet mapping did not generally extend inland in river valleys to include the entire estuary, and because it is desirable to augment the T-sheets and to cross-check them. Other sources and methods we used included the federal land surveys made in the 1850-1880 period, soil surveys, 1930s aerial photographs, other early maps, and various text sources. We were also able to cross-reference our estimates of pre-settlement tidal marsh with an early inventory of pre-settlement condition of tidal marshes published in 1885 (Nesbit 1885). To provide a basis for comparing our reconstruction of historical conditions to the current landscape, we also created a GIS

geodatabase of current conditions, primarily digitized from recent (1998-2000) aerial photographs in a manner designed to be comparable to the historical materials in detail.

Here we present a regional overview of the historical amounts, types and distributions of tidal wetlands and how these differ at present. The accompanying GIS data upon which this gross analysis is based can be used both for site-specific historical reconstruction and, along with descriptions made for intermediate time periods, to describe change at a smaller scale (see for example Collins, 2005).

Previous inventories of historical tidal wetlands in Puget Sound

Newspaper publisher Eldridge Morse, an early resident of the Snohomish River valley, made the first published inventory of tidal marsh (inclusive of saltmarsh and tidal freshwater marsh; see p. 6, Nesbit 1885) in the greater Puget Sound area. Morse provided an inventory of Puget Sound tidal marsh for a federal survey of tidal marshes (Nesbit 1885). Morse's inventory included extensive descriptions, especially of the larger river estuaries in eastern Puget Sound, and a quantitative summary. Probably completed in 1884, Morse's assessment was also an early change analysis; by his estimates, 38% of the Puget Sound region's tidal marsh had already been diked and reclaimed for agriculture. Morse's estimates are discussed in detail later in this chapter.

More recently, researchers have used the USC&GS T-sheets to inventory the historical extent of tidal marshes in different regions of the United States (e.g., see Atwater et al. 1979 for summary of investigations in the San Francisco Bay area). In the Puget Sound region, a federal study published in 1980 (Bortleson et al. 1980) used primarily T-sheets to estimate retrospective

change to tidal marshes (“subaerial” and “intertidal” wetlands) at eleven river deltas in the Puget Sound region. The 1980 study quantified undiked marsh at the time of the T-sheets surveys, made in the 1855-1899 period, and makes partial estimates of diked tide marshes not shown on the T-sheet surveys. Thom and Hallum (1990) summarized and synthesized the data from the Morse and Bortleson et al. studies. In an early phase of this study (Collins et al. 2003) we reported on reconstructions of the historical environments of several river estuaries in northern Puget Sound; the reconstruction showed that a considerable amount of land had been converted to agriculture prior to the T-sheets, especially estuarine scrub-shrub and riverine-tidal environments.

Approach to structuring data

Chapter 2 presents our approach to organizing data from our reconstruction of tidal wetlands. At the largest scale, we created 10 sub-basins, based in part on the oceanographic basins of Burns (1990), as described in Chapter 2, and shown in Figure 2-1. At the next smallest scale, we defined 20 typical wetland complexes, based on the geologic terrain, the topography created by glaciation, post-glacial changes in land and sea level and the erosional responses, the coastal geometry (accretionary, unembayed, or embayed), the dominance of fluvial versus wind and current energy, and whether the environment was marine, estuarine, or tidal freshwater. The resulting classification is summarized in Table 2-1. The 20 distinct wetland types are grouped into four major settings: (1) coastal landforms (cusate forelands, coastal spits, tombolos, and small coastal fringing marshes); (2) non-embayed stream mouth estuaries; (3) embayed estuaries, marshes and lagoons (exclusive of the major rivers draining the Cascades and Olympics); and (4) major river estuaries, which include in some cases extensive tidal freshwater floodplains.

Embayed estuaries, marshes and lagoons make up the largest grouping. Because it includes a variety of landform settings, it is further subdivided into three sub-groupings reflecting differences in geologic and base level histories (Table 2-1).

Within the larger complexes, we created identification codes for individual features, identified with unique numbers within townships. We recorded detailed narrative descriptions of wetland complexes and features, including the historical data available to us, and the assumptions we made in using the data. These descriptions are coded for use in conjunction with the GIS coverages.

Historical tidal wetlands in the Puget Sound region

Amount, type, and distribution

We mapped a total of 29,500 hectares of tidal marsh from 621 wetland complexes (Table 3-1 and Figure 3-1). This total leaves out a number of locations where wetlands are likely or certain to have existed but we lacked enough evidence at this time to map them; while this makes 621 a minimum number, because most of the unmapped wetlands are small, it does not significantly affect the aggregate wetland area. We included the area of blind tidal channels in our marsh area totals, and excluded other types of channels. Of the total, 42% was estuarine emergent marsh, 20% was estuarine scrub-shrub marsh, and 38% was tidal freshwater marsh (Table 3-1). A large amount of the total, 18,300 hectares, or 62%, was concentrated in the Whidbey Basin (Figure 3-2); the Whidbey Basin excludes the portion of the Skagit River that drained to Padilla Bay, and excludes the Samish River delta, both of which are counted in the San Juan Island/North Coast

sub-basin totals, but are both physiographically part of the greater Skagit River delta. If the Padilla Bay and Samish River tidal marsh were included in the Whidbey Basin total, it would total 22,400 hectares or 76% of the region's total.

Tidal wetlands were also heavily concentrated in the estuaries of the basin's major rivers. The major rivers draining the Cascade Range and Olympic Mountains accounted for 90% of the tidal wetland (Table 3-2). Over half of the region's tidal wetland area (53%) was in the wetland complex "ESK" that includes the deltas of the Stillaguamish, Skagit, and Samish rivers. [The text and accompanying figures uses area, in hectares, and frequency, the number of wetland complexes, as metrics.] As described in Chapter 2, these deltas were grouped together because the Skagit and Samish are both on the same delta created by massive mid-Holocene lahar deposition, and the Stillaguamish delta is continuous with the Skagit delta, and was also likely influenced by volcanic sedimentation. Seven major rivers within broad, low-gradient troughs created by sub-glacial fluvial erosion—the Lummi, Nooksack, Snohomish, Duwamish, Puyallup, Nisqually, and Skokomish—accounted for another 37% of the regional total (Table 3-2). The remaining major Olympic Peninsula rivers—the steep, narrow fan-deltas of the Hamma Hamma, Duckabush, Dosewallips, Quilcene, Dungeness, and Elwha rivers—accounted for only 1% of the regional total.

Primarily because of the dominant quantitative influence of the large river estuaries, tidal wetland area was unequally distributed throughout the study area (Figure 3-3). The four sub-basins lacking major rivers—the Western Inlets, Admiralty Inlet, Eastern Strait and Western Strait sub-basins—had a small fraction of the marsh in the other sub-basins, making it useful to consider the distribution of major rivers estuaries separately from the other complexes. Figure 3-

3, which shows the relative size of estuarine wetlands in the major river estuaries, reiterates the dominant importance of the Stillaguamish-Skagit-Samish deltas system, followed by the rivers in subglacial troughs, which in turn dwarf the east and north Olympic Mountains river estuaries. It also shows that, more generally, the area of tidal marsh associated with rivers in the north half of the study is much greater than the amount in the remainder of the study area. Among the river estuaries in glacial troughs in the southern part of the study area, the Puyallup and Nisqually estuaries had much more tidal marsh than the Duwamish. The figure also shows that the northern rivers were also unique in having more scrub-shrub wetland, and more riverine-tidal freshwater wetland than elsewhere in the study area. Thus the northern Sound river estuaries were both larger and more diverse than elsewhere.

The other 17 tidal wetland types described in Chapter 2 accounted for the remaining 10% of regional tidal marsh area. Of this amount (which when added to the Olympic Peninsula fan rivers, account for 11% of the total; see Table 3-2), the large barrier marshes and lagoons in arcuate embayments in the northern Sound accounted for the largest amount, about two-fifths (Table 3-3). Tidal wetlands associated with accretionary landforms—spits, cusped forelands, tombolos, and non-estuarine accretionary barrier wetlands—accounted for the next largest amount, nearly one quarter of the total, or 23%. Estuaries in drowned glacial topography, common in the southern half of the study area, accounted for 17% of area, the next largest amount; about two thirds of this amount was in the drowned glacial drainages generally located at the ends of the region's major inlets. The fan-deltas of the Olympic Peninsula rivers listed above accounted for another 6% of the total. The remaining five types of tidal wetlands altogether accounted for the remaining 17%.

While quantitatively less important, the wetland types that were generally small were much more numerous than the wetland types that were generally larger; Table 3-3 shows the number of wetland complexes by type and sub-basin. The smallest features—the unembayed coastal marshes and stream mouth wetlands—accounted for 34% of the total number of individual wetland complexes. The same was true of wetlands in incised stream valleys, which accounted for 12% of the total. On the other hand, the largest wetland complexes not associated with major rivers, the barrier wetlands in arcuate depressions in emergent glacial terrain, accounted for only 7% of the total number of complexes; the large complexes in the major river valleys of eastern Puget Sound were the least frequent, accounting for only 2%.

There are north-to-south and other regional differences among the 10 sub-basins in the distribution of non-large-river tidal wetland complexes (Figure 3-4 and Figure 3-5). Most of the tidal wetlands in the northern sub-basins are within the generally large barrier estuaries in arcuate embayments in emergent glacial terrain or associated with accretionary landforms, particularly cusped forelands, which also tended to be large in the north. The North Coast/San Juan Island area is anomalous in the north in having tidal wetlands distributed within a broader range of environments, including the rocky coves unique to this area and the Western Strait sub-region. This greater diversity in environments reflects the dominance of bedrock terrain intermixed with the influence of glacial sculpting, especially in the transitional margins of the sub-basin, and the diversity of energy environments. In contrast with the other northern sub-basins, the small amount of tide marsh in the Western Strait was within the rocky-cove estuaries of small coastal and foothill streams.

In the southern half of the Puget Sound region, tidal wetlands are primarily within lower energy environments: drowned glacial drainages or other drowned glacial topography, within drowned incised valleys, as small, unembayed coastal marshes, and small stream-mouth estuaries. The South Sound and Western Inlets sub-regions are the most dominated by lower-energy environments, and the environments of wetlands in the Central Sound and Hood Canal sub-regions are a mix of higher and lower energy levels. The generally smaller wetland complexes in the southern part of the region were more numerous compared to the generally larger features in the north (Figure 3-5). As indicated previously, in general the smaller features, which were more common in the south, were more numerous than the larger features. Figure 3-6 shows the relative areas of individual tidal wetland complexes historically in the study area, including major rivers (Figure 3-6A) and exclusive of them (Figure 3-6B); the area of the circle symbols in the figures are proportional to the wetland area.

Comparison to an 1884 inventory of tidal marsh in Puget Sound

Eldridge Morse's 1884 retrospective estimate of tidal marshes, described previously in this report, provides a check on our estimates that is unique in having been compiled within the first decades of the great land transformation associated with Euro-American settlement. It is also independent of our reconstruction; we used Morse's descriptions only locally with a few smaller wetlands and to supplement our map data. In addition to containing a great deal of descriptive information, Morse reported the size of most of the larger or more conspicuous tidal wetlands. His assessment is particularly detailed in the Snohomish, Stillaguamish and Skagit river deltas, reflecting their quantitative importance, and probably as well his residence in the village of Snohomish, which would have provided him a greater opportunity to examine his local rivers.

At the end of his systematic assessment, Morse provides a summary table, organized by county. The entries in his table total 28,800 hectares, although in the text he gives numbers that total 29,100 hectares. Depending on which of these is taken as the total, our estimate of 29,500 hectares agrees within either 1% or 2% of Morse's total (Table 3-4). Our estimates agree most closely with Morse's estimates for Skagit County, which is where we have made our most detailed reconstruction, and where Morse made one of his most detailed examinations. On the other hand, our estimates agree the least with his in the Snohomish River estuary; it appears that the difference in the two estimates is because we interpreted more of the Snohomish's freshwater wetland as tidally influenced than Morse did, apparently the "Marshland" district in particular, so that the discrepancy between our estimates for the Snohomish estuary reflect differences in hydrologic interpretation rather than in map area. In a few counties where our estimates are less than Morse's, the difference can be accounted by our having conservatively mapped a few wetlands that had been heavily urbanized in the 19th century, for example we mapped Salmon Bay's tidal wetlands conservatively, likely accounting for the difference in the two estimates for King County. After the Snohomish, the greatest discrepancy is in the east-Sound counties that he grouped together—Mason, Kitsap, Jefferson and Clallam counties, where Morse's estimate is greater than ours—which may reflect less detailed knowledge on Morse's part because of their distance and smaller quantitative importance. In any case, the two estimates are remarkably consistent overall.

Comparison to other estimates for Puget Sound

Eldridge Morse's study has received considerable less attention than the map study made a quarter-century ago by Bortleson et al. (1980). Made by hand-registering T-sheets and early

USGS topographic maps to modern topographic maps, and measuring the wetland area on the modern maps, the 1980 study focused on 11 river deltas. In comparing our estimates to those in the 1980 study, we have dropped the Dungeness River from the list because it is a small estuary; the 1980 report appears to have erroneously indicated the size of the Dungeness River tidal marsh as 10 times greater than supported by their map data and our reconstruction.

Table 3-5 compares our estimates with those published by Bortleson et al. (1980). The 1980 study differentiated “intertidal” and “subaerial” wetlands without definition, complicating comparison. Our estuarine wetland estimate is about two and half times greater than in the 1980 study, 152 km² compared to 62 km². The discrepancy is in large part because the earlier study didn’t estimate intertidal wetlands in the Samish, Skagit, or Stillaguamish river deltas, which had been heavily diked by the time of the USC&GS surveys in the mid 1880s, and because they excluded the expansive marshes to the north of the Skagit River’s North Fork. On the other hand, the earlier study overestimates the historical estuarine marsh in some estuaries. An overestimate of the Duwamish River’s intertidal marsh is apparently from misinterpreting the T-sheet symbology as saltmarsh on what was a fir-covered terrace located several meters above the floodplain and probably created by uplift during the Seattle Fault earthquake ca. 1,100 yr B.P. and subsequent fluvial downcutting. Elsewhere they interpret as intertidal marshes areas that we have mapped as freshwater marsh.

Their “subaerial” category includes tidal-freshwater as well as some of what we map as palustrine wetlands. To facilitate a comparison, we include in Table 3-5 palustrine wetlands that we mapped on the floodplain within the up-valley extent of tidal river influence, which encompasses the broader “nearshore wetland” category defined earlier in this report. We

included in this category all floodplain wetlands within the valley bottom where the main river is tidally influenced, so as to include wetlands that are palustrine rather than riverine-tidal in that they are not regularly inundated on a tidal cycle, but would be more frequently flooded during high water because of the augmenting effect of tidal backwater on floods. Without resolving ambiguities that arise from comparing the two estimates, our estuarine wetland estimate is two and a half times greater than the 1980 estimate, and our “nearshore wetland” total (332 km²) is half again as much as their higher estimate (202.6 km²) and twice their low estimate (152 km²).

The geology of tidal wetlands

Several geologic influences together substantially explain the distribution, amount, and type of tidal wetlands. The quantitatively most important, if spatially most concentrated, influence is that of volcanic deposition. As described in the previous chapter, the greater Skagit River delta was largely created during a mid-Holocene eruptive period of Glacier Peak, and the Stillaguamish River delta at least in part so. Similar mid- and late-Holocene lahar deposition from Mt. Rainier prograded the Duwamish and Puyallup embayments and created low-gradient estuaries; Mt. Baker lahars may have contributed to the Nooksack and Lummi deltas. Volcanic eruptions created the topography on which more than half of the region’s historical tidal marsh developed.

In contrast to the spatially concentrated influence of volcanic deposition, the glacial legacy is the most pervasive influence, and at numerous scales. Sub-glacial fluvial erosion created the wide, low-gradient troughs in which the large river estuaries are located. Smaller-scale erosional features provide the template for wetlands, especially in the southern study area, where they have

been drowned during the post-glacial rise in sea level. Coastal streams that have incised through the glacial fill to create valleys, later partially flooded, create additional estuarine environments. In the northern Puget Lowland, the combination of post-glacial land emergence, linear glacial topography, and coastal processes during sea level rise created the arcuate embayments where the largest non-riverine wetlands are located.

Wave and current energy, in interaction with an inexhaustible supply of readily erodible sand and gravel from shore bluffs of glacial deposits, is the third major influence. The resulting accretionary and barrier landforms provide the physical template for more than half of the tidal wetlands outside of the river valleys overall, and a considerably larger proportion in the northern part of the region. While additional factors are locally important, including recent tectonism associated with the system of faults that dissects the Puget Basin, and the effects of regional plate-tectonic strain, these three forces—volcanic deposition, the glacial legacy, and wave energy—are the most dominant. They are most coincident in the Whidbey Basin, which accounts for that basin's great concentration of tidal wetland.

Biogeographic and ecological implications

Regional gradients characterized the amount, distribution, and type of tidal marsh. Tidal marsh habitats were characterized by relative dispersal and concentration over at least two scales. On the scale of the Puget Sound region, tide marsh was concentrated within the Whidbey Basin. In a broad north-to-south gradient within the basin, habitats were either concentrated in more dispersed, larger complexes, or less dispersed in more frequent, smaller complexes in lower-energy environments typical especially of the Southern Sound and Western Inlets and much of

Hood Canal. There were also differences within the region in the distance with which tidal wetlands were dispersed relative to the large river mouths, and consequently access to extensive freshwater habitats.

The diversity of tidal marsh salinity environments was spatially patchy; the abundance of estuarine scrub-shrub wetlands and tidal freshwater wetlands conspicuously clusters in the north Sound rivers from the Snohomish to the Lummi-Nooksack river estuaries. Among the large rivers, the amount of tidal marsh was not proportional to the size of the river system (and the extent of its freshwater habitats), being determined instead by other, largely independent factors.

Comparison to the current condition

To compare to the current condition, we mapped wetlands at 460 of the historical complexes, using recent aerial photographs and the National Wetlands Inventory (NWI; see Chapter 1). Figure 3-7A shows the historical wetland complexes where we did not map tidal wetland from the recent photographs and NWI, and Figure 3-7B shows sites which we had identified as likely to have had wetlands historically, but where we lacked evidence to map them, but where wetlands were found in the current data.

We mapped an aggregate total of 5,650 hectares (Table 3-6). We have not at this time separated the amounts of tide marsh newly developed since the historical period from marsh that has been lost, or the causes of loss. Earlier, Boule et al. (1983) derived an estimate of 4,980 hectares of estuarine wetland by compiling published map sources [4,745 hectares of emergent marsh, 11 hectares of scrub-shrub, and 225 hectares of forested wetland]. Because of time constraints we have not evaluated the source of the discrepancy between the two estimates.

Aggregating losses in area with gains in area from newly accreted marshes, if our estimate is used, tidal marsh currently is 19% of the amount mapped historically; if the earlier estimate is used, there is 17% of the historical amount.

The size distribution of wetland complexes has shifted downward. Wetland complexes are generally smaller now than historically, with a median size about three-fifths the historical size, 0.93 hectares compared to 0.57 hectares (Figure 3-8A). The aggregate amount of tidal marsh in the very largest complexes declined disproportionately more, as did the amount of tidal marsh in the very smallest complexes (Figure 3-8B).

The deltas of the Skagit, Stillaguamish and Samish rivers quantitatively dominates the regional tide marsh nearly as much as it did historically, now accounting for 51% of the total, compared to 52% historically (Tables 3-7 and Figure 3-9). However, the estuaries of rivers in large glacial troughs account for a smaller portion of the total now than historically, totaling 23% of the regional total now, compared to 37% historically. The steep-fan river estuaries of the Olympic Peninsula constitute a relatively greater proportion of the total than they did historically, totaling 5% now compared to 1% historically. Figure 3-10 shows graphically the distribution of tidal wetland area among the estuaries of major rivers indicated by our current conditions mapping; to facilitate visual comparison with Figure 3-3, both figures have the same symbol scale. The disproportionate loss of tidal wetland from the estuaries in large glacial troughs is accounted for by the dramatic declines in the Lummi and Puyallup rivers. While the loss of tidal marsh in the Duwamish estuary is nearly total, the absolute amount was relatively small because the historical amount was relatively small compared to other estuaries in its category.

Tidal marsh located elsewhere than the estuaries of large rivers accounts for twice the proportion for which it accounted historically, 21% now compared to 10% historically (Tables 3-6 and 3-2). This relative gain in importance reflects relatively small losses in some sub-basins relative to others (Figure 3-11 compared to Figure 3-4). The South Sound, Hood Canal, Western Strait sub-basins have lost the least wetland (from complexes exclusive of the major rivers). The Central Sound, Fraser Lowland, and Whidbey Basin have lost the most proportionately. In the South Sound and Hood Canal the wetlands in drowned glacial drainages account for the largest amount of the totals (Figure 3-11), and relatively more than historically (Figure 3-4). In the Fraser Lowland, Admiralty Inlet and Whidbey Basins the barrier wetlands in arcuate embayments have become proportionately less significant, and wetlands in accretionary landforms have become proportionately more important; wetlands in accretionary landforms have also become proportionately more significant in the East Strait and San Juan Islands/North Coast sub-basins. Figure 3-12A shows the spatial distribution and size of individual wetlands; compared to Figure 3-6A, it shows the notable losses in wetland area in the Central Sound and the general diminishment in the number and sizes of the larger complexes that existed in the north Sound, and the relatively small change in the number and size of wetland in the South Sound and Hood Canal.

Including all wetland complexes, the Whidbey Basin (which includes the Snohomish, Skagit, and Stillaguamish rivers) has had the largest absolute decline, followed by the San Juan Islands/North Coast (which includes the Padilla Bay part of the greater Skagit River delta, and the Samish River), the Fraser Lowland (which includes the Lummi and Nooksack rivers), and the Central Sound (which includes the Duwamish and Puyallup rivers; Figure 3-12A).

Proportionately, the Central Sound, San Juan Islands/North Coast, Fraser Lowland, and Whidbey Basin all have less tidal marsh remaining than the regional average of 17-19% (Figure 3-13B). The Central Sound also shows the greatest percentage decline in the number of complexes remaining (Figure 3-13C), while the South Sound lost the greatest number of complexes (Figure 3-13D), primarily the smaller fringing coastal marshes, which is also the type of wetland having lost the largest number of complexes (Figure 3-14B); Figure 3-14B also shows that overall, wetlands in unembayed stream mouth estuaries and cusped forelands have also been substantially diminished in number.

In summary, tidal wetlands now amount to about 17-19% of their historical extent, including wetlands newly created since the historical reference condition. There have been declines in both the number and size of wetlands. About half of current tidal marsh is concentrated in the greater Skagit River delta area, nearly as much as historically. In contrast, rivers in glacial troughs account for a smaller portion of the total than they did historically, reflecting in large part the substantial loss in area from the Lummi, Duwamish, and Puyallup river estuaries. Other wetland types in aggregate have experienced less of a relative decline. Some of these wetland types have lost much more than others, notably the large barrier marshes in arcuate embayments in the north Sound, as have some sub-basins; the northern Sound and Central Sound sub-basins have lost the most area proportionally, and the Hood Canal, South Sound and West Strait sub-basins have proportionally the most remaining tide marsh.

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Table 3-1. Aggregate amount and type of tidal marsh mapped in the study area for historical conditions.

TYPE	AREA (hectares)
Estuarine	18,400
Emergent (EEM)	12,400
Scrub-shrub (ESS)	6,000
Riverine-tidal (RT)	11,100
Tidal wetlands	29,500

Table 3-2. Aggregate amount and type of historical tidal marsh mapped in the study area in estuaries of major rivers compared to other locations.

COMPLEX TYPE	AREA (hectares)			
	EEM	ESS	RT	TOTAL
ESK	6,130	4,470	4,770	15,360
ERG	3,110	1,500	6,280	10,890
ERF	150	30	6	180
OTHER	2,960	60	0	3,020

Table 3-3. Aggregate amount of tidal marsh in different complex types, and frequency of different complexes.

COMPLEX TYPE	AREA (hectares)	NUMBER OF COMPLEXES
ESK	15,362	6
ERG	10,888	7
EBE	655	14
EBM	472	13
NCF	402	85
EGD	398	20
ERF	183	6
EBL	176	5
EGT	175	45
NBM	156	34
NSP	141	50
NCM	108	145
ERE	98	4
ERC	61	36
EIF	57	15
NTO	48	17
ESM	34	44
EIV	30	41
NCM/B	28	22
ESM/D	19	15
TOTAL	29,500	624

Table 3-4. Comparison of tidal marsh estimates from this study with 1884 estimates by Eldridge Morse. At the time of Morse’s inventory, Thurston County had not yet been created and was part of Pierce County. He grouped Mason, Kitsap, Jefferson and Clallam counties. While Morse’s tabular data totals 28,816 hectares, in the text he cites numbers totaling 29,138 hectares (“Upon the east side of Puget Sound, including Island and San Juan Counties, are 67,000 acres [27,115 hectares] of strictly tide-marsh land...Upon the west side of Puget Sound and on the Skokomish, Hood’s Canal, the Strait of Fuca, and around the head of Puget Sound are 5,000 acres [2,023 hectares]of tide marsh....” Morse, in Nesbit, 1885, p. 110-111.)

COUNTY	TIDAL MARSH (hectares)	
	Morse (1884)	This study
Pierce and Thurston	2,590	2,210
King	486	420
Snohomish	7,285	8,860
Skagit	12,950	13,060
Whatcom	1,619	2,020
Island	1,619	1,330
San Juan	243	100
Mason, Kitsap, Jefferson and Clallam	2,024	1,500
TOTAL	28,816	29,490

Table 3-5. Estimates of historical nearshore riverine wetlands from this study compared to estimates by Bortleson et al. (1980). Parenthetical numbers included in sub-aerial wetland column for the 1980 study included their higher estimates “based on vegetation and landforms of wetland area present prior to its conversion and before the initial C&GS topographic survey under natural conditions” (Bortleson et. al. 1980).

RIVER NAME	RIVERINE NEARSHORE WETLAND (km ²)						
	BORTLESON ET. AL. (1980)			THIS STUDY			
	“INTER-TIDAL”	“SUB-AERIAL”	TOTAL	ESTUARINE	RIVERINE -TIDAL	PALUSTRINE	TOTAL
Nooksack	6.7	4.5	11.2	1.1	6.6	0.3	8.1
Lummi	14	5.8	19.8	5.8	5.0	0.5	11.3
Samish		1.9 (11)	1.9 (12.9)	19.2	0.0	16.7	35.9
Skagit		16 (29)	16 (45)	68.7	40.1	18.8	127.6
Stillaguamish		3 (10)	3 (13)	17.6	7.6	3.7	28.8
Snohomish	13	39	52	16.6	47.5	16.7	80.8
Duwamish	8.5	2.6	11.1	1.7	1.7	1.9	5.3
Puyallup	7.4	10	17.4	11.1	0.0	6.8	17.9
Nisqually	7.4	5.7	13.1	7.8	1.7	0.0	9.5
Skokomish	5	2.1	7.1	2.6	0.3	4.0	6.9
	62.0	90.6 (119.7)	152.6 (202.6)	152.0	110.5	54.3	332

Table 3-6. Aggregate amount and type of tidal marsh mapped in the study area for current conditions.

TYPE	AREA (hectares)
Estuarine	4,740 (84%)
Emergent	4,600 (81%)
Scrub-shrub	140 (3%)
Riverine-tidal	910 (16%)
Tidal wetlands	5,650 (100%)

Table 3-7. Aggregate amount and type of tidal marsh mapped in the study area for current conditions in estuaries of major rivers compared to other locations.

COMPLEX TYPE	AREA (hectares)			
	EEM	ESS	RT	TOTAL
ESK	2,479	56	349	2,884
ERG	838	12	450	1,300
ERF	233	6	37	276
OTHER	1,052	66	76	1,195

Figure Captions

Figure 3-1. Locations of historical wetland complexes. The number of complexes is a minimum number because it excludes locations where wetlands existed or likely existed but for which we lacked sufficient map information. For most large river estuaries, one dot represents the estuary; the larger and more complicated Skagit delta is represented by three complexes (the part draining the Skagit River downstream of its forks into Skagit Bay, draining Sullivan Slough and the south half of the Swinomish Slough to Skagit Bay, and the part draining the north half of the Swinomish Slough and the Skagit delta north of the North Fork and into Padilla Bay), the Stillaguamish into two (separating the wetlands on Island County from Snohomish County), and the Dungeness with two (separating the main river mouth and the Meadowbrook Creek distributary).

Figure 3-2. Relative area of historical tidal wetlands in different generalized complex types compared between 10 sub-basins. The generalized types are groupings from Table 2-1. **Wetland area is proportional to the *area* of the pie symbol in this and subsequent figures.**

Figure 3-3. Relative area, historically, of estuarine emergent, estuarine scrub-shrub, and riverine-tidal wetlands compared between estuaries of major rivers draining the Cascade Range and Olympic Mountains. EEM: estuarine emergent wetland; ESS: estuarine scrub-shrub wetland; RT: riverine-tidal wetland.

Figure 3-4. Historical tidal wetland area, grouped by wetland type and aggregated in sub-basins. Excludes estuaries of the following large rivers: complex types ESK (Skagit, Samish and Stillaguamish rivers); ERG (rivers in glacial troughs, including the Lummi, Nooksack,

Snohomish, Duwamish, Puyallup, Nisqually, and Skokomish rivers); and ERF (steep fan/deltas draining the eastern and northern Olympics, including the Hamma Hamma, Duckabush, Dosewallips, Quilcene, Dungeness, and Elwha rivers). The wetland type codes are summarized in Table 2-2 and explained in Chapter 2. Note the 10X scale change compared to the preceding Figure 3-3.

Figure 3-5. Historical frequency of different types of tidal wetland complexes, grouped within 10 sub-basins; excludes the major river deltas listed in the caption for Figure 3-4.

Figure 3-6. (A) Historical area of individual wetland complexes. As in the other pie diagrams, wetland area is proportional to the symbol *area*. (B) Panel A, but without the major river complexes ESK and ERG, and a scale 2X that in panel (A). Excluded are types ESK (Skagit, Samish and Stillaguamish rivers) and ERG (rivers in glacial troughs, including the Lummi, Nooksack, Snohomish, Duwamish, Puyallup, Nisqually, and Skokomish rivers). The ERF rivers (Hamma Hamma, Duckabush, Dosewallips, Quilcene, Dungeness, and Elwha rivers) are included.

Figure 3-7. (A) The location of tidal wetland complexes where we identified wetlands from recent aerial photographs and NWI data; also shown are the locations where wetlands were mapped historically but were not evident in current data. (B) Wetland complexes mapped from current data, but where insufficient data existed to map them historically.

Figure 3-8. Statistical distribution of the areas of individual wetland complexes currently and historically. (A) Each box encloses 50% of the data. Horizontal line within box represents median. The lines extending from the top and bottom of boxes indicate minimum and maximum

values, excepting outlier values (circles) greater than the inner quartile plus 1.5 times the inner two quartiles; these outliers are not shown. (B) Cumulative size frequency of tidal marsh complexes historically and currently.

Figure 3-9. Relative area of current tidal wetlands in different generalized complex types compared between 10 sub-basins. The generalized types are groupings from Table 2-1. Scale is the same as in Figure 3-2, the parallel figure for historical conditions.

Figure 3-10. Relative area, currently, of estuarine emergent, estuarine scrub-shrub, and riverine-tidal wetlands compared between estuaries of major rivers draining the Cascade Range and Olympic Mountains. Symbols have the same scale as those used in Figure 3-3, the parallel figure for historical conditions.

Figure 3-11. Current tidal wetland area, grouped by wetland type and aggregated in sub-basins. Excludes estuaries in large rivers (ESK, ERG, and ERF): complex types ESK (Skagit, Samish and Stillaguamish rivers); ERG (rivers in glacial troughs, including the Lummi, Nooksack, Snohomish, Duwamish, Puyallup, Nisqually, and Skokomish rivers); and ERF (steep fan/deltas draining the eastern and northern Olympics, including the Hamma Hamma, Duckabush, Dosewallips, Quilcene, Dungeness, and Elwha rivers). Note the factor of 2X scale change compared to the preceding Figure 3-9. The scale of Figure 3-11 is the same as that in Figure 3-4, the parallel figure for historical conditions.

Figure 3-12. (A) Current area of individual wetland complexes. As in the other pie diagrams, wetland area is proportional to the symbol *area*. (B) Panel A, but without the major river

complexes ESK or ERG (but including complex ERF, the steep fan/delta estuaries), and a scale 2X that in panel (A).

Figure 3-13. Change in tidal wetlands from historical to current, grouped by sub-basin. (A) area change, in hectares; (B) percent change in wetland area; (C) change in number of tidal wetland complexes; (D) percent change in number of tidal wetland complexes.

Figure 3-14. Change in tidal wetlands from historical to current, grouped by complex type. (A) change in area, in hectares; (B) change in number of tidal wetland complexes.

Figure 3-1

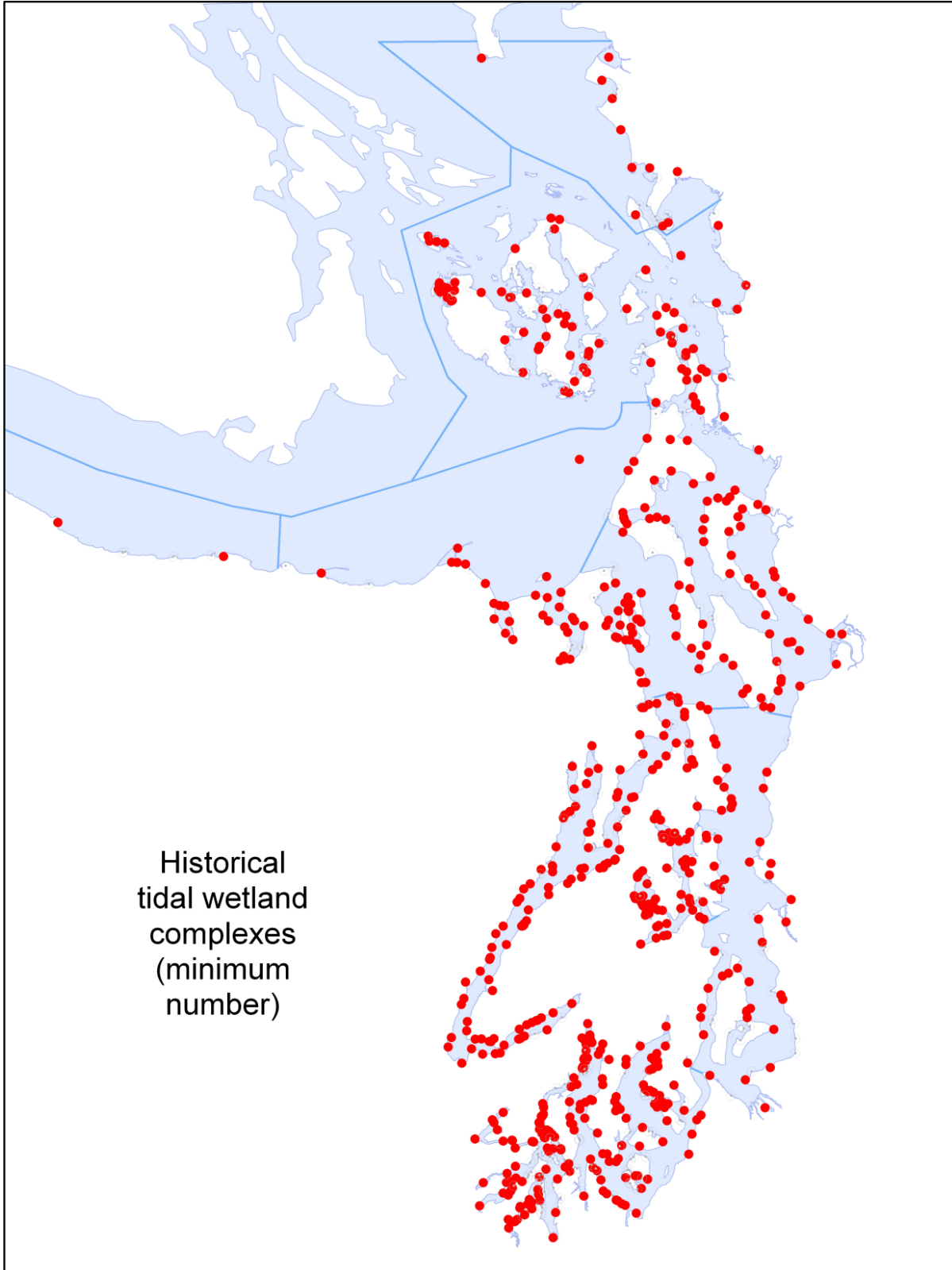


Figure 3-2

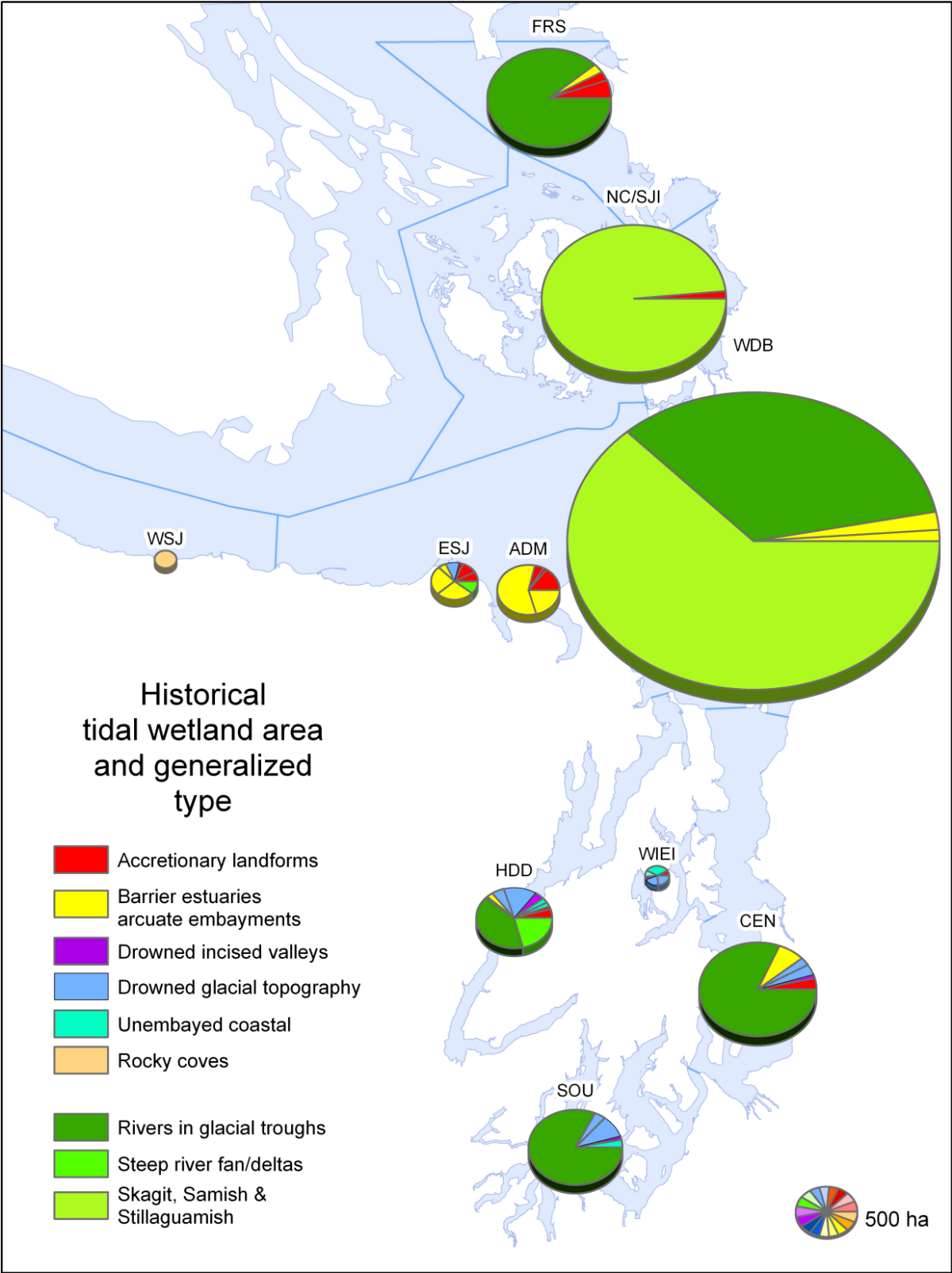


Figure 3-3

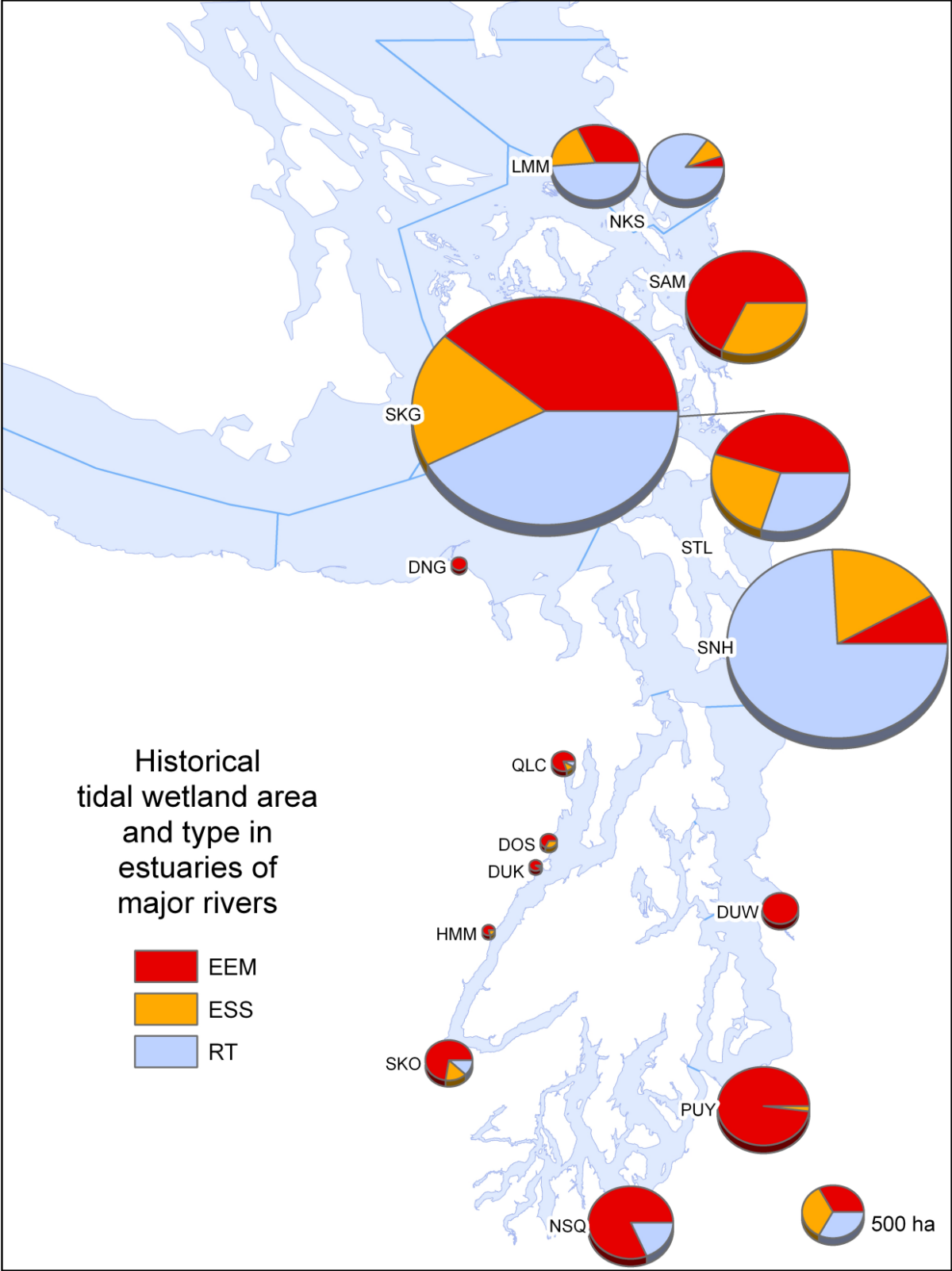


Figure 3-4

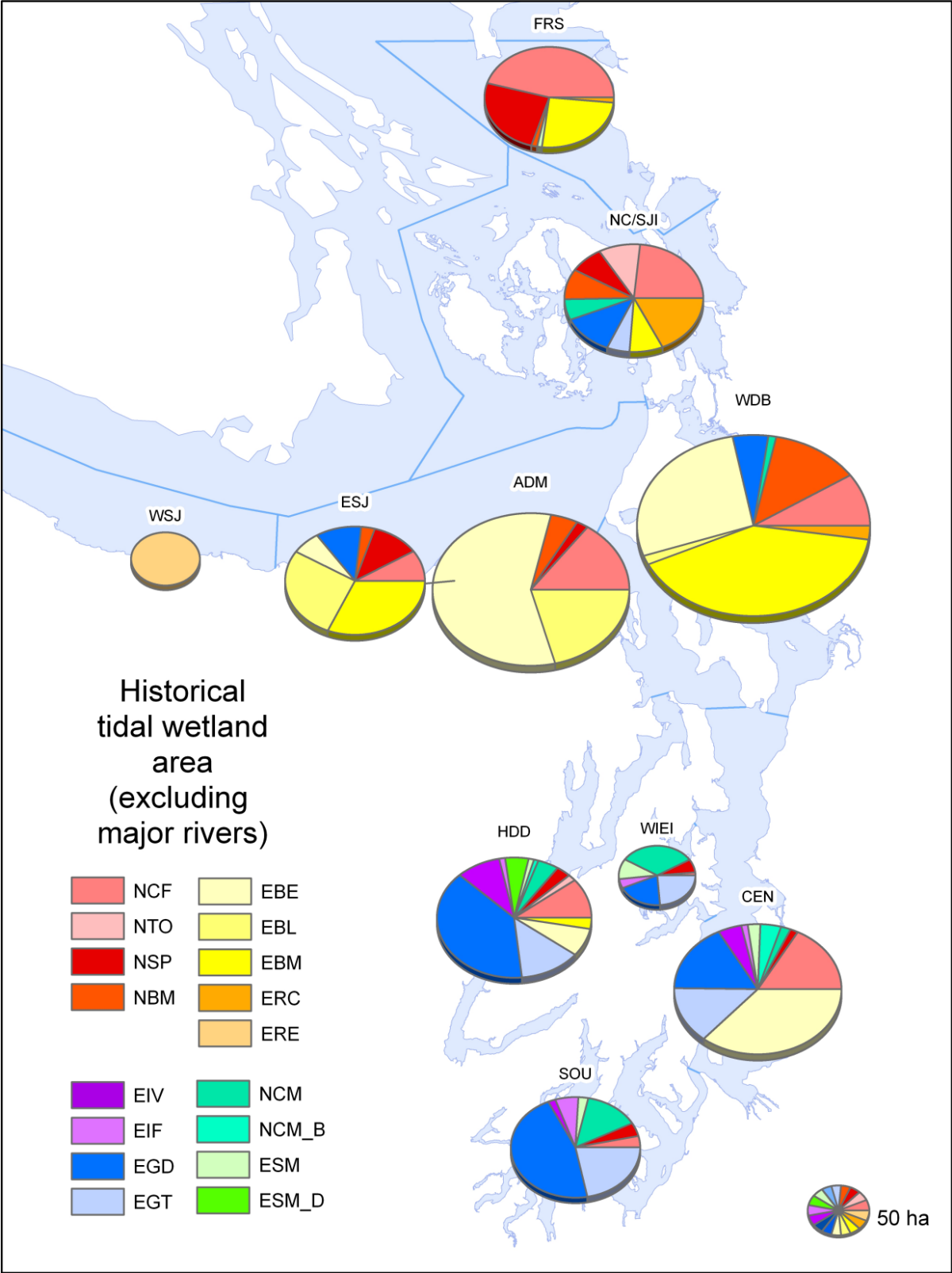


Figure 3-5

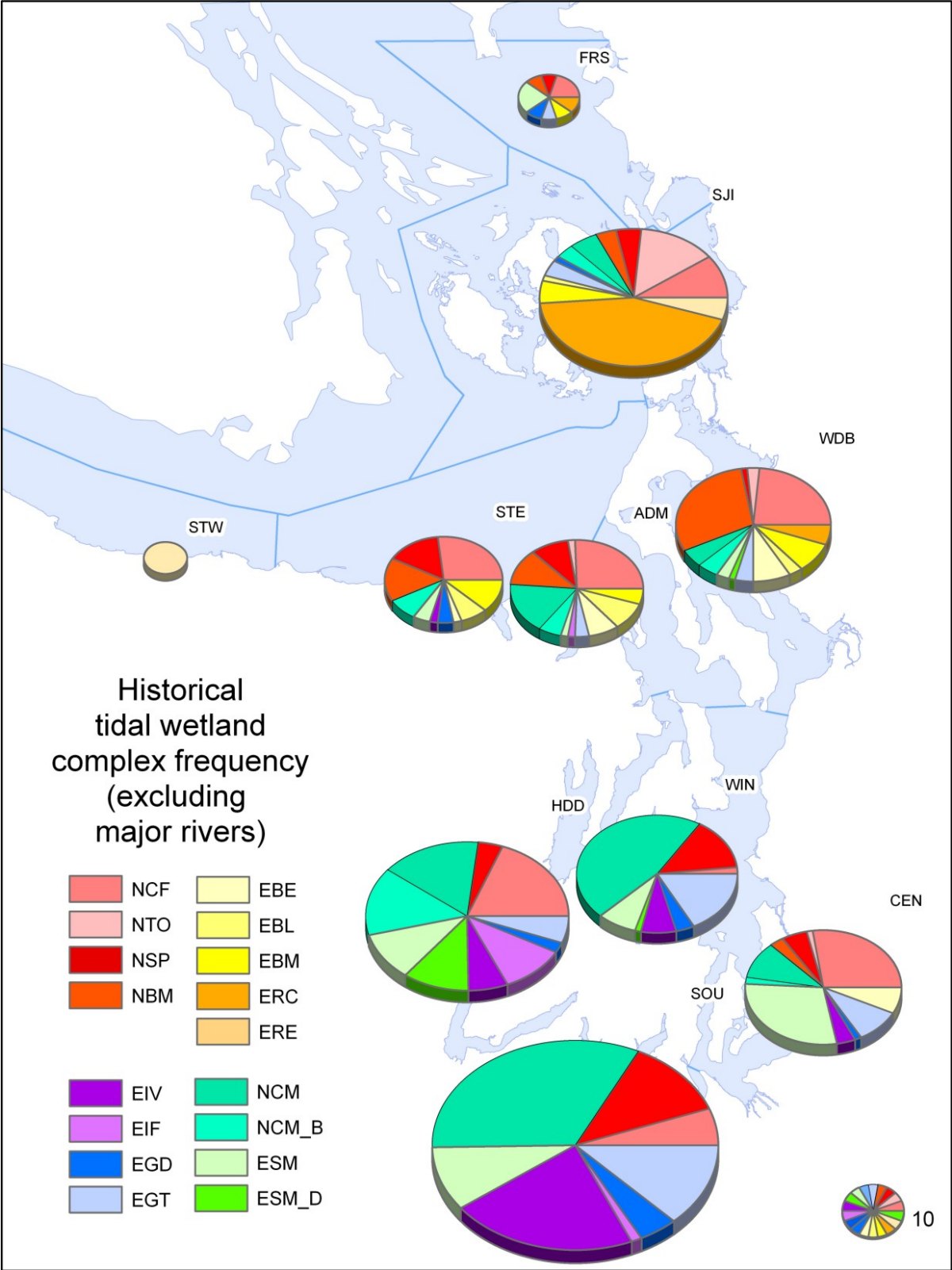


Figure 3-6A

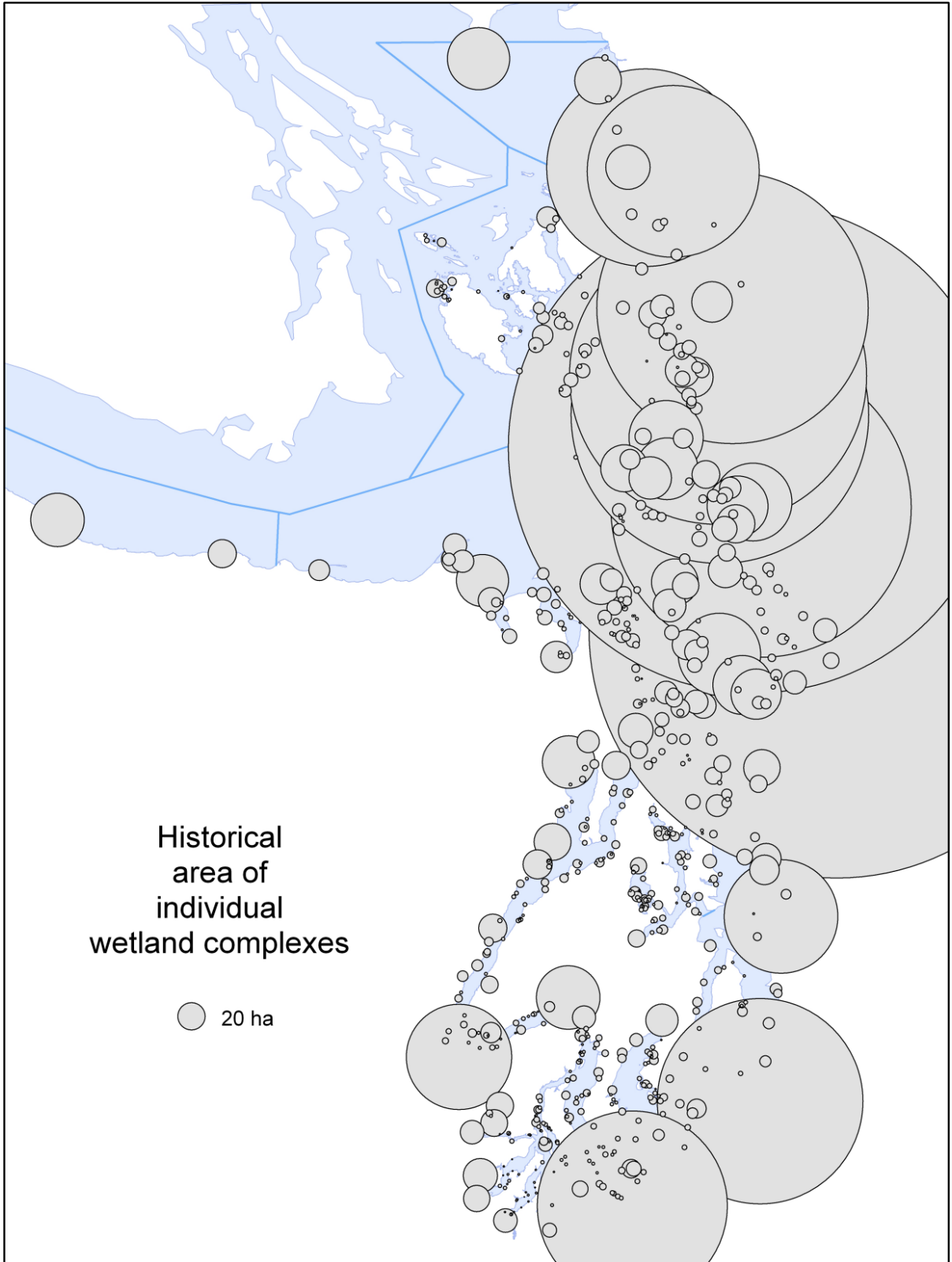


Figure 3-6B



Figure 3-7A

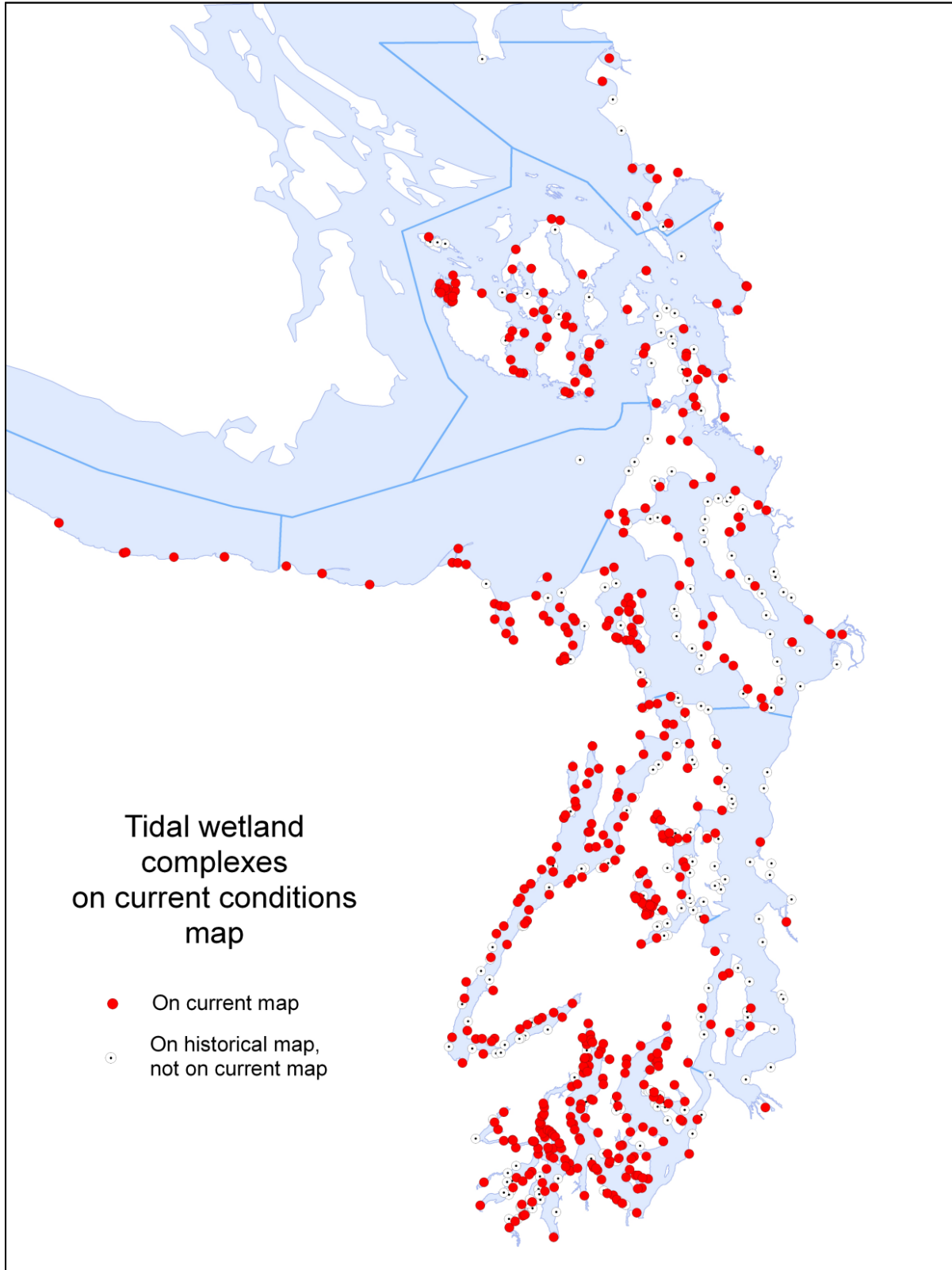


Figure 3-7B

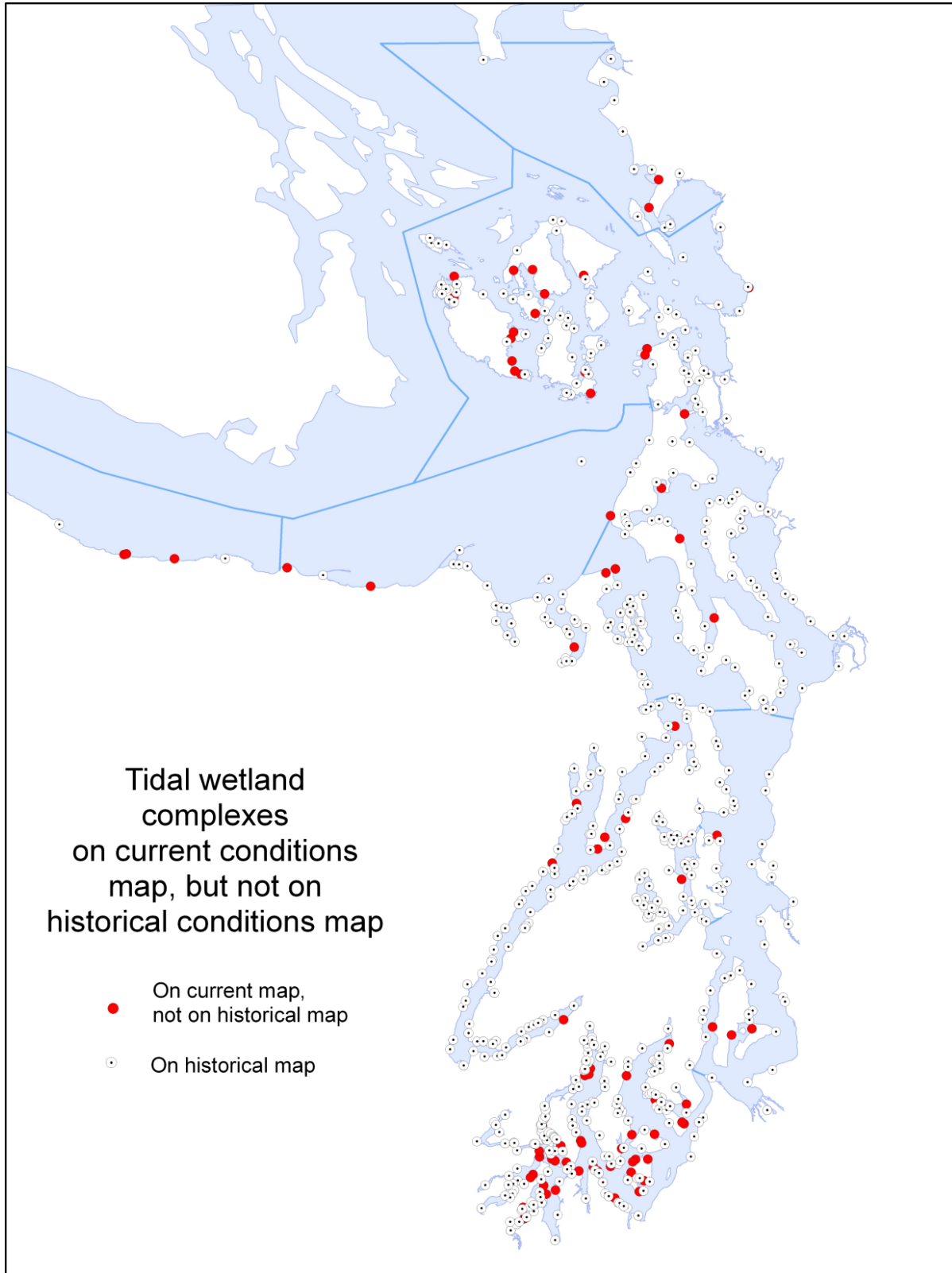
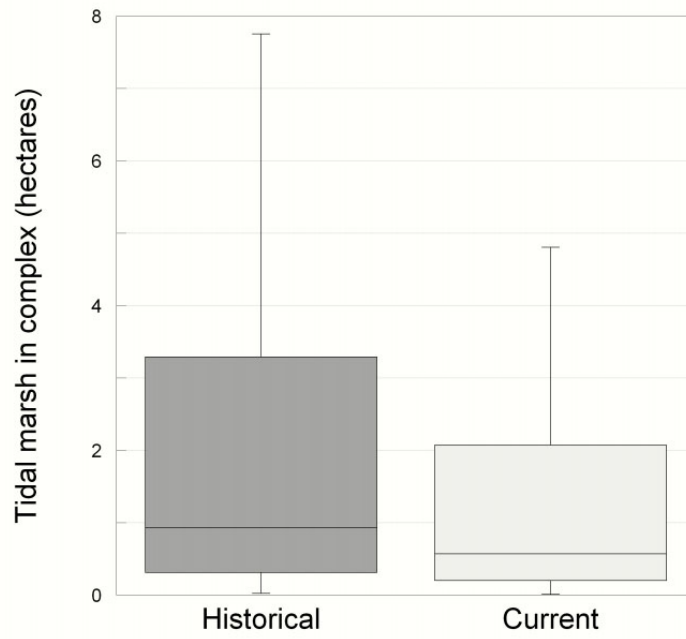


Figure 3-8

A



B

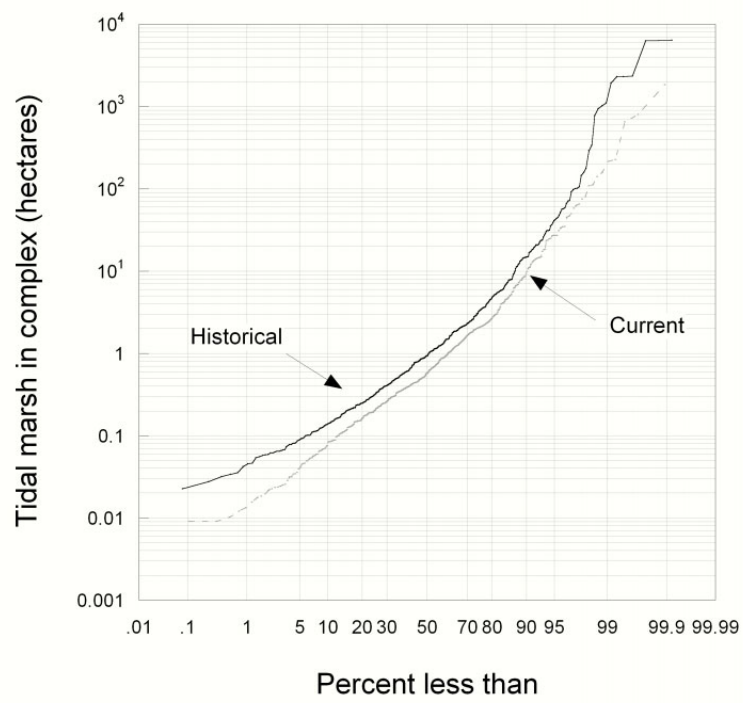


Figure 3-9

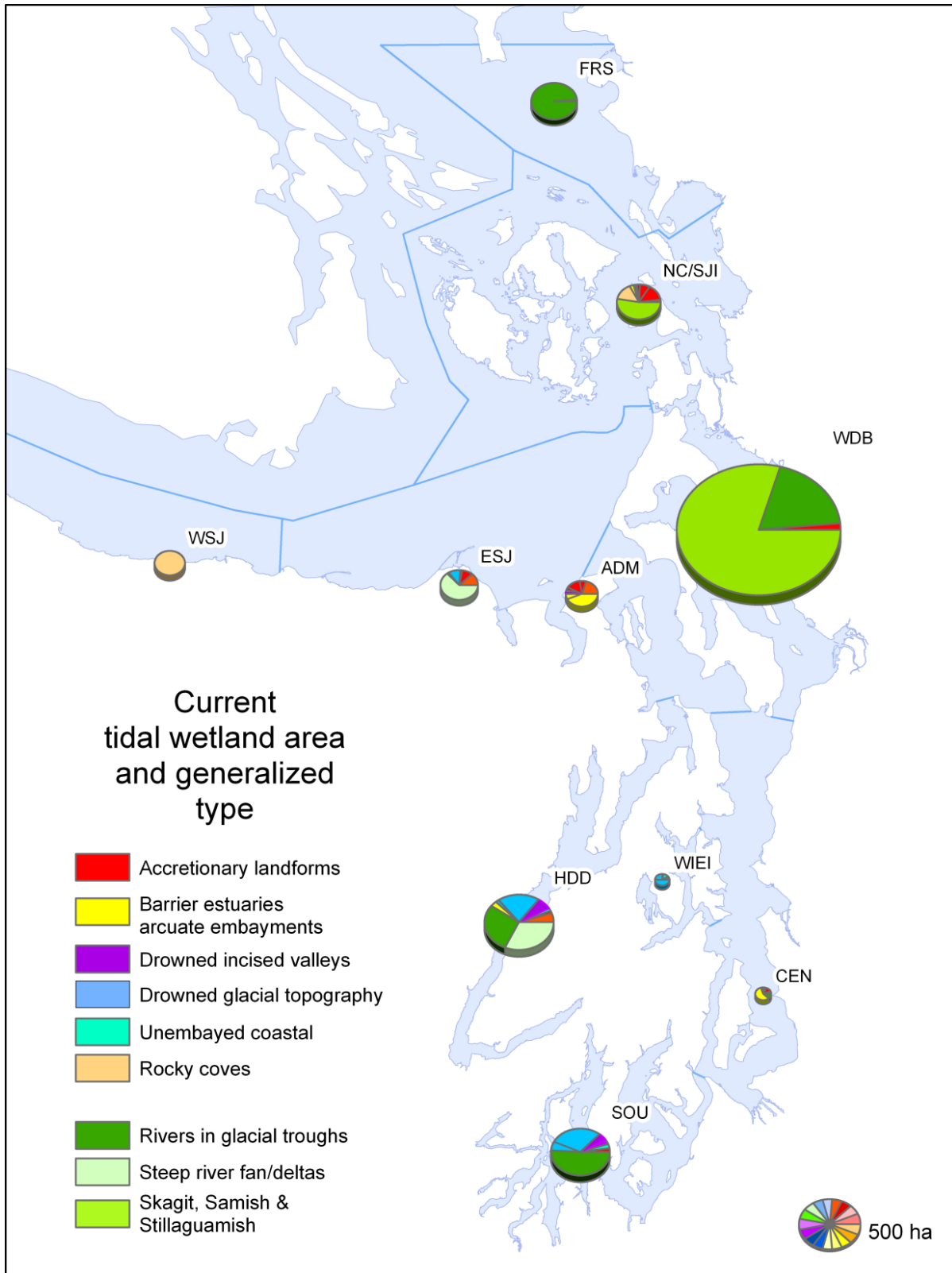


Figure 3-10

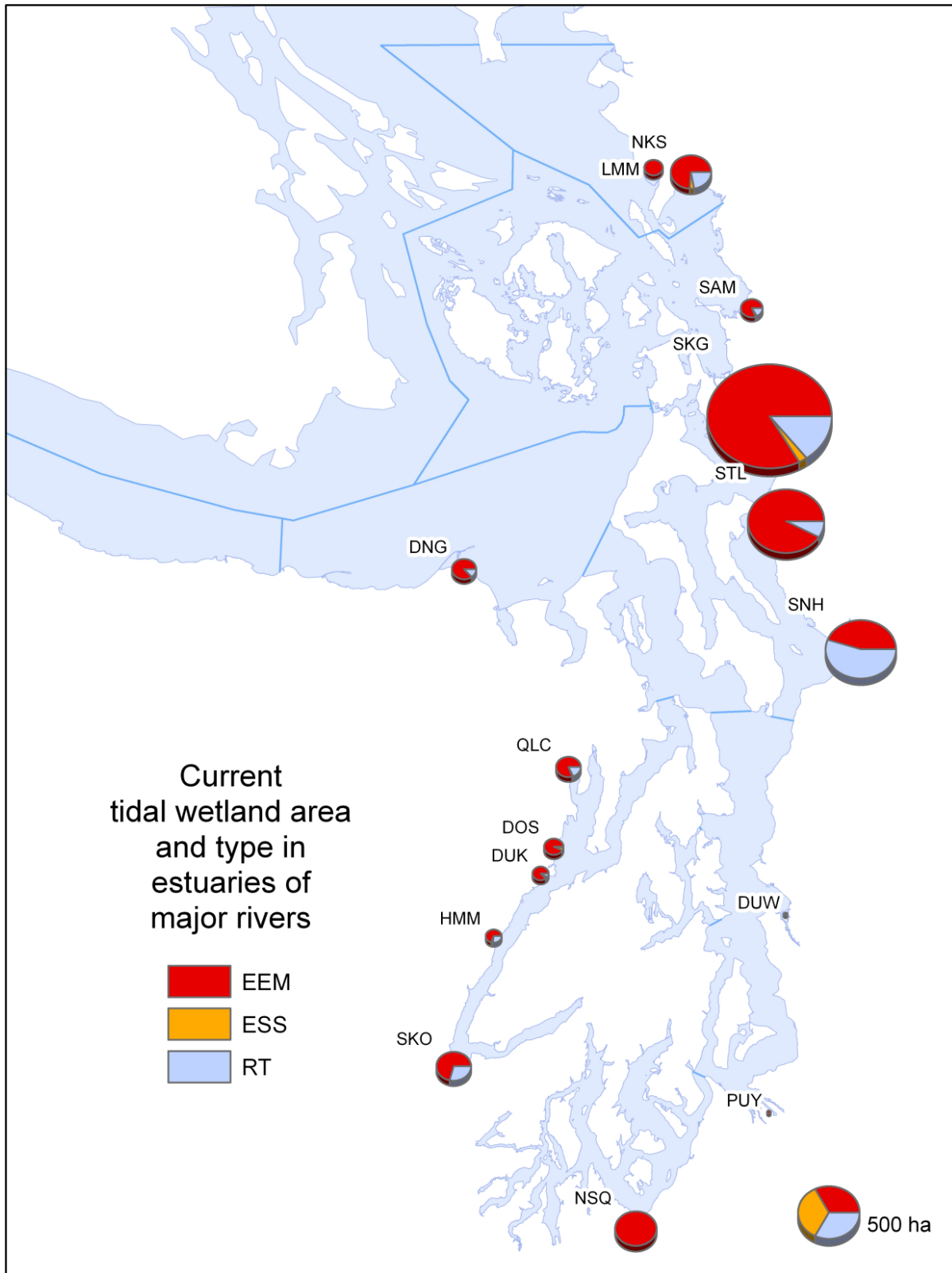


Figure 3-11

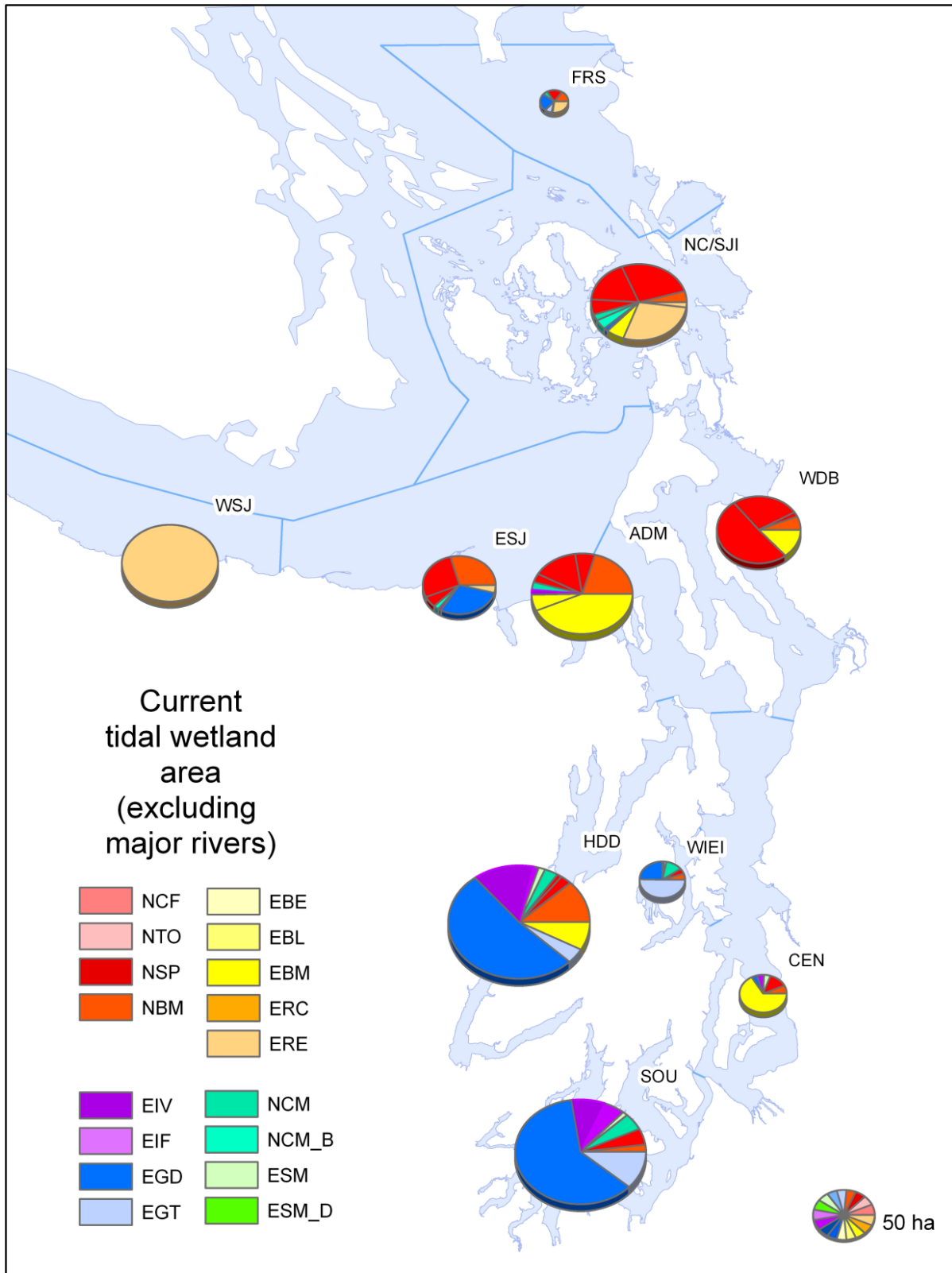


Figure 3-12A

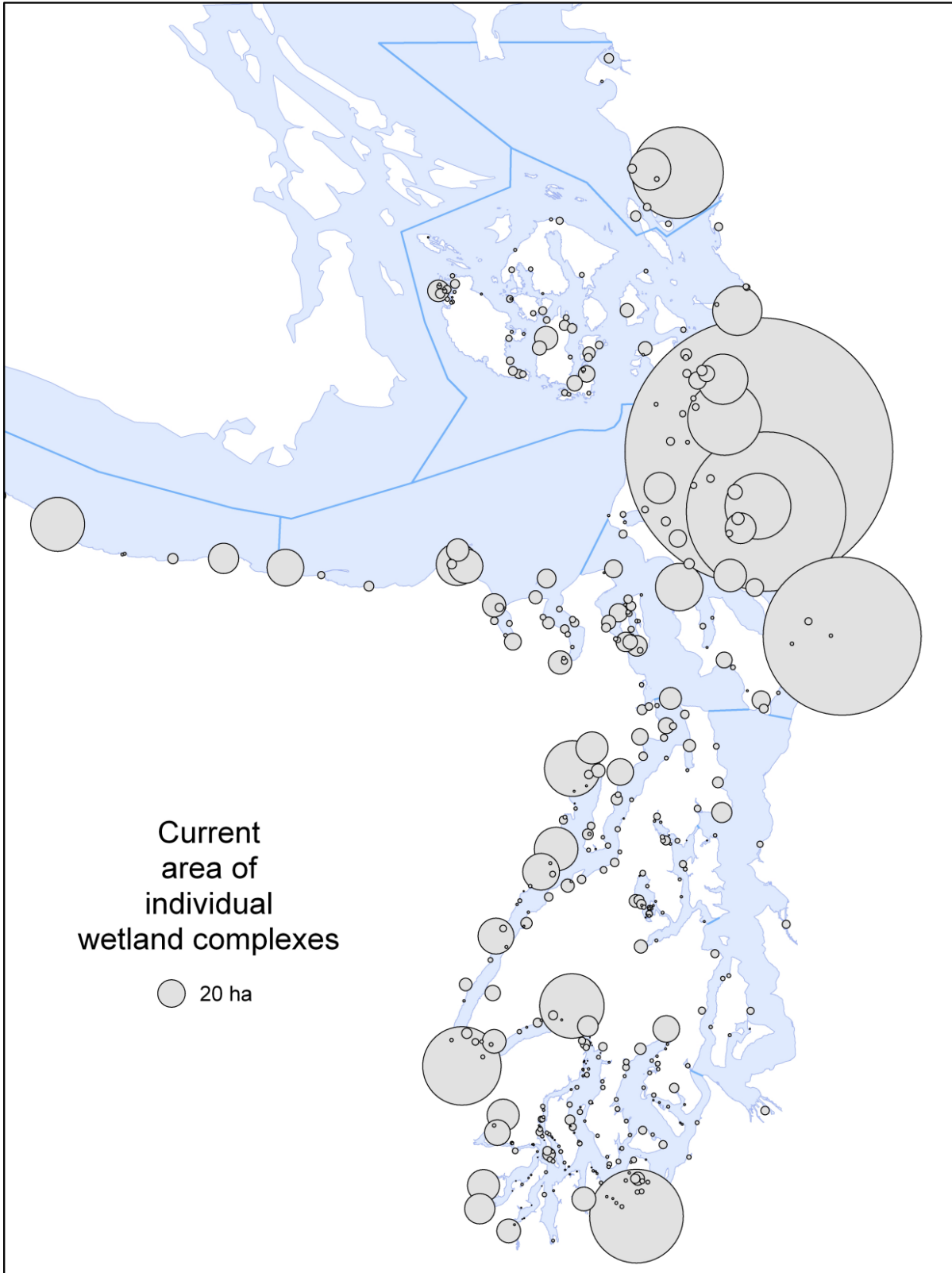
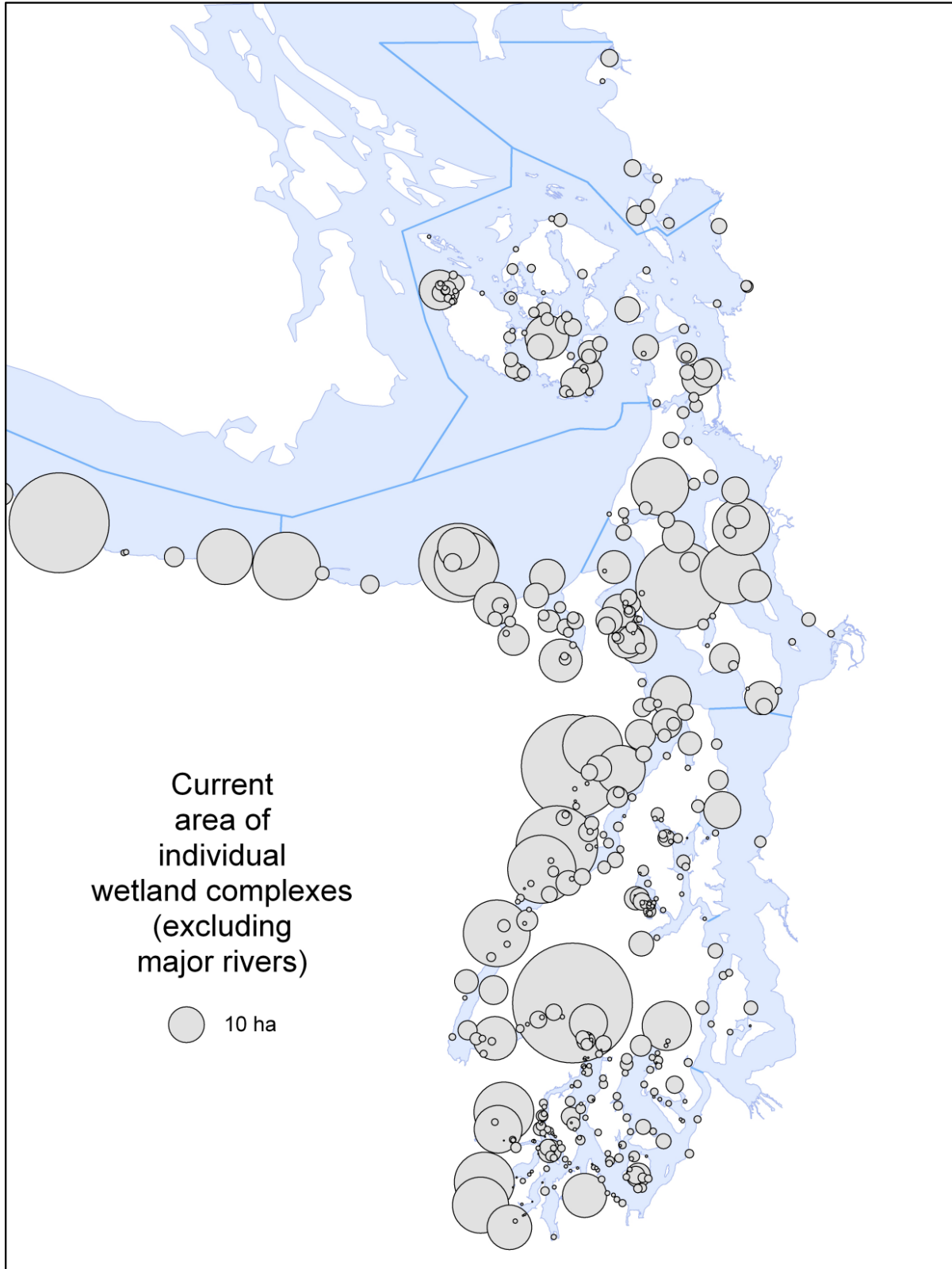
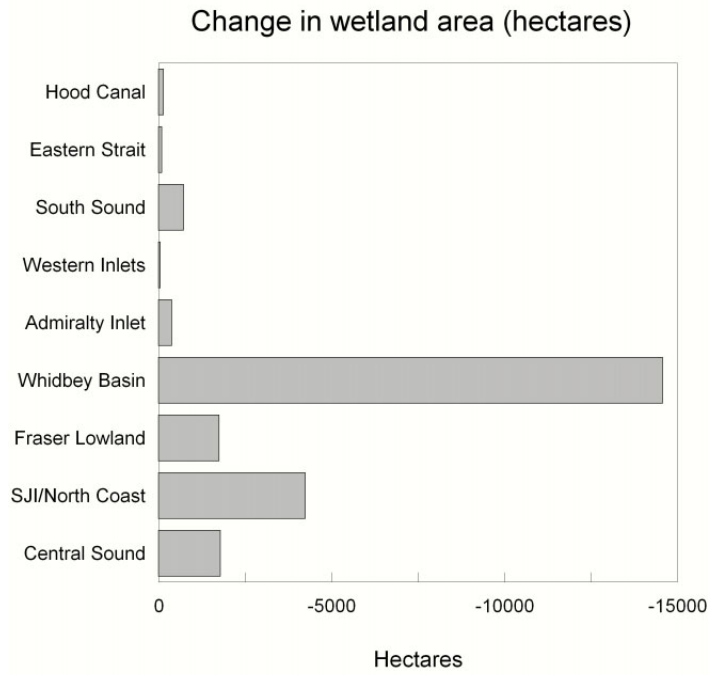


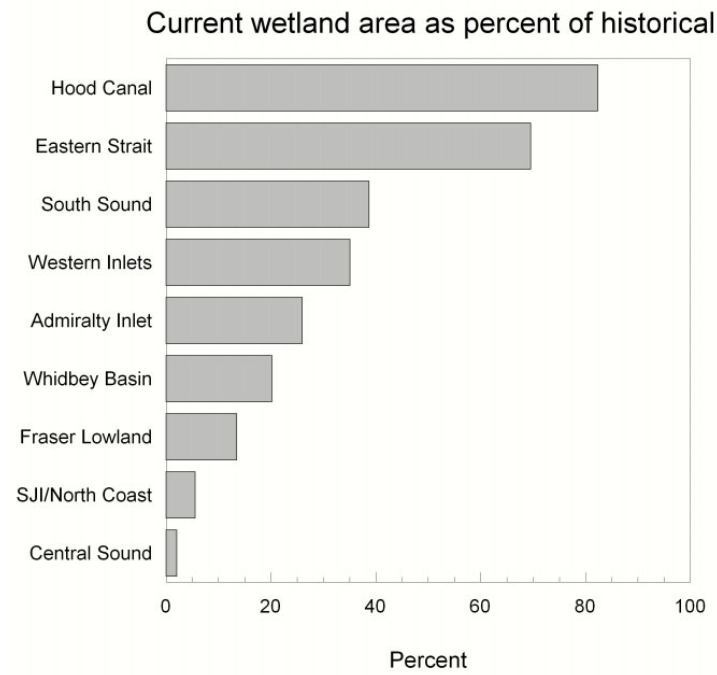
Figure 3-12B



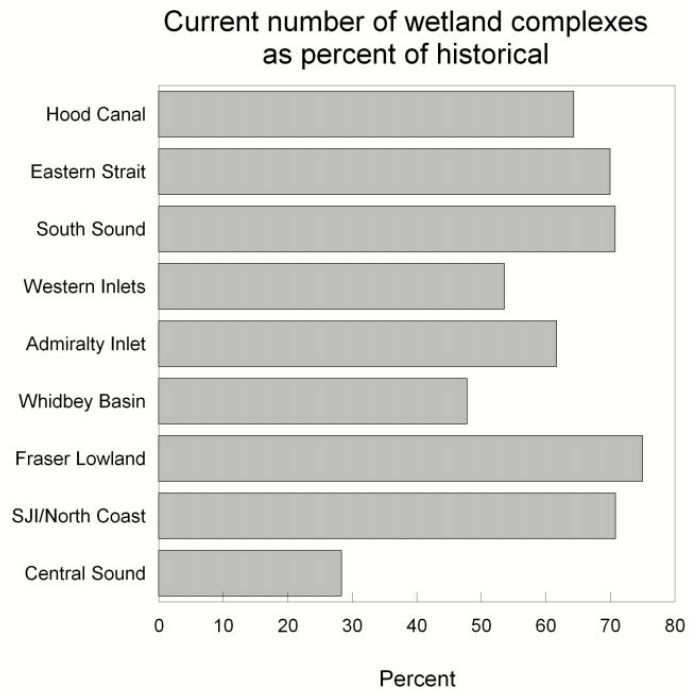
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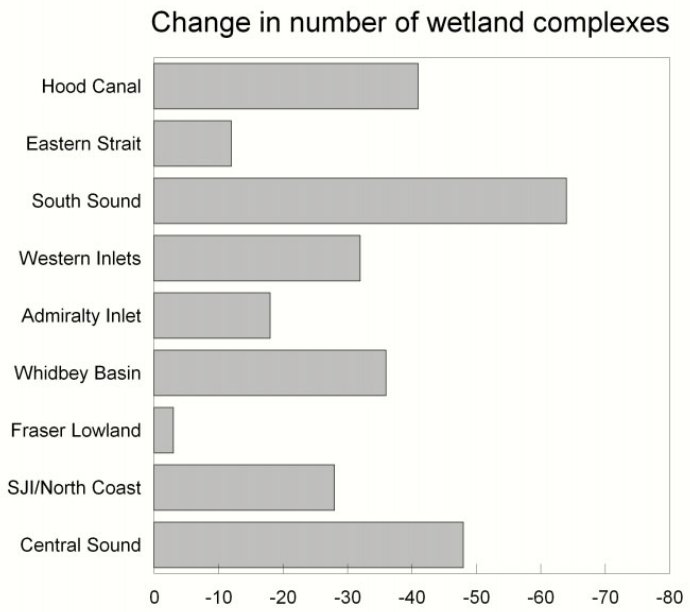
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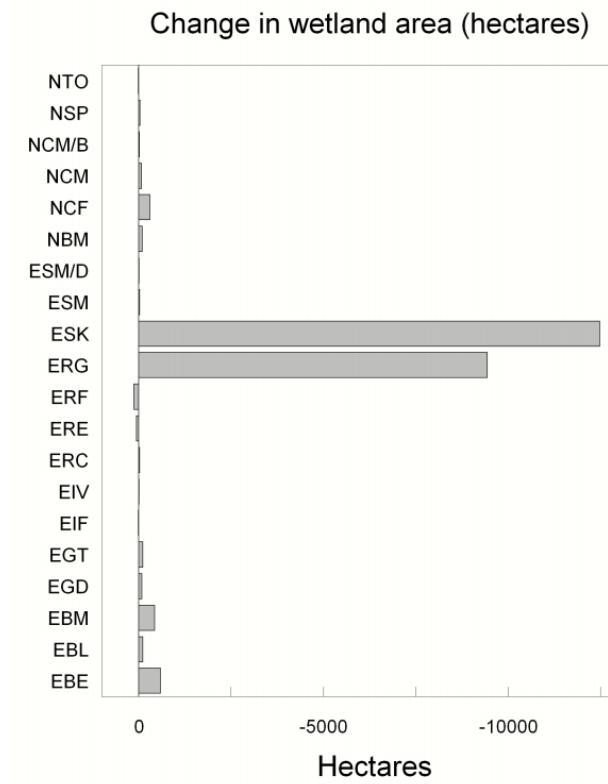
C



D



A



B

