Tidal Wetland Prioritization for the Necanicum River Estuary

Emergent, shrub and forested tidal wetlands, looking south from Avenue S bridge over Neawanna Creek, September 2009. Photo by Laura Brophy.

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This project was a joint endeavor of Green Point Consulting and the Estuary Technical Group of the Institute for Applied Ecology. The mission of the Estuary Technical Group is to restore estuarine habitats, improve estuarine restoration results, and advance the understanding of estuarine ecosystems through cost-effective application of the best available science. The mission of the Institute for Applied Ecology is to conserve native ecosystems through restoration, research and education.

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Abbreviations

CREST	Columbia River Estuary Study Taskforce
CSC	Coastal Services Center
DEM	Digital Elevation Model
DLCD	Oregon Department of Land Conservation and Development
DSL	Oregon Department of State Lands
GeoTIFF	Georeferenced Tagged Image File Format (e.g., computerized aerial photographs)
GIS	Geographic Information Systems (computerized mapping)
GPS	Global Positioning System
HGM	Hydrogeomorphic (as in, the HGM method for wetland functional assessment)
HMT	Highest measured tide (also called “highest observed water level”)
LiDAR	Light Detection And Ranging (a remote sensing technology)
LMZ	Landward migration zone (for tidal wetlands)
LWI	Local Wetland Inventory
NAIP	National Agricultural Imagery Program
NAVD88	North American Vertical Datum of 1988 (an elevation reference system)
NCLC	North Coast Land Conservancy
NGVD29	National Geodetic Vertical Datum of 1929 (an elevation reference system)
NOAA	National Oceanographic and Atmospheric Administration
NRCS	Natural Resource Conservation Service
NWI	National Wetland Inventory
ODA	Oregon Department of Agriculture
ODFW	Oregon Department of Fish and Wildlife
ORBIC	Oregon Biodiversity Information Center
ORWAP	Oregon Rapid Wetland Assessment Protocol
OWEB	Oregon Watershed Enhancement Board
PDF	Portable Document Format
US-EPA	U.S. Environmental Protection Agency
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey

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Study overview

Important note: The term "tidal wetlands" is used throughout this study to refer to current and former tidal wetlands. This project did not identify regulatory boundaries or delineate wetlands; site boundaries were taken from existing National Wetland Inventory mapping, with supplementary data from NOAA tidal datums and the LiDAR-based digital elevation model. Mapped areas may contain uplands, and unmapped wetlands may exist outside the boundaries of the mapped areas.

This study identified and characterized current and likely former tidal wetlands in the Necanicum River estuary (in the emergent, shrub, and forested classes), and used ecological criteria to prioritize these wetlands for conservation and restoration activities. The project is intended for use in strategic planning of voluntary conservation and restoration efforts; products are not intended for regulatory use and do not meet federal mapping standards. We generated GIS layers of current and former tidal wetlands from existing National Wetland Inventory (NWI) maps, supplemented by expert local field knowledge, LiDAR-derived elevation, and recent aerial orthophotographs. Using the LiDAR-derived elevation to locate areas within tidal range (below highest measured tide at a nearby NOAA tide station), we mapped 37 current and former tidal wetland sites, totaling 401A (162.3 ha). This figure approximately doubles the previously identified tidal wetland area in the estuary. The higher elevation zones identified in this study may be inundated only occasionally. However, including these higher areas in tidal wetland conservation and restoration planning will benefit both current resource management, and adaptive planning for future climate change and sea level rise.

We characterized alterations to the identified sites, and calculated priority rankings to create five priority groups. The five sites in the highest priority group were all part of the Neawanna Creek sub-estuary: forested tidal wetlands ("tidal swamps") in the Mill Creek wetland complex; the Stanley Lake wetland complex; tidal marsh along Neawanna Creek; and the mill pond/forested wetland complex at the south end of Seaside (including the area known as "Shangrila"). Ten medium-high priority sites included brackish tidal marshes at Neawanna Point and elsewhere along the Neawanna and Necanicum; and shrub tidal wetlands on the west bank of the Necanicum just south of Avenue U (east side of golf course). Twenty-two other sites rank medium or lower, but all of the sites provide important ecosystem services and wetland functions, and all wetlands are protected by applicable federal and state laws.

Introduction

Project goals and approach

Throughout the Pacific Northwest and the United States, there is increasing recognition of estuarine contributions to watershed and marine processes. This recognition has generated new interest in tidal wetland conservation and restoration. In Oregon, overall losses of tidal wetlands since the 1850's are estimated at 70% (Thomas 1983, Boule and Bierly 1987, Good 2000, Christy 2004), so there is a clear need for restoration. Conservation of remaining tidal wetlands is equally important. Because each estuary offers a wide variety of restoration and conservation opportunities, strategic planning is needed to reach conservation and restoration goals.

This prioritization is designed to provide strategic focus for tidal wetland conservation and restoration actions undertaken in partnership with willing landowners. The study highlights locations in the Necanicum River estuary where tidal wetland restoration or conservation action may offer the biggest ecological "bang for the buck" – that is, the highest potential to protect or increase estuary functions. The information provided by this study provides a basis for working with interested landowners to develop site-specific action plans.

This study's products are meant for active use. The shapefiles, spreadsheets and maps can be used to organize information about tidal wetlands and estuary conservation activities. The estuary is a dynamic place, so we recommend regular updating of site-specific data, as well as verification of the details in this report before site-specific action planning. Sufficient data are provided for fine-tuning site selection and action planning; these data (and additional new data) can also be used to re-rank sites using alternative methods if desired.

This prioritization uses ecological factors to rank sites for both conservation and restoration actions. Criteria for prioritization included size of site, tidal channel condition, connectivity to other wetlands, salmonid diversity, historic vegetation type, and diversity of current vegetation types. Information on these characteristics was obtained from publicly available data, field reconnaissance (generally offsite observation), aerial photograph interpretation, and local knowledge. Number of landowners, ownership type, and land use zoning are can also be important in restoration planning; they are briefly addressed in this report.

This study has no regulatory intent or significance; it is intended only to foster conservation and restoration by interested and willing landowners. This project did not delineate wetlands; site boundaries were taken from existing NWI mapping, with supplementary data from NOAA tidal datums and the LiDAR DEM. *Mapped areas may contain uplands, and unmapped wetlands may exist outside the boundaries of the mapped areas.*

This prioritization is not intended to be an assessment of wetland functions. Assessment of tidal wetland functions is a separate endeavor (Adamus 2006, Adamus *et al.* 2009a) and was not within the scope of this analysis. However, the prioritization criteria used in this study – the same criteria used in the Oregon estuary assessment method (Brophy 2007) – were selected because they strongly influence tidal wetland functions.

This prioritization is intended to provide a broad perspective and help guide decisions; it should not be used to eliminate any site from consideration for restoration or conservation. In other words, all tidal wetlands are important (and all are protected under state and federal regulations). Prioritization is simply a way to focus action planning on sites where the return for that effort may be the greatest.

This study strives for transparent methods, simplicity, flexibility, and accessibility. The data sources, data manipulations, scoring methods, and results are thoroughly documented and all analyses are repeatable. A limited number of criteria were used, to make results understandable. All of the data that were used to calculate priority rankings are shown in this report and can be accessed, checked for accuracy, and updated as needed.

Throughout this study, we actively sought input from local experts and resource specialists to improve our results. This information has been included in the site characterization and prioritization, the site information table, and this written report.

This study's map of tidal wetlands of the Necanicum River estuary differs from past maps, and probably will differ from future maps. Each map is the product of project goals, available data, and specific mapping methods. Since differences between maps can create confusion, we have tried to make our methods clear and consistent. See **Methods** below for more information on the methods we used to relate land surface elevations, tidal water levels, and spatial distribution of tidal wetlands.

Study area and tidal wetland classes included

This study included all tidal wetlands in the Necanicum River Estuary up to the head of tide for the Necanicum River and tributaries (Map 1). Although mapping of the head of tide was beyond the scope of this study, we worked with the North Coast Land Conservancy to conduct limited water level data collection, and found that actual head of tide is further upstream than the published head of tide for the Necanicum, Neawanna and Neacoxie (OR DSL 2007).

The estuary includes all tidal water bodies adjacent and tributary to the Necanicum (Stanley Lake, Neacoxie Creek, Neawanna Creek, Mill Creek, Johnson Creek, and smaller tidal tributaries and water bodies). Emergent, scrub-shrub and forested tidal wetlands were included in this study; consistent with statewide methods (Brophy 2007), aquatic bed wetlands (eelgrass and algae beds) were not included, due to the different resource management requirements for these habitat classes. Following the Oregon Estuary Assessment method (Brophy 2007), this study also excluded former tidal wetlands that have been completely filled and converted to developed uses such as industrial, commercial and residential sites.

Definition of tidal wetlands

Several definitions of tidal wetlands have been used through the years, but for this assessment, we included any wetlands in the emergent, scrub-shrub and forested classes that met the following definition: *A tidal wetland is a wetland that is periodically inundated by tidal waters, generally daily at high tide or monthly during spring tides, but at least annually*. This definition was used in the hydrogeomorphic assessment method (HGM method) for Oregon's tidal wetlands (Adamus 2006) and in the Estuary Assessment module of the Oregon Watershed Assessment Manual (Brophy 2007). Emergent, scrub-shrub and forested wetland classes are defined in Cowardin *et al*. (1979), and we followed those definitions in this study.

Tidal waters are any waters that rise and fall with the tides, regardless of salinity (Definition of Waters of the United States, 2012). Salinity in tidal waters ranges from full ocean salinity to completely fresh in the "freshwater tidal" zone, where river flows are "held up" by the tides.

The frequency of tidal inundation in tidal wetlands varies by wetland type and landscape setting. For example, low marsh is typically inundated by the tides on a daily basis, but high marsh is inundated only on higher-high tides during spring tide cycles (new or full moon). Some tidal wetlands (particularly in the middle and upper portions of our estuaries) undergo tidal inundation only in winter, when high river flows add to the high tide elevation.

We used high-resolution elevation data (LiDAR "bare earth" digital elevation model, Map 2), published tidal datums (particularly Mofjeld *et al*. 2004), local knowledge, regional expertise, aerial photographs, field water level data (Map 13), and other data to locate likely current and former tidal wetlands within the study area. See **Methods** below for details.

Summary of results

Tidal wetland area: Working from existing NWI maps, and enhancing those maps using geospatial data, field observation, and aerial photograph interpretation, we identified 401A (162.3 ha) of likely current and historic tidal wetlands (emergent, shrub and forested classes) in the Necanicum River estuary (Map 3). This estimate is approximately double the previous estimates of historic tidal wetlands in these classes. The increase in mapped tidal wetland area in our study is due to the methods we used. In brief, we used newly available LiDAR DEM to find areas within tidal range, and supplemented the LiDAR DEM with limited field collection of water level data. Our estimate of tidal range was based on published tidal datums for the Necanicum estuary (Mofjeld *et al*. 2004), information from local experts (Horning 2011), and our research into the influence of coastal Oregon river flows on tidal water levels (Brophy *et al.* 2011, Huang *et al*. 2011).

Many of the tidal wetlands we mapped are farther from the estuary's tidal water bodies than previous tidal wetland mapping. This is especially true in the Mill Creek and Shangrila wetlands, and the wetlands surrounding Stanley Lake. Tidal inundation in these areas may be infrequent, and it is possible that some of these areas do not inundate tidally. However, based on available data, these areas are likely to experience at least occasional inundation due to tidal forces, particularly during high winter flows. Further, based on current global sea level rise predictions of 2 to 5ft by 2100 (Jevrejeva *et al.* 2010), these areas are likely to experience much more tidal inundation over the next 100 years. Including these areas can help guide strategic planning for tidal wetland conservation under sea level rise scenarios, as recommended in Oregon's Climate Change Adaptation Framework (OR DLCD 2010).

Alterations: Within the mapped tidal wetlands, we defined 37 sites (Map 3) and characterized conditions within these sites, focusing on site-specific alterations (Maps 11-12). Flow restrictions were considered site-specific alterations, even if the restriction was offsite. The results show that 11 sites totaling 143A (about 36% of the historic tidal wetland area) have undergone major alterations that greatly restrict tidal flows. The majority of the major alterations are non-dike flow restrictions, such as culverts, roadways, and other filled areas between the site and the tidal water body. An additional 120A have minor alterations, and 67A have no site-specific alterations (though all sites are affected by estuary-wide changes).

Prioritization: We prioritized the 37 tidal wetland sites for restoration and conservation actions (Map 4). Six ecological prioritization criteria contributed to site rankings: tidal channel condition (including connection to tidal flows), size of site, wetland connectivity, salmonid diversity, historic wetland type, and diversity of vegetation classes (Maps 5-10). We defined five priority ranking groups: high, medium-high, medium, medium-low, and low. The high priority group contains five sites totaling 233A. These are the largest sites in the study: forested tidal wetlands ("tidal swamps") in the Mill Creek wetland complex; the Stanley Lake wetland complex; two tidal marsh sites along Neawanna Creek; and the mill pond/forested wetland complex at the south end of the study area (including the area known as "Shangrila"). Ten medium-high priority sites (65A) included brackish tidal marshes at Neawanna Point and elsewhere along the Neawanna and Necanicum; and scrub-shrub tidal wetlands on the west bank of the Necanicum just south of Avenue U. Twenty-two other sites rank medium or lower, but it is important to recognize that all of the sites provide vital ecosystem services and wetland functions.

Land ownership: Land ownership strongly affects the feasibility, planning, and logistics of restoration and conservation actions. We determined the approximate number of landowners and land ownership type for each site and mapped the results (Maps 15-16) to help with site-specific action planning. Due to the development that surrounds the Necanicum estuary, most sites have several to many landowners, and ownership is generally a mix of private and conservation/public ownership. The conservation/public category includes North Coast Land Conservancy properties as well as public parks and city land managed for wetland conservation.

Sea level rise adaptation planning: To assist climate change adaptation, we used the LiDAR DEM to map the "landward migration zone" (LMZ) for tidal wetlands in the Necanicum estuary (Map 14). This is the area located just above current tidal range. For those sites with substantial available area for landward migration, we summarized the area within 1m, 2m and 3m of the highest measured tide at the nearest active long-term NOAA tide station (11.5ft NAVD88 at Garibaldi) (Mofjeld *et al.* 2004). The available landward migration zone (LMZ) in the Necanicum estuary is constrained by adjacent development and landforms, but several sites in the study have substantial landward migration zones. The most prominent are the Mill Creek wetlands (Site 4), Stanley Lake wetlands (Site 8), Shangrila (Site 25), and the Circle Creek wetlands, which are currently slightly above tidal range. These sites are already in the high priority group (except for Circle Creek, which is not a study site because its elevation is slightly above tidal range). The fact that these sites have large LMZs adds additional weight to their prioritization.

Conclusion: Mapping of tidal wetlands is a complex and challenging task; results depend on project goals, methods, and available data. This study identified a much larger tidal wetland area than past maps of the estuary, due to the methods used; future efforts will no doubt differ from this study's maps as available information improves and conditions change. Despite the challenges, this study provides useful, updated tools for managing tidal wetland resources in the Necanicum River estuary, particularly in light of potential climate change impacts.

Products

The following products are provided with this report:

1. Written report (paper and PDF formats). Contains background, methods, results, and the following appendices:

> **Appendix 1. Maps.** Maps of study area, prioritization scores, ownership, alteration types, and water level logger locations.
>
> **Appendix 2. Site ranking tables**:
>
> > Table 1: Site rankings, sorted by rank (top down)
> > Table 2: Site rankings, sorted by site number
>
> **Appendix 3. Site information tables** (including a key to table fields): ranking factors and scores. This information duplicates the GIS shapefile attribute table.
>
> **Appendix 4. Water level data.** Data from water level loggers installed during the course of this study.
>
> **Appendix 5. Restoration principles.** General principles of sustainable tidal wetland restoration in the Pacific Northwest.
>
> **Appendix 6. Restoration approaches.** General guidelines for restoration actions in Oregon's estuaries.

2. GIS shapefile of study sites (Nec_tidalw_FINAL_1jun2012.shp), containing all of the attributes in the site information table in **Appendix 3**. Projection is UTM Zone 10N NAD83; full metadata are provided with the shapefile.

3. Excel spreadsheet of site information (Nec_tidalw_analysis_FINAL_1jun12.xlsx). The Excel file contains a duplicate of the shapefile attribute table and the site information tables in **Appendix 3**, as well as analysis tables.

All of these products are necessary for accurate understanding of results. If any of the above products are missing, please contact Laura Brophy at Green Point Consulting, (541) 752-7671 or e-mail Laura@GreenPointConsulting.com for replacements.

Background information

Classification of the Necanicum River estuary

Geologically, the Necanicum estuary is classified as a partially-mixed drowned river mouth estuary (Bottom *et al*. 1979). Drowned river mouth estuaries were formed when coastal river valleys flooded as sea levels rose after the last ice age (Emmett *et al*. 2000). In terms of land use, the Necanicum River estuary is classified by the Oregon Department of Land Conservation and Development (DLCD) as a Conservation Estuary. Other estuaries in this category include Netarts Bay, Nestucca River, Siletz Bay, Alsea Bay, and Winchuck River. DLCD states that

Conservation Estuaries “shall be managed for long-term uses of renewable resources that do not require major alterations of the estuary” (State of Oregon 2012).

General locations of tidal wetlands in the Necanicum

The geomorphology of the Necanicum estuary is unique among Oregon’s estuaries. The landscapes in and around the estuary are characterized by north-south oriented dune ridges alternating with long, narrow wetland swales, typical of the Clatsop Plains (Reckendorf *et al*. 2001). The wetland swales can be very long from north to south, and there is very little elevation change along their length. For the swales that originate in the estuary, the extent of tidal influence is limited not just by elevation, but also by distance from the bay, and by hydrologic restrictions, both manmade and natural.

Oregon’s tidal wetlands include aquatic bed habitats (eelgrass and algae beds, exposed only briefly during lower low tides), emergent marsh (low and high marsh), scrub-shrub wetlands, and forested wetlands. (Tidal scrub-shrub and forested wetlands are collectively known as “tidal swamps.”) The Necanicum River estuary contains all of these tidal wetland habitat types. As in other estuaries, the low marsh is located near the ocean on the fringes of the main tidal water bodies. Consistent with statewide methods (Brophy 2007), this study does not address aquatic bed habitats (mud flats, eelgrass and algae beds), for which management issues and methods are quite distinct.

Tidal wetlands are found throughout the full range of salinities, from the marine salinity zone up to the freshwater tidal zone. Wetlands in the low-salinity and freshwater portions of Oregon’s outer coast estuaries have been little studied and poorly mapped. In the maps of the 1970s and 1980s that formed the basis for Oregon’s estuarine land use planning process (Akins and Jefferson 1973), as well as more detailed studies of the Necanicum River estuary (Maine 1979), many upper estuary brackish and freshwater tidal wetlands were not mapped. The Oregon Estuary Plan Book mapping for the Necanicum River estuary (Cortright *et al*. 1987) does not include any of the forested tidal wetlands in the upper portions of the estuary. The National Wetland Inventory shows wetlands in these areas, but does not classify them as tidal wetlands (USFWS 2010). One of our goals for this study was to improve the mapping of tidal wetlands in the upper Necanicum River estuary.

Tidal wetland functions

Tidal wetlands serve many vital functions in the watershed. Many of these functions are evaluated in the hydrogeomorphic functional assessment method for tidal wetlands of the Oregon coast (Adamus 2006). These functions include water quality protection (sediment detention and stabilization, nutrient and contaminant stabilization and processing), ecological support (food chain support, native vegetation support), and wildlife habitat (for fish, birds, invertebrates, and mammals).

The value of tidal wetland functions may be enhanced by the location of these wetlands in the landscape—low in the watershed, in an economically important nursery zone for anadromous and marine organisms, and immediately below concentrations of the agricultural and developed land uses that can generate warmed, polluted surface waters.

In Oregon, interest in salmon has brought attention to the salmon habitat functions of tidal wetlands. Tidal wetlands are important to salmon population size, diversity and viability in Oregon and the Pacific Northwest (Simenstad 1983, Solazzi *et al*. 1991, Miller and Sadro 2003, Bottom *et al*. 2004). The health of Pacific Northwest salmon populations depends on a continuum of diverse habitats across freshwater, estuarine and marine zones. Tidal wetlands are considered a crucial link in this chain, providing rearing habitat characterized by a highly productive food web, deep meandering channels for shelter from predators and high velocity river flows, cool water temperatures, and a brackish-freshwater interface for physiological adaptation to marine salinities. These tidal wetland features contribute to accelerated juvenile salmon growth during estuarine rearing, in turn supporting increased ocean survival.

Mapping provided by the Oregon Department of Fish and Wildlife (ODFW) shows that the Necanicum watershed supports spawning runs of chinook (introduced), chum, coho and steelhead (ODFW 2011), and the estuary also supports runs of sea-run cutthroat trout (Maine 1979, Snyder *et al*. 2002). As juveniles of these species move through the estuary on their way to the ocean, they all use the estuary, though length of residence time varies by species and life history strategy (e.g. Bottom *et al.* 2004, 2008).

The full value of tidal wetland functions is not generally recognized in our economic system. Several authors have estimated the value of various tidal wetland functions; the values below are all from Costanza *et al.* (1997). Overall, the ecosystem services valuation of tidal marsh is estimated at a minimum of $4043 per acre per year ($4043/A/yr), placing it fourth among the highest-valued ecosystems on earth. (The top three are open-water estuarine habitats, freshwater swamps and floodplains, and seagrass and algae beds.) Of all ecosystems on earth, tidal marshes and swamps rate by far the highest in waste treatment (recovery and removal of excess, mobile nutrients); the minimum estimated value for this function is $2710/A/yr. Tidal and freshwater marshes and swamps together form the world's most important environmental "capacitors;" that is, these ecosystems absorb and moderate drastic environmental fluctuations like flooding, storm damage, and drought (valued at more than $1837/A/yr). Tidal marshes are the second-highest ranking ecosystems in the world for food production ($186/A/yr), habitat and refuge for rare organisms ($68/A/yr), and recreation ($266/A/yr).

Human uses

People have always used Oregon's estuaries intensively. Native Americans occupied villages on the lowlands near the sea, where easy-to-access waters with abundant fish and shellfish provided transportation and food. After European settlement, many estuary lands were filled for towns and industrial sites, diked and converted to agriculture, dredged for navigation, or otherwise altered. Grassy tidal marshes were diked for pasture. In the tidal swamp zone, trees were harvested and tidal channels were blocked so that the lands could be converted to pasture or home sites.

Since European settlement about 150 years ago, human activities have led to a 70 to 90% loss of Oregon's tidal wetlands (Boulé and Bierly 1987, Good 2000, Christy 2004). However, the rate of change has slowed in recent years. Estuary zoning and wetland protection regulations have helped reduce human impacts to tidal wetlands (Good 1997). Today, many groups – such as the North Coast Land Conservancy – are restoring tidal wetlands to regain their original functions. A broader goal is to reconnect these wetlands to other natural areas, re-establishing the landscape array of ecosystems that once spread from ocean to ridgetop.

The Necanicum River estuary has undergone many changes since European settlement. Former tidal wetlands in the lower estuary have been filled for residential and urban development, and adjacent areas (on former sand dunes) are also developed. However, substantial areas of tidal wetland remain – particularly along Neawanna Creek. Due to the small size of the estuary, agricultural conversion has been limited, and little diking has occurred. Most of the alterations to the estuary consist of flow restrictions due to road systems and restrictive culverts. These alterations are discussed in more detail in **Estuary alterations** below, and in the individual **Site narratives**.

Estuary alterations

Alterations to estuaries can affect an entire estuary, individual sites (e.g. dikes and ditches), or multiple sites (river mouth tide gates, tributary stream tide gates, and roadways or developments that block flow to large areas). This assessment focuses on alterations affecting individual sites or multiple sites, because these types of alterations can be used to distinguish among sites, allowing us to establish priorities for conservation and restoration activities. However, estuary-wide alterations are discussed briefly below.

Estuary-wide alterations

Estuary-wide alterations affect all tidal wetlands in an estuary, even wetlands with no site-specific alterations. Examples of estuary-wide alterations include jetties that affect tidal exchange and river flow patterns; upstream dams that strongly influence freshwater outflows (such as those on the Columbia River); and widespread land use practices that alter sediment movement and peak flows (like extensive clear-cutting in upper watersheds, and impervious surfaces affecting upstream hydrology). More subtle estuary-wide changes can result from introduced species like European beachgrass, which stabilizes sand spits at the estuary mouth, resulting in altered flows and sediment deposition patterns. It is difficult to quantify the effect of these landscape-scale changes on individual tidal wetland sites.

In the Necanicum, there is little navigational use of the waterway, and there are no jetties at the mouth of the river. However, natural water flow and sediment dynamics are limited by development around the mouth of the Necanicum. For example, infrastructure for the City of Seaside (sewage ponds, storage buildings) is located on the south bank of the Necanicum near the river mouth, and these areas must therefore be protected against channel migration and bank erosion. On the other hand, strong tidal forces, storm surges, river floods, dynamic channel movements and sediment erosion/deposition patterns have placed limits on human activities in this area. For example, in the 1960's a would-be developer placed fill material to create an artificial spit on the south side of the bay, with the intention of building a development on the spit. However, high river flows and tides eventually breached the artificial spit, the development was abandoned, and the fill material has washed away (Adamus *et al*. 2005, Wallace 2009).

Site-specific alterations and their effects on tidal wetland functions

The main types of site-specific tidal wetland alterations on the Oregon coast are dikes, tide gates, ditches, restrictive culverts, fill placement (including dredged material disposal), road and railroad crossings and embankments, dams, channel armor, excavation, tillage, grazing, driftwood removal, and logging and brush clearing in tidal swamps. Invasive species are another type of alteration (though generally not a deliberate one); the scale of impacts from invasive species can range from site-specific to coast-wide.

Of these alterations, the types most prevalent in the Necanicum River estuary are restrictive culverts, road crossings and embankments, channel armoring, fill material, and excavation. Most of these alterations are associated with urban and rural residential development. Little diking of tidal wetlands has occurred in the Necanicum, due to the limited agricultural land use in the area. Although some diking is present along the Necanicum River south of Seaside, this diking serves to control river floods rather than to keep daily tides out of the adjacent pastures (Maine 2009-2010). Alterations to specific tidal wetland sites are described in **Site Narratives** below.

The alterations to the Necanicum estuary's tidal wetlands have definitely changed tidal flows. By definition, tidal flows create the unique functions of tidal wetlands, so these alterations reduce, alter or eliminate all tidal wetland functions. Examples of visible wetland changes due to altered tidal flow can include a decrease in tidal channel complexity, a shift in the composition and distribution of vegetation communities, changes in soil biology and chemistry, altered salinity, and altered patterns of sediment erosion and deposition.

In many cases, sites where tidal flows have been reduced or eliminated undergo soil subsidence. This is a gradual lowering of the soil surface elevation caused by soil compaction, decomposition (oxidation) of organic plant material in the soil, and loss of buoyancy when tidal influence is removed (Frenkel and Morlan 1991). Many of Oregon's diked tidelands have undergone 2 to 4 feet of subsidence. In the Necanicum estuary, subsidence does not appear to have been widespread, probably because of the area's land use history, geomorphology and soils. As described above, agricultural land uses do not predominate in Necanicum estuary. The Necanicum estuary is characterized by dune ridge topography typical of the Clatsop Plains (Reckendorf *et al*. 2001). This topography is not conducive to large-scale commercial agriculture, even pasture. As a result, the diked pastures common to other Oregon estuaries are lacking in the Necanicum – a sharp contrast to the agricultural landscape of many drowned river mouth estuaries elsewhere on the Oregon coast, such as the Tillamook Bay estuary just 30 miles south.

Former tidal wetlands that are no longer tidally influenced because of human alteration may still be wetlands, and may still perform many wetland functions. These areas may become nontidal freshwater wetlands due to soil subsidence and impeded freshwater drainage. However, many of the original functions (such as salmonid habitat and osmotic transition zones) may be greatly reduced or completely lost. Examples in the Necanicum estuary include many of the small wetlands east of Wahanna Road, which have been disconnected from tidal flows and are currently nontidal freshwater wetlands.

Even where tidal flows are still present, human alterations can strongly affect tidal wetland functions. For example, ***Ditches*** change tidal flow patterns and channel morphology, affecting nearly all tidal wetland functions. For example, ditches are usually shallower and broader than natural tidal wetland channels, creating warmer water conditions that reduce habitat value for juvenile salmon. Ditches speed water flow off a site, reducing duration of inundation and diminishing wetland area. ***Road and railroad crossings*** can greatly affect water flow patterns by blocking channels and redirecting or impeding both subsurface flows and "sheet flow" (non-channelized surface flow). ***Tillage*** and ***grazing*** compact soils, contribute to erosion of channel banks, and reduce vegetation diversity and wildlife habitat. ***Channel armor*** and ***riprap*** reduce vegetation diversity and channel shading, eliminate "edge" foraging for aquatic organisms including salmon, and can cause erosion in adjacent areas. ***Excavation, fill*** and ***dredged material disposal*** change site elevations, water flow patterns, and soil biology, altering the many wetland functions that depend on these basic physical characteristics of tidal wetlands. ***Logging*** and ***driftwood removal*** directly reduce wildlife habitat, alter productivity and food webs, and reduce channel shading. ***Invasive species*** can strongly alter the character of a tidal wetland. For example, New Zealand mudsnails can rapidly dominate the benthic fauna in a brackish or freshwater tidal wetland, reducing prey availability for salmon (Bersine *et al*. 2008).

Earthquakes and tsunamis

Earthquakes and tsunamis create major changes to estuarine landscapes – but these are changes caused by natural rather than human forces. Cascadia subduction zone earthquakes have occurred repeatedly in the Pacific Northwest, and a major earthquake of this type would have serious consequences for the community of Seaside and the Necanicum estuary. Along with damage from the quake itself, the associated tsunami would very likely inundate much of the community of Seaside (Tsunami Pilot Study Working Group 2006). In addition, major landscape changes would likely result from land surface subsidence accompanying a subduction zone earthquake, as well as from erosion of land surfaces due to tsunami currents. We did not attempt to incorporate such cataclysmic events into this study's prioritization. However, the possibility of a major quake adds incentive for protection and restoration of tidal wetlands for several reasons: tidal wetlands can help buffer developed areas from tsunami flows; and protection and restoration of tidal wetlands in the upper reaches of the estuary can help provide "insurance" against wetland loss due to coastal subsidence (or more gradual sea level rise).

Restoration: Removing alterations and restoring natural processes

Tidal wetland restoration generally focuses on removal of human alterations. Dikes can be breached or removed; tide gates replaced with fish-friendly models or self-regulating gates that remain open except during extreme high tides. Road crossings with restrictive culverts can be replaced with bridges or culverts can be resized to allow free exchange of tidal flow. Ditches can be filled, and meandering channel remnants reconnected.

Removal of human alterations is the most practical restoration approach, often the most economical, and generally the approach with the highest chances of success (Mitsch 2000, Simenstad and Bottom 2004) because it re-establishes the natural processes that form and maintain tidal wetlands. These natural processes (tidal flows, sediment deposition, organic matter accumulation, and so on) are necessary for the return of tidal wetland functions over time (see **Appendix 5, Restoration Principles**). Successful re-establishment of natural forces minimizes the need for further human intervention after restoration, maximizing long-term restoration effectiveness.

Restoration of tidal flow is the most important component of tidal wetland restoration design. Other restoration techniques may be needed, such as meander restoration, reconnection of freshwater flows, removal of invasive species, and planting of woody species (in areas suitable for tidal swamp). Table 13 shows potential restoration actions corresponding to specific site alterations. Other details are provided in **Appendix 6**, **Restoration approaches.**

Methods

This study prioritized tidal wetland sites for conservation and restoration, using existing data, aerial photograph interpretation, field reconnaissance, and local knowledge.

Information sources

We mapped and characterized tidal wetlands in the Necanicum River estuary using publicly accessible data, local knowledge, and new information from aerial photo interpretation and field reconnaissance. Geographic information systems (GIS) software was used to organize, analyze and display data for this study. GIS data came from a variety of publicly available sources; sources are listed in Table 1. Further details on data sources and methods are provided below.

This assessment followed the methods outlined in the Estuary Assessment module of the Oregon Watershed Assessment Manual (Brophy 2007). The method uses existing GIS wetland maps as a base layer. The recommended base layer is either the National Wetland Inventory (NWI), or GIS data created by Scranton (2004). Scranton (2004) maps tidal wetlands but categorizes many areas as “restoration consideration areas” and states that these areas require ground-truthing. After reviewing the two base map options and applying our knowledge of tidal wetland ecology on the Oregon coast and in the Necanicum River estuary, we determined that the NWI provided the most suitable base map for this study. Local wetland inventories (LWIs) for Seaside and

Gearhart have been completed and would have been a useful addition to the NWI base layer, but GIS data from the LWIs were not available within the necessary timeframe for this study.

As described in Brophy (2007), the National Wetland Inventory's classification of wetlands can be inaccurate, particularly in the middle and upper estuary zones. Therefore, to determine which of the NWI wetlands might be subject to tidal influence, other data sources were needed. The best sources proved to be elevation data (LiDAR DEM), and field water level data collected in collaboration with the North Coast Land Conservancy. We supplemented these data with other data listed below. To define sites suitable for action planning, we merged and/or split the NWI mapping units following the methods described in **Site definition** below.

Three sets of aerial orthophotographs were analyzed to define and characterize sites: 2005 color infrared images from US EPA/Oregon DLCD, and 2005 and 2009 true color orthophotos (1/2m GeoTIFFs) from the National Agricultural Imagery Program (NAIP) (Table 1).

Interviews with local and regional experts provided important information for this study. Tom Horning of Horning Geoscience provided geological context, literature references, and information on fluvial and tidal water levels. Katie Voelke and Celeste Coulter of the North Coast Land Conservancy (NCLC) and former NCLC Director Neal Maine were particularly helpful in providing local knowledge and community perspective for this study. Neal Wallace (Public Works Director for the City of Seaside) provided historical context, land use information, and culvert locations.

We conducted field reconnaissance in fall 2005, fall 2009 and winter 2010 to gain information on site conditions and hydrologic connections. Our field observations were generally made from publicly accessible vantage points; a few sites were visited with landowner permission.

Table 1. Information sources and descriptions

Information source	Provider	Data type	Scale	Metadata available? (Y/N)	Complete?* (Y/N)
2009 true color aerial orthoimagery http://oregonexplorer.info/imagery/AccesstheImagery/StreamImagery	NAIP 2009	Raster	1/2m pixel	Yes	Yes
2005 color infrared aerial orthoimagery http://www.coastalatlas.net/downloads/rasters/cir2005_nec_mosaic.zip	US EPA/OR DLCD 2005	Raster	1:20,000	Yes	Yes
2005 true color aerial orthoimagery http://oregonexplorer.info/imagery/AccesstheImagery/StreamImagery	NAIP 2005	Raster	1/2m pixel	Yes	Yes
Digital Raster Graphics (digitized USGS quadrangle maps) ftp://159.121.106.159/imagery/DRG_24K/	USGS	Raster	1:24,000	Yes	Yes
LiDAR "bare earth" Digital Elevation Model http://www.oregongeology.org/sub/lidardataviewer/index.htm	OWEB	Raster	See LiDAR metadata	Yes	Yes
Head of tide for the mainstem river and tributaries http://navigator.state.or.us/sdl/data/shapefile/tide.zip	DSL	Shapefile	n/a	Yes	Yes
National Wetlands Inventory http://www.fws.gov/wetlands/Data/Mapper.html	USFWS	Shapefile	1:24,000	Yes	Yes
Tidal wetlands of Oregon's Coastal Watersheds (Scranton 2004) http://www.coastalatlas.net/downloads/shapes/tidal_marsh.zip	Scranton 2004	Shapefile/ geodatabase	Unknown	Yes	Yes
SSURGO soil survey http://www.or.nrcs.usda.gov/pnw_soil/or_data.html	NRCS	Coverage and Tabular	1:24,000	Yes	Yes
Historic vegetation http://www.pdx.edu/sites/www.pdx.edu.pnwlamp/files/glo_coast_2008_03.zip	ORBIC	Shapefile	1:24,000	Yes	Yes
Oregon Estuary Plan Book http://www.coastalatlas.net/downloads/shapes/necanicum_habs.zip, http://www.coastalatlas.net/downloads/shapes/necanicum_sighabs.zip	Oregon Coastal Atlas	Shapefile	1:5000 unless noted	Yes	Yes
Salmon distribution and habitat use types http://rainbow.dfw.state.or.us/nrimp/information/fishdistdata.htm	ODFW	Coverage	Generally 1:100,000	Yes	Yes
Clatsop County tax parcels (land ownership)	Clatsop County	Shapefile	unknown	No	Yes

* "Complete" indicates the data covered the entire study area

Extent of tidal influence

The Oregon Estuary Assessment method (Brophy 2007) uses a combination of existing GIS data, aerial photograph interpretation, soils mapping, historic vegetation mapping, field reconnaissance, local knowledge, and other data to evaluate the current and historic extent of tidal influence. However, we found that many of the indicators of past tidal influence used in the Estuary Assessment method were not particularly useful in the Necanicum River estuary. For example, altered wetlands elsewhere on the Oregon coast can often be found by inspecting aerial photos for dikes, turbulence pools indicating restrictive culverts, and highly sinuous remnant tidal channels. However, in the Necanicum, dikes are rare, and the dune ridge topography means that many tidal channels are relatively straight rather than highly sinuous. The dune ridge topography has also facilitated the disconnection of former tidal wetlands by roadways and general urban/rural residential fill activity. These manmade features, along with the general "dune ridge" topography and geology of the area, have restricted the power and reach of the tides. Tidal "forcing" appears to weaken rapidly with increasing distance from the mouth of the river, and restrictive culverts generally lack turbulence pools (or at least those pools are not generally visible in aerial photos).

LiDAR data

Fortunately, we had a powerful new resource for this estuary assessment that was not yet available when the Oregon Estuary Assessment method was developed: high-resolution elevation data obtained with LiDAR technology (Watershed Sciences Inc. 2009). The LiDAR "bare earth model" (also called a "digital elevation model" or DEM) is a depiction of the ground surface developed through processing of the LiDAR data (NOAA CSC 2011). The availability of the LiDAR DEM allowed us to estimate land areas that might be subject to tidal inundation – either currently or historically (prior to human alteration of the estuary).

Upper elevation boundary

As described in **Definition of tidal wetlands** above, tidal wetlands are inundated by tidal waters at least once annually (Adamus 2006). However, locating areas in the landscape that inundate at this frequency (or may have done so historically) would require a complete hydrologic model of the entire estuary (incorporating the effects of river flows), and such a model is not available. Instead, we selected an upper elevation boundary or "cutoff" for mapping tidal wetlands, and used the LiDAR DEM to find NWI wetlands below that elevation boundary (see **Site definition** below). The upper elevation boundary we used was 11.5ft NAVD88; this elevation was selected because it is the highest measured tide at the nearest active NOAA tide station, Station 9437540 at Garibaldi (see below).

NOAA tidal datums and highest measured tide

Tidal datums and their relationship to geodetic elevations (such as the NAVD88 datum used in the LiDAR DEM) are obtained from NOAA's Tides and Currents website (NOAA CO-OPS 2012). The two active NOAA tide stations closest to the Necanicum estuary are the Garibaldi station (#9437540) and Astoria station (#9439040). Tides at the Astoria station are likely to be quite different from those at the Necanicum estuary due to the distinct characteristics of the Columbia River estuary, so we used datums from the Garibaldi station. Although NOAA does not publish the relationship between tidal datums and the NAVD88 geodetic datum at the Garibaldi datums page (http://tidesandcurrents.noaa.gov/data_menu.shtml?stn=9437540 Garibaldi, OR&type=Datums), that information was published by NOAA in a 2004 technical memorandum (Mofjeld *et al*. 2004). (Although Mofjeld *et al*. also published tidal datums for the Necanicum estuary at Seaside, they did not list a value for highest measured tide for the Necanicum.)

Highest measured tide ("HMT"—also referred to as "highest observed tide," "highest observed water level," or "maximum observation") makes a reasonable upper boundary for mapping tidal wetlands, for several reasons. First, it is the only published tidal datum above Mean Higher High Water (MHHW), and Oregon's high marsh and tidal swamp wetlands generally occur above MHHW. For example, Brophy (2009) found that elevations of high marsh and tidal swamps in the Siuslaw River estuary ranged from around 0.4 to 1.5ft above local MHHW; and Brophy et al. (2011) found that elevations of high marsh and tidal swamp in the Coos, Siletz and Nehalem estuaries ranged from 0.3 to 0.5ft above local MHHW. Second, HMT is a jurisdictional boundary, used in defining the upper limit for the State of Oregon's removal-fill jurisdiction within estuaries (Oregon Administrative Rules 141-085-0515(2) and 141-085-0510(97)). Third, strategic planning for adaptation to climate change (particularly sea level rise) raises the importance of including areas near the upper limit of tidal influence, rather than omitting these areas. Even if these areas currently are seldom inundated by the tides at current sea levels, they are likely to be inundated more often in the near future if sea level rise projections (OCCRI 2010) are accurate. Finally, in the freshwater tidal zone, the added water heights due to "backup" of river flows can raise high tide water levels well beyond what would be predicted by tides alone (Huang *et al.* 2011). Because of this added "fluvial component" of the tidal inundation regime, tidal wetland studies need to include areas above typical higher high tides. The expected additional water height due to combined tidal and fluvial forces can be determined for specific locations using a modeling approach (Huang *et al.* 2011), but such modeling was beyond the scope of this project.

Water level data collection

The LiDAR DEM gave us valuable information on ground surface elevations within the study area, allowing us to draw a tentative outer boundary for tidal wetlands in reference to tidal datums. However, because of the area's geomorphology, we felt that a limited field study of water levels in the middle and upper estuary would be a helpful supplement to this study, to help determine the extent of tidal influence.

We assisted the North Coast Land Conservancy (NCLC) in one initial installation of a water level logger (Onset model U20-01-001) at Shangrila (Site 25). NCLC staff subsequently downloaded the logger and redeployed it at 5 other locations (Map 13) during fall 2009 through summer 2010. NCLC then provided the data to us for analysis. NCLC also worked with staff from the Columbia River Estuary Study Taskforce (CREST) to survey elevations of the loggers using a laser level; elevations were determined by tying the survey to existing benchmarks within the estuary. See **Results: Water level data** below for more details.

Site definition

To provide strategic guidance for tidal wetland restoration and conservation, this study defined analysis units called "sites." In general, a site is a contiguous wetland area with strong internal hydrologic connectivity and a consistent level of alteration. The goal of site definition was to create analysis units that are appropriate for action planning, while recognizing the ecological importance of large contiguous blocks of wetland. Land ownership in itself was generally not used to define sites, but since different landowners often use the land differently, site boundaries often ended up following ownership boundaries.

As described above, the National Wetland Inventory was used as the base layer for this project; NWI "polygons" (wetlands mapped within the NWI GIS layer) were the source for site boundaries in nearly all cases. NWI polygons were included in sites if most of their area was below our tidal wetland "cutoff" elevation of 11.5ft NAVD88 (based on the LiDAR DEM). If a particular NWI wetland polygon contained some areas below 11.5ft NAVD88 but also had large areas above that elevation, the polygon was split and only low areas were included in this assessment. Conversely, if there was a large area of low ground (well below 11.5ft) immediately adjacent to one of our study sites, but that low ground was not mapped in the NWI, the low ground was digitized and included in our assessment. However, we only added low ground to our sites if the area was undeveloped, and only if it was large (or provided important connectivity between NWI polygons). Only a few low areas were added in this way: about 0.5A was added to NWI polygons to form Site 1, about 6.7A was added to Site 8 (Stanley Lake), and about 1.4A was added to Site 37. *The methods used for this mapping do not meet federal mapping standards (FGDC 2009) and are intended for nonregulatory use only*.

The minimum size for a site defined in this study was 0.5A; isolated wetlands smaller than 0.5A were excluded from the study. However, NWI polygons smaller than 0.5A that were close to other wetlands were retained and merged with the adjacent areas as appropriate.

As stated in <u>Project Goals and approach</u> above, this study did not delineate wetlands. Existing data (NWI mapping, the LiDAR DEM, and NOAA tidal datums) were used to define sites. The mapping resulting from this study does not have any regulatory significance; mapped areas may contain uplands, and unmapped wetlands may exist outside the boundaries of the mapped areas.

Using the data sources listed above, along with information from local and regional experts and field reconnaissance, we merged and split the selected NWI polygons to create sites. The NWI separates wetlands into different mapping units according to wetland system and class (Cowardin 1979). The system level classifies wetlands as marine, estuarine, riverine, lacustrine, or palustrine, or riverine, and the class level addresses vegetation type (emergent, shrub, or forested for our study). For this study, we did not assume that the system level classification was correct; if our analysis indicated that an NWI mapping unit was likely to be a current or former tidal wetland, it was included in our study regardless of its NWI classification. Similarly, we did not divide sites by vegetation type. A major goal of this estuary prioritization process is to recognize interconnected, contiguous tidal wetland areas as a single site if possible, *particularly* if that site incorporates a range of elevations and plant communities. Such a continuum of plant communities has very high ecological value, because it allows movement of animals from one wetland zone to another in response to their needs or changing environmental conditions. So, most of this project's sites were formed by merging polygons of different NWI classes.

Site numbering

In general, sites are numbered from the river mouth upstream to the head of tide (Map 3). Sites 1-25 are on the Neawanna; Sites 26-37 are on the mainstem Necanicum River.

Prioritization method

This prioritization uses the methods described in the Oregon Estuary Assessment method (Brophy 2007). The Estuary Assessment method was developed through extensive field experience, literature review and peer review by a team of regional experts in tidal wetland ecology and restoration. We developed and applied the method in our comprehensive studies of the Nehalem, Yaquina, Alsea, Siuslaw and Umpqua River estuaries (Brophy 1999, 2005; Brophy and So 2005a, 2005b, 2005c). Coast-wide LiDAR data were not yet available when the Estuary Assessment module was written, but for the current study, we used newly available (2009) LiDAR data to assist our identification of extent of historic tidal wetlands.

Restoration sites vs. conservation sites and joint prioritization

This study, like the statewide method (Brophy 2007), used a single set of criteria to prioritize all sites, whether they are obviously in need of restoration ("restoration sites") or are primarily in need of protection ("conservation sites"). In the Necanicum River estuary, distinctions between restoration and conservation sites are somewhat blurred, compared to other Oregon estuaries where former tidal wetlands have been diked, ditched, and converted to agricultural uses. For example, many tidal wetlands in the Necanicum have few site-specific alterations, but their hydrologic connection to tidal flow is affected by road crossings, peripheral fills, and other offsite alterations. The magnitude and effects of such offsite hydrologic disturbance cannot easily be determined in a study like this one. However, even without knowledge of the magnitude and effects, efforts to improve hydrologic connections are a good approach to re-establishing valued wetland functions.

Because of the lack of clear distinctions between restoration sites and conservation sites in the Necanicum, we did not divide sites into these two categories. The estuary as a whole presents a continuous spectrum of degree of alteration, and so do many individual sites. For example, many sites are altered and offer restoration opportunities, but also currently provide substantial wetland functions. Many relatively undisturbed sites offer some restoration opportunities, such as improved culverts on the upslope side, removal of introduced non-indigenous species, or creation of native vegetation buffers. The appropriate actions usually derive from the alterations present. For more guidance, see **Restoration recommendations** below, and **Appendix 6** (**Restoration approaches**).

Prioritization criteria

The following ecological criteria were used to prioritize sites:

1. Size of site
2. Tidal channel condition
3. Wetland connectivity
4. Salmonid diversity
5. Historic wetland type
6. Diversity of vegetation classes

Each site was scored for each of these criteria, and the criterion scores were summed for a total site score (Map 4). The resulting total score represents a site's likelihood of contributing to tidal wetland functions in its current or restored state. After scoring, the sites were grouped into five priority categories (high, medium-high, medium, medium-low, and low). These rankings are intended to provide a broad perspective and help guide decisions. **The rankings should not be used to eliminate any site from consideration for restoration or conservation actions. In other words, all tidal wetlands are important**; prioritization is simply a way to focus action planning on sites where the return for that effort may be the greatest.

Non-ecological criteria, such as number of landowners, landowner type, and availability of landward "migration zones" for upslope migration of tidal wetlands under sea level rise scenarios, also affect restoration decision-making. These factors are addressed in the sections **Land ownership** and **Landward Migration Zones** below.

Table 2 shows a summary of the criteria used to prioritize sites, the data sources, and the scoring levels for each criterion.

Table 2. Summary of prioritization criteria

Factor	Data source	Description	Levels
Size of site	Map of sites	Size in hectares. Threshold size for including a site is 1 ha.	Convert full range of values for study area to scores of 1 (smallest) to 5 (largest).
Tidal channel condition	Aerial photograph interpretation	Observe aerial photographs for visible tidal flow restrictions, ditching, and dikes.	Scale of 1 to 5 (1= poor channel condition/tidal exchange; 5=good condition, full tidal exchange). See scoring matrix below.
Wetland connectivity	National Wetland Inventory	Total area of other wetlands (emergent, scrub-shrub, and forested wetlands) outside site and within a 0.5 mile buffer around site perimeter.	Convert full range of values for study area to scores of 1 (smallest area) to 5 (largest area).
Salmonid diversity	ODFW salmonid distribution data (streamnet.org)	Number of salmon stocks spawning in river or tributary upstream of site (including chinook, chum, coho and steelhead).	Number of stocks rescaled to scale of 1 to 5 (score of 1 = 0 stocks; score of 5 = 4 stocks).
Historic wetland type	Oregon Biodiversity Information Center historic vegetation mapping	Proportion of site that was historically swamp (either forested or shrub swamp)	Full range of values for study area rescaled to scores of 1 (smallest proportion) to 5 (largest proportion).
Diversity of current vegetation types	National Wetland Inventory/Aerial photograph interpretation	Number of Cowardin vegetation classes (emergent, scrub-shrub, forested wetlands) mapped on site.	One Cowardin class = score of 1 Two Cowardin classes = 3 Three Cowardin classes = 5
TOTAL SCORE			Sum of all 6 criteria scores, double-weighting the channel condition score. Maximum possible score = 35; minimum possible score = 7.

Map 4 shows the results of the prioritization; see **Results and discussion** for details and interpretation. The sections below provide rationale for each prioritization criterion.

Size of site

Site size is recognized as an important factor in wetland prioritization methods (Lebovitz 1992, Schreffler and Thom 1993, White *et al*. 1998, Costa *et al*. 2002). The size of a wetland is closely related to the level of functions it provides. All other factors being equal, bigger is simply better when it comes to providing ecosystem services. The science of biogeography (McArthur and

Wilson 1967) has established that larger sites are more self-sustaining, have higher diversity of plant and animal species, and have greater ability to buffer against outside pressures and disturbances such as pollution and invasive species. Larger sites can also present an efficiency of scale, reducing the per-acre cost of restoration.

Site size was calculated in ESRI ArcMap software ("calculate geometry" tool). The threshold for including a site in this study was 0.5A. Site size was rescaled to obtain a size score ranging from 1 (smallest site in study area) to 5 (largest site in study area). Map 5 shows the results of the site size scoring.

Tidal channel condition

Channel morphology and tidal connectivity are important indicators of tidal wetland function and overall hydrologic condition. Site alterations such as ditching, diking, tide gates, restrictive culverts, and roads impede or prevent tidal flow and alter tidal channel structure, resulting in lower channel complexity and shorter total channel length. Highly altered channels and blocked tidal flow reduce tidal wetland functions, and make restoration more difficult and more expensive.

As described above, site-specific alterations in the Necanicum River estuary do not include the extensive dike/tide gate systems typical of other Oregon estuaries. However, restrictive culverts, other tidal flow restrictions, and ditching are widespread in the Necanicum.

Tidal channel condition was evaluated using aerial photographs, field reconnaissance, and local knowledge. Each site was scored using the scoring matrix shown in Table 3. Four subfactors contributing to tidal channel condition were evaluated: tidal exchange, tide gate location, ditching, and remnant channels. Each of these subfactors was assigned a score ranging from 1 (highly altered condition) to 5 (low alteration). The four subfactor scores were averaged to obtain a tidal channel condition score ranging from 1 (highly altered/low tidal connectivity) to 5 (relatively unaltered/intact tidal connectivity).

The "tide gate location" subfactor scores the location of the tidal restriction (tide gate or other tidal restriction) in three categories (offsite, onsite, or none). Tidal restrictions in the Necanicum River estuary were usually culverts; very few of these had tide gates. In some cases tidal flows are blocked by roads or other filled areas.

Table 3. Tidal channel condition scoring matrix

Subfactor	Highly- altered condition		Medium alteration		Least-altered condition	
	Description	Score	Description	Score	Description	Score
Tidal exchange	None	1	Restricted	3	Full	5
Tide gate location	Offsite	1	Onsite	3	No tide gate	5
Ditching	Heavy	1	Some	3	None	5
Remnant channels	None	1	Some	3	Many*	5

*or, channels are undisturbed

Map 6 shows the results of the tidal channel condition scoring.

Wetland connectivity

In landscape ecology terms, connectivity (spatial connection of habitats to one another) is the opposite of fragmentation (isolation of habitats). Wetlands with good connectivity – those located near other wetlands and connected via stream or narrow wetland corridors – can perform many of their functions better, compared to isolated wetlands (Adamus and Field 2001, Amezaga *et al.* 2002, Adamus 2006). If a particular wetland is disturbed, the creatures that depend on it for shelter and livelihood may need to move to another nearby wetland. Mobile species such as anadromous fish, shorebirds, waterfowl, and native landbirds and mammals often feed and rest in several wetlands, so a single isolated wetland does not serve their needs. Interconnected salt marsh, brackish marsh and freshwater wetlands offer juvenile salmon the opportunity to adjust to ocean salinities before migrating to the sea.

Wetland connectivity also buffers environmental change. Each type of tidal wetland occupies a specific elevation range relative to sea level – but sea level itself is slowly changing. Land uplift and subsidence due to tectonic activity are fairly rapid in places; for example, Cape Blanco is estimated to be rising at a rate of about a foot every 100 years (Komar 1998). At the same time, the world's sea level is also rising (OCCRI 2010), though the rate of sea level rise relative to the land surface varies along the length of the Oregon coast. However, periodic earthquakes can change this relationship radically; the earthquake of 1700 caused a subsidence of about 3 feet in the land surface across much of the Oregon coast (Leonard *et al*. 2004). Adding to these geologic scale changes, human activities may also have caused major changes in the location of head of tide in some estuaries. For example, head of tide in the Coquille estuary appears to have shifted about 4 miles downstream since the 1850's (Benner 1992).

To quantify wetland connectivity for each site, the total area of NWI-mapped wetlands in the emergent (EM), shrub (SS) and forested (FO) classes within a half-mile buffer around the perimeter of each site was calculated using ESRI ArcMap software ("buffer" and "intersect" tools). Both tidal and nontidal wetlands were included in the area.

This method represents two minor departures from the standard Estuary Assessment method (Brophy 2007). First, the Estuary Assessment method also includes aquatic bed habitats (eelgrass and algae beds) in the analysis. However, there are no aquatic bed habitats mapped in the NWI for the Necanicum estuary. Although the Estuary Plan Book maps about 4A (1.6ha) of aquatic beds in the estuary, the mapping appears to be quite inaccurate; about half the mapped areas are located on dry land rather than in channels. (This is probably due to poor registration of the Estuary Plan Book GIS layers with other data layers.) Because of the lack of well-registered, current data and the very small area of aquatic bed habitats, these habitats were not included in the connectivity criterion.

Second, a half-mile buffer was used instead of a 1-mile buffer for summing the wetland areas close to each site. Half-mile and 1-mile buffers were initially created and visually evaluated;

results showed that in this small estuary, 1-mile buffers crossed the sand ridges that act as basin divides, generally resulting in inclusion of wetlands from other drainages. For example, for the relatively isolated sites along the mainstem Necanicum, the 1-mile buffers included the western portions of the wetlands along the Neawanna. Therefore, half-mile buffers were chosen; they more accurately reflected the actual connectivity of wetlands in this basin.

Map 7 shows the results of the wetland connectivity analysis.

Salmonid diversity

Estuarine wetlands provide important rearing and foraging habitat for juvenile salmonids prior to their ocean entry (Bottom *et al*. 2004, 2008). ODFW's StreamNet fish distribution mapping (http://www.streamnet.org/mapping_apps.cfm) shows that the Necanicum basin supports spawning runs of four salmonid species: chinook, coho, steelhead, and chum. In addition, the estuary supports spawning runs of sea-run cutthroat trout (Maine 1979, Snyder *et al*. 2002). The chinook are introduced, but the rest of the species are native to the basin (Maine 1979, Snyder *et al*. 2002). All of these anadromous fish must migrate through the estuary, so all of the tidal wetland sites in the estuary could potentially provide salmonid habitat functions. However, some sites are located along the migration corridors for all of the species, whereas other sites are located on tributaries that support spawning populations of fewer salmonid species. Sites located along migration corridors for a larger number of salmon species were given priority in this study.

Ideally, a prioritization like this one would rank sites by using precise and high-resolution data on abundance and distribution of juvenile salmonids in tidal channels and streams. However, no such comprehensive, consistent, and appropriate-scale data were available for this study. Therefore, sites were scored by using the available salmon distribution mapping, without regard to the population condition or size. This was considered acceptable, since the remainder of the prioritization criteria also address factors that strongly affect salmon habitat functions (site size, channel condition, wetland connectivity, historic wetland type, and vegetation diversity).

Scoring for salmonid diversity used the mixed-scale (1:24,000 to 1:100,000) salmonid distribution mapping described above (StreamNet mapping) (ODFW 2011). The StreamNet mapping does not include sea-run cutthroat distribution, so this scoring process includes only the other four species (chinook, coho, steelhead and chum). The total number of salmonid stocks using the adjacent river or stream was determined using the StreamNet data. The number of stocks was then rescaled to derive the salmon habitat connectivity score ranging from 1(0 stocks) to 5 (all 4 stocks).

This score is not intended to evaluate actual use levels; comprehensive surveys of juvenile salmonid use of tidal wetlands in the Necanicum are not available. In fact, comprehensive surveys of juvenile salmonid foraging and distribution in tidal wetlands are not yet available for any of Oregon's estuaries, though several studies have documented salmonid behavior in estuaries (e.g. Miller and Sadro 2003, Bottom *et al*. 2004).

Map 8 shows the results of the salmonid diversity analysis.

Historic wetland type

A major goal of estuarine restoration is to re-establish the full suite of habitat types that were historically present. Simenstad and Bottom (2004) state that "Restoration plans should be designed to restore ecosystem complexity, diversity, and riparian-flood plain connectivity based on the historic estuarine landscape structure." Of all tidal wetland types in Oregon, tidal swamps have been the most heavily affected by development and agricultural conversion. Estimates of tidal swamp losses since the 1850's within Oregon's estuaries and sub-estuaries range from 90 to 95% (Thomas 1983, Brophy 2005), compared to about 70% for tidal marshes (Graves *et al*. 1995, Christy 2004, Brophy 2005).

Tidal forested and scrub-shrub wetlands (tidal swamps) have unique characteristics supporting salmonid habitat functions. In addition to providing the usual benefits of brackish-to-freshwater tidal wetlands—an osmotic transition zone, a rich foraging environment, and deep, cool channels with overhanging banks for shelter from predators—tidal forests also have trees and shrubs that provide additional shade, physical shelter and large woody debris. Woody vegetation, leaf fall, and root masses provide habitat structure and detrital contributions to the food web. Because of these characteristics, and because of their disproportionate losses to development, former tidal swamps were prioritized within this study.

Most of the tidal swamp historically found in Oregon was spruce swamp, with Sitka spruce (*Picea sitchensis*) as the dominant tree species (Jefferson 1975, Thomas 1983). Sitka spruce swamp and shore pine swamp were also found in the Necanicum estuary (Christy *et al.* 2001, Hawes *et al.* 2002). Regardless of the tree or shrub species present, nearly all of these swamp areas were cleared early in the 20th century. Therefore, we used historic vegetation mapping (Christy *et al.* 2001, Hawes *et al.* 2002) to locate areas of former swamp within the tidal wetland zone. The historic vegetation layer was intersected with the sites layer in ESRI ArcMap to determine the proportion of each site that was historically swamp. This proportion was then rescaled to derive the historic vegetation score ranging from 1 (0% swamp) to 5 (100% swamp).

The results of the historic wetland type analysis are shown in Map 9.

Diversity of current vegetation types

Many wetland functional assessment methods use diversity and interspersion of vegetation cover classes as an indicator of functional level (Roth *et al*. 1996, Adamus and Field 2001, Adamus 2006). Diversity of cover classes provides a variety of habitat types, resulting in more ecological niches and presumably higher animal species diversity. Cowardin cover classes (Cowardin *et al*. 1979) were used to define vegetation diversity for this project. The three Cowardin classes included in this study are emergent (dominated by grass, sedges, or other herbaceous vegetation), scrub-shrub (dominated by shrubs), and forested (dominated by trees). To obtain a vegetation diversity score, we visually inspected each site to determine the number of Cowardin cover classes present. The total number of cover classes on a site was rescaled to obtain each site's score, ranging from 1 (1 cover class) to 5 (3 cover classes).

Map 10 shows the results of the vegetation diversity analysis.

Scoring method

Each prioritization factor (criterion) was scored for each individual site on a scale of 1 to 5. On the scoring scale, 1 represents relatively poor condition and 5 corresponds to the best condition based on this study's prioritization factors (i.e., large size, good channel condition, high wetland connectivity, high number of salmon species, high percent historic swamp, high vegetation type diversity). For the total score, all six scores were added to get a total score (TOT_SCO in the site information table), with the tidal channel condition score double-weighted because tidal hydrology is a very important controlling factor that affects all tidal wetland functions and restorability. The formula for the total score is:

TOT_SCO = [SIZE_SCO] +(2* [TCC_SCO])+ [WLCN_SCO] + [NTYP_SCO] + [SWMP_SCO] + [CWDN_SCO]

Abbreviations in the formula above are explained in **Appendix 3**, Table 1.

After scoring, the sites were placed in the "ranking groups" shown in Map 4, Table 5, and the tables in **Appendix 2**. These groups provide an easy way of visualizing scores on a map. Differences of one group (e.g., medium *versus* medium-low or medium-high *versus* high) should not be considered significant, because sites on either side of the dividing line may have very similar scores. Scores for each ranking criterion and the total score can be found in both the ranking tables (**Appendix 2**) and the site information table (**Appendix 3**).

It is important to note that the priority groups and the underlying scores should be used as a **general guide** for action planning, not a final arbiter of the absolute priority or ecological value of each site. To fine-tune action planning decisions, we recommend reviewing the details contained in the site information table, as well as the supplemental data contained in the next sections of this report (**Landward migration zone mapping**, **Land ownership**, and **Land use planning and zoning**).

Landward migration zone mapping

Climate change adaptation planning requires awareness of areas that may become tidal wetlands under sea level rise scenarios. These areas – the "landward migration zone" for tidal wetlands – are good candidates for conservation or restoration activities right now. Protecting these areas from development may offer multiple advantages: reduction of potential earthquake and tsunami damage, and maintenance of adequate tidal wetland resources if lower-lying wetlands become submerged due to sea level rise.

Although mapping of the landward migration zone ("LMZ") is not part of the Estuary Assessment Method (Brophy 2007), we included this analysis to provide an additional planning tool for estuarine resource management. To map the LMZ, ESRI ArcGIS Spatial Analyst software was used to classify and map three elevation zones, using the LiDAR DEM. The elevation zones were 1m, 2m and 3m above this project's upper boundary for tidal wetlands (HMT=11.5ft NAVD88), representing sea level rise (SLR) scenarios of 1m, 2m, and 3m respectively:

- ***11.5-14.78 ft NAVD 88 (1m sea level rise)***
- ***14.78-18.06 ft NAVD88 (2m sea level rise)***
- ***18.06-21.33 ft NAVD88 (3m sea level rise)***

We selected the first two elevation ranges because they bracket the medium to upper range of recent semi-empirical SLR projections for the year 2100. These projections range from 0.59 to 2.15m, based on Vermeer and Rahmstorf (2009), Grinsted *et al.* (2009), and Jevrejeva *et al*. (2010), as cited in the Oregon Climate Assessment Report (OCCRI 2010). The Oregon Climate Assessment Report (OCCRI 2010) suggests that these projections may underestimate global SLR, since their methods do not account for potential future changes in ice flows (Rahmstorf 2010). Therefore, we included a third elevation range extending to 3m above HMT.

Developed areas are not suitable LMZs, so these areas were excluded from our LMZ mapping. This required heads-up digitization of LMZ boundaries in developed areas, which was very time-consuming. To limit the time required and maximize useful information for land management, LMZs were digitized only for sites that have relatively large LMZs (Sites 4, 7, 8, 15, 21, 24, 25 and 37).

Land ownership

Land ownership for tidal wetland sites was analyzed to assist in the decision-making and action planning process. We used a GIS layer of tax parcels for Clatsop County to determine the approximate number of landowners and the type of ownership for each site. (Given the relatively coarse scale of the NWI GIS data, the exact number of landowners for each site could not be determined in the GIS; such determinations must be made on the ground using property boundary surveys.) Three types of land ownership were defined: Conservation/public, private non-conservation, and mixed (Table 4).

The number of landowners at a site can affect restoration logistics, because the more landowners are involved, the more difficult it can be to coordinate restoration activities. The type of ownership of a site also affects decision-making. Private *versus* public ownership may influence the potential for loss of a wetland since it influences the likelihood of development. Ownership type may also influence the cost of restoration and the appropriate avenues and strategies for restoration.

Other site ranking protocols (Lebovitz 1992, Dean *et al*. 2000) have included ownership type as a ranking criterion. However, the statewide Oregon Estuary Assessment method (Brophy 2007) used for this study focuses on ecological factors, and land ownership, in itself, is not an ecological factor. Of course, land ownership is closely related to land use and intensity of alteration, but those factors are reflected in the other scoring criteria such as tidal channel condition, vegetation diversity, and wetland connectivity.

Because land ownership can change rapidly, we recommend verifying ownership in the earliest stages of planning site-specific actions. In addition, it is important to contact appropriate authorities before planning conservation or restoration actions that could affect roads and railroads. This is particularly important for the Necanicum, since the available GIS landowner data layer did not generally list ownership for road or railroad rights-of-way.

Table 4. Land ownership categories

Category	Description
Conservation / public	City, county, state, and federal land, plus parks and protected areas such as land trust properties
Private non-conservation	Land owned by individuals or corporations, not known to have protected status (though some properties may have conservation easements, etc.)
Mixed	Mixture of the above ownership types

Land-use planning and zoning

Land-use planning affects estuary lands in many ways. All cities and counties in Oregon have local comprehensive plans and associated land use regulations. The comprehensive planning documents produced by the Cities of Seaside and Gearhart are highly relevant to this study. These plans contain resource inventories, analyses and priorities which are used in the development of local land use policies.

We did not conduct detailed assessment of local land-use ordinances or overlays for this assessment, but we did analyze generalized land use zoning for the study sites. The generalized land use zoning information was downloaded from the Oregon Spatial Data Library (http://www.oregon.gov/DAS/EISPD/GEO/sdlibrary.shtml). Sites were intersected with the zoning layer and the proportion of each zoning category on each site was calculated in ESRI ArcMap.

This zoning analysis addresses only a small part of the land-use planning context within the estuary. Thus, one of the first steps that should be taken in site-specific action planning is to consult directly with local (City and County) planning staff. See the Oregon Watershed Assessment Manual's Estuary module (Brophy 2007) for further details.

Results and discussion

Site prioritization is shown in Map 4 (**Appendix 1**); total score and scores for each criterion are provided in **Appendix 2**. A detailed site information table is provided in **Appendix 3**. Scores for the individual prioritization criteria are summarized in Maps 5 through 10 (**Appendix 1**). Detailed results are described below, and narrative descriptions of some sites are provided.

Prioritized sites

Ranking tables (**Appendix 2**, Tables 1 and 2) show the total prioritization scores and individual prioritization criterion scores for all sites, sorted by rank and by site. To provide a visual summary of results, we divided the study sites into five priority groups: High, medium-high, medium, medium-low, and low (Map 4). The ranking groups were calculated within ESRI ArcMAP using the "Jenks natural breaks" classification method applied to the total prioritization score. The Jenks method uses natural groupings to divide the data into the desired number of categories (in this case, five). As described in **Methods** above, these ranking groups can be used as general guides for planning conservation and restoration actions in the estuary, but **it is important to recognize that a separation of one ranking group does not have much significance**, since sites on either side of the dividing line may have similar scores.

Of the 37 sites totaling 401A, only 5 sites were ranked "high," but these constituted 233A— over half the total area (Table 5). These are the estuary's largest sites: the Stanley Lake and Mill Creek wetland complexes, and Shangrila. These sites are located in the Neawanna sub-basin, where they generally have good connectivity to other wetlands and to salmon migration corridors. Ten sites (about 16% of the wetland area, or 65A) were ranked "medium-high." Most of the remaining sites (20 sites, totaling 86A) were in the medium and medium-low groups. Only two sites (17A) were ranked "low;" these lower-ranked sites should not be considered substantially different from the "medium-low" sites due to the factors listed above.

Table 5. Number of sites and area (acres) in each priority group

Priority group	Number of sites	Acres
High	5	232.7
Medium-high	10	65.1
Medium	11	36.6
Medium-low	9	49.6
Low	2	17.0
Grand Total	37	401.0

This prioritization is a first step in strategic planning for conservation and restoration in the Necanicum River estuary. In general, the next step in action planning involves outreach to find those landowners interested in restoring or conserving the identified sites. Once willing and interested landowners are located, a variety of site-specific activities can begin, including preliminary onsite assessment, verification of alterations and potential restoration or enhancement actions, monitoring of current conditions, determination of land ownership boundaries, regulatory contacts to determine required permits, archaeological investigations, and many other steps to maximize the chances of effective results.

Lower-priority sites are important, too

Although this study prioritizes sites to assist in conservation and restoration planning, **no tidal wetland is unimportant**. Conservation of all existing tidal wetlands is recommended, because the majority of tidal wetlands in the estuary have been converted to other uses, and those being restored may take decades or more to recover their original functions (Frenkel and Morlan 1991). Similarly, restoration of all tidal wetlands is important. A “low” priority ranking in this project does not mean that the low-ranked wetland is ecologically unimportant, nor does it imply that the site should be given reduced protection in a regulatory context. As discussed above, this study has no regulatory significance or intent. It is intended only to provide a strategic approach to conservation and restoration of tidal wetlands in the estuary.

Total historic tidal wetland area

This study’s estimate of total current and historic tidal wetland area in the Necanicum River estuary (401A) is substantial increase over previous estimates. This estimate is:

- 92% higher than the 209A of estuarine wetlands estimated from LANDSAT imagery classification by Snyder *et al.* (2002) during the Necanicum Watershed Assessment;
- 100% higher than the 200A of tidal wetlands mapped in the National Wetland Inventory (including tidally-influenced palustrine wetlands) (USFWS 2010);
- 89% greater than the area mapped by Scranton (2004);
- 272% greater than the estimate in the 2000 Oregon State of the Environment report (Good 2000); and
- 193% greater than the area mapped in the Oregon Estuary Plan Book (Cortright *et al*. 1987).

As described in the **Introduction**, the increase in mapped tidal wetland area in our study is due to our methods. The use of the LiDAR DEM and field collection of water level data allowed us to identify many areas within tidal range that had not previously been considered part of the estuary. Although some of the areas identified may not be inundated often by the tides, we felt that it was important in this broad assessment to include all possible tidal wetlands. These slightly higher elevation lands are also an important part of strategic planning for tidal wetland conservation under sea level rise scenarios, as recommended in Oregon’s Climate Change Adaptation Framework (OR DLCD 2010).

Alterations to tidal wetlands

We classified each study site as having major alterations, minor alterations, or no alterations; restoration sites were in a category of their own. About 1/3 of current and former tidal wetlands in the Necanicum estuary have major alterations; these include eleven sites totaling 143A (Tables 6 and 7). Most of these alterations consist of tidal flow restrictions caused by culverts, road crossings, and general development-related fill activities in surrounding areas. (Shangrila is an exception to the rule in this group; although it has major alterations, these consist of excavation and fill within the mill pond area rather than restriction of tidal flows.) Another third of the total area has minor alterations; this group includes eight sites totaling 120A. One of the largest sites, the 71A Stanley Lake wetland complex, is an active restoration site, with restoration activities that began in the 1980s and continue today.

In Tables 6 and 7, as well as the site information tables (**Appendix 3**), the same type of alteration can be classified as either a "major" alteration or a "minor" alteration depending on its intensity. The classification was generally based on how much of the site was affected by the alteration. For example, a culvert or ditch that affected only a small part of a site was classified as a minor alteration, whereas a culvert that restricted all flow into and out of a site, or ditching that completely replaced all natural channels on a site, were classified as major alterations.

Table 6. Tidal wetland area (acres) by alteration type and intensity

	Area (acres)				
Alteration type(s)*	**Major alterations**	**Minor alterations**	**No alterations**	**Restoration Site**	**Grand Total**
C	16.7	15.4	0.0	0.0	32.1
CD	4.4	0.0	0.0	0.0	4.4
CDFX	13.9	0.0	0.0	0.0	13.9
CF	7.9	0.0	0.0	0.0	7.9
CFXY	0.0	0.0	0.0	71.3	71.3
CX	3.0	0.0	0.0	0.0	3.0
D	14.5	47.2	0.0	0.0	61.7
DFX	82.3	27.4	0.0	0.0	109.7
DY	0.0	13.7	0.0	0.0	13.7
F	0.0	2.4	0.0	0.0	2.4
FY	0.0	2.8	0.0	0.0	2.8
X	0.0	11.4	0.0	0.0	11.4
none	0.0	0.0	66.8	0.0	66.8
Grand Total	**142.7**	**120.3**	**66.8**	**71.3**	**401.0**

* Alteration abbreviations: C = restrictive culvert, tide gate or other non-dike tidal restriction (on or off site); D = ditching; F = fill material (within site boundaries); X = excavation; Y = diking or berms.

Table 7. Number of study sites by alteration type

Alteration type(s)*	Major	Minor	None	Restoration Site	Grand Total
C	4	1			5
CD	1				1
CDFX	1				1
CF	1				1
CFXY				1	1
CX	1				1
D	2	2			4
DFX	1	1			2
DY		1			1
F		1			1
FY		1			1
X		1			1
None			17		17
Grand Total	11	8	17	1	37

* Alteration abbreviations: C = restrictive culvert, tide gate or other non-dike tidal restriction (on or off site); D = ditching; F = fill material (within site boundaries); X = excavation; Y = diking or berms.

Alterations by historic vegetation type

Alterations to tidal wetlands can vary depending on the wetland type. For example, in many Oregon estuaries, tidal swamps (tidal wetlands dominated by woody species) have been more strongly impacted by human activities than tidal marshes. Brophy (2005) documented tidal wetland losses in the Siuslaw River estuary, and found that a much higher proportion of tidal swamps (shrub and forested tidal wetlands) had been lost compared to tidal marshes. Disproportionate losses of tidal swamp have also been reported for Youngs Bay in the Columbia River estuary (Thomas 1983), and our observations strongly suggest this is true across the entire Oregon coast (Brophy, unpublished).

In the Necanicum River estuary, the predominant historic vegetation type was Sitka spruce tidal swamp; this vegetation type occupied about 190A of our estimated historic tidal wetland area, about half of the total (Table 8). About 43% of this historic Sitka spruce swamp acreage (81.4A) has undergone major alterations (Table 8), 27% (51.8A) has minor alterations, and only about 17% (31.6A) remains relatively unaltered. Similar levels of alteration have affected the other historic vegetation types.

Interestingly, about a quarter of the estuary was mapped as open water in the historic vegetation mapping (Table 8); much of this was located in the Stanley Lake complex. We did not specifically investigate these changes; they could be the result of human-induced hydrologic change (such as drainage of the interdunal water body and/or grading of the land surface), or natural sedimentation and succession.

Table 8. Tidal wetland area (acres) by historic vegetation type and alteration intensity

	Area (acres)				
	Alteration Intensity				
Historic vegetation type	Major	Minor	None	Restoration Site	Grand Total
Sitka spruce swamp	81.4	51.8	31.6	25.0	189.8
Shore pine swamp	17.7	12.2	15.5		45.5
Coastal headland		9.4			9.4
Marsh	35.1	22.6		3.5	61.2
Open water	8.5	24.2	19.6	42.8	95.1
Grand Total	142.7	120.3	66.8	71.3	401.0

It is important to remember that all tidal wetlands—even the relatively unaltered sites—are affected by overall estuary and watershed changes, such as alterations to sand and sediment transport regimes, and freshwater flow changes associated with dominant land uses such as timber harvest and urbanization. Assessment of such watershed-scale changes was beyond the scope of this study.

Water level data

The water level gauges installed by NCLC at Avenue G, Pacific Way, Mill Creek, and Shangrila all showed clear evidence of tidal influence (**Appendix 4**, Figures 1-2). Water levels at Stanley Creek and in the interior of the Circle Creek wetlands did not show evidence of tidal influence. However, we obtained water level data from the mouth of Circle Creek (at its confluence with the Necanicum River), the product of a hydrology study performed by Herrera Environmental Consultants (2010). The data showed clear tidal influence in summer, though river flows predominate during winter and spring (**Appendix 4**, Figure 3).

The water level loggers used for the water level monitoring are accurate to within 0.5inch, but the "absolute elevations" of the water levels presented in **Appendix 4** (that is, the elevations relative to the NAVD88 datum) must be considered provisional. These elevations were obtained by converting the logger's native datum (water level relative to sensor) to geodetic datum using the elevations provided by the survey crew. However, the survey crew did not record key benchmark data (namely, the benchmark's elevation datum, the installing agency's name, the benchmark ID number, or photographs of benchmarks). This problem became evident when we calculated water levels for the loggers at Pacific Way and Shangrila, using the elevations provided by the survey crew and assuming the applicable logger elevations were tied to benchmarks referenced to NAVD88. The resulting water levels were about 3ft lower than would be expected. We suspected that a datum inconsistency may be the problem, and these particular benchmarks may have actually been referenced to NGVD29. When we converted the data accordingly (from NGVD29 to NAVD88), water levels were reasonable. ***Because of these possible datum inconsistencies and resulting uncertainties in elevations, the data in Appendix 4 should be interpreted with caution, and be used only for gaining a preliminary understanding of possible tidal influence at these locations. If water levels are to be measured again at these or other locations, the logger installations should be professionally surveyed.***

The clear evidence of tidal influence at Shangrila, the mouth of Circle Creek, and the Neacoxie at Pacific Way show that the published heads of tide for these areas (OR DSL 2007) are inaccurate. Published head of tide for the Necanicum is near Avenue U, but the data provided by Herrera Environmental Consultants (2010) shows tidal influence at the mouth of Circle Creek (about ½ mile south of Avenue U). Published head of tide for the Neawanna is just south of Avenue S, but the gauge at Shangrila (about ¼ mile farther south) showed very strong tidal influence (e.g., 4ft tide range in December). Published head of tide for the Neacoxie is at Pacific Way, but the gauge data at that location show at least 1.5ft of tidal range. The actual tide range at this location is greater, because low tides were not recorded due to the gauge being out of water at low tide.

Water levels at the Circle Creek gauge did not show any tidal influence (**Appendix 4,** Figure 4). This logger's elevation could not be surveyed due to dense vegetation and distance from existing benchmarks. NCLC staff report heavy beaver activity in the Circle Creek wetlands; beaver dams may prevent tidal influence from extending into the wetlands, or may damp any existing tidal effects. Additional monitoring could provide insight into the presence or absence of tidal water level fluctuations at other locations in the Circle Creek wetlands. See **Circle Creek wetlands** below for more information.

Landward migration zones

Table 9 shows the landward migration zone (LMZ) for the eight sites that had the largest LMZs. In several cases, LMZs are "shared" among several sites; this can be seen in the LMZ map (Map 14). Where LMZs are shared, the site with the broadest access to the LMZ is listed first in Table 9.

The total area of all mapped LMZs was 811A; Sites 4, 8, 25 and the Circle Creek wetlands (plus Site 37) constituted 94% of this total (761A). These sites—the Mill Creek wetlands, Stanley Lake complex, Shangrila, and the Circle Creek/Site 37 area—offer the highest resilience to sea level rise, as measured by available landward migration area. Protection of these LMZs from development would help maintain this resilience.

Table 9. Size of Landward Migration Zone (LMZ) for the 8 sites with largest LMZs

Available landward migration area for each site is shown for three elevation zones above highest measured tide (HMT=11.5ft NAVD88 at NOAA Garibaldi tide station).

	Cumulative available landward migration zone (acres)				
Site*	Within 1m (3.28ft) above HMT	Within 2m (6.56ft) above HMT	Within 3m (9.84 ft) above HMT	Size of site (A)	3m LMZ as % of site area
4 (and 3,5,6)	155.0	205.8	218.4	43.7	500%
7	2.1	3.7	3.7	2.4	157%
8 (and 12)	32.6	39.3	44.8	71.3	63%
15 (and 14)	9.4	11.8	11.9	13.9	85%
21	3.0	13.6	17.2	1.1	1549%
24	9.7	15.3	16.8	8.0	210%
25	34.6	75.4	99.3	82.3	121%
Circle Creek & Site 37	115.5	307.2	398.9	n/a	n/a**

* The size of the LMZ was calculated only for those sites which have substantial landward migration area. Sites in parentheses share the landward migration area with the main listed site.
** Circle Creek has no defined area, since it is not a study site; therefore LMZ as percent of site area could not be calculated.

Land ownership

The number of landowners was summarized for each site using three categories: 1 owner, 2-5 owners, and more than 5 owners (Table 10, Map 15).

Table 10. Summary of number of landowners per site

Number of owners	Number of sites	Total area (acres)
1	3	5.7
2-5	15	81.0
>5	19	314.3

As shown in Table 10, most of the study sites have multiple landowners. Land ownership in the Necanicum River estuary is mostly private and consists mainly of small parcels (often residential).

All other factors being equal, the logistics of restoration or land protection are usually simpler for a site with a single owner. For sites with more than one owner, several landowners may reach an agreement on restoration or conservation of their parcels; if not, it may be possible to begin action on sub-areas of the site without affecting other areas. The feasibility of such partial restoration should be considered during the earliest stages of action planning for a site.

Land ownership type for each site *as a whole* is shown in Map 16 and Table 11. We did not calculate the acreage of each specific landowner type within each site (that is, for mixed ownership sites, we did not calculate the acreage of public/conservation *versus* private non-conservation ownership).

Table 11. Summary of land ownership type (for each site as a whole)

Ownership type	Number of sites	Total area (acres)
Entirely conservation/public	4	8.4
Entirely private non-conservation	10	36.3
Mixed	23	356.2

Since sites were defined on the basis of hydrologic connectivity and land alterations, not ownership (see **Site definition** above), most sites have mixed ownership within their boundaries. For example, most of Site 1 (Neawanna Point) is owned by the North Coast Land Conservancy, but the northern portion of the site along the Neacoxie includes parts of several residential parcels ("private non-conservation" ownership category). Therefore, the ownership category for the site as a whole is mixed.

Land use planning

Zoning

Tidal wetlands of the Necanicum River estuary exist in an urban and residential context, as shown by generalized land use zoning. The predominant zoning on study sites is "Seaside UGB" (Urban Growth Boundary) (67%), with "Lakes and Wetlands" second at 14%. The "Pacific Ocean" zone occupies about 11% of the site area, near the major tidal water bodies and at Stanley Lake (Table 12). The predominantly urban zoning illustrates the challenges of conservation and restoration in this small estuary, where developed land uses predominate.

Table 12. Area in each generalized land use zoning class, by study site

	Area (acres)							
Site	Ag-Forest	Estuarine	Lakes and Wetlands	Various Rural Residential	Gearhart UGB	Seaside UGB	Pacific Ocean	Grand Total
1		0.6			3.3	3.2	8.3	15.4
2					0.9	3.2	0.1	4.2
3					4.4			4.4
4			9.2	8.6	5.4	20.5		43.7
5			0.6			5.9		6.5
6						1.0	1.7	2.8
7						1.1	1.2	2.4
8						57.9	13.5	71.3
9						0.0	1.5	1.5
10						0.8	2.7	3.5
11						0.7	3.2	3.9
12						7.9		7.9
13						0.1	0.6	0.8
14						9.7		9.7
15						13.9		13.9
16						13.7		13.7
17						8.9		8.9
18						3.9		3.9
19						5.3		5.3
20						1.7		1.7
21						1.1		1.1
22						21.6		21.6
23						27.4		27.4
24	2.3		5.0			0.7		8.0
25	3.5		40.0			38.9		82.3
26						0.1	4.2	4.3
27						3.3	8.1	11.4
28							0.6	0.6
29						0.5	0.1	0.6
30						1.3		1.3
31						2.2		2.2
32						1.5		1.5
33						2.3		2.3
34						3.0		3.0
35						3.1		3.1
36						1.5		1.5
37						3.5		3.5
Grand Total	5.8	0.6	54.8	8.6	13.9	271.5	45.9	401.0

Data limitations

In any spatial analysis, it is possible for errors in the original data to be carried forward through data processing steps, resulting in inaccuracies in the final results. However, the processing methods used in this study reduced the potential for errors, because the broad conclusions drawn (i.e., ranking groups) are not dependent on highly accurate data. In other words, the data used are adequate for the analyses conducted.

This study used aerial photograph interpretation, existing data, and field investigation (usually observation from offsite) to characterize the sites in this study. Such "remote" data are inherently less accurate than data collected onsite in the field. Therefore, landowner contacts and site visits are recommended early in the restoration or conservation planning process, to verify the data presented in this report.

Although this prioritization used criteria that are strongly related to wetland functions, the prioritization is not intended to assess specific site functions. Assessment of tidal wetland functions requires onsite fieldwork for each site assessed (Simenstad *et al.* 1991, Adamus 2006, Adamus *et al*. 2009) and is not within the scope of this study.

In this study, we attempted to include the full historic extent of tidal wetlands in the estuary. However, it may not be possible to restore the full historic range of tidal influence at every site. (See **Appendix 5**, **Restoration Principles** for details.) Factors such as urban and residential development, subsidence, agricultural activities (e.g., cultivation, ditching, draining, and channeling), remaining dikes and other obstructions (e.g., roads), and basin-wide hydrologic changes all affect the potential to restore tidal exchange on a site. Field investigation is needed at any site where restoration is planned. Field investigation should include elevation surveys, water level (tidal range) measurements, analysis of water flow barriers, plant community analysis, and other measurements as needed to determine the feasibility of restoring tidal influence and tidal wetland habitats at the site. Expert assistance is recommended for these analyses.

Restoration recommendations

Planning restoration for altered sites is a technically demanding task. Some principles and general recommendations are provided in **Appendices 5 and 6 (Restoration Principles** and **Restoration Approaches)**. Additional guidance is found in the Oregon Watershed Assessment Manual's estuary module (Brophy 2007) and in other resources listed there.

This study does not provide site-specific restoration design recommendations, because additional data from field monitoring are needed to develop restoration plans. However, Table 13 below shows some potential restoration actions for each alteration type.

For all sites, the top priority for site action is protection of existing wetlands. After that is accomplished, further action may be taken to restore resources as described in Table 13.

Tidal wetland restoration options generally focus on restoring tidal flow, because the most common alteration is restriction or elimination of tidal flow. For grazed sites, an important restoration option to consider is simply removal of grazing or setback of grazing from the wettest areas (including channels). For every site, native plantings (particularly of woody species) should be considered in portions of the site where the elevation and salinity are appropriate for growth of shrubs or trees; expert advice is often useful in deciding where woody plantings are likely to succeed. All sites would also benefit from protection or establishment of a native vegetated buffer around the margins of the site. Many sites in the study area already have such a buffer, but some do not.

The general alteration types observed in the Necanicum estuary, and some potential restoration actions for each alteration type, are listed in Table 13 below. Specific decisions among these options (and others) will require careful consideration of site characteristics and restoration goals. Some of the listed restoration actions may be inappropriate for particular sites; only careful onsite assessment can determine the appropriate actions.

Table 13. Alteration types and applicable restoration options

Alteration type	Abbreviation	Potential restoration alternatives
Restrictive culvert / tide gate	C	Tidal reconnection through excavation of historic tidal channel connections; tide gate removal; replacement of restrictive culvert with bridge; installation of self-regulating tide gate for controlled tidal exchange; installation of fish-friendly tide gate
Diking	Y	Dike breaching; dike removal; dike setbacks
Ditching	D	Channel meander reconnection; ditch filling; meander restoration
Fill	F	Removal of fill
Excavation	X	Filling of artificially excavated areas (fill to historic wetland grade, based on nearby reference areas)
None	None	No restoration action needed, but protect existing wetland; establish buffers; plant trees/shrubs where appropriate in former swamp areas or on natural levees; and apply other active wetland management techniques where needed

Beyond the site-specific actions listed above, it is important to consider conservation and restoration of nontidal wetlands and other habitats near the tidal sites in this study. The most effective conservation and restoration projects are those which protect or restore habitat linkages and connections (see **Appendix 5**, **Restoration Principles**). The slightly-brackish to freshwater tidal zone of the estuary may offer particularly high habitat values (Simenstad and Bottom 2004), so linking sites in this zone to adjacent nontidal wetlands may offer great benefits.

Cultural resources

Before European settlement, Oregon’s estuaries were widely used by Native American peoples for dwellings, gathering places, and a source of livelihood. Therefore, every estuary restoration project should be conducted with awareness that there may be cultural resources within or near the project area. State and federal laws prohibit destruction or disturbance of known archaeological sites. In the case of inadvertent discovery of cultural resources, state and federal laws require that the project be halted and the appropriate Tribe be contacted immediately. To understand the historic and cultural context of each site, and to avoid possible impacts to cultural resources in the Necanicum River estuary, we recommend consultation with the Clatsop-Nehalem tribes (503-895-5643, info@clatsop-nehalem.com) during the early phases of site-specific project planning.

Invasive species

Three invasive plant species are of special concern in the Necanicum River estuary: Cordgrass (*Spartina* spp.), purple loosestrife (*Lythrum salicaria*), and reed canarygrass (*Phalaris arundinacea*). These species are important for several reasons: 1) They are wetland plants which can occupy large areas of tidal and formerly tidal marsh sites, to the exclusion of native species; 2) They are on the Oregon Department of Agriculture's "T" list (ODA 2011a), indicating they are considered economic threats to the state; 3) Two of the three (cordgrass and loosestrife) are tolerant of brackish water, making them particular threats in the estuary.

ODA asks individuals who observe "T" list weed species to call 1-866-INVADER to report the observations.

Cordgrass (*Spartina* spp.) has not been documented in the Necanicum River estuary, but is considered a serious threat to Oregon estuaries in general. Several species of cordgrass are invasive in the Pacific Northwest, and two (smooth cordgrass and saltmeadow cordgrass) have been documented in Oregon (ODA 2011b, 2011c). Monitoring for cordgrass is important to prevent its further spread and establishment in new areas. People working in estuaries throughout Oregon are advised to familiarize themselves with cordgrass species, maintain vigilance, and report any new populations to the Oregon Department of Agriculture at 1-866-INVADER.

Purple loosestrife (*Lythrum salicaria*) is an invasive, non-native wetland plant that is considered a serious threat to freshwater and brackish wetlands throughout the Pacific Northwest. It has invaded large portions of the Columbia River estuary (Ferrarese *et al.* 2010), but is not officially documented in the Necanicum estuary, based on the Oregon Weedmapper application (http://www.weedmapper.oregon.gov/). Landowners should be informed of the possible presence of loosestrife in the estuary, and control efforts should be undertaken as soon as possible if its presence is confirmed.

Reed canarygrass (*Phalaris arundinacea*) is found in the low-brackish to freshwater tidal portion of the estuary, particularly in disturbed areas and along stream banks. This species is not tolerant of highly saline water, so it is also common in altered tidal wetlands where salt water has been excluded by diking, tide gates, or restrictive culverts. Its native or non-native status has been disputed; recent studies suggested the species may be native, but the invasive populations may be a non-native genotype (Antieau 1993). Regardless of its native or non-native status, it is considered undesirable and is generally invasive, forming dense single-species stands in disturbed sites. At sites where reed canarygrass is dominant, restoration plans should include methods for reed canarygrass control or suppression. Woody plantings such as willows and Sitka spruce are often the most effective control method, since the low to fresh salinities that allow reed canarygrass growth are also appropriate for woody species.

Several other invasive species are found in the Necanicum and should be controlled within restoration or conservation sites. The Oregon Weedmapper application (http://www.weedmapper.oregon.gov/) shows several populations of Himalayan, Japanese and giant knotweed (*Polygonum polystachyum, P. cuspidatum,* and *P. sachalinense* respectively). These species are a concern not just in the estuary, but also in nontidal wetlands throughout the watershed.

Site narratives

In this section, narrative descriptions are provided for several of the higher-ranking sites and other sites that have particular characteristics of interest. This information may be important for decision-making, and should be reviewed before contacting landowners or taking other actions in the estuary. **For all of these sites, the highest priority action is conservation of the existing wetlands.** Other potential actions are described below and in the **Restoration recommendations** section above. Notes for other sites are provided in the shapefile attribute table, and duplicated in the site information table (**Appendix 3**, Table 2).

Site 1 (Neawanna Point): This site has very high scenic and educational value, since it is adjacent to Highway 101. Because of its visibility, it offers a good opportunity to increase public awareness of tidal wetlands. Maine (1979) described this site as the largest salt marsh in the estuary, and recommended that it be protected. It was acquired by the North Coast Land Conservancy and has been the site of many educational and conservation activities. Tidal flow to the northern portion of this site, extending up the Neacoxie, is reduced by culverts, including those at G Street and Pacific Way. These culverts were installed in the 1970's, replacing former bridges at those locations. Prior to the substitution of culverts for the bridges, tidal influence extended north to Gearhart Road (Maine 2009-2010).

Fringing tidal wetlands extend further up the Neacoxie (such as those visible from the Pacific Way bridge, described as Marsh 16 in Maine [1979]), but these wetlands are under 0.5A in size and therefore were not included in this study (see **Site definition** above).

The lower portion of this site was among the 120 tidal wetlands that were studied during development of the hydrogeomorphic (HGM) assessment method for tidal wetlands of the Oregon coast (Adamus *et al.* 2005). The following is an excerpt from Adamus *et al.* (2005) describing the site:

> *Wetland 761 (6 acres, mainly on public land) is approximately 10% high marsh and 90% low marsh. It is located along the Gearhart shore of the estuary, at the confluence of the Neacoxie and Neawanna. Considerable shifting of the river's course and associated sediments has occurred in the channel here, especially during unusually high tide events in 1967 and 1998 (CSTC 2001). This followed attempts in the 1960s to fill much of the south spit of the Necanicum River.*

Agrostis stolonifera dominates the high marsh, and Salicornia virginica the low marsh. A nontidal shrub wetland borders the north side, and most of the rest of the upland edge is bordered by dunegrass.

Site 2: The small drainage here is known as the Little Neacoxie. Tidal exchange within this site is very restricted by three small culverts, one about 350ft south of Sons of Norway Road, one at Sons of Norway Road, and one at Avenue G. Water is impounded and beaver activity is evident upstream of the culverts.

Site 4 (Mill Creek and Cullaby Creek wetlands): Site 4 has a unique landscape setting, in a wide interdunal swale that runs a long distance north from just east of the Seaside Municipal Airport. Interdunal wetlands are a typical feature of the Clatsop Plains, as described by Reckendorf *et al*. (2001). This swale has a very low elevation gradient; flow is generally southward, but northward flow can also occur in winter (Maine 2009-2010). The site is ecologically important because of its hydrologic connection with the Gearhart Bog, an outstanding example of rare coastal bog that supports several rare plant communities and species.

The wetlands of Site 4 have not generally been considered part of the Necanicum River estuary; no previous study or mapping of the estuary includes them. However, wetland surface elevations in the area are below the highest measured tide level used for this study (<11.5ft NAVD88), and field monitoring of water levels in Mill Creek confirmed that there is strong tidal influence in the stream (**Appendix 4**, Figure 1). Therefore, these wetlands were included in our study. The boundaries of Site 4 were established using the same elevation used for all sites (11.5ft NAVD88). However, Horning (2009-2010) noted that the highest tides can back up as far as Hillila Road, about ½ mile further north. Therefore, tidal wetlands may extend further north in this area.

Between the late 1950s and 1997, tidal flows to Site 4 were blocked by tide gates at the mouth of Mill Creek, under the Highway 101 bridge (Maine 2009-2010). The tide gates were removed in 1997 (Maine 2009-2010), restoring tidal exchange to both Mill Creek and the Stanley Lake wetlands (see **Site 8** below). However, tidal and nontidal flows within the northern portion of Site 4 are still somewhat restricted by the 3 east-west roadways that cross the wetland north of Avenue G.

Of all the tidal wetlands in this study, Site 4 has the largest Landward Migration Zone (Table 9, Map 14), and is therefore likely to be the most resilient to sea level rise. The site's large LMZ is due to the geomorphic setting of the site – in an broad interdunal swale that extends many miles to the north. (The Neacoxie wetlands are also interdunal, but the interdunal swale at Site 4 is much wider – ¼ to ½ mile wide in most areas, compared to only 100-200ft for the Neacoxie.) Depending on future land use and road maintenance, the landward migration zone for Site 4 could extend even further north than the area shown in Map 14. Our analysis defined the LMZs as limited by infrastructure such as roads and developed areas, so the LMZ for Site 4 was bounded by Salminen Road, which crosses the low ground about ½ mile north of the site. However, appropriate hydrologic connections under the roads that cross the wetland (such as bridges or large culverts) could allow the LMZ to extend for miles to the north, helping to maintain critical tidal wetland area under sea level rise scenarios.

Site 8 (Stanley Lake complex): This area was cut off from tidal influence by the tide gates at the mouth of Mill Creek until the gates were removed in 1997 (Maine 2009-2010). Prior to the removal of the tide gates, the area had been affected by human uses in several ways: A rectangular trout pond was excavated, and other areas were excavated to create wetlands as mitigation for wetland fill activity at the RV park ("Leisure Time Resorts") to the east.

The site's tidal exchange was restored through the 1997 removal of the Mill Creek tide gates; tidal flows enter and exit the wetland under the Lewis and Clark Road (Crown Camp Road) bridge. Bridged road crossings like this one are greatly preferable to restrictive culverts. The 40ft width of the bridge opening is about 10% of the wetland's full width (~400ft). Sheet flow to and from the site during high water events is restricted by this relatively narrow opening, which may affect wetland functions such as nutrient export.

Recently, fill material has been removed to restore wetlands on the east side of the site; this work is ongoing.

This site was among the 120 tidal wetlands that were studied during development of the hydrogeomorphic (HGM) assessment method for tidal wetlands of the Oregon coast (Adamus *et al.* 2005). The following is an excerpt from Adamus *et al*. (2005) describing the site:

> *Wetland 767 (19 acres, partly on public land) is approximately 1% high marsh and 99% low marsh. This is the former Stanley Lake, to which tidal circulation was restored very recently. Before restoration, a 17-acre portion of the eastern shore where Thompson Creek enters had been recontoured as a nontidal wetland mitigation site. Agrostis stolonifera dominates the high marsh, Salicornia virginica the low marsh.*

Site 12: This site is separated from the Stanley Lake complex by a narrow ridge, which appears to be partly natural, and partly filled as a residential access road or driveway. Its hydrologic connection to Stanley Lake could not be determined from aerial photographs or the LiDAR DEM. Field investigation is recommended to determine how water flows into and out of this site, and whether it has been affected by the restoration of tidal flows to Stanley Lake.

Site 15: This site occupies an area just below and just above 11.5ft NAVD88, southwest of Stanley Lake. A house is located on a peninsula of high ground extending northwards into the lowest, north central portion of the site. We generally excluded residential areas from our study, but due to the low elevation and central location of the building site, it was included within this site's boundary. We recommend contacting the landowner to learn more about this site, its wetland resources, and possible conservation or restoration actions for the future.

Part of this site (less than 1A) was excavated for a wetland mitigation site (Maine 2009-2010). The excavation forms a rectangular depression with three raised mounds in the center.

Site 16: Like many sites in the study, this site is affected by adjacent development – in this case, residences along Wahanna Road. Fill material forms the northern boundary of the site; some of the filled areas are not currently developed. Further development and/or peripheral fill activity could definitely reduce this wetland's functions.

A stormwater outfall carries drainage through the middle of the site, opposite Shore Terrace. The hydrologic connection between this outfall and Stanley Creek drainage to the east could not be determined during this study. The pipe appears to have been tide gated in the past, but the flap is missing.

Site 21: This site is adjacent to China Creek, and appears to be hydrologically connected to the creek (as is Site 20 to the north). However, the precise nature of the connection could not be determined without further fieldwork beyond the scope of this study.

Sites 22 and 23: These two sites form the largest brackish marsh in the Necanicum estuary. Despite past ditching on site 23, current condition is excellent, with native vegetation dominant throughout the site. Maine (1979) described the plant community as dominated by tufted hairgrass, Pacific silverweed, salt grass and bulrush (*Scirpus*); these species are still dominant at the site, showing its stability over the past 32 years.

Sites 18, 19, 22 and 23 were among the 120 tidal wetlands that were studied during development of the hydrogeomorphic (HGM) assessment method for tidal wetlands of the Oregon coast (Adamus *et al.* 2005). The following is an excerpt from Adamus *et al*. (2005) describing the area:

> *Wetland 787 (33 acres, mostly on private land), is approximately 95% high marsh and 5% low marsh. Both sides of the channel were assessed. A small stormwater outfall pipe is located on the western edge, and another at the south end. A 1939 aerial photograph shows extensive ditching on this site. Argentina egedii dominates the high marsh, Schoenoplectus americanus the low marsh, and a large stand of Schoenoplectus tabernaemontanii also is present.*

Site 24: This site consists of a pasture adjacent to Neawanna Creek. The higher parts of the pasture (beyond the site's boundary to the east) are above highest measured tide, so they were not included in this study. However, wintertime stream flows can be "held up" by high tides, extending tidal inundation further upstream than might be expected from tidal datums alone (Brophy 2009, Brophy *et al*. 2011, Huang *et al*. 2011). Evaluation of the fluvial component of the inundation regime was not within the scope of this study, but this effect could potentially increase the area defined as tidal wetland east of Site 24. In addition, the higher ground east of Site 24 provides landward migration opportunities for the tidal wetlands (Table 9, Map 14).

Site 25 (Shangrila): This large site provides a range of habitat types, including a substantial area of forested wetlands as well as several excavated mill ponds. The northern edge of the site includes the gradient from brackish tidal marsh to brackish tidal swamp—a gradient that is rare within the Necanicum River estuary. Beaver activity is evident in the forested wetlands south of the mill ponds. The site has a substantial landward migration zone to the south, but the LMZ is blocked from connection to the broader Necanicum River floodplain by Highway 101.

The northernmost emergent wetland portion of this site was among the 120 tidal wetlands that were studied during development of the hydrogeomorphic (HGM) assessment method for tidal wetlands of the Oregon coast (Adamus *et al.* 2005). The following is an excerpt from Adamus *et al*. (2005) describing the site. Note that the description does not include the forested wetlands south of the pond area. Also, note that the site's main tidal connection is to Neawanna Creek, rather than the Necanicum:

> *Wetland 791 (Mill Ponds, 7 acres, entirely on public land), is approximately 90% high marsh and 10% low marsh. Argentina egedii dominates the high marsh, Carex lyngbyei the low marsh. Much of the site was excavated sometime between*

1939 and 1950 to establish a rock quarry, and subsequently the ponds supported wood storage for a planing mill and later a shingle mill until the 1960s. Recently a narrow tidal connection was established to the Necanicum River. A plant list and bird data for the site are at: *http://home.pacifier.com/~neawanna/observatory/plants.html*.

Site 33: This small wetland is described in Maine (1979) as the remainder of a larger wetland, most of which was filled for the adjacent housing development to the west.

Site 34 (Mantel Lake and associated wetlands): Mantel Lake is tidal, although tidal exchange is restricted at the lake's outlet. The wetlands to the west range in elevation from under 8ft (typical elevation of high marsh in this area) to around 10ft NAVD88. This wetland is the remnant of a larger tidal wetland that was filled for housing developments in the 1980s (Maine 2009-2010).

Circle Creek wetlands

The extensive wetlands surrounding Circle Creek (at the south end of the study area) were not included in this study, because ground surface elevations within the wetlands do not appear to be within tidal range, based on the information available to us. Soil surface elevations within the wetlands (from the LiDAR DEM) are around 13-14ft NAVD88, slightly higher than current tidal range (see **Methods: Extent of tidal influence** above). In addition, we worked with the North Coast Land Conservancy to monitor water levels during January and February 2010 at a relatively accessible location within the northern portion of the Circle Creek wetlands (Map 13), and the results did not show tidal influence even during high flows (**Appendix 4**, Figure 4).

However, we view the Circle Creek wetlands as "potentially tidal" because there are several areas of uncertainty in the data. First, the culverts at the mouth of Circle Creek are very likely restricting the influence of the tides. If this connection were fully open, it is possible that the tides could affect water levels within the Circle Creek wetlands, particularly in winter when Circle Creek and Necanicum River flows are backed up by high tide and storm surge events. Maine (2009-2010) described how winter flood events push head of tide in the Necanicum River as far upstream as the junction of Highways 26 and 101 – about 3 miles upstream of the mapped head of tide (OR DSL 2007). This observation, along with the flood control dikes along the Necanicum River south of Seaside, suggests that tidal influence in the floodplain could also extend well above the elevation limits used in this study.

Second, due to funding and staffing limitations, we measured water levels at only one location in the Circle Creek wetlands; more extensive water level monitoring would provide much better information on the presence or absence of tidal influence. Third, the LiDAR DEM can have a positive bias (i.e., it can overestimate the elevation of the soil surface), if dense vegetation blocks the LiDAR signal from reaching the soil (Toyra *et al.* 2003, Sadro *et al*. 2007). In Oregon, this has been observed in areas of dense slough sedge (So 2010) – and dense slough sedge is common within the Circle Creek wetlands (Coulter 2010). If the LiDAR DEM has a positive bias in this area, portions of the Circle Creek wetlands may actually be within tidal range. The accuracy of the LiDAR DEM could be determined through ground-truthing using optical survey equipment or GPS survey systems with high vertical accuracy (such as RTK-GPS); however, surveying within these wetlands' dense vegetation is very challenging.

Because of these uncertainties, we recommend further study of tidal and nontidal hydrology within the Circle Creek wetlands.

Regardless of their current tidal status, the Circle Creek wetlands offer a good opportunity for climate change adaptation in the Necanicum River estuary. Due to their elevation just above current tidal range, these wetlands are likely to become tidal under current sea level rise projections. The wetlands are well connected to the broad floodplain of the Necanicum River to the south, so there is an ample landward migration zone (Table 9, Map 14). Thus, the Circle Creek wetlands could provide considerable mitigation for other tidal wetlands lost due to rising sea levels.

Intended uses and limitations of mapping

This study is meant for use in strategic planning of voluntary restoration and conservation activities; products are not intended for regulatory use. The maps produced in this study were derived from existing mapping (the National Wetland inventory). Users of the maps produced in this study should be aware that there may be upland areas within mapped wetlands, and there may be unmapped wetlands and tidal waters of the state that are subject to state and/or federal regulation under State Removal-fill Law, Federal Clean Water Act or Federal Rivers and Harbors Act. Furthermore, because the NWI uses the Cowardin definition of a wetland, which is different from the definition of a regulatory wetland subject to state and federal regulations, not all NWI wetlands are necessarily subject to regulation.

Literature cited

Adamus, P.R. 2006. Hydrogeomorphic (HGM) assessment guidebook for tidal wetlands of the Oregon coast, Part 1: Rapid assessment method. Produced for the Coos Watershed Association, Oregon Department of State Lands, and US-EPA Region 10. Charleston, Oregon: Coos Watershed Association. Accessed 5/31/12 at http://www.oregon.gov/dsl/WETLAND/docs/tidal_HGM_pt1.pdf.

Adamus, P.R. 2005. Science review and data analysis for tidal wetlands of the Oregon coast. Part 2 of a Hydrogeomorphic Guidebook. Report to Coos Watershed Association, US Environmental Protection Agency, and Oregon Dept. of State Lands, Salem. Accessed 5/31/12 at http://www.oregon.gov/dsl/WETLAND/docs/tidal_HGM_pt2.pdf.

Adamus, P.R., J. Larsen, and R. Scranton. 2005. Wetland profiles of Oregon's coastal watersheds and estuaries. Part 3 of a Hydrogeomorphic Guidebook. Report to Coos Watershed Association, US Environmental Protection Agency, and Oregon Depart. of State Lands, Salem. Accessed 5/31/12 at http://www.oregon.gov/dsl/WETLAND/docs/tidal_HGM_pt3.pdf.

Adamus, P.R., and D. Field. 2001. Guidebook for hydrogeomorphic (HGM)-based assessment of Oregon wetland and riparian sites. Oregon Division of State Lands, Salem, Oregon.

Adamus, P., J. Morlan, and K. Verble. 2009a. Manual for the Oregon Rapid Wetland Assessment Protocol (ORWAP). Version 2.0. Oregon Dept. of State Lands, Salem, Oregon.

Adamus, P., J. Morlan, and K. Verble. 2009b. Oregon Rapid Wetland Assessment Protocol (ORWAP): calculator spreadsheet, databases, and data forms. Oregon Dept. of State Lands, Salem, Oregon.

Akins, G.J., and C.A. Jefferson. 1973. Coastal wetlands of Oregon. Oregon Coastal Conservation and Development Commission, Salem, Oregon. 190pp.

Amezaga, J.M., L. Santamaría, and A.J. Green. 2002. Biotic wetland connectivity—supporting a new approach for wetland policy. *Acta Oecologica* 23: 213–222.

Antieau, C. J. 1993. Biology and management of reed canarygrass, and implications for ecological restoration. Washington State Department of Transportation, Seattle.

Benner, P.A. 1992. Historical reconstruction of the Coquille River and surrounding landscape. Sections 3.2, 3.3 in: The action plan for Oregon coastal watersheds, estuaries, and ocean waters. Near Coastal Waters National Pilot Project, Environmental Protection Agency, 1988-1991. Portland, Oregon: Conducted by the Oregon Department of Environmental Quality.

Bersine, K., E. F. Brenneis, R. C. Draheim, A. M. Wargo Rub, J. E. Zamon, R. K. Litton, S. A. Hinton, M. D. Sytsma, J. R. Cordell, and J. W. Chapman. 2008. Distribution of the invasive New Zealand mudsnail (*Potamopyrgus antipodarum*) in the Columbia River Estuary and its first recorded occurrence in the diet of juvenile Chinook salmon (*Oncorhynchus tshawytscha*). *Biological Invasions* 1387-1395.

Bottom, D. L., G. Anderson, A. Baptista, J. Burke, M. Burla, M. Bhuthimethee, L. Campbell, E. Casillas, S. Hinton, K. Jacobson, D. Jay, R. McNatt, P. Moran, G. C. Roegner, C. A. Simenstad, V. Stamatiou, D. Teel, and J. E. Zamon. 2008. Salmon life histories, habitat, and food webs in the Columbia River Estuary: an overview of research results, 2002-2006. National Marine Fisheries Service, Seattle, Washington. 52 p. https://pisces.bpa.gov/release/documents/documentviewer.aspx?doc=P108100

Bottom, D., I. Fleming, K. Jones, and S. Simenstad. 2004. Salmonid use of restored estuarine wetlands: Regional application of the Salmon River estuary study. Oregon Sea Grant project #R/ECO-14.

Bottom, D., B. Kreag, F. Ratti, C. Roye, and R. Starr. 1979. Habitat classification and inventory methods for the management of Oregon estuaries. Oregon Dept. of Fish and Wildlife, Portland, Oregon.

Boulé, M.E., and K.F. Bierly. 1987. History of estuarine wetland development and alteration: what have we wrought? *Northwest Environmental Journal* 3(1): 43-61.

Brophy, L.S. 1999. Final Report: Yaquina and Alsea River basins estuarine wetland site prioritization project. Report to the MidCoast Watersheds Council, Newport, OR. Green Point Consulting, Corvallis, OR. 50 pp plus appendices. Accessed 5/31/12 at http://hdl.handle.net/1957/3961.

Brophy, L.S. 2005. Tidal wetland prioritization for the Siuslaw River estuary. Report to the Siuslaw Watershed Council, Mapleton, Oregon. Green Point Consulting, Corvallis, Oregon. 88 pp. Accessed 5/31/12 at http://hdl.handle.net/1957/19035.

Brophy, L.S. 2007. Estuary Assessment: Component XII of the Oregon Watershed Assessment Manual. Report to the Oregon Department of Land Conservation and Development, Salem, Oregon and the Oregon Watershed Enhancement Board, Salem, Oregon. Green Point Consulting, Corvallis, Oregon.134 pp. Accessed 5/31/12 at http://www.oregon.gov/OWEB/docs/pubs/wa_estuary/estuary_assessment_2007.pdf

Brophy, L.S. 2009. Effectiveness monitoring at tidal wetland restoration and reference sites in the Siuslaw River estuary: A tidal swamp focus. Prepared for Ecotrust, Portland, Oregon. Green Point Consulting, Corvallis, Oregon. 125pp. Accessed 5/31/12 at http://rfp.ciceet.unh.edu/display/related.php?chosen=269.

Brophy, L.S. 2004. Yaquina estuarine restoration project: Final report. Prepared for the MidCoast Watersheds Council, Newport, Oregon. Green Point Consulting, Corvallis, Oregon. 99 pp.

Brophy, L.S., C.E. Cornu, P.R. Adamus, J.A. Christy, L. Huang, A. Gray, M.A. MacClellan, J.A. Doumbia, and R.L. Tully. 2011. New tools for tidal wetland restoration: Development of a reference conditions database and a temperature sensor method for detecting tidal inundation in least-disturbed tidal wetlands of Oregon, USA. Report to the Cooperative Institute for Coastal and Estuarine Environmental Technology (CICEET), Durham, NH. Accessed 5/31/12 at http://hdl.handle.net/1957/25763.

Brophy, L.S., and K. So. 2005a. Tidal wetland prioritization for the Nehalem River Estuary. Prepared for USFWS Coastal Program, Newport Field Office. Green Point Consulting, Corvallis, Oregon. 62 pp. Accessed 5/31/12 at http://hdl.handle.net/1957/19031.

Brophy, L.S., and K. So. 2005b. Tidal wetland prioritization for the Smith River (Umpqua) Estuary. Prepared for USFWS Coastal Program, Newport Field Office. Green Point Consulting, Corvallis, Oregon. 69 pp. Accessed 5/31/12 at http://hdl.handle.net/1957/19034.

Brophy, L.S., and K. So. 2005c. Tidal wetland prioritization for the Umpqua River Estuary. Prepared for USFWS Coastal Program, Newport Field Office. Green Point Consulting, Corvallis, Oregon. 84 pp. Accessed 5/31/12 at http://hdl.handle.net/1957/19033.

Christy, J.A. 2004. Estimated loss of salt marsh and freshwater wetlands within the Oregon Coastal Coho ESU. Oregon Natural Heritage Information Center, Oregon State University.

Christy, J. C., E. R. Alverson, M. P. Dougherty, S. C. Kolar, C. W. Alton, S. M. Hawes, J. A. Hiebler, and E. M. Nielsen. 2001. Classification of historic vegetation in Oregon, as recorded by General Land Office surveyors. Oregon Natural Heritage Program, 9 May 2001.

Cornu, C.E. 2005. Restoring Cox, Dalton and Fredrickson Creek Marshes. South Slough NERR Coastal Resource Management Series. CRMS-2005-2. Coos Bay, Oregon.

Cortright, R., J. Weber, and R. Bailey. 1987. The Oregon estuary plan book. Oregon Dept. of Land Conservation and Development, Salem, Oregon.

Costa, J, J. Rockwell and S. Wilkes. 2002. Atlas of tidally restricted salt marshes in Buzzards Bay watershed. Buzzards Bay Project National Estuary Program / Massachusetts Office of Coastal Zone Management. Wareham, MA. Accessed 5/31/12 at http://www.buzzardsbay.org/smatlasmain.htm.

Costanza, R, R. d'Arge, R. de Groot, S. Farberk, M. Grasso, B. Hannon, K. Limburg, S. Naeem, R. V. O'Neill, J. Paruelo, R. G. Raskin, P. Sutton, & M. van den Belt. 1997. The value of the world's ecosystem services and natural capital. *Nature* 387: 253-260.

Coulter, C. 2010. Stewardship Director, North Coast Land Conservancy. Personal communication.

Cowardin, L.M., V. Carter, F.C. Golet, and E.T. LaRoe. 1979. Classification of wetlands and deepwater habitats of the United States. Performed for Office of Biological Services, Fish and Wildlife Service, U.S. Department of the Interior, Washington, D.C.

Dean, T., Z. Ferdana, J. White, and C. Tanner. 2000. Skagit estuary restoration assessment. People for Puget Sound and U.S. Fish and Wildlife Service. May 2000. Accessed 5/31/12 at http://proceedings.esri.com/library/userconf/proc00/professional/papers/pap230/p230.htm.

Definition of waters of the United States. 2012.33 C.F.R. Part 328. Accessed 5/31/12 at http://www.nap.usace.army.mil/cenap-op/regulatory/documents/regs/33cfr328.pdf

Emmett, R. R. Llanso, J. Newton, R. Thom, M. Hornberger, C. Morgan, C. Levings, A. Copping, and P. Fishman. 2000. Geographic signatures of North American west coast estuaries. *Estuaries* 23(6): 765-792.

FGDC (Federal Geographic Data Committee). 2009. Wetlands Mapping Standard. FGDC Document Number FGDC-STD-015-2009. Accessed 5/31/12 at http://www.fgdc.gov/standards/projects/FGDC-standards-projects/wetlands-mapping.

Ferrarese, E., R.J. Garono, S. Long, P. McEvoy, F. Grevstad, and S. Schooler. 2010. Assessment of purple loosestrife biocontrol agent populations on the Columbia River. Earth Design Consultants, Inc., Corvallis, Oregon.

Frenkel, R.E., and J.C. Morlan. 1991. Can we restore our salt marshes? Lessons from the Salmon River, Oregon. *The Northwest Environmental Journal* 7:119-135.

Giannico, G. and J. Souder. 2005. Tide gates in the Pacific Northwest: Operation, types, and environmental effects. Corvallis: Oregon Sea Grant (ORESU-T005-001), Oregon State University.

Good, J.W. 2000. Summary and current status of Oregon's estuarine ecosystems. Section 3.3 in Oregon State of the Environment: Full Report. Oregon Progress Board, Salem, Oregon. Accessed 5/31/12 at http://egov.oregon.gov/DAS/OPB/soer2000index.shtml

Good, J. W. 1997. Oregon CZM profile: Protection of estuaries and coastal wetlands. Unpublished report prepared as part of the National Coastal Zone Effectiveness Study. Corvallis, Oregon: Oregon Sea Grant and Marine Resource Management Program, College of Oceanic and Atmospheric Sciences, Oregon State University.

Graves, J.K, J.A. Christy, P.J. Clinton and P.L. Britz. 1995. Historic habitats of the lower Columbia River. Report to Lower Columbia River Bi-State Water Quality Program, Portland, Oregon. Columbia River Estuary Task Force, Astoria, Oregon. 14 pp. + maps and GIS coverage.

Grinsted, A., J. C. Moore, and S. Jevrejeva. 2009. Reconstructing sea level from paleo and projected temperatures 200 to 2100 AD. *Climate Dynamics* 34(4): 461-472.

Gwin, S.E., M.E. Kentula, and P.W. Shaffer. 1999. Evaluating the effects of wetland regulation through hydrogeomorphic classification and landscape profiles. *Wetlands* 19(3): 477-489.

Hawes, S.M., J.A. Hiebler, E.M. Nielsen, C.W. Alton, J. A. Christy and P. Benner. 2008. Historical vegetation of the Pacific Coast, Oregon, 1855-1910. ArcMap shapefile, Version 2008_03. Oregon Natural Heritage Information Center, Oregon State University. Accessed 5/31/12 at http://www.pdx.edu/sites/www.pdx.edu.pnwlamp/files/glo_coast_2008_03.zip.

Herrera Environmental Consultants. 2010. Circle Creek property hydrologic study. Prepared for the North Coast Land Conservancy, Seaside, Oregon. Herrera Environmental Consultants, Seattle, Washington.

Hood, G. 2004. Indirect environmental effects of dikes on estuarine tidal channels: Thinking outside of the dike for habitat restoration and monitoring. *Estuaries* 27(2): 273-282.

Horning, Tom. 2009-2010. Horning Geoscience. Personal communication.

Huang, L., L. Brophy, and C. Lindley. 2011. Fluvial effects on coastal flooding in the U.S. Pacific Northwest. *Proceedings of Solutions to Coastal Disasters* 2011, Anchorage, AK. 12 pp.

Jefferson, C.A. 1975. Plant communities and succession in Oregon coastal salt marshes. Ph.D. thesis, Department of Botany and Plant Pathology, Oregon State University, Corvallis, Oregon. 192 pp.

Jevrejeva, S., J. Moore, and A. Grindsted. 2010. How will sea level respond to changes in natural and anthropogenic forcings by 2100? *Geophysical Research Letters* 37, L07703. DOI: 10.1029/2010GL042947.

Komar, P.D. 1998. The Pacific Northwest Coast: Living with the shores of Oregon and Washington. Duke University Press, Durham and London.

Lebovitz, A. 1992. Oregon estuarine conservation and restoration priority evaluation: Opportunities for salmonid habitat and wetlands functional enhancement in Oregon's estuaries. Technical report to Oregon Trout, Portland, Oregon.

Leonard, L.J., Hyndman, R.D., and Mazzotti, S. 2004. Coseismic subsidence in the 1700 great Cascadia earthquake: Coastal estimates versus elastic dislocation models. *Geological Society of America Bulletin* 116: 655-670.

Maine, Neal. 2009-2010. Personal communication.

Maine, N. 1979. Necanicum Estuary Inventory. Oregon Dept. of Fish and Wildlife, Portland.

McArthur, R.H., and E.O. Wilson. 1967. The theory of island biogeography. Princeton University Press, Princeton, New Jersey.

Miller, B.A., and S. Sadro. 2003. Residence time and seasonal movements of juvenile coho salmon in the ecotone and lower estuary of Winchester Creek, South Slough, Oregon. *Transactions of the American Fisheries Society* 132: 546-559.

Mitsch, W.J. 2000. Self-design applied to coastal restoration. *In* Weinstein, M.P., and D.A. Kreeger. 2000. Concepts and Controversies in Tidal Marsh Ecology. Kluwer, Boston.

Mofjeld, H.O., A.J. Venturato, F.I. González, and V.V. Titov. 2004. Background tides and sea level variations at Seaside, Oregon. NOAA Technical Memorandum OAR PMEL-126, Contribution 2736 from NOAA/Pacific Marine Environmental Laboratory. Accessed 5/31/12 at http://www.pmel.noaa.gov/pubs/PDF/mofj2736/mofj2736.pdf.

National Research Council. 1992. Restoration of aquatic ecosystems: Science, technology and public policy. National Academy Press, Washington, DC.

NOAA CO-OPS (National Oceanic and Atmospheric Administration Center for Operational Oceanographic Products and Services). 2012. Tides and currents website. Accessed 5/31/12 at http://tidesandcurrents.noaa.gov/.

NOAA CSC (National Oceanic and Atmospheric Administration Coastal Services Center). 2011. Metadata for 2009 Oregon Department of Geology and Mineral Industries (DOGAMI) Oregon Lidar: North Coast. Accessed 12/15/11 at http://csc.noaa.gov/dataviewer/webfiles/metadata/or2009_dogami_north_coast_template.html.

OCCRI (Oregon Climate Change Research Institute). 2010. Oregon climate assessment report. K.D. Dello and P.W. Mote (Eds.). College of Oceanic and Atmospheric Sciences, Oregon State University, Corvallis, Oregon. Accessed 5/31/12 at http://occri.net/wp-content/uploads/2011/01/OCAR2010_v1.2.pdf.

ODA (Oregon Department of Agriculture). 2011a. Noxious weed policy and classification. Accessed 5/31/12 at http://www.oregon.gov/ODA/PLANT/WEEDS/docs/weed_policy.pdf.

ODA (Oregon Department of Agriculture). 2011b. Smooth cordgrass. Accessed 5/31/12 at http://www.oregon.gov/ODA/PLANT/WEEDS/profile_smoothcordgrass.shtml.

ODA (Oregon Department of Agriculture). 2011c. Saltmeadow cordgrass. Accessed 5/31/12 at http://www.oregon.gov/ODA/PLANT/WEEDS/profile_saltmeadowcordgrass.shtml.

ODFW (Oregon Department of Fish and Wildlife). 2011. Fish distribution/habitat GIS data. Accessed 5/31/12 at http://www.streamnet.org/mapping_apps.cfm.

OR DLCD (Oregon Department of Land Conservation and Development). 2010. Oregon Climate Change Adaptation Framework. Accessed 5/31/12 at http://www.oregon.gov/ENERGY/GBLWRM/docs/Framework_Final_DLCD.pdf.

Oregon Department of State Lands. 2007. Oregon heads of tide. Accessed 5/31/12 at http://navigator.state.or.us/sdl/data/shapefile/tide.zip.

Peterson, C.D., H.M. Jol, T. Horning, and K.M. Cruikshank. 2010. Paleotsunami inundation of a beach ridge plain: Cobble ridge overtopping and interridge valley flooding in Seaside, Oregon, USA. Journal of Geological Research 2010: DOI 10.1155/2010/2796989. Accessed 5/31/12 at http://downloads.hindawi.com/journals/jgr/2010/276989.pdf.

Rahmstorf, S. 2010. A new view on sea level rise. *Nature Geoscience* 4:44-45.

Reckendorf, F., C. Peterson, and D. Percy. 2001. The dune ridges of Clatsop County. Oregon Department of Geology and Mineral Industries Open File Report O-01-07. Accessed 5/31/12 at http://nwdata.geol.pdx.edu/Coastal-studies/duneridges/html/report.html.

Roth, E., R. Olsen, P. Snow, and R. Sumner. 1996. Oregon freshwater wetland assessment method. Wetlands Program, Oregon Division of State Lands, Salem, Oregon.

Sadro, S., M. Gastil-Buhl, and J. Melack. 2007. Characterizing patterns of plant distribution in a southern California salt marsh using remotely sensed topographic and hyperspectral data and local tidal fluctuations. Remote Sensing of Environment 110:226-239.

Scranton, R. 2004. The application of geographic information systems for delineation and classification of tidal wetlands for resource management of Oregon's coastal watersheds. Thesis, Marine Resource Management Program, Oregon State University, Corvallis.

Shreffler, D. K. and R. M. Thom. 1993. Restoration of urban estuaries: New approaches for site location and design. Washington Department of Natural Resources, Olympia, Washington.

Simenstad, C.A. ("Si"). 2005. University of Washington School of Aquatic and Fishery Sciences. Personal communication.

Simenstad, C.A. 1983. The ecology of estuarine channels of the Pacific Northwest coast: A community profile. U.S. Fish and Wildlife Service. FWS/OBS-83/05. 181 pp.

Simenstad, C.A., and D.L. Bottom. 2004. Guiding ecological principles for restoration of salmon habitat in the Columbia River estuary. Accessed 5/31/12 at http://www.fish.washington.edu/research/wet/publications/ecol_principles.doc.

Simenstad, C.A., C.D. Tanner, R.M. Thom, and L.D. Conquest. 1991. Estuarine habitat assessment protocol. EPA/910/9-91-037. U.S. Environmental Protection Agency, Region 10, Office of Puget Sound, Seattle, Washington.

Snyder, K.U., T.J. Sullivan, R.B. Rayond, E.H. Gilbert, and D.L. Moore. 2002. Necanicum River watershed assessment. E&S Environmental Chemistry, Corvallis, Oregon. Accessed 12/15/11 at http://hdl.handle.net/1957/3969.

So, Khemarith. 2010. U.S. Fish and Wildlife Service, Oregon Coast National Wildlife Refuge Complex. Personal communication.

Solazzi, M.E., T.E. Nickelson, and S.L. Johnson. 1991. Survival, contribution, and return of hatchery coho salmon (*Oncorhynchus kisutch*) released into freshwater, estuarine, and marine environments. *Canadian Journal of Fisheries and Aquatic Sciences* 57: 906-914.

State of Oregon. 2012. Oregon Administrative Rules, Department of Land Conservation and Development, Division 17: Classifying Oregon Estuaries. Accessed 5/31/12 at http://arcweb.sos.state.or.us/pages/rules/oars_600/oar_660/660_017.html.

Thayer, Gordon W., Teresa A. McTigue, Ronald J. Salz, David H. Merkey, Felicity M. Burrows, and Perry F. Gayaldo. (Eds.). 2005. Science-based restoration monitoring of coastal habitats, Volume Two: Tools for monitoring coastal habitats. NOAA Coastal Ocean Program Decision Analysis Series No. 23. NOAA National Centers for Coastal Ocean Science, Silver Spring, Maryland. 628 pp. plus appendices.

Thomas, D.W. 1983. Changes in Columbia River Estuary habitat types over the past century. Astoria, Oregon. Columbia River Estuary Data Development Program, Columbia River Estuary Study Taskforce. 98 p.

Töyrä, J., A. Pietroniro, C. Hopkinson, and W. Kalbfleisch. 2003. Assessment of airborne scanning laser altimetry (lidar) in a deltaic wetland environment. Canadian Journal of Remote Sensing 29(6): 718-728.

Tsunami Pilot Study Working Group. 2006. Seaside, Oregon, tsunami pilot study—Modernization of FEMA flood hazard maps. U.S. Geological Survey Open-File Report 2006-1234, Version 1.0.

US EPA/OR DLCD (U.S. Environmental Protection Agency/Oregon Department of Land Conservation and Development). 2005. Intertidal color infrared aerial mosaic of Necanicum River estuary. Accessed 5/31/12 at: http://www.coastalatlas.net/downloads/rasters/cir2005_nec_mosaic.zip

USFWS (U.S. Fish and Wildlife Service). 2010. National Wetland Inventory digital data. Accessed 5/31/12 at http://www.fws.gov/wetlands/data/Data-Download.html.

Vermeer, M., and S. Rahmstorf. 2009. Global sea level linked to global temperature. *Proceedings of the National Academy of Sciences of the United States of America*, 106(51): 21527-21532.

Wallace, N. 2009. Public Works Director, City of Seaside. Personal communication.

Watershed Sciences, Inc. 2009. LiDAR remote sensing data collection, Department of Geology and Mineral Industries, Oregon North Coast. Submitted to Oregon Department of Geology and Mineral Industries, Portland, Oregon.

White, J., T. Dean, Z. Schwartz, and C. Tanner. 1998. Site selection for estuarine habitat restoration: A model criteria. People for Puget Sound, Seattle, Washington. 9 pp.

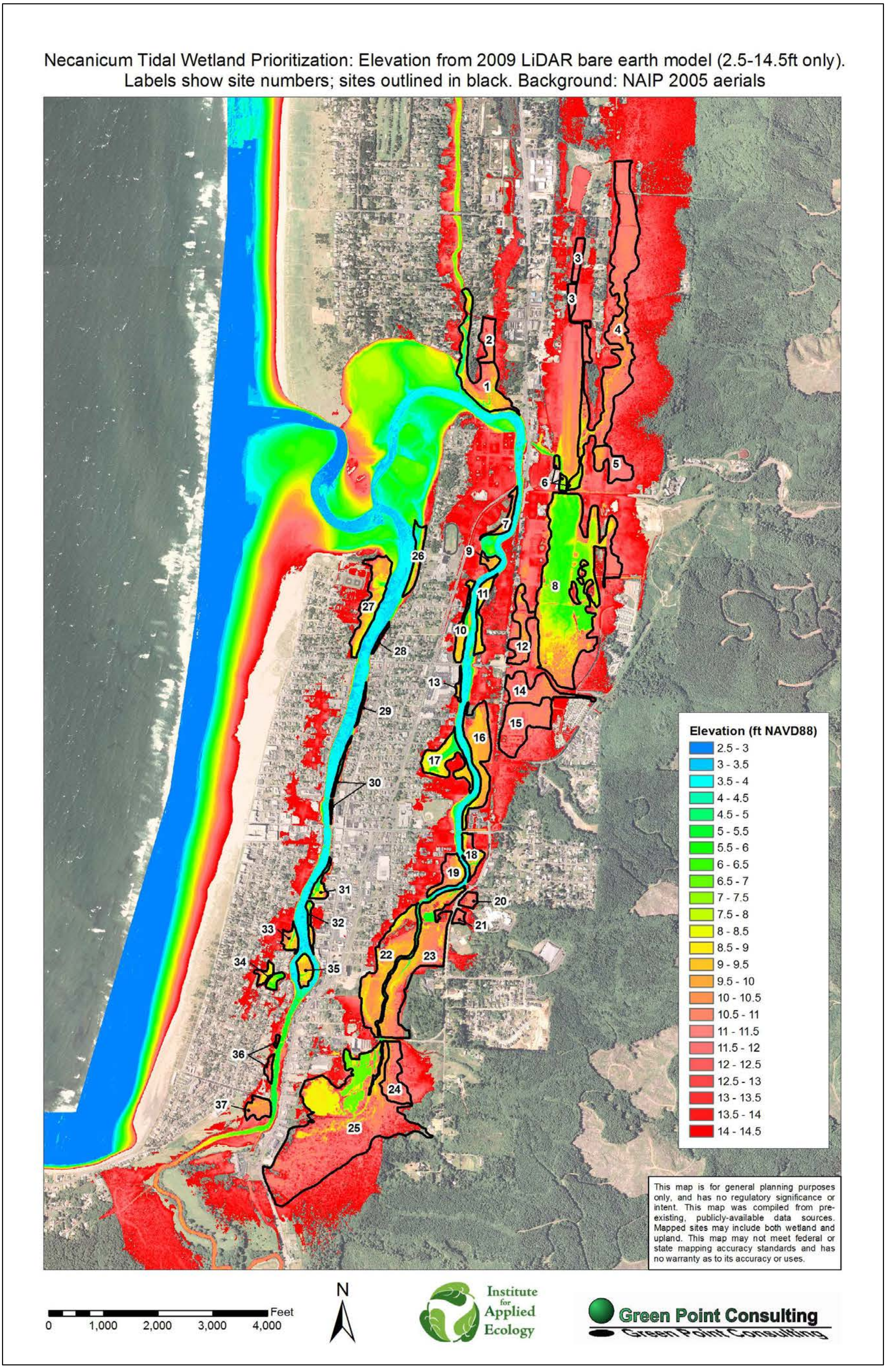
Zedler, J.B. 2001. Handbook for restoring tidal wetlands. CRC Press, Boca Raton, Florida.

Appendix 1. Maps

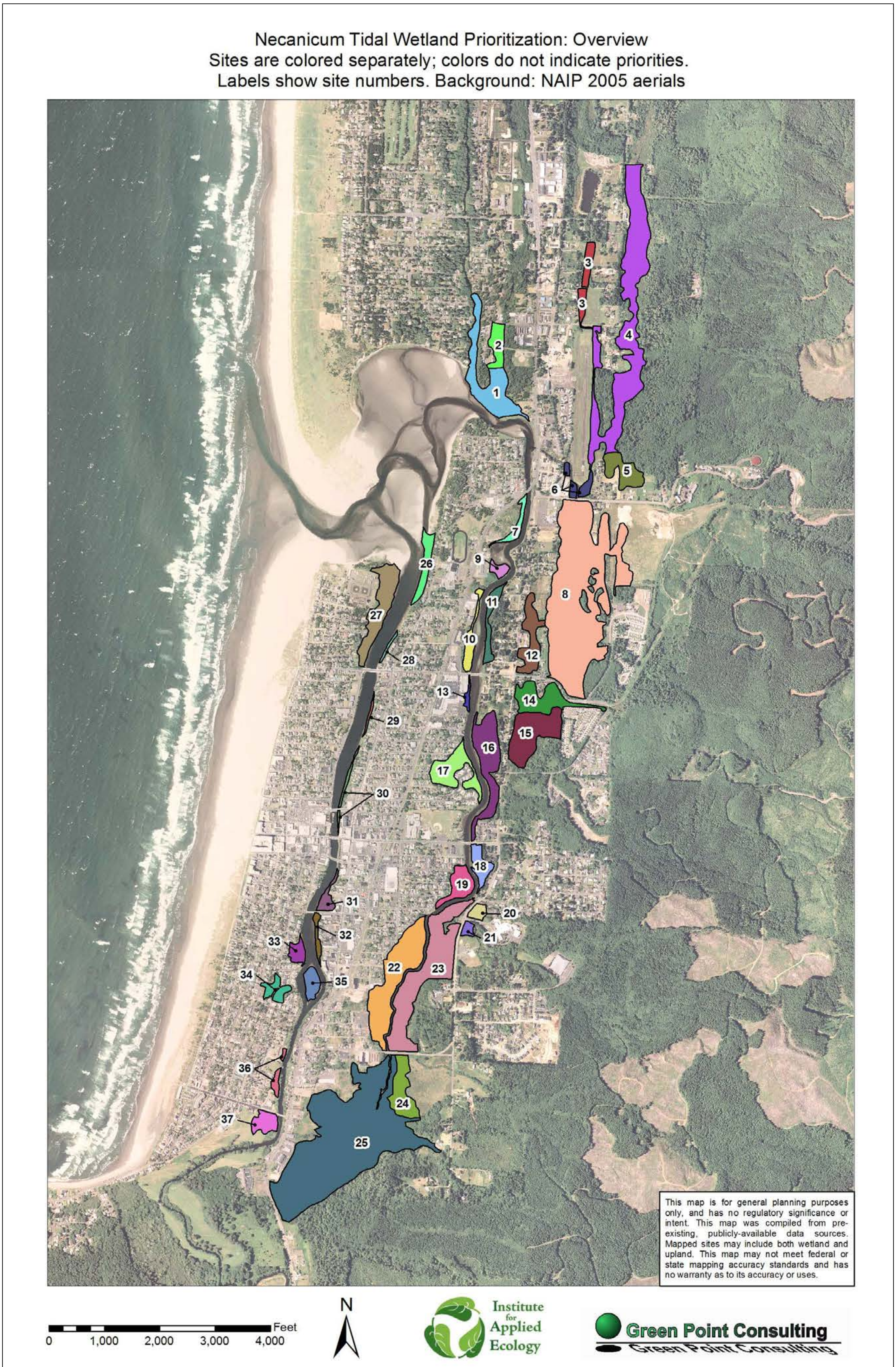
1. Place names
2. Ground surface elevation (LiDAR bare earth model)
3. Current and former tidal wetlands identified (with site numbers)
4. Total prioritization score
5. Score for size of site
6. Score for tidal channel condition
7. Score for wetland connectivity
8. Score for salmonid diversity
9. Score for historic vegetation type
10. Score for diversity of vegetation classes
11. Intensity of alterations
12. Alteration types
13. HOBO water level loggers and published head of tide
14. Landward migration zones for tidal wetlands
15. Number of landowners
16. Landowner type

Necanicum Tidal Wetland Prioritization: Place names
Background: NAIP 2005 aerials

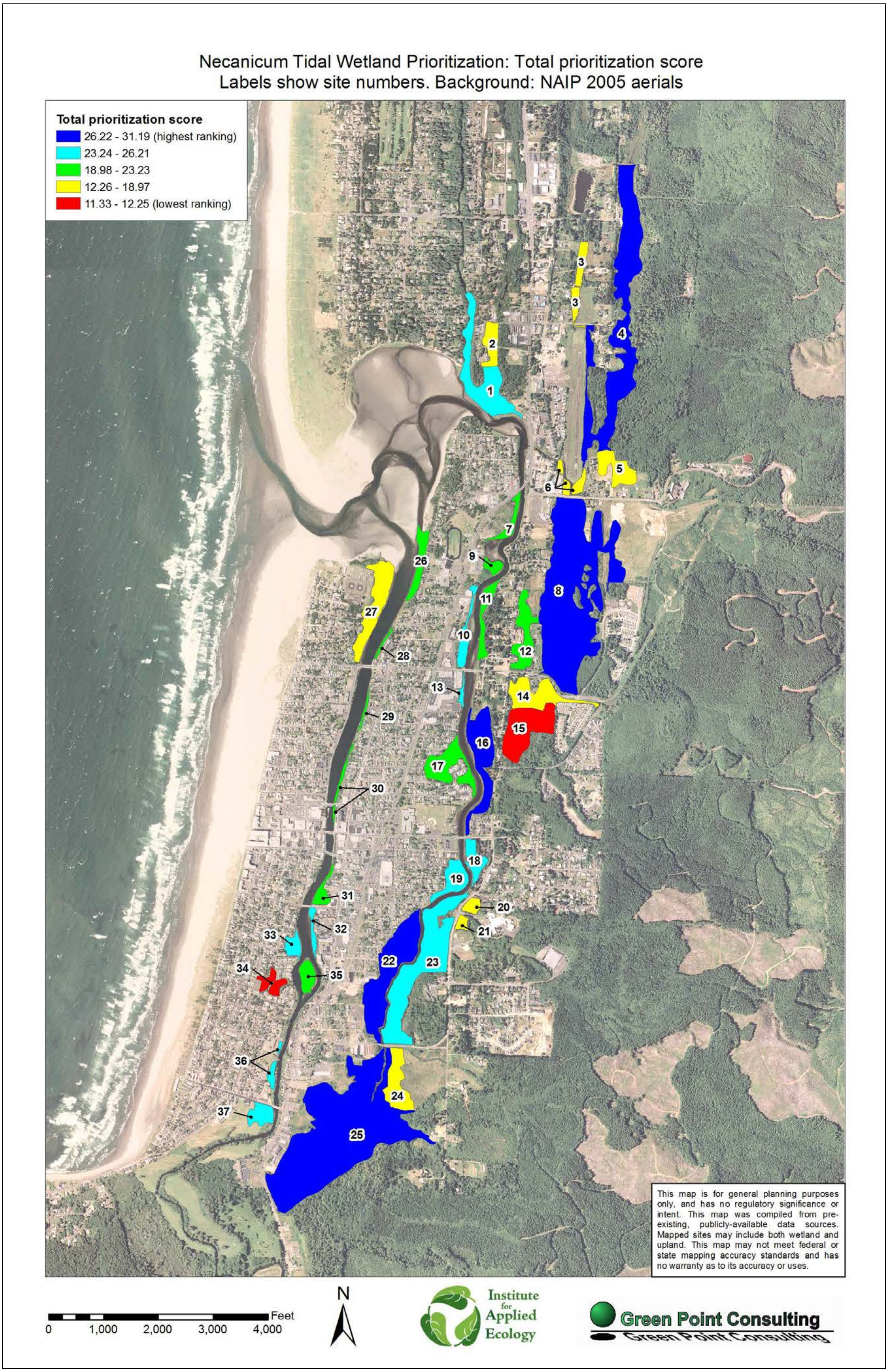
Map1: Place names



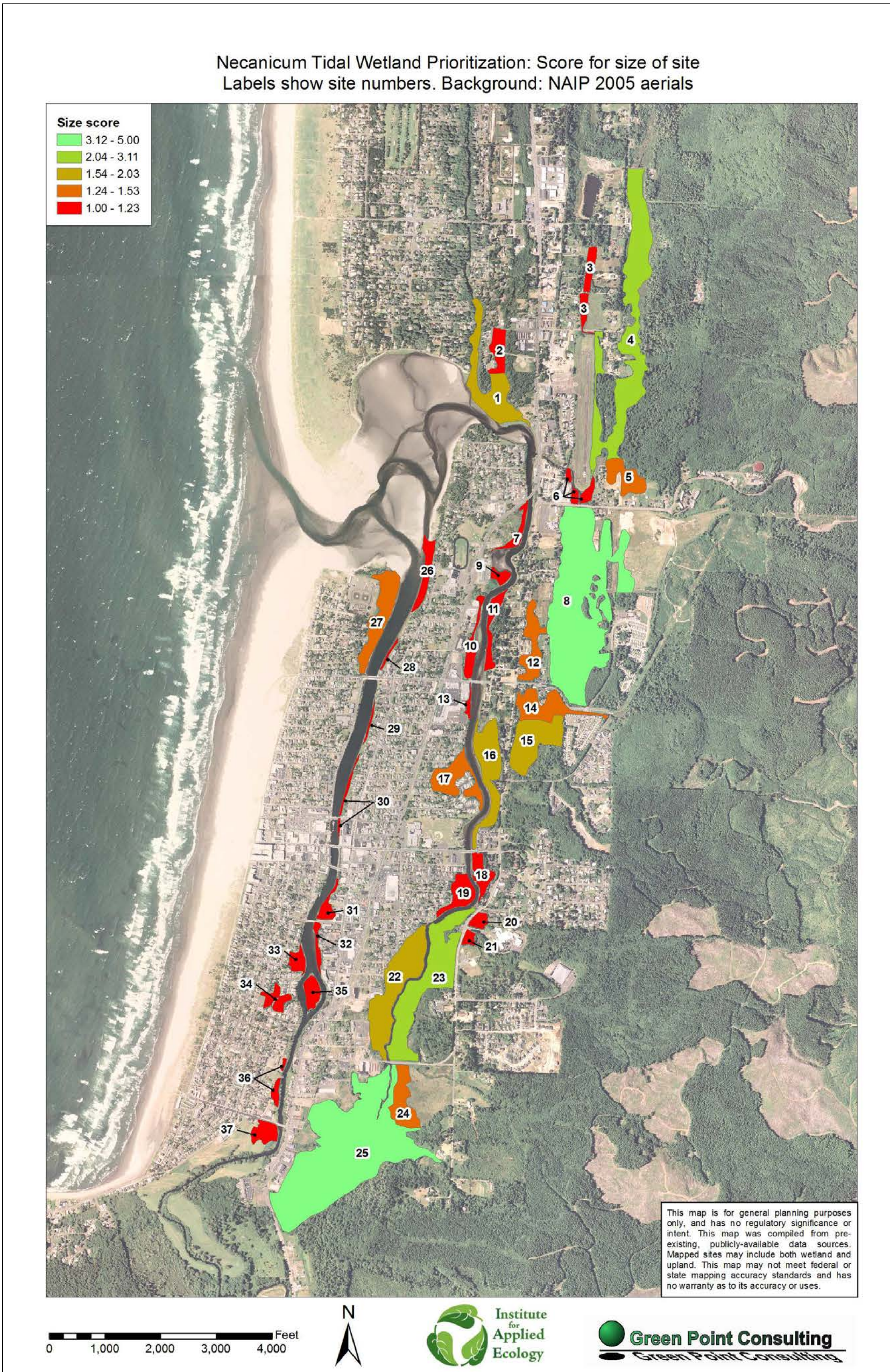
Map 2: Ground surface elevation (2009 LiDAR bare earth model). Colors show elevations between 2.5 and 14.5ft NAVD88.



Map 3: Current and former tidal wetlands identified, with site numbers (sites colored separately)

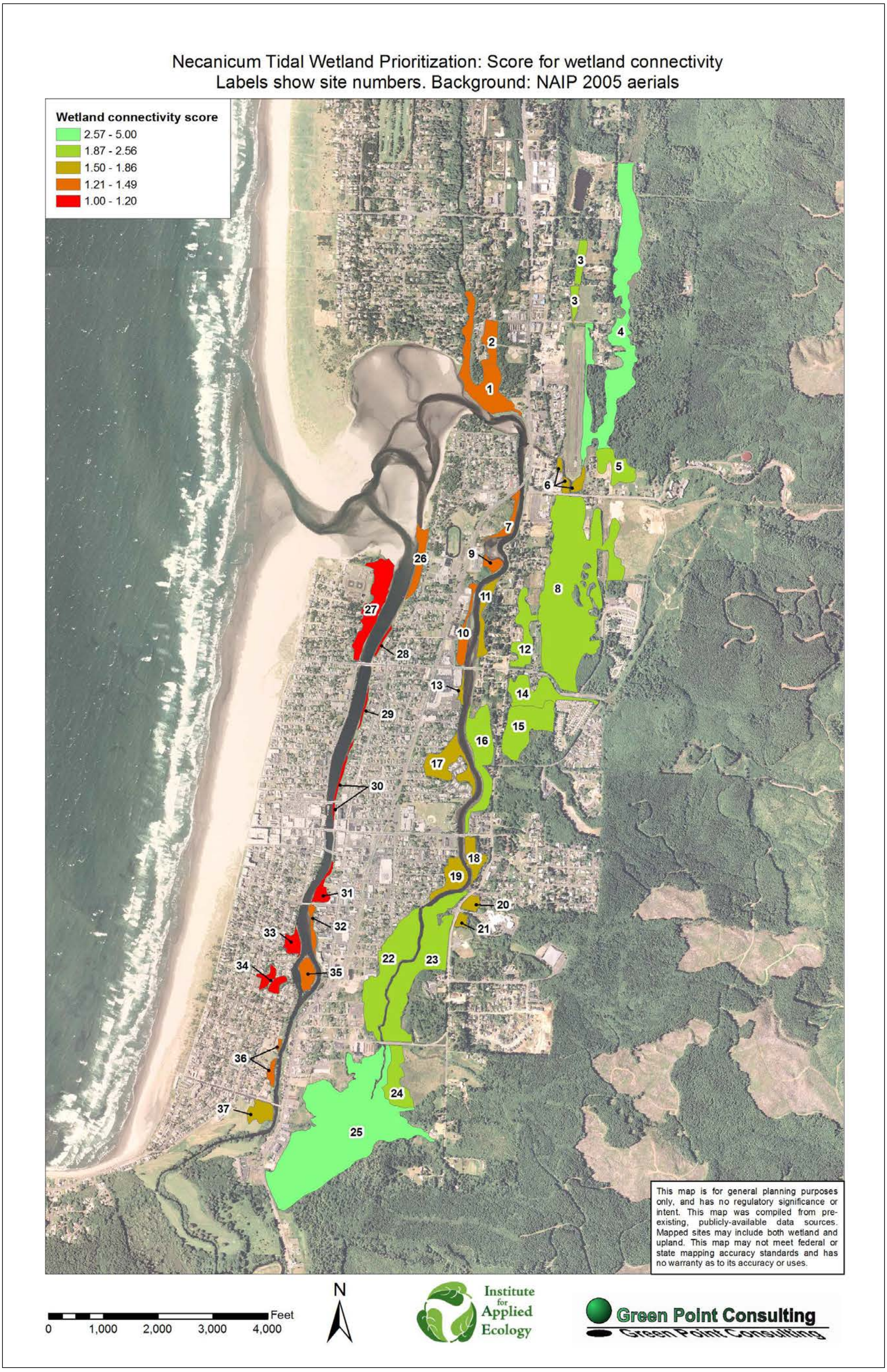


Map 4: Total prioritization score

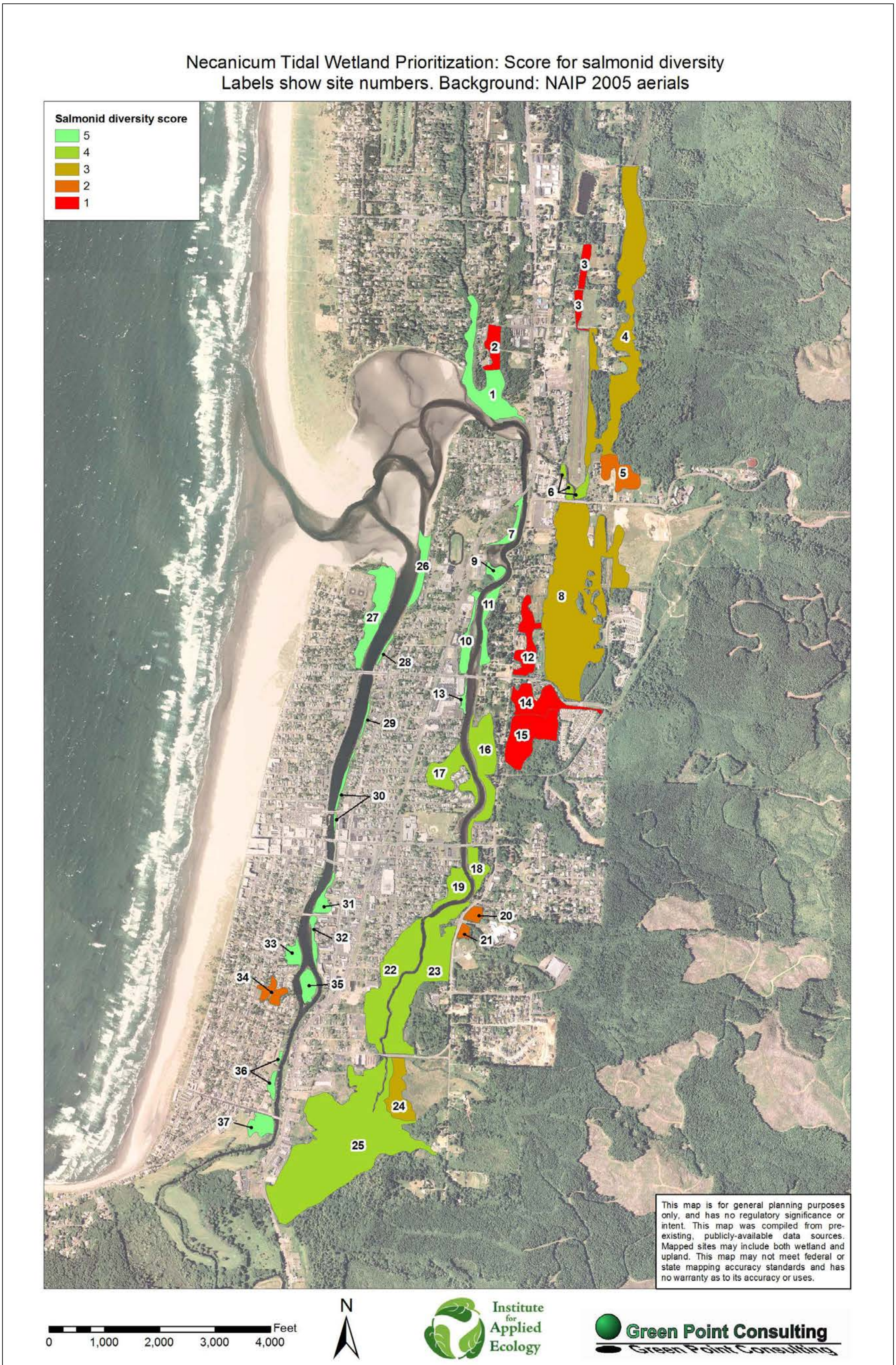


Map 5: Score for size of site

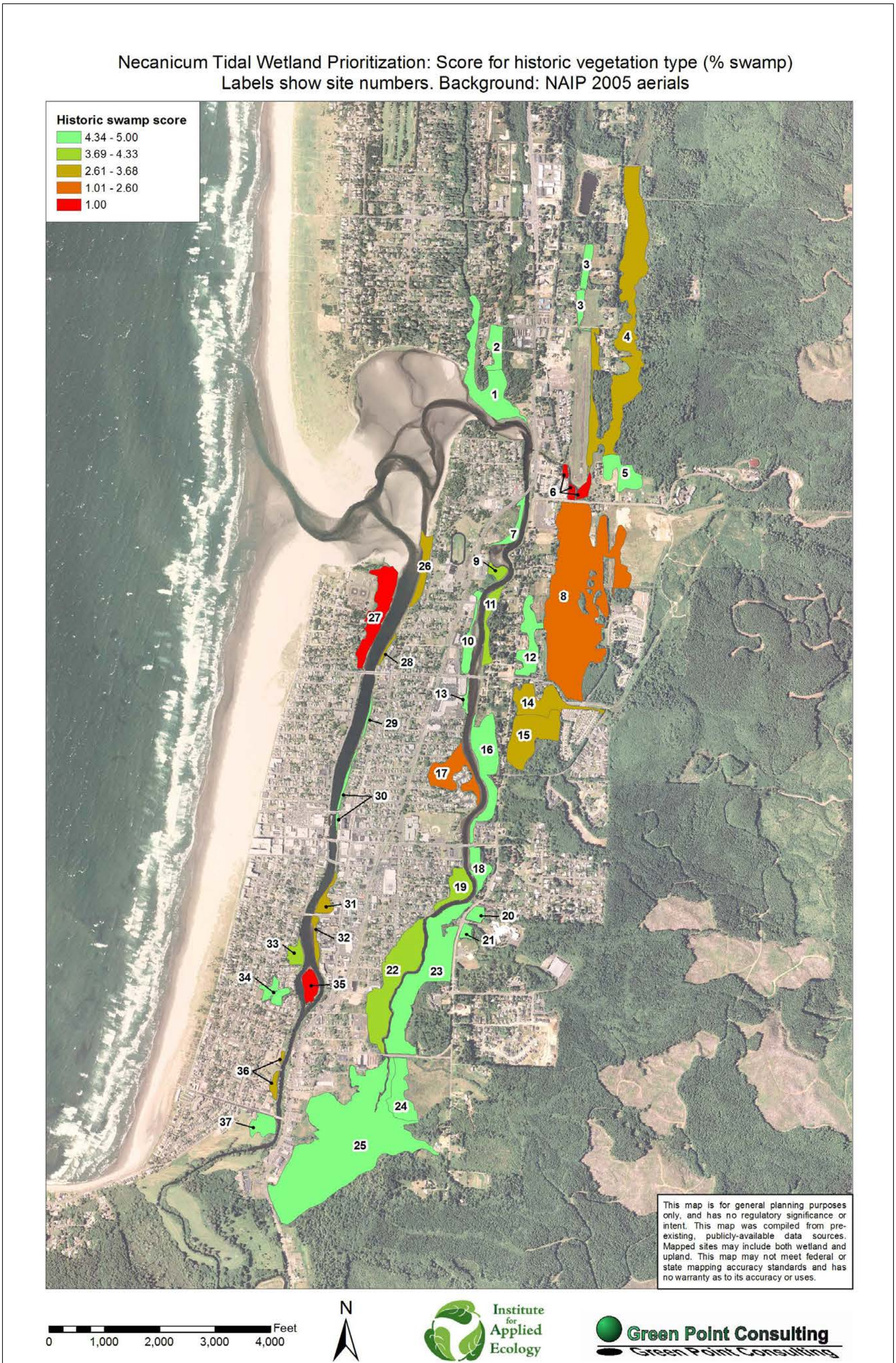
Map 6: Score for tidal channel condition (including tidal connection)



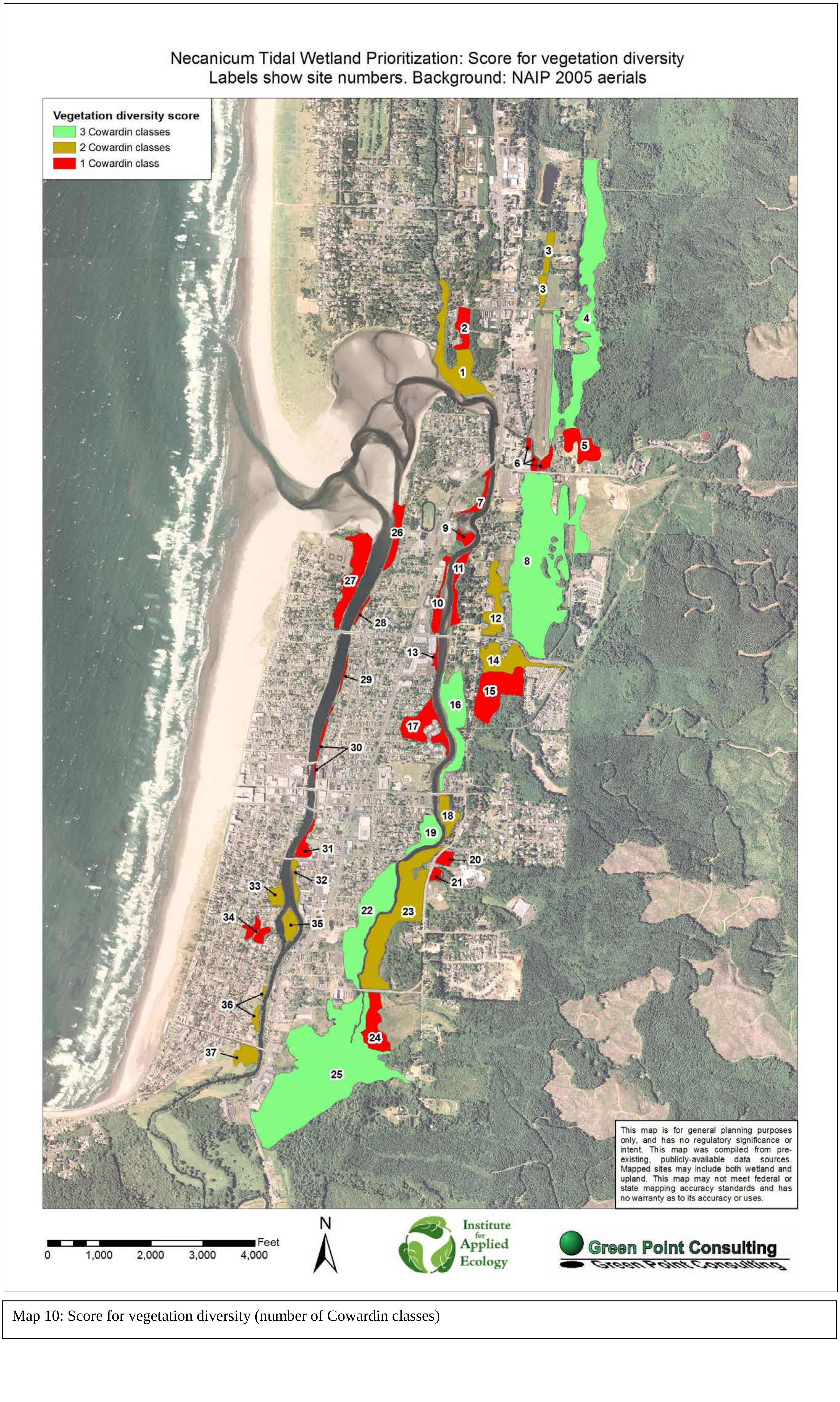
Map 7: Score for wetland connectivity (total wetland area within a 0.5-mile buffer around site)



Map 8: Score for salmonid diversity (number of salmon stocks using connected tidal stream)

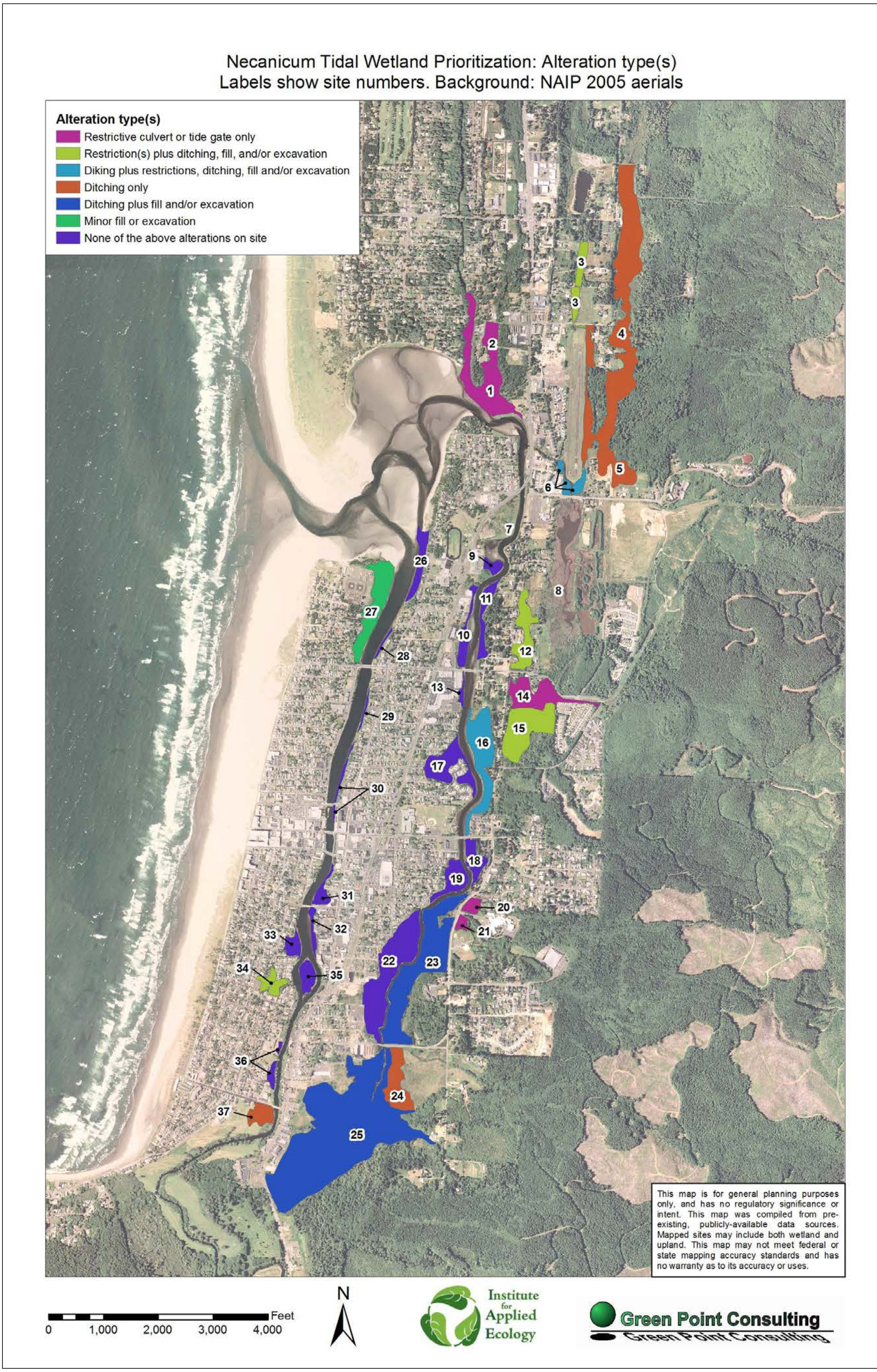


Map 9: Score for historic vegetation type (proportion of site that was historically swamp)



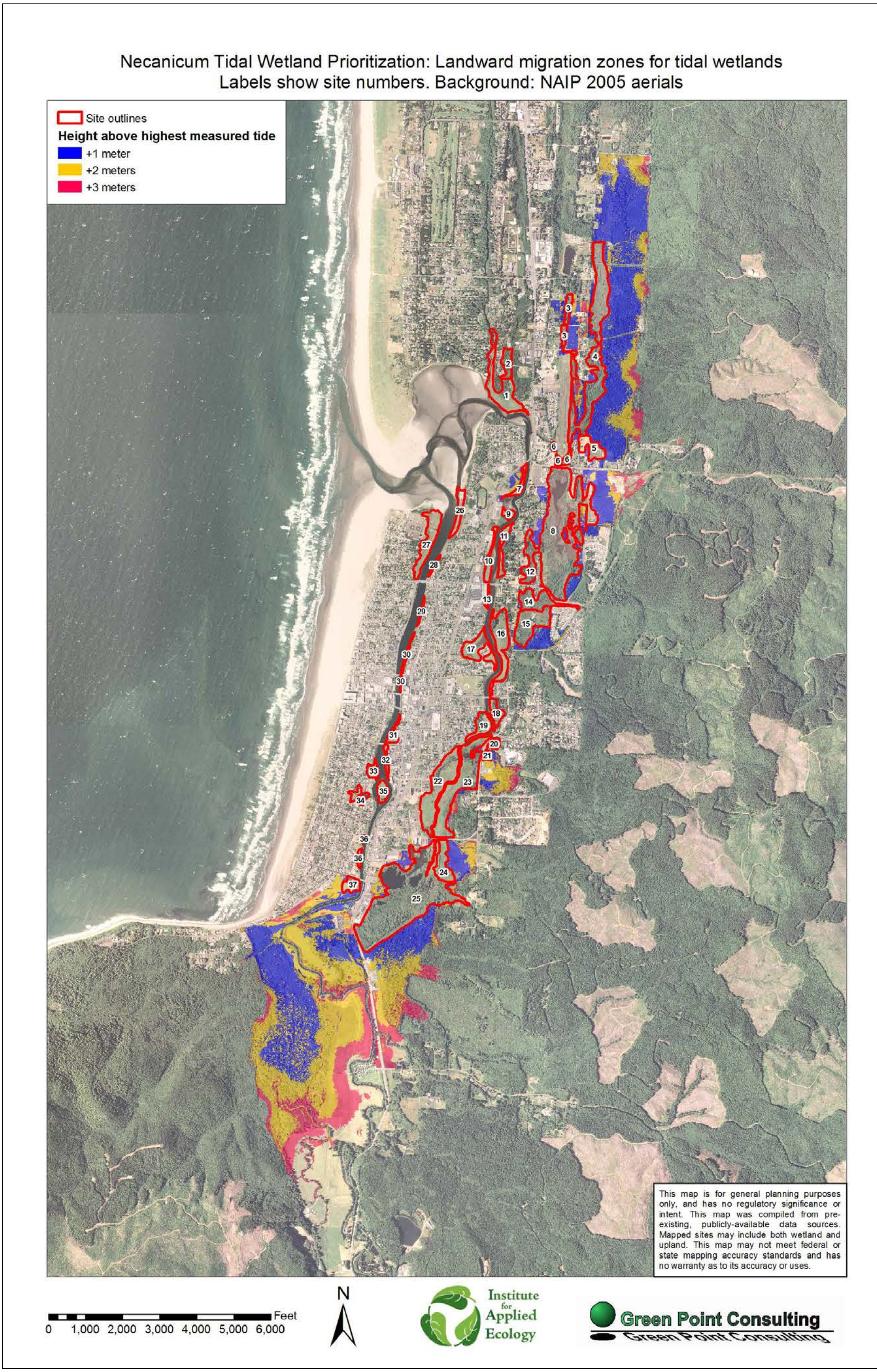
Map 10: Score for vegetation diversity (number of Cowardin classes)

Map 11: Intensity of alterations



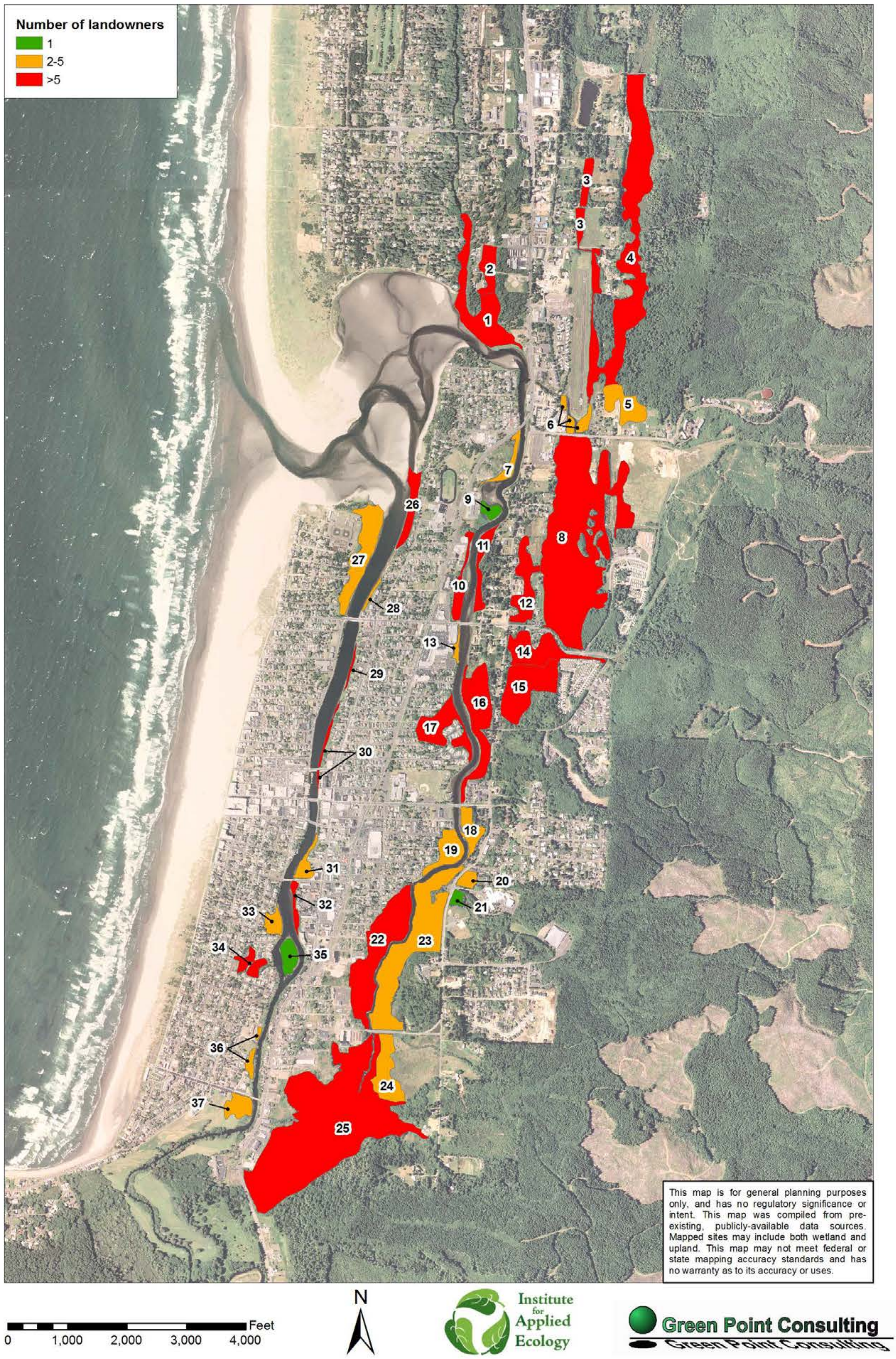
Map 12: Alteration types

Map 13: HOBO water level logger locations and published head of tide



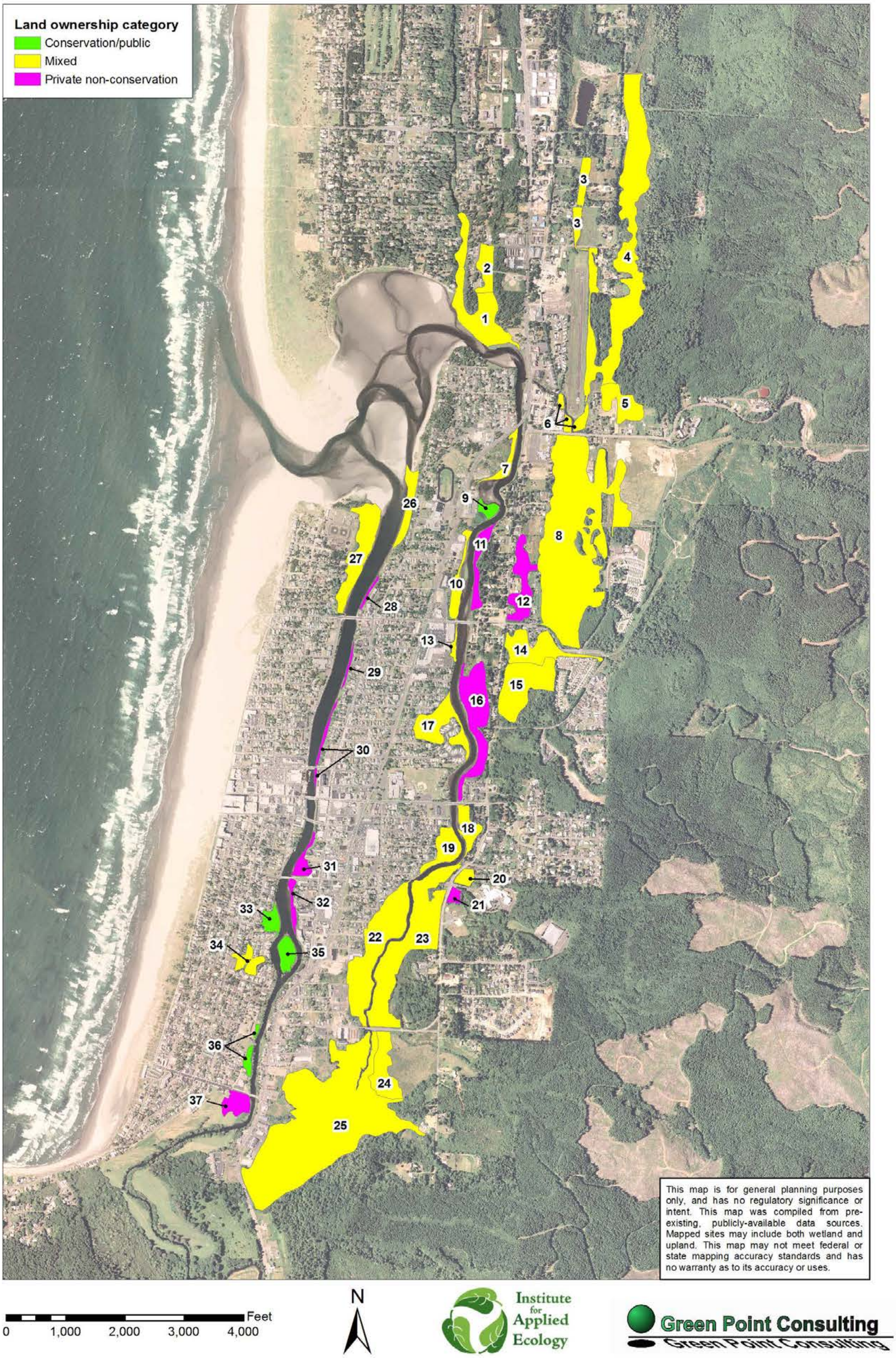
Map 14: Landward migration zones for selected tidal wetlands

Necanicum Tidal Wetland Prioritization: Number of landowners
Labels show site numbers. Background: NAIP 2005 aerials



Map 15: Number of landowners

Necanicum Tidal Wetland Prioritization: Land ownership type
Labels show site numbers. Background: NAIP 2005 aerials



Map 16: Landowner type

Appendix 2. Ranking tables

Table 1. Scores for individual prioritization criteria and total score, sorted by rank

Site number	Size score	Tidal channel condition score*	Wetland connectivity score	Salmonid diversity score	Historic swamp score	Current vegetation diversity score	Total score*	Ranking group
25	5.00	4.33	3.53	4.0	5.00	5.0	31.19	High
4	3.11	5.00	5.00	3.0	3.11	5.0	29.22	High
22	2.03	5.00	2.47	4.0	4.27	5.0	27.77	High
16	1.64	5.00	2.05	4.0	5.00	5.0	27.69	High
8	4.46	5.00	2.35	3.0	2.60	5.0	27.41	High
19	1.23	5.00	1.65	4.0	4.33	5.0	26.21	Medium-high
1	1.73	5.00	1.47	5.0	4.98	3.0	26.18	Medium-high
23	2.32	4.33	2.56	4.0	4.90	3.0	25.44	Medium-high
18	1.16	5.00	1.59	4.0	4.98	3.0	24.73	Medium-high
37	1.15	4.33	1.74	5.0	4.82	3.0	24.37	Medium-high
33	1.09	5.00	1.14	5.0	4.01	3.0	24.24	Medium-high
36	1.04	5.00	1.30	5.0	3.48	3.0	23.82	Medium-high
10	1.14	5.00	1.49	5.0	5.00	1.0	23.63	Medium-high
32	1.05	5.00	1.26	5.0	3.28	3.0	23.59	Medium-high
13	1.01	5.00	1.59	5.0	4.90	1.0	23.50	Medium-high
7	1.09	5.00	1.34	5.0	4.80	1.0	23.23	Medium
29	1.00	5.00	1.05	5.0	5.00	1.0	23.05	Medium
30	1.04	5.00	1.00	5.0	5.00	1.0	23.04	Medium
11	1.17	5.00	1.79	5.0	4.05	1.0	23.01	Medium
9	1.05	5.00	1.40	5.0	4.30	1.0	22.75	Medium
26	1.18	5.00	1.24	5.0	3.57	1.0	21.99	Medium
28	1.00	5.00	1.20	5.0	3.66	1.0	21.86	Medium
31	1.08	5.00	1.07	5.0	3.68	1.0	21.83	Medium
12	1.36	4.33	2.29	1.0	5.00	3.0	21.31	Medium
17	1.41	5.00	1.65	4.0	2.20	1.0	20.26	Medium
35	1.12	4.33	1.29	5.0	1.00	3.0	20.07	Medium

Site number	Size score	Tidal channel condition score*	Wetland connectivity score	Salmonid diversity score	Historic swamp score	Current vegetation diversity score	Total score*	Ranking group
6	1.11	5.00	1.86	4.0	1.00	1.0	18.97	Medium-low
24	1.37	3.00	2.46	3.0	5.00	1.0	18.83	Medium-low
14	1.45	3.67	2.23	1.0	3.65	3.0	18.67	Medium-low
27	1.53	4.33	1.04	5.0	1.00	1.0	18.23	Medium-low
20	1.05	3.67	1.71	2.0	5.00	1.0	18.10	Medium-low
5	1.29	3.00	2.33	2.0	5.00	1.0	17.62	Medium-low
2	1.18	3.67	1.49	1.0	5.00	1.0	17.01	Medium-low
21	1.03	3.00	1.82	2.0	5.00	1.0	16.85	Medium-low
3	1.19	1.67	2.39	1.0	5.00	3.0	15.92	Medium-low
34	1.12	1.00	1.13	2.0	5.00	1.0	12.25	Low
15	1.65	1.00	2.17	1.0	3.51	1.0	11.33	Low

*Tidal channel condition score is double-weighted in calculating the total score.

Table 2. Scores for individual prioritization criteria and total score, sorted by site

Site number	Size score	Tidal channel condition score*	Wetland connectivity score	Salmonid diversity score	Historic swamp score	Current vegetation diversity score	Total score*	Ranking group
1	1.73	5.00	1.47	5.0	4.98	3.0	26.18	Medium-high
2	1.18	3.67	1.49	1.0	5.00	1.0	17.01	Medium-low
3	1.19	1.67	2.39	1.0	5.00	3.0	15.92	Medium-low
4	3.11	5.00	5.00	3.0	3.11	5.0	29.22	High
5	1.29	3.00	2.33	2.0	5.00	1.0	17.62	Medium-low
6	1.11	5.00	1.86	4.0	1.00	1.0	18.97	Medium-low
7	1.09	5.00	1.34	5.0	4.80	1.0	23.23	Medium
8	4.46	5.00	2.35	3.0	2.60	5.0	27.41	High
9	1.05	5.00	1.40	5.0	4.30	1.0	22.75	Medium
10	1.14	5.00	1.49	5.0	5.00	1.0	23.63	Medium-high
11	1.17	5.00	1.79	5.0	4.05	1.0	23.01	Medium
12	1.36	4.33	2.29	1.0	5.00	3.0	21.31	Medium
13	1.01	5.00	1.59	5.0	4.90	1.0	23.50	Medium-high
14	1.45	3.67	2.23	1.0	3.65	3.0	18.67	Medium-low
15	1.65	1.00	2.17	1.0	3.51	1.0	11.33	Low
16	1.64	5.00	2.05	4.0	5.00	5.0	27.69	High
17	1.41	5.00	1.65	4.0	2.20	1.0	20.26	Medium
18	1.16	5.00	1.59	4.0	4.98	3.0	24.73	Medium-high
19	1.23	5.00	1.65	4.0	4.33	5.0	26.21	Medium-high
20	1.05	3.67	1.71	2.0	5.00	1.0	18.10	Medium-low
21	1.03	3.00	1.82	2.0	5.00	1.0	16.85	Medium-low
22	2.03	5.00	2.47	4.0	4.27	5.0	27.77	High
23	2.32	4.33	2.56	4.0	4.90	3.0	25.44	Medium-high
24	1.37	3.00	2.46	3.0	5.00	1.0	18.83	Medium-low
25	5.00	4.33	3.53	4.0	5.00	5.0	31.19	High

Site number	Size score	Tidal channel condition score*	Wetland connectivity score	Salmonid diversity score	Historic swamp score	Current vegetation diversity score	Total score*	Ranking group
26	1.18	5.00	1.24	5.0	3.57	1.0	21.99	Medium
27	1.53	4.33	1.04	5.0	1.00	1.0	18.23	Medium-low
28	1.00	5.00	1.20	5.0	3.66	1.0	21.86	Medium
29	1.00	5.00	1.05	5.0	5.00	1.0	23.05	Medium
30	1.04	5.00	1.00	5.0	5.00	1.0	23.04	Medium
31	1.08	5.00	1.07	5.0	3.68	1.0	21.83	Medium
32	1.05	5.00	1.26	5.0	3.28	3.0	23.59	Medium-high
33	1.09	5.00	1.14	5.0	4.01	3.0	24.24	Medium-high
34	1.12	1.00	1.13	2.0	5.00	1.0	12.25	Low
35	1.12	4.33	1.29	5.0	1.00	3.0	20.07	Medium
36	1.04	5.00	1.30	5.0	3.48	3.0	23.82	Medium-high
37	1.15	4.33	1.74	5.0	4.82	3.0	24.37	Medium-high

*Tidal channel condition score is double-weighted in calculating the total score.

Appendix 3. Site information tables

Table 1. Key to site information table fields (and site shapefile attributes)

Table 2, Part 1

FID	Internally generated feature ID number
Shape	Feature type
Site_num	Site number
Size_acres	Size of site in acres
Shape_Area	Size of site in square meters
HGM_CD	Hydrogeomorphic classes of wetlands within this site (if any), from Scranton (2004)
NWI_CD	Cowardin classes of wetlands within this site, from National Wetland Inventory mapping
NOTES	Notes about site characteristics
SIZE_SCO	Size score (scale of 1 to 5, 5 is largest)
TID_X	Tidal exchange score (1=none, 3=restricted, 5=full)
TG_LOC	Score for location of tidal restriction (restrictive culvert, tide gate or other restriction) (1=offsite, 3=onsite, 5=no tide gate or restriction)
DITCH	Ditching score (1=heavily ditched, 3=somewhat ditched, 5=unditched)
RMCH	Remnant channel score (1=no remnant channels, 3=some, 5=many)
TCC_SUM	Tidal channel condition sum (TID_X + TG_LOC + DITCH + RMCH)
TCC_SCO	Tidal channel condition score (TCC_SUM/4)

Table 2, Part 2:

WCON_SZ	Area of other wetlands within 0.5 mile buffer (sq m)
WCON_SCO	Wetland connectivity score (scale of 1 to 5)
Stocks	List of salmonid stocks using the tidal water body connected to the site
N_STOCKS	Number of salmonid stocks using the tidal water body connected to the site
NSAL_SCOR	Score for number of salmonid stocks (scale of 1 to 5)
SWMP_SZ	Area of site that was historically swamp (forested wetland) (sq m)
SWMP_PCT	Percent of site that was historically swamp
SWMP_SCO	Score for percent of site that was historically swamp (scale of 1 to 5)
CWDN_SCO	Score for number of NWI Cowardin classes on site (1 class=score of 1, 2 classes=score of 3, 3 classes=score of 5)
TOT_SCO	Sum of all 6 component scores, with tidal channel condition double-weighted. TOT_SCO = SZ_SCO + 2(TCC_SCO) + WLCN_SCO + NTYP_SCO + SWMP_SCO + CWDN_SCO.
PRI_GRP	Priority ranking group (high, medium-high, medium, medium-low, or low)
No_owners	Number of landowners for site (grouped into 1, 2-5, and >5 landowners)
Owner_type	Land ownership type (private non-conservation, public/conservation, or mixed)
ALT_TYP	Types of alterations present (C=restrictive culvert or tide gate, D=ditched, Y=dike, F=fill, X=excavation)
ALT_GRP	Intensity of alterations (major or minor), based on types of alterations and degree of alteration (from aerial photo interpretation or site reconnaissance)

Table 2, part 1: Site information table -- size, classification, notes, tidal channel condition

Site_num	Size_acres	Shape_Area	HGM_CD	NWI_CD	NOTES	SIZE_SCO	TID_X	TG_LOC	DITCH	RMCH	TCC_ SUM	TCC_ SCO
1	15.41	62366.93	MSL, MSH	E2EMN, E2EMP, PFOC, E1UBL	Most of site has no alterations; north portion (1.3A, <10% of site) is somewhat restricted by 5ft culvert. [end]	1.73	5.00	5.00	5.00	5.00	20.00	5.00
2	4.23	17100.62		PFOC	Two restrictive culverts (C12, C13). Likely beaver activity. [end]	1.18	3.00	3.00	5.00	5.00	16.00	3.67
3	4.35	17622.56		PEMCd, PEMC, PSSC	Tidal restriction likely due to multiple culverts, airport fill. 2005 aerial: livestock crossings suggest active/recent grazing. [end]	1.19	3.00	1.00	3.00	3.00	10.00	1.67
4	43.68	176761.16		PFOC, PSSC, PFOA, PSSR, PEMC, R1UBV	Extensive forested land to E of site. Sandy soil, peaty in wettest areas. Limited ditching on W edge. [end]	3.11	5.00	5.00	5.00	5.00	20.00	5.00
5	6.47	26194.66		PEMCd	Mowed, recent grazing. [end]	1.29	5.00	5.00	1.00	3.00	14.00	3.00
6	2.75	11142.11	MSL	E2EMN	East portion of site has a dike, but dike is breached in 2 places. Photo suggests other disturbance in past. Surrounded by development. [end]	1.11	5.00	5.00	5.00	5.00	20.00	5.00
7	2.36	9550.26	MSL	E2EMP	Narrow fringing tidal marsh (generally <100ft wide). Small area of fill at N end of site (old roadway/dike). [end]	1.09	5.00	5.00	5.00	5.00	20.00	5.00
8	71.32	288631.74	RCA, MSL, W, UP	PEMC, PSSR, PUBVx, PFOR, E2USN, E2SSN, E2SSP, E2EMP, R1UBV, E2EMN, PEMB	Restored site; some filled areas and berms remain. Aerial suggests beaver activity at S end of site. [end]	4.46	5.00	5.00	5.00	5.00	20.00	5.00
9	1.54	6223.79	MSL	E2EMN	Encroaching fill at SW corner. [end]	1.05	5.00	5.00	5.00	5.00	20.00	5.00
10	3.46	14019.54	MSL	E2EMN	Narrow fringing tidal marsh (generally <100ft wide). [end]	1.14	5.00	5.00	5.00	5.00	20.00	5.00
11	3.93	15901.93	MSL	E2EMN	Narrow fringing tidal marsh (generally <100ft wide). Site appears to be used by local residents -- foot paths along bank of Neawanna. [end]	1.17	5.00	5.00	5.00	5.00	20.00	5.00
12	7.89	31914.43		PEM/SSC, PEMC, PSSC	Appears hydrologically connected to Stanley Lake complex, but flow path is unclear. Some areas impounded, possibly due to adjacent fill and/or beaver activity. [end]	1.36	3.00	5.00	5.00	5.00	18.00	4.33
13	0.77	3125.21	MSH	E2EMN	Narrow fringing tidal marsh (generally <100ft wide); utility line crosses site. [end]	1.01	5.00	5.00	5.00	5.00	20.00	5.00
14	9.67	39130.05		PSSC, PFOC	Hydrologically connected to Stanley Lk complex. Limited tidal influence due to elevation, roadway, culverts, and beaver activity. [end]	1.45	3.00	3.00	5.00	5.00	16.00	3.67
15	13.92	56331.51		PUBHx, PEMC	May be hydrologically connected to Stanley Lk complex and/or Neawanna to the west. Much of site is mowed/cleared; excavation and fill (for wildlife habitat?) at S end. [end]	1.65	3.00	1.00	3.00	1.00	8.00	1.00
16	13.71	55499.63	MSL, MSH, RCA	PSSR, E2EMN, E2EMP, PFOR	LiDAR shows remains of a low dike on N half (breached); Mattison reports former dike on S half, but not evident in LiDAR. Site appears to be fully tidal at present. Some fringing tidal swamp on margins of site. [end]	1.64	5.00	5.00	5.00	5.00	20.00	5.00
17	8.88	35936.56	MSL, MSH	E2EMN, E2USN	Site is a tsunami coulee (Peterson *et al.* 2010). [end]	1.41	5.00	5.00	5.00	5.00	20.00	5.00
18	3.86	15626.12	MSL, MSH	E2EMP, PFOR	Parking lots to east are very close to site's main tidal channel. [end]	1.16	5.00	5.00	5.00	5.00	20.00	5.00

Site_num	Size_acres	Shape_Area	HGM_CD	NWI_CD	NOTES	SIZE_SCO	TID_X	TG_LOC	DITCH	RMCH	TCC_ SUM	TCC_ SCO
19	5.32	21548.55	MSL, MSH	E2EMN, PSSR, PFOR, E2EMP	West third of site appears to be tidal swamp (shrub/forested). [end]	1.23	5.00	5.00	5.00	5.00	20.00	5.00
20	1.65	6694.18		PSSC	Perched culvert (C4) to west prevents tidal exchange except on very high water events. Veg is native willow swamp(SALHOO/CAROBN). [end]	1.05	3.00	3.00	5.00	5.00	16.00	3.67
21	1.11	4492.35		PEMC	Disconnected from tides and impounded by Wahanna Road, perched culverts. [end]	1.03	3.00	1.00	5.00	5.00	14.00	3.00
22	21.64	87590.54	MSL, MSH	PEMS, PFOS, PEMR, PSSR	Least-disturbed high marsh, well-developed tidal channel system. Adjacent development to west. [end]	2.03	5.00	5.00	5.00	5.00	20.00	5.00
23	27.43	111024.58	MSL, MSH, W	PUBV, PFOR, E2EMP, PEMR	Most of site is least-disturbed high marsh. Some excavation and fill on north part of site. [end]	2.32	5.00	5.00	3.00	5.00	18.00	4.33
24	8.02	32448.08	MSH, F, W	PEMC	Aerials indicate past grazing, but currently little used. Veg is mix of native freshwater wetland and non-native pasture species. HGM indicates fill on SW side, but that appears to be an error. [end]	1.37	5.00	5.00	1.00	3.00	14.00	3.00
25	82.30	333071.24	MSL, MSH, RCA, F, W	PEM/SSR, PFOC, PSSC, PUBHx, PEMRx, PUBVx, PABVx, PEMRx, PABVx, PEMR, PEMFx	Extensive excavation and fill on north end (mill pond area). Natural gradient from high marsh into extensive shrub and forested tidal wetland. Aerial photo analysis suggests lots of beaver activity. [end]	5.00	5.00	5.00	3.00	5.00	18.00	4.33
26	4.28	17337.73	MSL, MSH	E2EMN, E2USP	Narrow fringing tidal marsh. [end]	1.18	5.00	5.00	5.00	5.00	20.00	5.00
27	11.38	46068.03	MSL, MSH	E2EMP, E2USN, E2EMN	Some excavation in northern 1/3 of site. [end]	1.53	5.00	5.00	3.00	5.00	18.00	4.33
28	0.56	2250.90	MSL, MSH	E2EMN	Narrow fringing tidal marsh. [end]	1.00	5.00	5.00	5.00	5.00	20.00	5.00
29	0.57	2301.29	MSH	E2EMN	Narrow fringing tidal marsh. [end]	1.00	5.00	5.00	5.00	5.00	20.00	5.00
30	1.29	5210.12	MSL, MSH	E2EMN	Narrow fringing tidal marsh. [end]	1.04	5.00	5.00	5.00	5.00	20.00	5.00
31	2.23	9008.15	MSL, MSH, W	E2EMN, E2EMP	Narrow fringing tidal marsh. [end]	1.08	5.00	5.00	5.00	5.00	20.00	5.00
32	1.53	6210.36	MSL, PF	PSSR, E2EMN	Narrow fringing tidal marsh. [end]	1.05	5.00	5.00	5.00	5.00	20.00	5.00
33	2.35	9496.01	MSL, W	E2EMP, PFOR	Small area of tidal swamp on W side of site. [end]	1.09	5.00	5.00	5.00	5.00	20.00	5.00
34	3.05	12328.95		PEMC, PUBHx	Mantel Lake and wetlands to west. Surrounded by development. Tidal inundation regime is altered by excavation and restrictive culverts. [end]	1.12	3.00	3.00	1.00	1.00	8.00	1.00
35	3.07	12438.66	MSH, PF	E2FOP, E2EMP	Island; possible minor ditching. [end]	1.12	5.00	5.00	3.00	5.00	18.00	4.33
36	1.47	5933.53		PFOR, PSSR	Narrow fringing forested wetland; limited tidal influence due to relatively high elevation. [end]	1.04	5.00	5.00	5.00	5.00	20.00	5.00
37	3.52	14262.74	RCA, PF	PEMR, PSSR	West portion (golf course) is mowed; east portion is rare shrub tidal wetland (tidal swamp). Minor ditching on north portion of site. [end]	1.15	5.00	5.00	3.00	5.00	18.00	4.33

Table 2, part 2: Site information table – scoring, ownership, alterations

Site_num	WCON_ SZ	WCON_ SCO	N_ STOCKS	Stocks	NSAL_ SCOR	SWMP_ SZ	SWMP_ PCT	SWMP_ SCO	CWDN_ SCO	TOT_SCO	PRI_GRP	No_owners	Owner_type	ALT_ TYP	ALT_ GRP
1	125304.50	1.47	4.00	chinook, chum, coho, steelhead	5.000	62118.37	99.60	4.98	3	26.18	Medium-high	>5	Mixed	C	minor
2	129597.89	1.49	0.00	none	1.000	17100.62	100.00	5.00	1	17.01	Medium-low	>5	Mixed	C	major
3	352112.34	2.39	0.00	none	1.000	17622.56	100.00	5.00	3	15.92	Medium-low	>5	Mixed	CD	major
4	992774.47	5.00	2.00	chum, coho	3.000	93274.32	52.77	3.11	5	29.22	High	>5	Mixed	D	minor
5	336233.31	2.33	1.00	coho	2.000	26194.66	100.00	5.00	1	17.62	Medium-low	2-5	Mixed	D	major
6	220795.54	1.86	3.00	chum, coho, steelhead	4.000	0.00	0.00	1.00	1	18.97	Medium-low	2-5	Mixed	FY	minor
7	91967.37	1.34	4.00	chinook, chum, coho, steelhead	5.000	9063.44	94.90	4.80	1	23.23	Medium	2-5	Mixed	F	minor
8	341363.85	2.35	2.00	coho, steelhead	3.000	115479.98	40.01	2.60	5	27.41	High	>5	Mixed	FXY	restor
9	107641.96	1.40	4.00	chinook, chum, coho, steelhead	5.000	5127.48	82.39	4.30	1	22.75	Medium	1	Conservation/ public	none	none
10	130564.96	1.49	4.00	chinook, chum, coho, steelhead	5.000	14019.54	100.00	5.00	1	23.63	Medium-high	>5	Mixed	none	none
11	203280.95	1.79	4.00	chinook, chum, coho, steelhead	5.000	12109.02	76.15	4.05	1	23.01	Medium	>5	Private non-conservation	none	none
12	326719.84	2.29	0.00	none	1.000	31914.43	100.00	5.00	3	21.31	Medium	>5	Private non-conservation	CF	major
13	154919.34	1.59	4.00	chinook, chum, coho, steelhead	5.000	3044.21	97.41	4.90	1	23.50	Medium-high	2-5	Mixed	none	none
14	311043.16	2.23	0.00	none	1.000	25920.00	66.24	3.65	3	18.67	Medium-low	>5	Mixed	C	major
15	298246.53	2.17	0.00	none	1.000	35308.20	62.68	3.51	1	11.33	Low	>5	Mixed	CDFX	major
16	267005.03	2.05	3.00	chum, coho, steelhead	4.000	55438.71	99.89	5.00	5	27.69	High	>5	Private non-conservation	DY	minor
17	169608.51	1.65	3.00	chum, coho, steelhead	4.000	10750.07	29.91	2.20	1	20.26	Medium	>5	Mixed	none	none
18	154442.88	1.59	3.00	chum, coho, steelhead	4.000	15529.72	99.38	4.98	3	24.73	Medium-high	2-5	Mixed	none	none

Site_num	WCON_ SZ	WCON_ SCO	N_ STOCKS	Stocks	NSAL_ SCOR	SWMP_ SZ	SWMP_ PCT	SWMP_ SCO	CWDN_ SCO	TOT_SCO	PRI_GRP	No_owners	Owner_type	ALT_ TYP	ALT_ GRP
19	169349.76	1.65	3.00	chum, coho, steelhead	4.000	17952.05	83.31	4.33	5	26.21	Medium-high	2-5	Mixed	none	none
20	182872.09	1.71	1.00	coho	2.000	6694.18	100.00	5.00	1	18.10	Medium-low	2-5	Mixed	C	major
21	210635.24	1.82	1.00	coho	2.000	4492.35	100.00	5.00	1	16.85	Medium-low	1	Private non-conservation	C	major
22	369741.92	2.47	3.00	chum, coho, steelhead	4.000	71700.54	81.86	4.27	5	27.77	High	>5	Mixed	none	none
23	392809.90	2.56	3.00	chum, coho, steelhead	4.000	108110.64	97.38	4.90	3	25.44	Medium-high	2-5	Mixed	DFX	minor
24	367788.05	2.46	2.00	chum, coho	3.000	32448.08	100.00	5.00	1	18.83	Medium-low	2-5	Mixed	D	major
25	632129.05	3.53	3.00	chum, coho, steelhead	4.000	333071.24	100.00	5.00	5	31.19	High	>5	Mixed	DFX	major
26	69426.16	1.24	4.00	chinook, chum, coho, steelhead	5.000	11120.03	64.14	3.57	1	21.99	Medium	>5	Mixed	none	none
27	18955.02	1.04	4.00	chinook, chum, coho, steelhead	5.000	0.00	0.00	1.00	1	18.23	Medium-low	2-5	Mixed	X	minor
28	59270.49	1.20	4.00	chinook, chum, coho, steelhead	5.000	1496.03	66.46	3.66	1	21.86	Medium	2-5	Private non-conservation	none	none
29	22275.12	1.05	4.00	chinook, chum, coho, steelhead	5.000	2301.29	100.00	5.00	1	23.05	Medium	>5	Private non-conservation	none	none
30	9402.78	1.00	4.00	chinook, chum, coho, steelhead	5.000	5210.12	100.00	5.00	1	23.04	Medium	>5	Private non-conservation	none	none
31	25500.28	1.07	4.00	chinook, chum, coho, steelhead	5.000	6028.36	66.92	3.68	1	21.83	Medium	2-5	Private non-conservation	none	none
32	72892.87	1.26	4.00	chinook, chum, coho, steelhead	5.000	3544.06	57.07	3.28	3	23.59	Medium-high	>5	Private non-conservation	none	none
33	45021.21	1.14	4.00	chinook, chum, coho, steelhead	5.000	7144.24	75.23	4.01	3	24.24	Medium-high	2-5	Conservation/ public	none	none
34	40816.18	1.13	1.00	none	2.000	12328.95	100.00	5.00	1	12.25	Low	>5	Mixed	CX	major
35	81537.54	1.29	4.00	chinook, chum, coho, steelhead	5.000	0.00	0.00	1.00	3	20.07	Medium	1	Conservation/ public	none	none
36	84100.99	1.30	4.00	chinook, chum, coho, steelhead	5.000	3683.36	62.08	3.48	3	23.82	Medium-high	2-5	Conservation/ public	none	none
37	192475.89	1.74	4.00	chinook, chum, coho, steelhead	5.000	13617.00	95.47	4.82	3	24.37	Medium-high	2-5	Private non-conservation	D	minor

Appendix 4. Water level data

North Coast Land Conservancy staff collected water level data to improve our understanding of the extent of tidal wetlands in the Necanicum River estuary. The data were not intended to establish head of tide or to model hydrology. However, the data provide useful information on the degree of tidal influence at the locations of the loggers during the gauged periods. *NOTE: Sensor elevations were determined through laser level survey tied to benchmarks, but due to possible datum inconsistencies, geodetic elevations (relative to NAD88) are should be viewed with caution, and should be verified. In particular, the Mill Creek elevations appear lower than expected.*

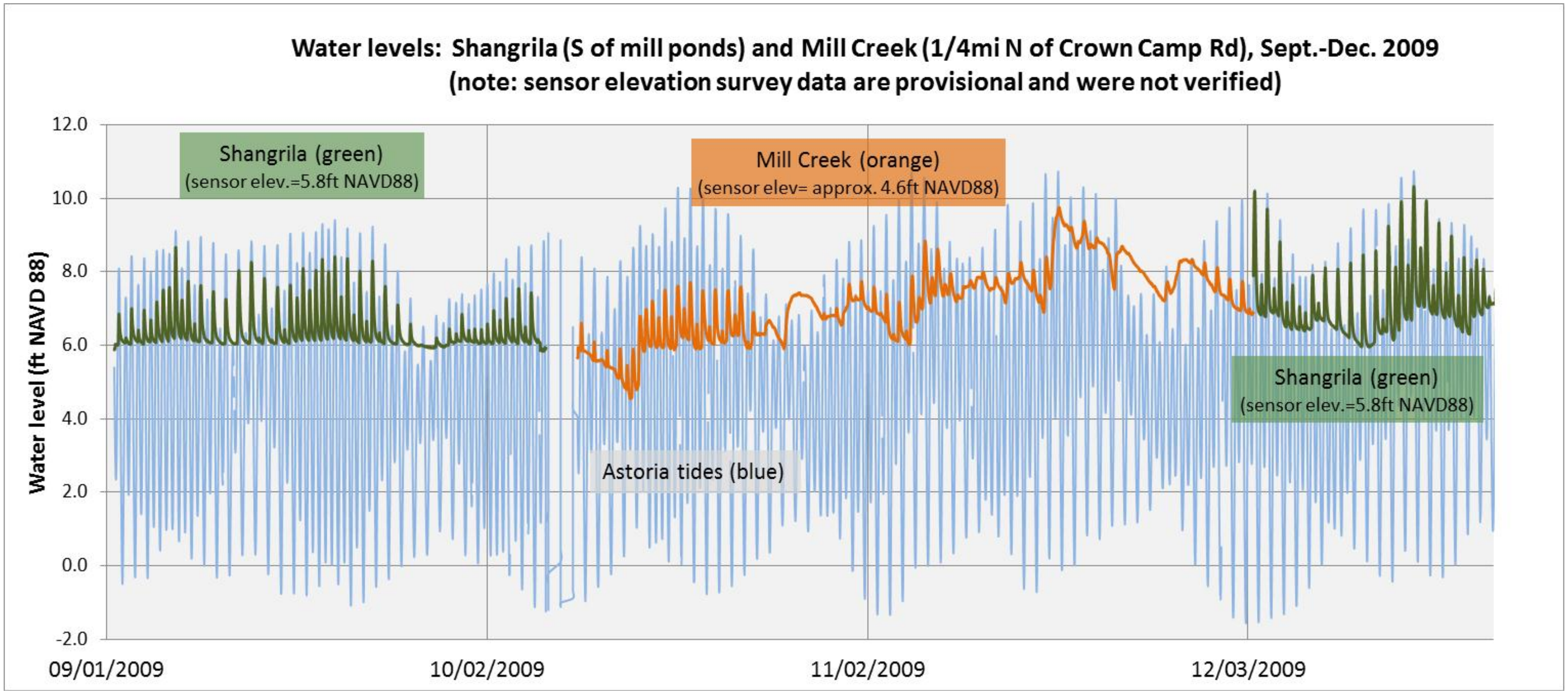


Figure 1. Water levels at tide gauges at Shangrila and Mill Creek relative to NAVD88, Sept.-Dec. 2009. Astoria tides are shown in blue for reference purposes. Tidal influence is strong at both sites. Nov.-Dec. flows in Mill Creek show a strong fluvial component (water levels are strongly affected by nontidal river streamflow). Shangrila remains strongly tidal during December, with peak tides ~3ft above base flows. *Note: Mill Creek water surface elevations are lower than expected; gauge elevation should be re-surveyed.*

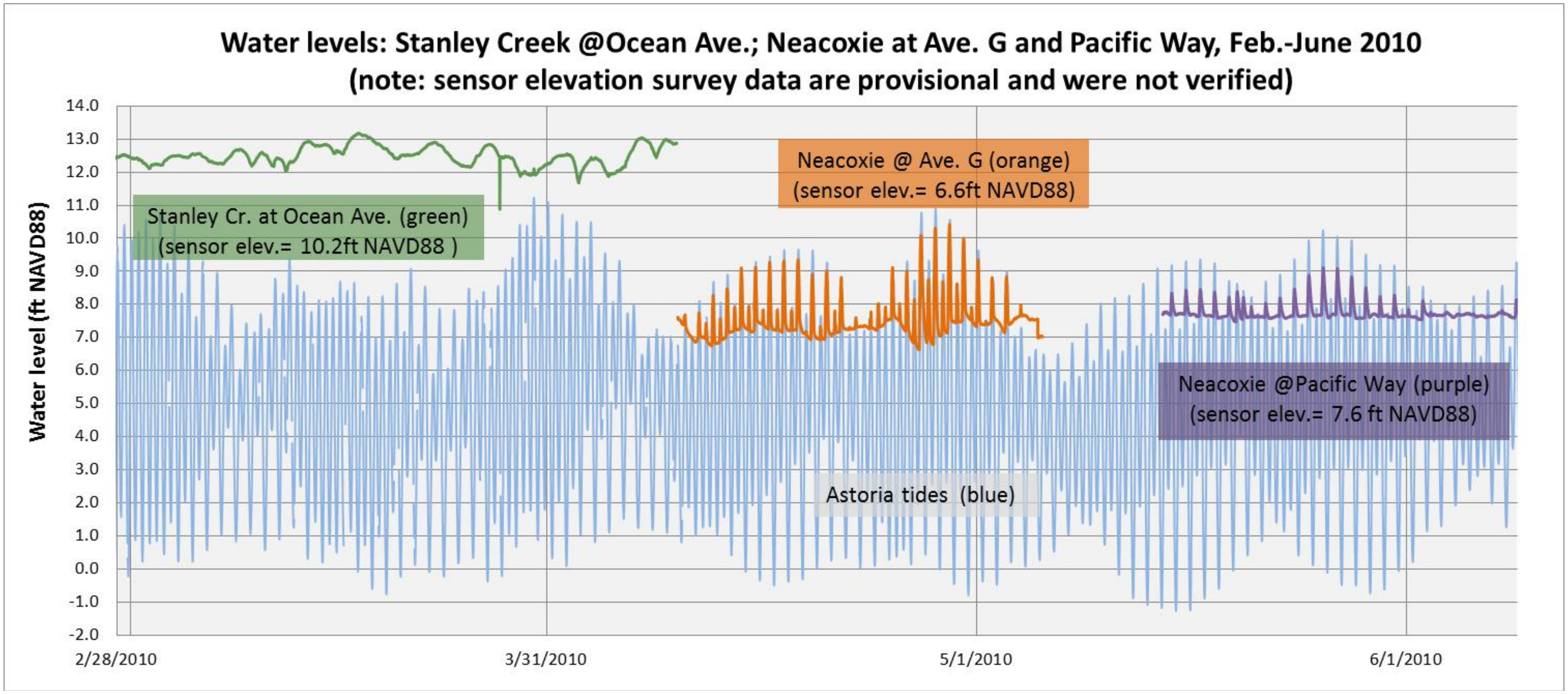


Figure 2. Water levels at gauges at Stanley Creek at Ocean Avenue, Neacoxie at Avenue G, and Neacoxie at Pacific Way, February through June 2010. Astoria tides are shown in blue for reference purposes. Tidal influence is absent at Stanley Creek during the period of record, but strong in the Neacoxie at Avenue G and Pacific Way. *NOTE: Sensor elevations were determined through laser level survey tied to benchmarks, but due to possible datum inconsistencies, geodetic elevations (relative to NAD88) are should be viewed with caution, and should be verified.*

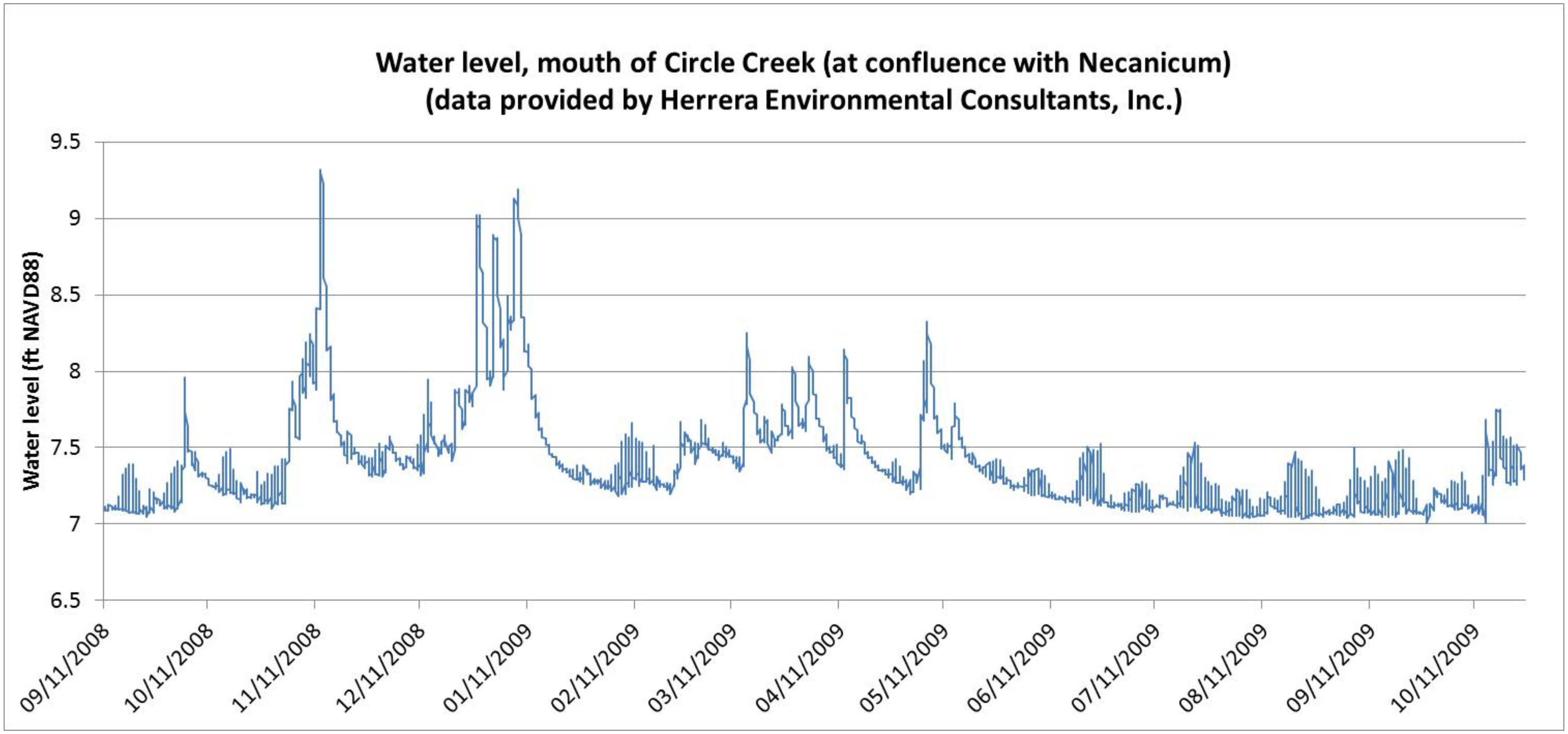


Figure 3. Water levels at the mouth of Circle Creek (at its confluence with the Necanicum River): Data collected and provided by Herrera Environmental Consultants as part of their hydrologic study of the Circle Creek property (Herrera Environmental Consultants 2010). Tidal influence is clearly seen during summer and fall, but the tidal effect is small (tide peaks are only about 6 inches above base flows). Fluvial effects (nontidal river flows) predominate during winter months.

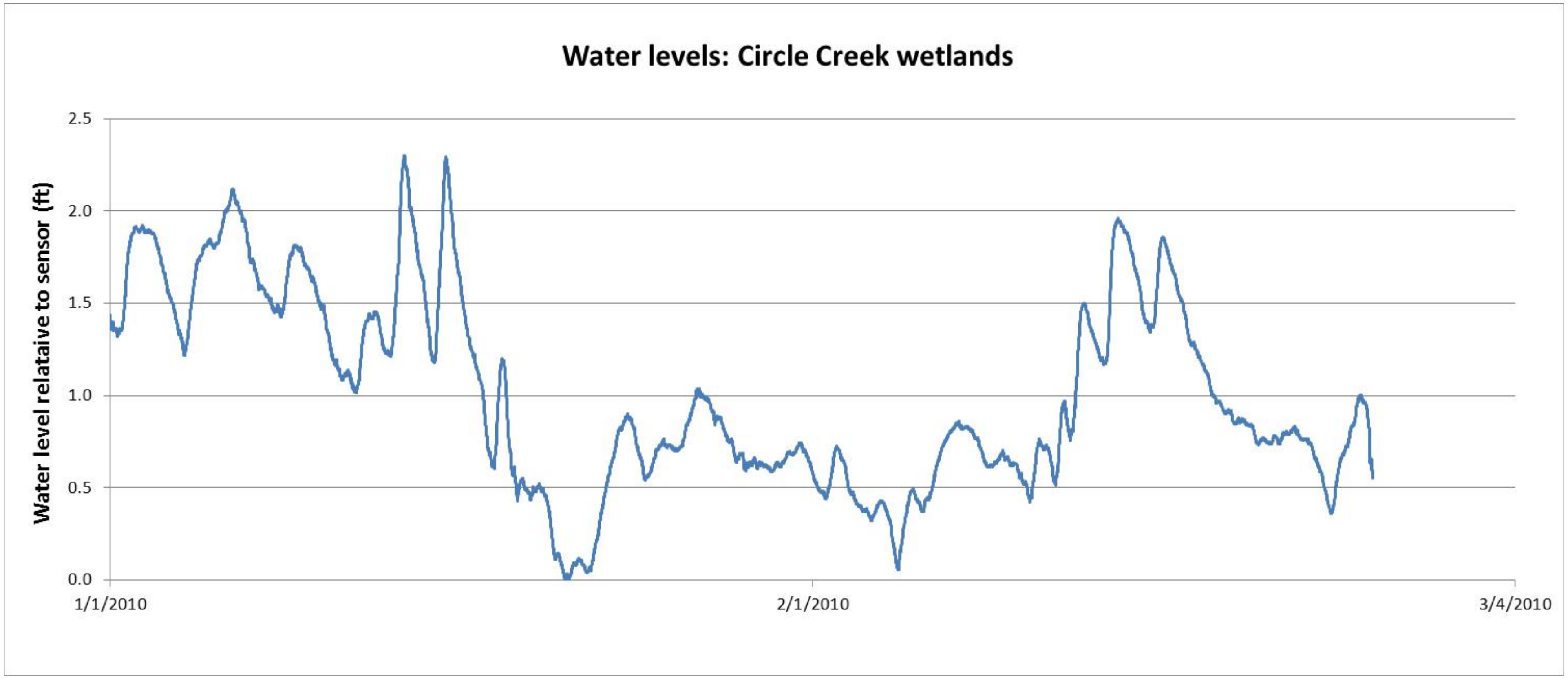


Figure 4. Water levels in the interior of the Circle Creek wetlands, relative to sensor. The NAVD88 elevation of this water level logger could not be surveyed due to its location in dense swamp. Tidal influence is not evident in these data.

Appendix 5. Restoration principles

Tidal wetland restoration is most likely to be successful if it follows basic principles of restoration design. The headings below are taken directly from the document, "Guiding ecological principles for restoration of salmon habitat in the Columbia River Estuary" (Simenstad and Bottom 2004). The text below each heading was written by this report's author (Laura Brophy) to address concerns specific to Oregon estuaries south of the Columbia River. These principles should be carefully incorporated into every restoration project.

Protect first – restore second

The immediate need for every current and former tidal wetland site in Oregon is protection of existing wetlands. This is particularly true for unaltered sites, but must also be considered for every altered site. Many former tidal wetlands are currently freshwater wetlands, and many are partially tidal ("muted tidal") wetlands. The balance of nontidal and tidal wetlands should be considered during each restoration project; ideally, no restoration should cause a net loss of wetland area or functions.

To conserve existing wetlands, the water sources, flow restrictions, and potential hydrologic effects of restoration actions must be carefully considered. In particular, freshwater wetlands formed by impoundment behind a tidal flow restriction (tide gate or restrictive culvert) should be carefully analyzed to determine the likely effects of removing the tide gate or upgrading the culvert. Tidal range outside the restriction must be compared to site elevations within the freshwater wetland, to ensure that restoration will in fact restore tidal wetland and not merely drain the current freshwater wetland.

Do no harm

In this assessment, restoration is defined as "return of an ecosystem to a close approximation of its condition prior to disturbance. ... Restoration is ... a holistic process not achieved through the isolated manipulation of individual elements" (National Research Council 1992). It is important to avoid manipulations that may harm existing wetland functions or prevent recovery of original functions. For example, some tidal wetland restoration projects have included construction of features (such as excavated ponds) that would not have been found in the wetland prior to human alteration. Pond excavation may provide more waterfowl habitat (a valued function), but may decrease foraging habitat and protective shelter for juvenile salmon. Excavation of ponds may also prevent recovery of the site's original hydrology, channel morphology, and associated functions such as nutrient processing and water temperature moderation.

Use natural processes to restore and maintain structure

Tidal wetlands are created by natural processes. The most distinctive and basic of these is tidal flow; examples of other natural processes include sediment and detritus deposition, freshwater input, groundwater flow, and nutrient cycling. The goal of restoration is to re-establish these natural processes where they have been altered by human disturbance. Restoration is generally more successful, more sustainable, and more cost-effective when it uses natural processes rather than engineered solutions (Mitsch 2000. Simenstad and Bottom 2004).

Restore rather than enhance or create

Enhancement is "the modification of specific structural features of an existing wetland to increase one or more functions based on management objectives, typically done by modifying site elevations or the proportion of open water" (Gwin *et al* 1999). Gwin goes on to state that "Although this term [enhancement] implies gain or improvement, a positive change in one wetland function may negatively affect other wetland functions." Enhancement should not be implemented if it results in a net loss of wetland functions or detracts from the main goal of restoration: to re-establish site conditions that existed prior to disturbance.

Wetland creation means making a wetland where one did not previously exist. By definition, wetland creation sites lack the natural processes that normally create tidal wetlands, so a much higher level of engineering is required to attempt to replicate those natural processes. Wetland creation may be unsuccessful and unsustainable, particularly in the long term, because it relies on human intervention and engineering rather than pre-existing natural forces (Mitsch 2000). Tidal wetland creation (making a new tidal wetland where tidal flow never existed previously) may even cause unexpected problems for other nearby tidal wetlands by altering the natural patterns of tidal flows. Hood (2004) documented offsite effects of diking, and similar offsite hydrologic responses might occur near areas excavated to form new tidal wetlands.

Incorporate salmon life history

Current research is rapidly expanding our knowledge of how salmon use Oregon's tidal wetlands, but our knowledge base is still very limited. To restore tidal wetlands for salmon habitat functions, a landscape approach is needed, focusing on connectivity of habitats and restoration of the full continuum of habitats needed by rearing and migrating juveniles. Some studies have suggested that the slightly brackish (oligohaline) zone of the estuary may be particularly important for osmotic transition, and may need to be strategically targeted for restoration (Simenstad and Bottom 2004). The oligohaline zone includes the tidal swamp habitat that is prioritized in this study.

Develop a comprehensive, strategic restoration plan

This study uses landscape-scale analysis and ecological principles to establish priorities for restoration – an approach that has been called "strategic planning for restoration." Strategic planning is preferable to "opportunistic restoration," which selects sites simply because they are available for restoration. Action planning subsequent to this study should continue to address ecosystem issues such as habitat interconnections, the effects of nearby (or distant) disturbance on project sites, and the relative scarcity of different habitats within the study area.

An important example of a strategic approach is combining tidal and nontidal wetland conservation and restoration actions. Sites in this study that have adjacent nontidal wetlands offer particularly valuable opportunities for protecting or restoring vital habitat connections and linkages and maximizing resilience to climate change. Planning for tidal wetland conservation and restoration should include adjacent nontidal wetlands and uplands whenever possible.

Use history as a guide, but recognize irreversible change

This study identifies all current and likely historic tidal wetlands. While most of these sites can probably be restored, some sites may be difficult to restore to their historic wetland type. Human land uses in the estuaries and their watersheds have caused long-term, estuary-wide changes. Examples include altered sediment and detritus deposition patterns; changed peak flows, water circulation patterns, and flooding regimes; and widespread fill, urbanization, and road building. These changes to the fundamental processes that historically created tidal wetlands may affect the “restorability” of some areas. In addition, subsidence (sinking of the soil surface) that occurs after diking and tidal disconnection can mean that former high marsh and tidal swamp sites restore to mud flats or low marsh rather than their original habitat types. Subsided sites may return to their original elevations through accretion of sediment, but the process may be very slow (Frenkel and Morlan 1991).

This study included all lands below highest measured tide at the nearest active NOAA tide station (Garibaldi). Some of these areas probably have infrequent tidal inundation – particularly areas distant from major tidal water bodies. However, the future may bring major changes in the form of sea level rise. Areas that are now inundated infrequently may become more frequently inundated in the near future. Therefore, it is important to consider not just historic conditions, but possible future conditions when planning conservation and restoration actions in the estuary. Onsite data collection (e.g. elevations relative to tidal and geodetic datums; tidal inundation; freshwater flows; and groundwater levels) will help inform site-scale and basin-scale climate change adaptation planning. These analyses are highly technical, so expert assistance is recommended.

Monitor performance both independently and comprehensively

Guidance from national and regional resource management agencies emphasizes that every tidal wetland restoration site should be monitored using established monitoring protocols (Simenstad *et al*. 1991, Zedler 2001, Thayer *et al.* 2005). Monitoring must begin before restoration is designed, because baseline information is very needed for critical design decisions. Monitoring should continue long after restoration to provide accountability for the restoration investment, to determine the effectiveness of the restoration actions, and to assist in adaptive management. Post-restoration monitoring is also needed to help guide future restoration efforts, because tidal wetland restoration is still very much a developing science. Development of an efficient, practical and effective monitoring program requires careful consideration of local and regional ecosystem characteristics, national and regional guidance and standards, and project goals. Expert assistance is highly recommended – as described below.

Use interdisciplinary science and peer review

Interdisciplinary technical assistance is needed for restoration design. Expertise may be needed in biology (such as botany and fish ecology), hydrology, geology, sedimentology, chemistry, statistics, engineering, and other fields. The best approach is to assemble an interdisciplinary advisory team as the first step in the site planning process – well before restoration design is begun. Such a team is invaluable in evaluating the biological soundness and technical feasibility of restoration goals, reviewing restoration alternatives, and designing the monitoring program.

Early consultation with the advisory team should establish baseline monitoring protocols, because baseline data are needed to develop a restoration design. Baseline monitoring will provide solid data on site characteristics critical to restoration design, such as site topography (elevations), tidal range, groundwater hydrology, current fish use, and plant communities (which are good indicators of long-term tidal and hydrologic conditions).

Appendix 6. Restoration approaches

This section provides some general considerations for tidal wetland conservation and restoration actions in the Pacific Northwest and Oregon in particular. Some of the topics, such as dike breaching, are more applicable to estuaries other than the Necanicum (where few tidal wetlands have been diked). However, review of these topics can still be useful to gain an understanding of general tidal wetland restoration approaches in Oregon. For all restoration projects, we recommend consultation with appropriate technical experts during early planning phases.

Permits and regulatory coordination

Restoration activities often require extensive coordination with many different regulatory agencies. Numerous permits and approvals may be needed, so it is important to start this process early to avoid unexpected obstacles or delays. Early contact with land use planning officials at the City, Port, County, and State levels is recommended to obtain comprehensive information. The Wetlands Program of the Oregon Department of State Lands, (503) 986-5200, can provide information about the process and recommended contacts.

Archaeological sites

Before European settlement, Oregon's estuaries were widely used by Native American peoples for dwellings, gathering places, and a source of livelihood. Therefore, every estuary restoration project should consider the possibility that there may be archaeological sites within or near the project area. State and federal laws prohibit destruction or disturbance of known archaeological sites. In the case of inadvertent discovery of cultural resources, state and federal laws require that the project be halted and the appropriate Tribe be contacted immediately. To understand the historic and cultural context of each site, and to avoid possible impacts to cultural resources, every restoration project should begin with consultation with the appropriate tribal groups.

Conservation and habitat linkages

The immediate need for every site in the study area is conservation of the existing wetlands. This is particularly true for the unaltered sites. Written landowner agreements for conservation (such as conservation easements and deed restrictions) are among the many useful tools for wetland conservation. At a minimum, current stewardship should be continued; additional conservation actions such as establishment of protective buffers may also be important to maintain existing functions. Many conservation and restoration sites offer good opportunities for education. School groups and local organizations can assist in planning, implementing, and monitoring conservation and restoration activities at tidal wetland sites. Public understanding leads to public support of wetland conservation.

It is important to identify and conserve adjacent nontidal wetlands as well as upland habitats when planning conservation at tidal wetland sites. The best conservation plans protect the linkages and connections that are vital to wetland and upland habitat functions. Protecting the gradient from tidal to nontidal wetlands may also help prevent loss of tidal wetlands in the event of sea-level rise due to sudden or gradual geomorphic or large-scale hydrologic change.

Dike breaching and dike removal

Although the Necanicum River estuary contains few dikes, many of Oregon's tidal wetlands have been diked to block tidal flows and allow conversion to pastures. Restoration in diked tidal wetlands generally includes dike breaching or dike removal. Dikes can be breached at selected locations, preferably at locations of former natural tidal channels. Alternatively, dikes can be removed completely, enhancing sheet flow, nutrient cycling and natural sedimentation patterns.

Dike breaching and removal can be technically challenging operations, with complex trade-offs in biological functions, hydrology, erosion and deposition patterns, costs, infrastructure issues, and engineering constraints. Techniques for successful dike breaching and dike removal are still evolving in Oregon, so early consultation with experts (such as wetland scientists, hydrologists, and engineers) is recommended before designing restoration.

Ditch filling and meander restoration

If a site has extensive ditching that has eliminated flow through meandering channels, ditch filling and meander restoration should be considered. Deep, winding, natural tidal channels with overhanging banks offer a higher quantity and quality of habitat for fish and other organisms, compared to shallow, broad, straight ditches. To redirect water through meandering remnant or restored channels, ditches may be filled or blocked. Ditch filling is generally more effective than plugging, because the relentless force of tidal ebb and flow will usually erode blockages placed in ditches (Brophy 2004, Cornu 2005). This is particularly true if the ditches are deeper than the remnant tidal channels – generally the case on grazing land where remnant channels are often filled with sediment and ditches are "scoured".

Partial excavation of meandering channels, preferably following visible or surveyed remnant channels, may speed the restoration process. However, excavation is not always recommended, and this process presents complex design questions and challenges. Excessive excavation of channels may dewater adjacent areas, much as ditching can. Input from experts (such as tidal wetland scientists, hydrologists, geomorphologists, and engineers) is required for this aspect of restoration.

If tidal action is strong at a site, excavation of remnant channels maybe unnecessary. "Self-design," in which water flows are allowed to create their own meandering path through processes of erosion and deposition, may be the best approach in many cases (Mitsch 2000). Self-design avoids the dilemma of water "not going where the engineers want it to go." Self-design also encourages diffuse flow of water across the site, which contributes to natural restoration of wetlands.

Culvert and tide gate upgrades

It can be difficult for basin-wide tidal wetland studies to assess conditions at specific tide gates and restrictive culverts. These structures cannot be directly viewed on aerial photographs, and they are difficult to characterize during brief field trips because they are often underwater at mid- to high tide, and/or hidden under dense overhanging vegetation.

During initial site-specific planning, careful evaluation is needed for all water inlets and outlets to and from candidate restoration or conservation sites. Measurements and observations should include:

- culvert invert elevations (the elevation of the bottom of the culvert above the streambed);
- the action of tide gates (free or impeded);
- differences in water levels at the upstream and downstream ends of culverts (at both high and low tide);
- impounded water on the upslope side;
- flow velocities relative to surrounding water bodies;
- other evidence of restricted or impeded water flow, including beaver activity.

Where existing culverts are impounding water on the upslope side, culvert upgrades might have unintended consequences such as loss of freshwater wetlands. If a proposed culvert upgrade might drain impounded wetlands, this loss should be balanced against the ecological benefits of the upgrade.

One restoration option is installation of "fish-friendly" tide gates, which increase fish access to streams and wetlands above the gate. Such devices may be a good choice where a landowner does not want to restore tidal flow. However, providing fish access to a site does not restore the ecological functions of tidal wetlands if tidal flow is still impeded. Tide gate removal (often accompanied by a culvert upgrade, or replacement of the culvert with a bridge) is a better option for restoration of the tidal wetland ecosystem, but the guidance above applies in all cases.

Water flow issues and property protection

Tidal wetland restoration usually alters surface water flows, and careful planning is necessary to ensure this does not damage property. Many tidal wetlands can be restored with no risk to adjacent properties, because restoration sites are often at a considerably lower elevation than nearby structures. However, it is still important to assess existing conditions and proposed changes to site hydrology and flow patterns when planning restoration. Particular attention should be paid to topography, elevations of buildings and infrastructure, tidal range, water table depths, and surface and subsurface water flow. Tidal range should be monitored or modeled during both normal and extreme events of tidal action, river or stream flow, and precipitation. The potential effects of water flow changes on nearby structures and properties should be carefully considered. Expert assistance should be sought from hydrologists and engineers experienced in the tidal zone.

Buffer establishment

Buffers around wetlands can greatly improve their functions by protecting habitats from sediment and nutrient-laden runoff, invasive species, fill intrusion, and other disruptive effects of human land uses. In addition, interfaces between wetlands and uplands are heavily used by many species of wildlife.

Buffer establishment around the margins of wetland sites should preferentially use native upland plantings. Native plantings require a weed control plan. Technical help from experts in native plant restoration and weed control is recommended.

Fill removal

The most expensive type of restoration is removal of large areas of fill material. Former wetlands that have been entirely filled were excluded from this study. Most of these areas have been converted to economically valuable uses – usually residential or commercial development, so they are not potential restoration sites. Even if a filled area has been abandoned from past economic uses, restoration via fill removal is very expensive and is also less likely to succeed, because the original soils are gone and there may be few native plant communities nearby to provide seeds and propagules for revegetation.

However, some sites have small areas of fill that could be removed to improve wetland functions. Old roadways that are no longer used, former home sites abandoned due to frequent flooding, and small areas of dredged material offer such opportunities.

Grazing reductions

Many coastal agricultural lands are used for pastures, and the resulting livestock production contributes to the local economy. However, livestock grazing alters plant communities and the physical structure of tidal and formerly tidal wetlands. Livestock degrade tidal channels, lowering the quality of fish habitat and altering water characteristics. Grazing compacts soils, leading to oxidation of soil organic matter and major changes in biological soil processes. Because grazing greatly reduces many wetland functions, removal or reduction of grazing is an important component of many tidal wetland restoration projects. The lowest, wettest portions of pastures may provide poor grazing and little economic return, so they are good candidates for grazing reductions and set-asides. Expansion of grazing set-asides beyond the boundaries of wetlands is also desirable, in order to establish upland buffers that enhance the biological functions of the wetland (see **Buffer establishment** above).