Modeling sea level rise impacts to Oregon's tidal wetlands: Maps and prioritization tools to help plan for habitat conservation into the future

Photos by Cinamon Moffett, 2011

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Prepared by:
Laura S. Brophy and Michael J. Ewald
Estuary Technical Group, Institute for Applied Ecology, Corvallis, Oregon

With assistance from:
Fran Recht, Pacific States Marine Fisheries Commission

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MidCoast Watersheds Council, Newport, Oregon

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Contents

Project Summary

Background: Tidal wetlands are important habitats for salmon and a diversity of other fish and wildlife species. They also trap sediment, buffer coastal communities from flooding and erosion, and perform other valued ecosystem services. Tidal wetlands currently exist just at and above sea level, and healthy tidal wetlands are able to adapt to slow sea level changes. But if sea level rises too fast, tidal wetland plant communities may not be able to persist at their current locations. To survive, these plants may have to move to areas of higher elevation. These higher areas are called "landward migration zones" ("LMZs"); they are potential future tidal wetlands under sea level rise ("SLR"). This project modeled and prioritized these LMZs. It was sponsored and supported by the MidCoast Watersheds Council (MCWC) and the Pacific States Marine Fisheries Commission and funded by the Oregon Watershed Enhancement Board and the U.S. Fish and Wildlife Service's Coastal Program.

Geographic scope: This project mapped LMZs for 23 estuaries on Oregon's coast south of the Columbia River. From north to south these are: Necanicum River, Nehalem River, Tillamook Bay, Netarts Bay, Sand Lake, Nestucca Bay, Salmon River, Siletz Bay, Yaquina Bay, Beaver Creek, Alsea Bay, Yachats River, Siuslaw River, Umpqua River, Coos Bay, Coquille River, New River Area, Sixes River, Elk River, Rogue River, Pistol River, Chetco River, and Winchuck River.

Modeling approach: This project used an elevation-based method (modified bathtub approach) to map current and future tidal wetlands. Elevation was obtained from LIDAR; projected SLR was obtained from recent, authoritative, and region-specific scientific literature. LMZs were modeled for six SLR scenarios that could be expected between now and the year 2160, but this study did not assume any specific timeframe for the scenarios modeled. Both lower and upper boundaries for LMZs were mapped, to allow determination of areas that would be lost due to conversion to mudflat under each SLR scenario.

Wetland types mapped: This project mapped potential future tidal wetlands in three vegetation classes: marsh, shrub and forested. We did not attempt to map the specific locations of each vegetation class, because the necessary data are not yet available. The study did not map seagrass beds, because their distribution is controlled not just by elevation, but also by other factors like water clarity and substrate type. However, the mapping does show areas that transition from vegetated tidal wetland to mudflat with rising sea level.

Diked and developed areas: The mapped LMZs are at appropriate elevations to support vegetated tidal wetlands, but may currently lack a connection to tidal waters (e.g. they might be behind a dike or tide gate). Mapping these areas helped identify lands vulnerable to SLR. The LMZ mapping did not exclude developed areas such as roads, parking lots, urban, industrial, or residential areas. Developed areas within LMZs may be at risk for inundation under SLR, but they are not likely to be suitable as future tidal wetlands. We accounted for developed areas by separately summarizing the area of LMZs on impervious versus non-impervious surfaces.

Sediment accretion: This study's LMZ maps did not account for rates of sediment accretion (although results were compared to models that do account for sediment accretion). Accretion is an important factor, but data on variability in accretion rates on the Oregon coast are lacking. Local groups may wish to incorporate local accretion data when interpreting study results.

Products: This study's products include a PDF map of the 4.7 ft SLR scenario for each estuary; a PDF prioritization map based on the 4.7 ft SLR scenario for each estuary; a presentation that explains the project and its products; a project flyer; and geospatial data (shapefiles of LMZs for the six SLR scenarios modeled, and a shapefile containing prioritization data and results). Products are available from MCWC: http://www.midcoastwatersheds.org/.

INTRODUCTION

Tidal wetlands are important habitats for salmon and a diversity of other fish and wildlife species. Tidal wetlands also provide a variety of other valued ecosystem services, such as trapping sediment, buffering coastal communities from flooding and erosion, and removing pollutants from surface water. With their winding, quiet channels, these wetlands are also popular for recreation, from fishing to kayaking and birdwatching. Appendix I contains more information on the importance of tidal wetlands.

Tidal wetlands are found around and slightly above sea level. These wetlands have a built-in capacity to adjust to sea level through accumulation of sediment and soil organic matter (Morris 2002). However, if sea level rises too fast or too far, these wetland ecosystems may not be able to persist at their current locations (Schile et al 2014). If tidal wetland plant communities are unable to survive the increased inundation associated with sea level rise, they will have to move to higher ground through dispersal of seeds, roots, or rhizomes. This process is called "landward migration," and the areas that could become future tidal wetlands are called “landward migration zones” (LMZs) in this study.

GOALS AND OBJECTIVES

The goal of this project is to assist coastal watershed councils, planners, resource managers and others in their efforts to ensure valued tidal wetland ecosystem services are sustained in the face of projected climate change. The project's objectives are: 1) map and summarize the area of LMZs (potential future tidal wetlands) for six sea level rise (SLR) scenarios within 23 estuaries on Oregon's outer coast; and 2) provide tools to help coastal groups set priorities among the mapped LMZs for conservation and restoration actions.

METHODS OVERVIEW

Decisions on the methods for this project were informed by the available budget, desired geographic scope, timeline, and project goals. Major components of the methods are described below; for more details on methods decisions and associated limitations of the study, see "**Discussion**" below, and metadata for the geospatial products (shapefiles).

<u>Geographic scope:</u> This study mapped LMZs for 23 estuaries on Oregon's outer coast south of the Columbia River (Figure 1). From north to south, these 23 estuaries are: Necanicum River, Nehalem River, Tillamook Bay, Netarts Bay, Sand Lake, Nestucca Bay, Salmon River, Siletz Bay, Yaquina Bay, Beaver Creek, Alsea Bay, Yachats River, Siuslaw River, Umpqua River, Coos Bay, Coquille River, New River Area (Twomile Creek South, Fourmile Creek, New River, Floras Creek), Sixes River, Elk River, Rogue River, Pistol River, Chetco River, and Winchuck River.

Sea level rise scenarios: This study mapped LMZs that could potentially become tidal wetlands (tidal marsh or tidal swamp) under six SLR scenarios that could occur between now and the year 2160. These scenarios were selected from projections provided by the 2012 West Coast Sea Level Rise study (NRC 2012), plus two additional scenarios within the range projected by a more recent NOAA report (NOAA/NOS 2017). For comparison to these six SLR scenarios, we also mapped "baseline LMZs" (no SLR), representing the extent of tidal wetlands at the time of this report.

Vegetation types: Tidal wetlands in Oregon fall into five broad classes: mudflats, aquatic beds (seagrasses, algae beds), emergent tidal wetlands (also called "salt marsh" and "tidal marsh"); shrub-dominated tidal wetlands ("scrub-shrub tidal swamp"), and forested tidal wetlands ("forested tidal swamp"). Consistent with the Oregon Watershed Enhancement Board's Estuary Assessment Method (Brophy 2007), this study focused on tidal marsh and tidal swamp (emergent, shrub and forested tidal wetlands), which share many management concerns and conservation/restoration strategies. **For simplicity, we refer to emergent, shrub and forested tidal wetlands as "vegetated tidal wetlands" or "tidal marsh and tidal swamp" in this report.** We did not map these vegetation types separately within the LMZs, because that would require detailed data on current and future salinity regimes, and that data is lacking (see "**Data gaps and recommendations for further analyses: Salinity**" below). This study also did not map seagrass beds or mudflats under SLR scenarios, but see "Eelgrass beds" below for a discussion of potential SLR effects on these wetland types.

Downslope losses: Sea level rise has two main effects on the locations of tidal wetlands in the landscape. On the upslope side, tidal wetlands may move towards higher ground as described above. On the downslope side, former tidal marsh and tidal swamp may convert to mudflats or other non-vegetated habitats once inundation is too frequent and too deep for the vegetation to survive. This project indirectly identified these "downslope losses;" they are the areas that were mapped as LMZs at lower SLR scenarios, but are no longer mapped as LMZs at higher SLR scenarios. For example, downslope losses at 4.7 ft SLR are shown on each estuary's "Current vs. 4.7 ft SLR LMZ" map (see "**Products**" below; see Appendix A, Map A1 for an example).

Flow barriers (dikes, tide gates, etc.): LMZs mapped in this study are at elevations appropriate for development of tidal marsh or tidal swamp (shrub or forested tidal wetlands), but they may currently be disconnected from tidal influence by flow barriers such as dikes, tide gates, roads, railroads, or fill material. In other words, the mapped LMZs are areas that would likely form vegetated tidal wetlands, if they were connected to the tides. Mapping these disconnected areas helps identify potential areas for restoration of tidal connections; this mapping also identifies areas that may be vulnerable to inundation under future SLR scenarios, if dikes or other barriers fail.

Developed areas: This project's LMZ mapping did not exclude developed areas such as roads, parking lots, urban, industrial, or residential areas. These areas were included in the maps because they are potentially vulnerable to flooding under the SLR scenario depicted. However, developed areas (as represented by impervious surfaces) were "blacked-out" in the prioritization maps to indicate they are unsuitable as potential future tidal wetlands. For more detailed information on developed areas and infrastructure at risk due to SLR, see the Oregon Coastal Management Program's (OCMP's) Sea Level Rise Exposure Inventory (OCMP 2017, http://www.coastalatlas.net/index.php/tools/planners/68-slr).

Sediment accretion: This study's scope did not include evaluation of sediment accretion rates or their effect on persistence of tidal wetlands at their current locations. In general, higher rates of sediment accretion would be expected to reduce or delay the impacts of sea level rise. Although sediment accretion is clearly an important factor in tidal wetland responses to sea level rise (Morris 2002, Schile et al. 2014, Thorne et al. 2015), detailed data on variability in sediment accretion rates across the Oregon coast are currently lacking. Local groups may wish to incorporate their own site-specific data when interpreting the results of this study. To provide some preliminary insight into this issue, we compared our study results to models that did account for accretion (see "**Comparison to other models**" below).

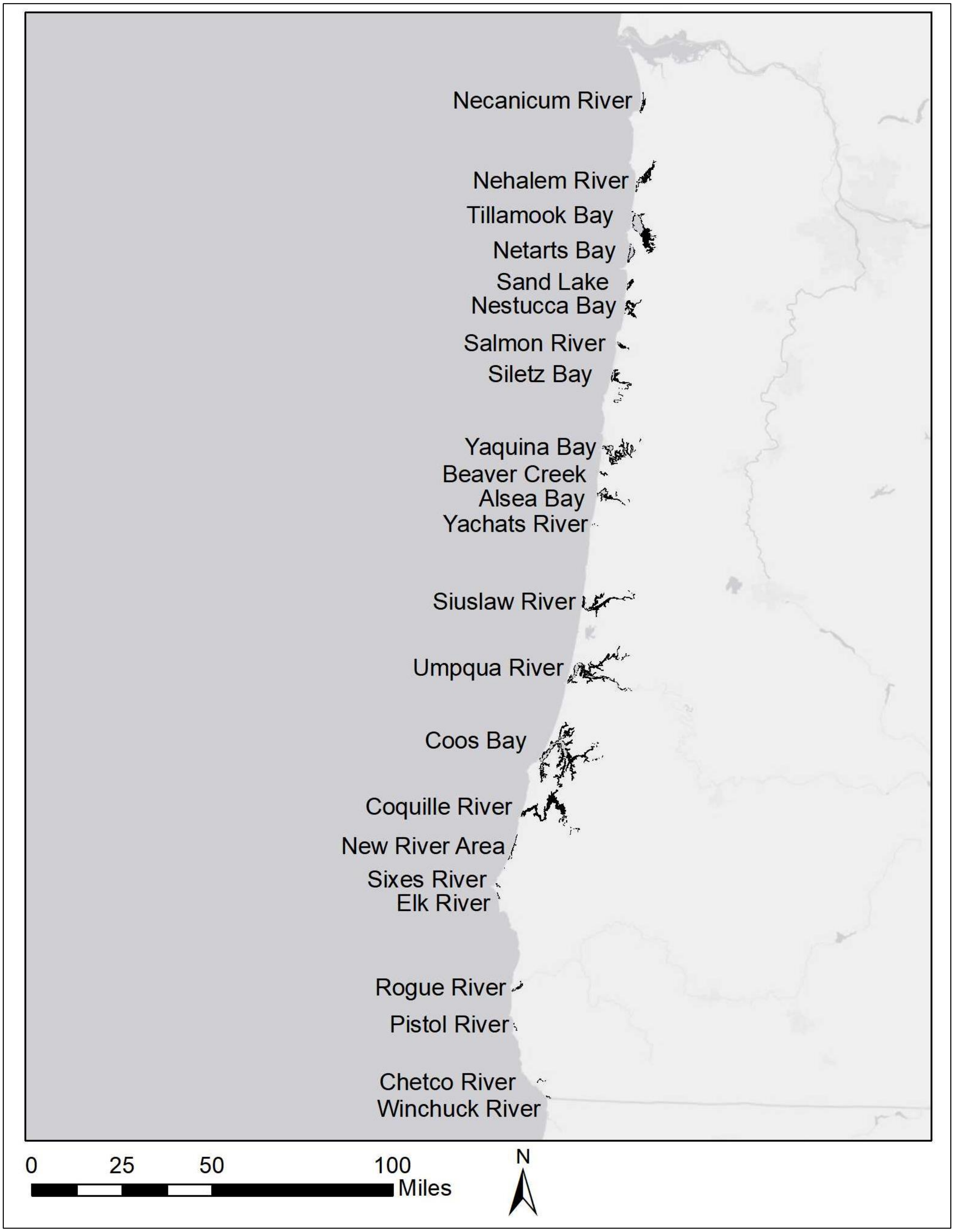

Figure 1. Oregon estuaries covered in LMZ mapping

MAPPING COMPONENTS

Current extent of tidal wetlands

The starting point for mapping future tidal wetlands is an accurate map of current tidal wetlands. For this project's baseline mapping (0 ft SLR), we used the same methods as recently updated estuary habitat maps generated by the Oregon Department of Land Conservation and Development (DLCD) (Lanier et al. 2014). Rather than directly using the DLCD products, however, we adapted the mapping to focus specifically on the area that is currently within the appropriate elevation range for vegetated tidal wetlands. The boundaries we used to map this area are described in "**Mapping boundaries**" below.

Landward migration zones ("LMZs")

This project mapped upslope areas that could become future tidal wetlands as sea level rises ("landward migration zones" or "LMZs"). These areas are at a suitable elevation to become vegetated tidal wetlands under each sea level rise (SLR) scenario (i.e. they are between the lower and upper boundaries described in "Mapping boundaries" below, for the specific SLR scenario). We used a modified "bathtub" approach to mapping: by mapping both the lower and upper boundaries for LMZs, maps show not just potential future tidal wetlands upslope, but also downslope losses where tidal wetlands convert to mudflat.

Conversion to mudflats

On the downslope side, the mapped LMZs exclude areas too low to support vegetated tidal wetlands (tidal marsh or tidal swamp). Therefore, although mudflats are not explicitly mapped, the map products can be used to locate "downslope losses," which are areas that would probably convert from tidal marsh or tidal swamp to mudflats, aquatic beds or open water under each SLR scenario. In map products, these are the areas that were mapped as LMZs in the baseline scenario (0 ft SLR) but are no longer mapped as LMZs at higher SLR scenarios. In tables of LMZ area (Appendix C, Tables C1-C4), these areas are represented by reductions in LMZ area compared to baseline.

Impervious surfaces

Within the LMZs, we identified areas located on impervious surfaces. To do this, we intersected the LMZs with the impervious surfaces layer provided by the Oregon Coastal Management Program (OCMP). The impervious surfaces dataset was produced at OCMP by sub-setting the Oregon coastal zone from a national raster dataset of impervious surfaces (Xian et al. 2011).

MAPPING BOUNDARIES

Lower boundary for LMZs

This study's lower boundary for mapped LMZs was Mean Tide Level (MTL), obtained from NOAA tide stations and incremented upwards using the SLR scenarios. This boundary was based on our team's field observations of the lower boundary of tidal marsh, as well as literature (Warren Pinnacle Consulting, Inc. 2012; Thorne et al. 2015). Areas below MTL are generally unvegetated (mudflats, aquatic beds, or channels). MTL values for each estuary were obtained from NOAA tide stations and adjusted as described in "**Tidal datum adjustments within estuaries**" below.

In the baseline LMZs (0 ft SLR), we removed (masked out) non-vegetated mudflats and aquatic beds located above MTL, because areas that are currently too low to be vegetated are very likely to remain non-vegetated with SLR. The non-vegetated mudflats and aquatic beds were obtained from the Geoform Component and Biotic Component (respectively) of estuary habitat mapping developed by the Oregon Coastal Management Program (OCMP), Oregon Department of Land Conservation and Development (Lanier et al. 2014), with some corrections based on our knowledge of the estuaries. In the baseline LMZs, we also included current vegetated tidal wetlands located below MTL (mainly tidal marsh in bay fringe settings), as mapped by the OCMP (Lanier et al. 2014), again, with some corrections based on our knowledge of the estuaries. These steps aligned the baseline mapping with the extent of current tidal wetlands, improving accuracy for calculations of change in tidal wetland area under SLR scenarios.

Upper boundary for LMZs

This study's upper boundary for mapped LMZs was the 50% exceedance elevation, obtained from NOAA's Extreme Water Level (EWL) modeling (https://tidesandcurrents.noaa.gov/est/) and incremented upwards using the SLR scenarios. This is the same boundary used in the 2014 OCMP Estuary Habitat Mapping project (Lanier et al. 2014; details of this method are provided in www.coastalatlas.net/documents/cmecs/EPSM_CoreGISMethods.pdf). Linear regression was used to derive 50% exceedance values for estuaries between NOAA's EWL stations. The 50% exceedance elevation was expressed as an increment above Mean Higher High Water (MHHW). MHHW values for each estuary were obtained from NOAA tide stations and adjusted as described in "**Tidal datum adjustments within estuaries**" below.

Tidal datum adjustments within estuaries

NOAA's VDatum tool (https://oceanservice.noaa.gov/facts/vdatum.html) allows users to determine the elevations of tidal datums at different locations within an estuary. VDatum was used to determine local values for relevant tidal datums (MTL, MHHW) within each estuary for this project. This method adjusted both the lower and upper boundaries for LMZs, because MTL is directly referenced in VDatum, while the 50% exceedance value for each estuary was added as a constant increment above MHHW (and MHHW is directly referenced in VDatum). These are the same methods used for OCMP's 2014 Estuary Habitat Mapping (Lanier et al. 2014).

TOPOGRAPHIC DATA

DOGAMI LIDAR digital elevation model (DEM)

LIDAR (Light Detection and Ranging) is a remote sensing method that can be used to generate high-accuracy topographic data in the form of Digital Elevation Models (DEMs). We used the LIDAR DEM provided by Oregon's Department of Geology and Mineral Industries (DOGAMI) for land surface elevations in this project. We also obtained data from NOAA DEMs where needed (see "**NOAA topobathy data**" below).

NOAA topobathy data

Some parts of the lower bays were inundated above MTL when the DOGAMI LIDAR was obtained, preventing construction of a continuous lower boundary for LMZs based on MTL. To address this problem, we obtained combined topography/bathymetry ("topobathy") data from NOAA (https://www.ngdc.noaa.gov/mgg/inundation/tsunami/). Within non-vegetated mudflats and aquatic bed habitats in the lower bays, we chose the lower of either the DOGAMI or NOAA DEMs as our elevation source, improving the accuracy of the MTL boundary.

SEA LEVEL RISE SCENARIOS

We mapped "baseline LMZs" (areas within the appropriate elevation range for vegetated tidal wetlands at the time of this report) and LMZs for six SLR scenarios: 0.8 ft (9 in = 23 cm), 1.6 ft (48 cm), 4.7 ft (1.42 m), 2.5 ft (75 cm), 8.2 ft (2.5 m), and 11.5 ft (3.5 m) above current sea level (Table 1). The 0.8 ft, 1.6 ft and 4.7 ft scenarios represent the upper end of the projected range of SLR for the years 2030, 2050 and 2100 respectively, for Newport, Oregon, provided by the West Coast Sea Level Rise Study (NRC 2012). The 2.5 ft scenario was selected to provide an intermediate point between the 1.6 ft and 4.7 ft scenarios. The 8.2 ft and 11.5 ft scenarios were selected to provide insight into possible future conditions beyond 4.7 ft (1.42 m) SLR, since sea level is unlikely to stop rising at that point. Based on the West Coast Sea Level Rise Study (NRC 2012) and additional new NOAA data (NOAA/NOS 2017), the 2.5, 8.2 and 11.5 ft scenarios represent intermediate-high SLR scenarios for the years 2070, 2130 and 2160 respectively.

Table 1. SLR scenarios used for LMZ mapping

English units	Metric units
0 ft (baseline or "initial condition")	0.00 m
0.8 ft (9 in)	0.23 m
1.6 ft	0.48 m
2.5 ft	0.75 m
4.7 ft	1.42 m
8.2 ft	2.50 m
11.5 ft	3.50 m

PRIORITIZATION

Overview

Working with a single SLR scenario – the 4.7 ft (1.42 m) scenario – we analyzed data on five factors that influence the importance and feasibility of conserving or restoring land within LMZs. We scored each factor and summed the scores for a total score. The total score and the underlying individual scores may be useful to local groups as they set priorities for actions within their estuary. The five factors are:

- Area of the LMZ at the 4.7 ft (1.42 m) SLR scenario
- Area of higher LMZs at the 8.2 ft (2.5 m) and 11.5 ft (3.5 m) SLR scenarios
- Land management (public vs. private)
- Generalized land use zoning
- Development status (number of structures)

We chose the 4.7 ft (1.42 m) SLR scenario as the basis for the prioritization for two reasons:

1) Across many estuaries, this was the earliest scenario that showed a very distinct change in distribution of tidal wetlands compared to the current time;
2) It represents a fairly long-range planning horizon, allowing adequate time for coastal groups to develop strategic plans and consider the range of potential approaches to conserving and restoring tidal wetland resources.

Analysis units (coastal catchments)

Any geographic prioritization requires careful selection of “analysis units” -- the geographic units within which prioritization factors (criteria) are summarized and scored. For a wetland study such as ours, the analysis units should be based on hydrologic connectivity; an example would be a “catchment” or “subwatershed” based on topography. The smallest available catchments for the Oregon coast were the National Hydrographic Dataset (NHDPlus V2) "coastal catchments" (URL: https://www.epa.gov/waterdata/nhdplus-pacific-northwest-data-vector-processing-unit-17. NHD Plus V2 catchments are smaller than and nest within HUC12 drainages, which are the smallest HUCs published in the national Watershed Boundary Dataset (USGS 2017). The specific file for the analysis units is: https://s3.amazonaws.com/nhdplus/NHDPlusV21/Data/NHDPlusPN/NHDPlusV21_PN_17_NHDPlusCatchment_02.7z. Since these were the smallest defined catchments for the Oregon coast, they provided the maximum resolution for our prioritization.

The LMZs for the 4.7 ft (1.42 m) SLR scenario were subdivided by these analysis units (NHDPlus V2 catchments); the resulting map features were referred to as "LMZ Units" (see "Score normalization" below). A few small areas of LMZs were located completely outside the catchments; these were omitted from the prioritization, since they were largely beach front areas and not actually within the estuaries.

Source data and scoring methods

Five criteria were scored for the prioritization, and scores for all five were normalized as described in "Score normalization" below:

1. Area of the LMZ: This shows the area of the LMZ Unit; it was obtained from LMZ Unit shapefile for the 4.7 ft (1.42 m) SLR scenario. LMZ Units with large LMZ area scored higher.

2. Further LMZ area: summed nonoverlapping area of LMZs within the subwatershed (NHDPlus V2 catchment) for both the 8.2 ft (2.5 m) and 11.5 ft (3.5 m) SLR scenarios combined. LMZ Units with more "further LMZ area" scored higher.

3. Land ownership (land management): 2015_LandManagementDraft.gdb downloaded 2016-09-11 11:11 am from http://www.odf.state.or.us/gis/data/Ownership/2015_LandManagementDraft.gdb.zip. From the metadata (at http://spatialdata.oregonexplorer.info/geoportal/rest/document?id=%7B9B644E0F-7A7D-4124-A50F-6B35C05626AE%7D): "*This data layer is an element of the Oregon GIS Framework. Land Management derived from BLM Ownership_poly: This theme portrays information representing fee land title and land manager of lands located in Oregon.*" LMZ Units with a greater areal proportion of public ownership scored higher. For details on scoring for this criterion, see Appendix D.

4. Zoning: zoning.zip downloaded 2016-09-11 12:53 am from http://navigator.state.or.us/sdl/data/shapefile/k100/zoning.zip. From the metadata: "*Generalized Zoning Coverage for the state of Oregon. The coverage is digitized from data collected from 1983 through 1986. Limited zoning changes have occurred since this* *time. This dataset represents the best STATEWIDE zoning coverage available for the state of Oregon."* LMZ Units with a greater areal proportion of non-developed zoning categories scored higher. For details on scoring for this criterion, see Appendix E.

5. Development status: We used a layer of structures derived from coastal LIDAR, provided by the Oregon Coastal Management Program. Since the LIDAR data were acquired in 2009, the structures data are also dated 2009. Although not current, these were the only comprehensive data available at the time of our study on number of structures, a suitable metric of development status. LMZ Units with fewer buildings scored higher.

Scoring:

Score	# of buildings
5	0
4	1-2
3	3-5
2	6-10
1	>10

Score normalization

For each factor (criterion), scores were normalized to a scale of 1 to 5. Normalization allows comparison of factors that may have very different absolute values.

Normalization was done both within each estuary (to allow comparison of LMZ Units within that specific estuary, regardless of the scores in other estuaries), and across all 23 estuaries (to allow comparison of scores across the whole coast).

Normalized scores were calculated as follows:

Method 1 (within each estuary):

$$\left\{4 * \frac{\text{(LMZ Unit value)} - \text{(minimum value for all LMZ Units in estuary)}}{\text{(maximum value for all LMZ Units in estuary)} - \text{(minimum value for all LMZ Units in estuary)}}\right\} + 1$$

Method 2 (across the 23 major estuaries):

$$\left\{4 * \frac{\text{(LMZ Unit score)} - \text{(minimum value for all LMZ Units across all 23 estuaries)}}{\text{(maximum value for all Units across all 23 estuaries)} - \text{(minimum value for all Units across all 23 estuaries)}}\right\} + 1$$

Total score

Total score was calculated as follows: The normalized scores for all factors (criteria) were added; the "further LMZ area" score was double-weighted to emphasize this very important factor (available space for potential future wetland migration). The highest possible total score was therefore 30 (five factors, each with a maximum score of 5 = 25; plus double weighting for "further LMZ area" = 30).

Ranking groups

Ranking groups were determined using the "Jenks natural breaks" algorithm within ArcGIS. This algorithm divides data into classes based on natural groups in the data distribution.

Within-estuary ranking groups were assigned based on scoring for the individual estuary, so that they reflect the range of scores within that estuary. Across-estuary ranking groups were based on the scores across all estuaries, so they reflect the ranking of a specific LMZ unit compared to all units on the entire Oregon outer coast. Across-estuary rankings were not used in the maps and did not tend to differ greatly from the within-estuary rankings; however, across-estuary rankings are available in the shapefiles and Excel tables (see "**Products**" below).

RESULTS

Maps

The main products from this study are the maps (GIS shapefiles and PDF maps). GIS products and online access URLs are listed in "**Products**" below. PDF maps and online access URLs are also listed in Products below; the PDF maps are described below.

Two sets of PDF maps were produced: "Current vs. 4.7 ft SLR LMZ maps" and "4.7 ft SLR LMZ prioritization maps." Example PDF maps are provided in Appendix A (Maps A1 and A2).

Current vs. 4.7 ft SLR maps
These maps show LMZs at 4.7 ft SLR, versus areas currently within vegetated tidal wetland elevation range. Each map covers one estuary (2 for the Coos Bay estuary). Colors and symbols show whether mapped areas are at elevations appropriate for tidal wetlands (emergent, shrub or forested), even if they are not currently tidal wetlands (for example, the areas depicted might be behind a dike or tide gate). That is, colors and symbols show whether the mapped areas would likely be vegetated tidal wetlands, if they were reconnected to the tides (and not in developed land uses). Four sets of colors and symbols show the following:

- Yellow areas: Potential future tidal wetlands at 4.7 ft SLR (the LMZ at 4.7 ft LMZ)
- Yellow, crosshatched areas: Areas currently within vegetated tidal wetland elevation range that would remain vegetated at 4.7 ft SLR
- Blue, crosshatched areas: Areas currently within vegetated tidal wetland elevation range that would convert to mudflat or open water at 4.7 ft SLR
- Solid blue areas: Areas that are currently mudflat or open water, or at an elevation below Mean Tide Level

These maps are useful for understanding how wetland locations will shift under 4.7 ft SLR; and provide clear visualization of areas that would probably convert to mudflat with 4.7 ft SLR.

4.7 ft SLR LMZ prioritization maps

These maps show prioritization ranking groups (high, medium-high, medium, medium-low, and low) for all LMZ units. Developed areas (impervious surfaces) are blacked-out. Each map covers one estuary (2 for the Coos Bay estuary). These maps can help support decisions on where to focus efforts to conserve and restore native habitats within potential future tidal wetlands (LMZs). Differences of one ranking group should not be considered significant; and it is important to remember that local communities may choose to use additional (or different) criteria to support their decisions on where to focus their actions.

Area of LMZs across SLR scenarios

The LMZ area values summarized below include only those portions of LMZs found on non-impervious surfaces (which are more likely to provide tidal wetland functions). Bar charts showing patterns of LMZ area across SLR scenarios by individual estuary are found in Appendix B. LMZ area (acres) and percent loss of LMZs by SLR scenario for all 23 estuaries are shown in Appendix C, Tables C1-C4.

General pattern across estuaries

Summed across all estuaries studied, projected LMZ area (potential tidal wetland area) rises slightly during the three lowest SLR scenarios (0.8 to 2.5 ft) as tidal inundation spreads onto slightly higher land surfaces (Figure 2, Table 2). Starting at the 4.7 ft SLR scenario, LMZ area declines sharply, with 21% loss at 4.7 ft, 45% loss at 8.2 ft, and 60% loss at 11.5 ft (Figure 2, Table 2).

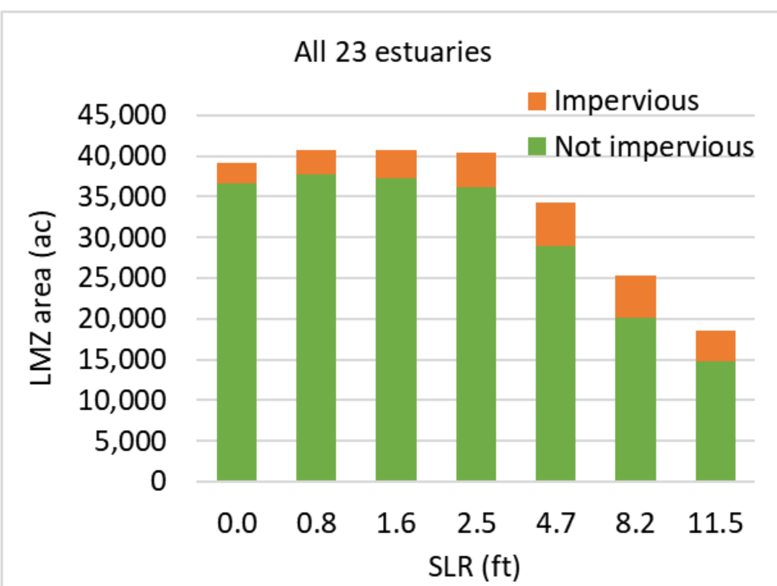

Figure 2. Change in LMZ area by SLR scenario

Table 2. Change in LMZ area by SLR scenario across all 23 estuaries (non-impervious surfaces)

	SLR scenario (ft)						
	0.0	0.8	1.6	2.5	4.7	8.2	11.5
Area (ac)	36,657	37,694	37,197	36,164	28,922	20,074	14,768
% change	0%	3%	1%	-1%	-21%	-45%	-60%

Projected losses are greater for the larger estuaries. Summing across the 13 estuaries with baseline LMZ area over 247 ac (100 ha), 32% of potential tidal wetland area is lost at 4.7 ft SLR, and over 2/3 of potential tidal wetland area is lost at 11.5 ft SLR (Table 3).

Table 3. Change in LMZ area, summed across the 13 largest estuaries (baseline LMZ >100 ha), by SLR scenario (non-impervious surfaces only)

	SLR scenario (ft)						
	0.0	0.8	1.6	2.5	4.7	8.2	11.5
Area (ac)	35,968	36,530	35,449	33,612	24,455	14,949	11,398
% change	0%	2%	-1%	-7%	-32%	-58%	-68%

Estuaries that follow the general pattern of LMZ change
Within individual estuaries, the most common pattern of LMZ change across SLR scenarios was the one described above ("**General pattern across estuaries**"), with projected LMZ area rising slightly during the lower SLR scenarios, then declining sharply at mid- to high SLR scenarios. Examples of this pattern include the Alsea Bay, Nestucca Bay, Tillamook Bay, Umpqua River, Nehalem River, Beaver Creek, Salmon River, Sand Lake, and Netarts Bay estuaries (Appendix B, Figure B1).

Estuaries with continuous LMZ losses across all SLR scenarios
The two estuaries with the most confined river valleys show early and continuous losses across all SLR scenarios. These include the Coos Bay estuary and the Yaquina River Estuary (Appendix B, Figure B1).

Estuaries with major gains in LMZ area
A few estuaries show striking gains in LMZ area with SLR. For example, the New River area (called "Twomile Creek South, Fourmile Creek, New River, Floras Creek" in OCMP mapping) shows a 20-fold increase in LMZ area at 4.7 ft SLR (1861 ac, compared to only 81 ac at baseline), and LMZ area continues to increase until the 11.5 ft SLR scenario, when it drops sharply (Appendix B, Figure B1). However, the degree to which future tides will push into the New River Area is uncertain. Currently, a very long sand spit and the associated constant deposition

of sands by waves limit tidal forcing inland. For further discussion, see "**Landscape setting (hydrodynamic and geomorphic processes)**" below.

Other estuaries that show strong increases in LMZ area across SLR scenarios are the Necanicum, Pistol, and Sixes (Appendix B, Figure B1); however, much of the added LMZ area in the Necanicum consists of developed land in Seaside. Although the Yachats, Elk, and Chetco also show high % increases in LMZ area, the absolute area of future LMZs for these estuaries is small (Appendix C, Tables C1-C4).

Impervious surfaces

As shown in the individual estuary bar charts (Appendix B, Figure B1), the proportion of LMZs located on impervious surfaces tends to increase with SLR. This indicates potential future land use conflicts between developed uses and tidal wetland resources. Land use planning can help reduce these conflicts (see "**Recommended actions**" below.

Locations (spatial displacement) of tidal wetlands

Because this study was spatially explicit, it revealed not only the total area of potential tidal wetlands under future SLR scenarios, but also the locations of those wetlands. Since land ownership is integral to resource management, the locations (and ownership) of future tidal wetlands are very important to their management. There are many cases in this study's results where the LMZ area isn't much different from baseline, but the LMZs are located in different places and have different ownership compared to their baseline locations. This is why these future potential tidal wetland areas are referred to as "landward migration zones." The "migration" or displacement of tidal wetlands will have major impacts on management of these wetlands.

The GIS products and PDF maps illustrate the changing locations of potential tidal wetlands, but some numbers summed across the entire study area help clarify the magnitude of the change:

- At 4.7 ft SLR, of the 34,229 acres of potential tidal wetlands, only 11,362 acres (33%) are in the same locations as our current tidal and potential tidal wetlands.
- At 8.2 ft SLR and 11.5 ft SLR, there is ***no overlap*** with current wetlands. (This is expected, since these SLR values exceed the current elevation range of tidal wetlands.)

Prioritization

Higher-priority LMZ Units are shown in blue and green on the prioritization maps (see Appendix B, Map B2 for an example). Since area is an important criterion for the prioritization, larger LMZs and those located on broad, relatively flat floodplains tend to score higher than small LMZs in steeper landscape settings. However, some smaller, privately-owned LMZs in lower bays are also prioritized, mainly because the analysis units in the lower bays tend to be large, resulting in high scores for the area criteria. See "**Usage notes: Prioritization**" below for further discussion.

Other prioritized LMZs tend to be on publicly-owned, non-developed land such as U.S. Forest Service lands, State Parks, and County lands.

An Excel file containing all of the data for the prioritization is provided among the products (see "**Products**" below). This gives local groups the option to analyze the underlying data differently, or to use different criteria to set priorities. For some recommendations, see "**Data gaps and recommendations for further analyses**" below.

DISCUSSION

Significance

Because of steep topography and the limited width of the coastal plain, Oregon's outer coast estuaries are vulnerable to climate change and sea level rise. With SLR above 4.7 ft, there is likely to be considerable loss of valued tidal wetland resources. Sediment accretion may reduce this loss, but different studies show very different potential for accretion as a mitigating factor. Restoration of subsided, diked lands through dike removal is a good way to begin; the sooner available sediment can be restored to these areas, the more chance they have to equilibrate with future SLR. However, to ensure tidal wetland functions are available in the future, it will be very important for coastal groups to build and continue relationships with upslope landowners of LMZs, and to begin to plan for conservation and restoration of native habitats within these areas.

Scope of modeling

Decisions on the scope of modeling for this project were informed by the available budget, desired geographic scope, timeline and project goals. Major modeling decisions were introduced in the "**Methods overview**" above; the sections below provide further discussion of model scope and implications.

Flow barriers (dikes, tide gates, etc.)
This study's model did not account for artificial (man-made) water flow barriers such as dikes, tide gates, roads, railroads, or fill material. Areas within the appropriate elevation range for vegetated tidal wetlands were mapped as part of the LMZs, regardless of whether they are currently disconnected. This was a deliberate choice, made for several reasons:

1) *We want to assist coastal groups with identification of diked/disconnected areas vulnerable to SLR.* Many diked agricultural lands on the Oregon coast are lower in elevation (often by 2 to 3 ft or more) compared to undiked tidal wetlands. This elevation

loss ("subsidence") is due to post-diking compaction of soil, loss of soil organic matter through oxidation, and other factors (Frenkel and Morlan 1991). These subsided areas are vulnerable to flooding even at current sea level, and a good drainage system is needed to make these areas agriculturally productive. Typical drainage systems (e.g. dike/tide gate systems) will have reduced function with SLR, particularly for gravity drainage systems which rely on an adequate low tide drainage period. Where land surfaces and ditch flow paths are at low elevations relative to rising sea levels, the low tide drainage period may no longer be adequate for drainage, and therefore economic productivity of the diked areas is likely to decrease.

2) *Groundwater will rise with SLR*, reducing productivity of diked lands; this is particularly true for subsided areas.
3) *The effectiveness of hydrologic barriers like dikes and tide gates will change over time and with SLR.* For example, increasing storm intensity (predicted in climate change models) generally leads to dike erosion and dike breaches. Maintenance of dikes and tide gates is dependent on the economic value of the land uses behind them; and that value is affected by drainage system functionality, which can decrease with SLR (see items 1 and 2 in this paragraph). If barriers are not maintained for economic, logistical, or other reasons, the areas behind them will become vulnerable to flooding.

The above also applies to areas within tide range that are located behind other types of flow barriers like flood gates, restrictive culverts, and road and railroad embankments. These were included in the mapping, for the same reason that diked areas were included.

Developed areas

Developed areas within tide range are vulnerable to flooding due to SLR. They were included in the LMZ mapping because to omit them would be visually and conceptually misleading. However, developed areas generally ranked low in the prioritization, and they are not generally expected to be a focus for tidal wetland restoration for social, economic and biological reasons. For example, intensively-developed areas are likely to be protected from future tidal inundation with seawalls, levees, or similar structures. Soils or substrates in developed areas (often paved surfaces or coarse fill material) are not well-suited to support of future tidal wetland functions. The cost of converting developed areas to functional wetlands is likely to be high, so less-developed areas are generally more appropriate for consideration as potential future tidal wetlands.

Sediment accretion

This study's scope did not include evaluation of sediment accretion rates or their effect on potential persistence of tidal wetlands at their current locations. In general, higher rates of sediment accretion would be expected to reduce or delay the impacts of sea level rise. Although sediment accretion is clearly an important factor in tidal wetland responses to sea level rise (Morris 2002, Schile et al. 2014, Thorne et al. 2015), detailed data on variability in sediment accretion rates across the Oregon coast and within individual estuaries do not currently exist. Local groups may wish to incorporate their own site-specific data when interpreting the results of this study.

We compared our study results to models that did account for accretion (see "**Comparison to other models**" below). This comparison provided some insight into the importance of accretion modeling in assessing potential SLR impacts to tidal wetlands.

Beyond these model comparisons, it is important to note that other recent studies (Peck 2017) suggest that accretion rates might be adequate to allow tidal wetlands to remain in their current locations under some SLR scenarios. However, even if accretion allows tidal wetlands to persist in their current locations under SLR, the areas identified in this study provide ecologically important gradients from tidal wetlands to nontidal wetlands and uplands. The LMZ maps can therefore be useful to identify areas well-suited for conservation and restoration of native species and their habitats.

Landscape setting (hydrodynamic and geomorphic processes)

Our model is elevation-based. Although we did use VDatum to adjust tidal datums, our model does not evaluate tidal forcing, wave action, erosion, or other dynamic interactions of coastal topography, water and sediment.

<u>Example: Sand spits.</u> The model did not evaluate the potential for tidal forcing to extend into areas behind long sand spits (e.g. New River). Such areas may experience less tidal inundation than would be expected based on elevation alone; if so, future tidal wetlands may be less extensive than our mapped LMZs. On the other hand, erosion and breaching of sand spits due to increased storm intensity could have the opposite effect, increasing tidal forcing in areas that have had little tidal influence in the past. Sand spits and other topographic barriers may not retain the same physical form under SLR and climate change scenarios, so the future of these areas may be difficult to predict (Ruggiero et al. 2013).

<u>Example: Dynamic river channels.</u> This study's model used elevation to determine potential future tidal wetland areas. In some very dynamic, high-gradient river channels such as the Rogue River, some of the areas in the baseline LMZs (i.e., currently within the appropriate elevation range for vegetated tidal wetlands) are gravel bars. Many of these gravel bars currently support little or no vegetation due to high-velocity flows, active deposition and erosion, and dynamic channel movement. As higher gravel bars fall within future tide ranges under SLR scenarios, they may or may not become vegetated tidal wetlands depending on these physical processes. Further analysis on a site-specific basis is needed to understand potential tidal wetland functions in these areas under SLR scenarios.

River flooding

In winter, high river flows and river floods elevate water levels above those predicted by outer coast tide stations alone. Our model did not account for river flows (the "fluvial component" of the inundation regime) or how climate change may alter them. This decision was made during development of OCMP's Estuary Habitat Mapping project (Lanier et al. 2014), and was retained for the LMZ project for consistency and to allow coastwide mapping within this project's timeframe and cost limitations. The upper boundary for tidal wetlands is based on NOAA's 50% exceedance values, which are based on measurements and models for tide stations near the mouths of estuaries. Although the 50% exceedance elevation was ground-truthed as an appropriate upper boundary for Oregon's outer coast tidal wetlands in general (Lanier et al. 2014), the 50% exceedance values do not incorporate the additional inundation caused by high river flows, particularly upriver in more confined river valleys. Our team has documented the substantial added inundation due to typical winter river flows in Oregon (Brophy 2009, Brophy et al. 2011, Huang and Brophy 2011). However, incorporation of the fluvial component requires more sophisticated modeling (e.g. hydrodynamic modeling) which wasn't possible within this project's scope, budget, and timeline (particularly coastwide).

Ecosystem services of tidal wetlands

This study did not attempt to evaluate ecosystem functions or services provided by potential future tidal wetlands, which could differ considerably from current tidal wetlands.

Example: Dune fields and sand spits. Large areas of LMZs are mapped in dune fields and sand spits (e.g. south of the mouth of the Siuslaw River, and north of the mouth of the Umpqua River). The sandy soils in these areas probably function very differently in terms of salmon prey production, soil organic matter content, carbon sequestration, and other functions compared to the more prevalent fine-textured soils commonly found in our outer coast tidal wetlands. In addition, the sandy soils of spits may be less likely to form the deep, narrow channels typical of tidal wetlands in finer-textured soils (Brophy 2007). Deep, narrow channels provide excellent shelter for juvenile salmon, so the salmonid habitat functions of tidal wetland channels on sand spits -- if in fact channels form at all -- might be lower. Potential future tidal wetland functions of current uplands or nontidal wetlands could be evaluated on a site-by-site basis using existing functional assessment methods (e.g. Adamus 2006) or other approaches.

Vertical land motion and earthquakes

The movement of the earth's tectonic plates causes gradual land uplift and subsidence (vertical land motion), and the rates of this motion vary across the Oregon coast. These differences in land motion could affect LMZ mapping, because rising land (uplift) experiences less SLR relative to land surfaces, whereas falling land (subsidence) experiences more SLR relative to land surfaces. However, we did not attempt to account for this type of gradual vertical land motion in our study, because we do not expect it to have a major impact on study results, for the following reasons:

1. VLM differences across the Oregon coast (~2-3 mm/yr) are 1-2 orders of magnitude less than the uncertainty in elevation and SLR (the two factors we used to map LMZs). LIDAR-based elevation uncertainty is around 10-20 cm (Watershed Sciences 2009a, 2009b; Ewald 2013), and SLR uncertainty is 25 - >130 cm, depending on the year (NRC 2012). In mapping impacts of SLR, Gesch (2013) recommended against adding model parameters whose magnitude is less than the uncertainty of the other primary parameters.
2. Since projected SLR increases exponentially in models, but VLM doesn't increase exponentially, the impact of VLM on relative SLR decreases with time. Therefore, differences in VLM are likely to have little impact on final study products such as the prioritization, which is based on a higher scenario of 4.7 ft SLR.

In contrast to gradual VLM (or relatively gradual SLR due to climate change), a large subduction zone earthquake in our study area (a "Cascadia event") is likely to cause rapid post-seismic subsidence – that is, a sudden drop in the elevation of coastal land surfaces -- during and immediately after the quake (Atwater et al. 2015, Madin and Burns 2013). The potential impact of an earthquake on Oregon's outer coast tidal wetlands is beyond the scope of this study; however, many of the mapped LMZs would probably be vulnerable to inundation after a major earthquake. Vegetated tidal wetlands would gradually re-form in new locations based on the degree of subsidence, as they did after the last major Cascadia earthquake in 1700 (Atwater et al. 2015).

Eelgrass beds

Eelgrass (*Zostera* spp.) beds are important habitat for salmonids and many other species. This project's scope did not include mapping of future eelgrass beds under SLR scenarios, but we investigated sources of information on this topic. The distribution of eelgrass beds is dependent not only on substrate elevation (water depth), but also on salinity, light attenuation (water clarity), substrate characteristics, slope, wave exposure, current velocities, and other factors (Kairis and Rybczyk 2010, Clinton et al. 2014). Clinton and others at U.S. EPA in Newport, Oregon recently constructed a GIS model that maps eelgrass distribution under SLR scenarios (Clinton et al. 2014), with elevation (bathymetry), distance to the mouth of the estuary, and distance to the center of the channel (thalweg) as the major inputs. The EPA team developed and applied the model in the Tillamook Bay, Yaquina River and Alsea River estuaries (Clinton et al. 2014). The EPA team also collaborated with Warren Pinnacle, Inc. to incorporate this approach into a new version of the Sea Level Affecting Marshes Model (SLAMM) (Lee et al. 2014). This model (or a similar approach) could be used to model future eelgrass distribution for other Oregon estuaries under SLR scenarios.

Source data limitations

Like all models, this study's model results were subject to the limitations of the source data. The limitations most relevant to this study are described below. Other limitations of the source datasets can be found in their metadata and other associated documents.

LIDAR DEM inaccuracy due to vegetation interference: Vegetation can prevent the LIDAR signal from reaching the ground surface, resulting in elevations in the DEM that are higher than the actual ground surface. However, choice of the 50% exceedance elevation for the upper boundary of mapped tidal wetlands and LMZs compensates to some extent for this problem, because we ground-truthed the 50% exceedance boundary using field data on tidal wetland extent. This ground-truthing is described in the reports and metadata for OCMP's 2014 Estuary Habitat Mapping (Lanier et al. 2014). Vegetation interference has been measured for tidal wetlands in Oregon, and varies by vegetation type (Ewald 2014, Buffington et al. 2016), so the LMZ mapping may still be affected by this error source in some areas.

<u>LIDAR DEM inaccuracy due to high tide inundation:</u> The type of LIDAR used for the DOGAMI DEM reflects off the water surface, rather than penetrating the water to show the underwater topography (bathymetry). As a result, the topographic data in the DEM can show the water surfaces rather than the soil surface. This is an issue in two situations: 1) high tide; and 2) lakes and other water bodies.

1) <u>High tide:</u> Specifications for LIDAR data acquisition for the DOGAMI DEM did not include acquisition at low tide. In a few of our study estuaries, the tide was high when the LIDAR data were acquired, covering mudflats, aquatic beds and even some tidal marsh surfaces. As a result, the DOGAMI LIDAR DEM shows the water surface instead of the ground surface. Although we corrected for these errors where possible using NOAA topobathy DEM (see "NOAA topobathy data" above), in some cases the NOAA DEM contained the same errors found in the DOGAMI DEM, so we were unable to correct the data. This led to inaccuracies in the LMZ mapping.

<u>Example:</u> In the Sand Lake Estuary, a large area of tidal marsh was inundated at the time of the DOGAMI LIDAR data acquisition, so the DEM shows the water surface, which is elevated above the actual soil surface. The topobathy DEM from NOAA showed the same errors, so it could not be used to correct the DOGAMI DEM. As a result, the erroneously high "ground" surface (actually the water surface) means that the LMZ model underestimates the amount of inundation, leading to the area converting to mudflat later than it would convert if the DEM were accurate. This error was detected through comparison to an adjacent part of the marsh that was not inundated during the LIDAR flight. Correcting this type of inaccuracy would require acquisition of better elevation data, which was not possible within this project’s scope, timeline and budget.

<u>2) Lakes and other water bodies:</u> For coastal lakes, the DOGAMI LIDAR DEM shows the water surface rather than the ground surface. The LIDAR signal reflects off the water surface, rather than penetrating the water to show the bathymetric surface, so water surfaces can't easily be separated from ground surfaces. This project’s limited timeline and budget did not allow each water body to be manually removed from the dataset. When local groups work with this project’s products, we recommend they identify these water bodies using local knowledge and if desired, omit them from their planning process.

COMPARISON TO OTHER STUDIES

WARMER and SLAMM models

We compared our LMZ model results to two other models of SLR effects on tidal wetland extent: the WARMER model (applied at several Oregon locations in Thorne et al. 2015) and the SLAMM model (applied in two Oregon estuaries in Clough and Larson 2010a and 2010b).

There are two sites on the Oregon coast where both WARMER and SLAMM have been applied, allowing us to compare all three models (LMZ, WARMER and SLAMM): these are Bandon Marsh National Wildlife Refuge (Coquille River Estuary) and Siletz Bay National Wildlife Refuge (Siletz Bay Estuary). The highest SLR scenario for the WARMER model runs was 4.7 ft, and SLAMM runs also extended to that elevation, so we compared results for all scenarios up to that SLR elevation (including baseline).

At Bandon Marsh NWR, the area where all three models were applied was the Bandon Marsh Unit (west of Highway 101). Results from all three models showed a very similar area of vegetated tidal wetlands at all SLR scenarios, with model results diverging by only 10-20% (Figure 3).

At Siletz Bay NWR, the three models showed similar results at the 0.8, 1.6 and 2.5 ft SLR scenarios, but the WARMER model showed much smaller area of vegetated tidal wetlands at the 4.7 ft SLR scenario (Figure 4). This was most likely due to the methods used in the study: instead of using a tidal datum such as MTL for the lower boundary of vegetated tidal marsh, the WARMER model application for this project used a field-derived elevation for the lower edge of low marsh, and incremented that value upwards for each SLR scenario. Since the field-derived lower marsh boundary elevation at Siletz Bay NWR was high (5.8 ft = 1.78 m NAVD88, compared to 4.33 ft = 1.32 m at Bandon), marsh converted to mudflat earlier at Siletz compared to Bandon. Thus, the differences in model outputs for the Siletz are the combined result of different modeling methods and the local topography at Siletz Bay NWR.

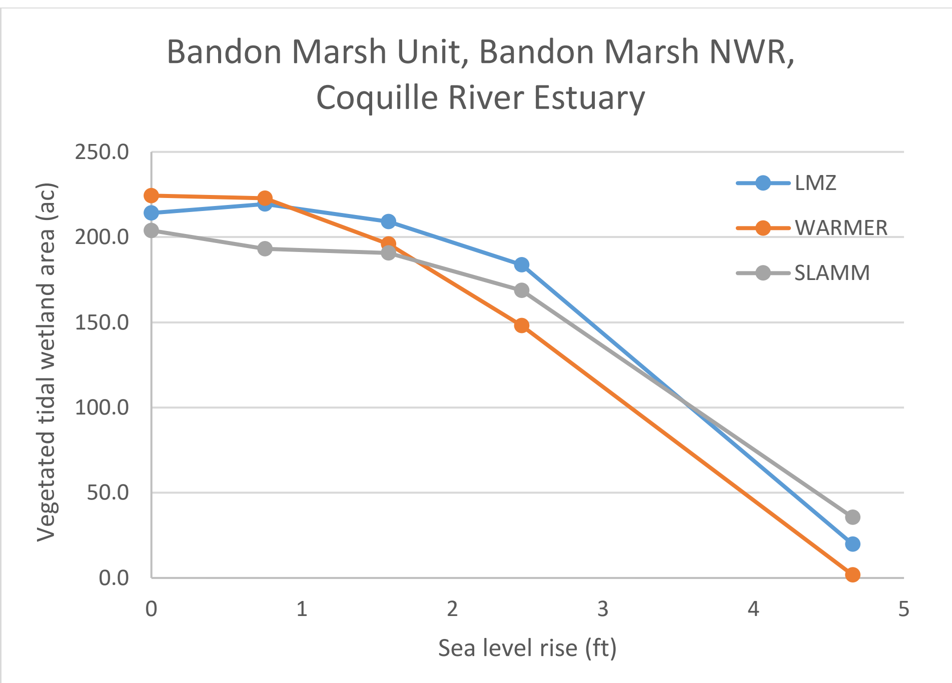

Figure 3. Comparison of vegetated tidal wetland area from WARMER, SLAMM, and LMZ models, Bandon Marsh Unit, Bandon Marsh NWR, at baseline and 4 SLR scenarios

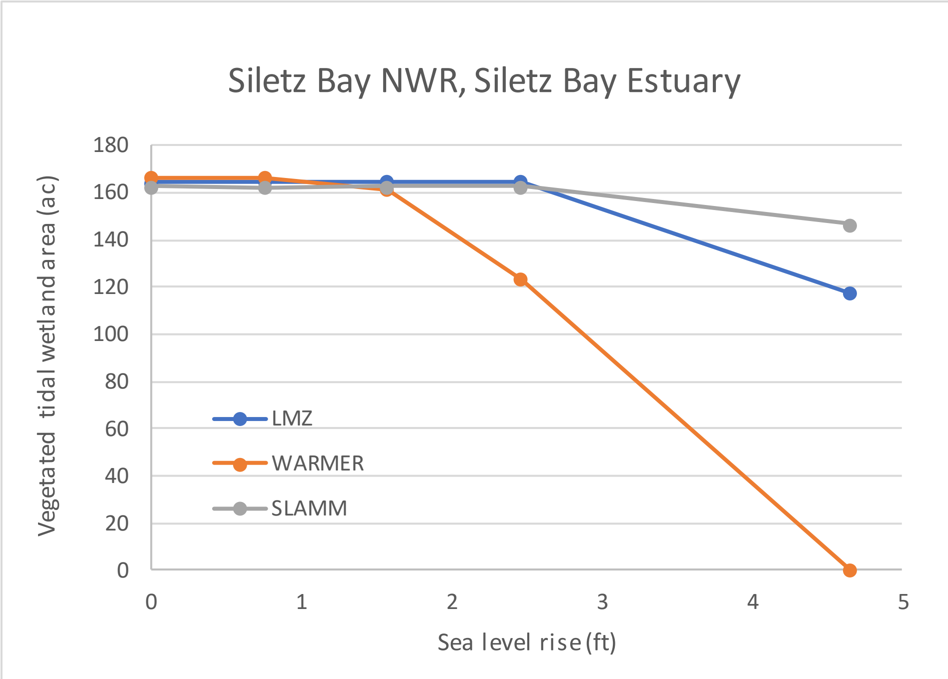

Figure 4. Comparison of vegetated tidal wetland area from WARMER, SLAMM, and LMZ models, Siletz Bay NWR, at baseline and 4 SLR scenarios

Maps comparing the WARMER, SLAMM and LMZ model output are presented in Appendix A (Maps A3-A6). Like the area figures above, the maps show generally similar patterns of wetland loss under SLR scenarios, except for Siletz Bay NWR, where the low marsh threshold was elevated in the WARMER model.

Interestingly, although both the WARMER and SLAMM models attempt to account for accretion, neither model showed a noticeable reduction in tidal wetland losses compared to the LMZ model (which did not account for accretion). WARMER uses local data on accretion (obtained from radioisotope analysis of deep soil cores), yet WARMER model output showed very similar wetland losses compared to our LMZ study. The only exception was at the 2.5 ft and 4.7 ft SLR scenarios at Siletz Bay NWR, where WARMER showed much higher losses compared to the LMZ model. This difference was clearly not due to the accretion factor, which would have reduced losses relative to the LMZ model. Regression analysis for the WARMER model showed that sediment accumulation rate was responsible for only 17% of the observed model results (Thorne et al. 2015). By contrast, the two factors used in our LMZ model (SLR and ground surface elevation) accounted for 72% of model results (Thorne et al. 2015). These regression results explain why the models have similar output (except for the 4.7 ft SLR results for Siletz Bay, as described above).

Yaquina Conservation Plan

The Yaquina Estuary Conservation Plan "prioritizes the conservation needs and opportunities for the Lower Yaquina watershed from an ecological perspective" (Bauer et al. 2011). The project's Atlas included a map series entitled "Sea Level Rise;" the maps are "intended to qualitatively evaluate the potential of a particular area as a migration zone." The Sea Level Rise maps depict NWI-mapped wetlands and uplands below the 15 ft NAVD88 contour. Neither the maps nor the report provide any analysis of change in habitat area at any SLR scenario. Therefore, there were no data in the Yaquina Conservation Plan which could be compared to our LMZ results.

Coquille Vulnerability Assessment

This project was a "a science-based effort to identify how key habitats, species, areas and resources in the Coquille River estuary and associated lowlands are likely to be affected by future climate conditions" (Mielbrecht et al. 2014). The project included application of the SLAMM model to analyze changes in 22 habitat classes within the Coquille River estuary under several SLR scenarios. The highest SLR scenario included in the report is the "2050 mid SLR scenario" (0.7 ft = 8 in = 21 cm), a SLR increment similar to our 0.8 ft (23 cm) scenario.

Non-comparable habitat classifications can create challenges in comparing SLAMM model results to current Oregon estuary habitat mapping (including our LMZ model). For example, the report for the Coquille SLAMM model does not describe how the upslope boundary for the modeled area was determined – information critical to interpreting model outputs. To try to derive comparable data, we used the habitat classification crosswalk table in the assessment's Appendix D (Mielbrecht et al. 2014b) to select four habitat classes that should be comparable to our LMZ mapping: Inland-Fresh Marsh, Transitional Salt Marsh, Irregularly-flooded Marsh, and Regularly-Flooded Marsh. According to the crosswalk table, these classes are equivalent to the following Cowardin classifications, respectively: Tidal Freshwater Wetlands, Tidal Freshwater Wetlands, Tidal Salt Marsh (high), and Tidal Salt Marsh (low).

If the SLAMM model's thresholds were equivalent to ours, these four habitat classes should be equivalent to our LMZs, because they are all described as "tidal." To estimate the comparability of the models, we used the baseline ("current") habitat area in Tables 3 and 4 of the assessment's appendices. The total area of these three categories at baseline ("current") in the Coquille SLAMM run was 32,588 ac (13,188 ha). This total is more than four times greater than our baseline LMZ area of 7,758 ac, and more than 6 times greater than earlier estimates of historical tidal wetland area for the Coquille, around 4900 ac (Good 2000). Although the Coquille Assessment report provides almost no interpretation of the data in Tables 3 and 4, this area discrepancy at baseline appears to indicate that the SLAMM baseline area included large areas above current tide range, making the data non-comparable to our LMZ data. Furthermore, the SLAMM classification (at least the one used in this run) does not distinguish between nontidal diked wetlands within tide range (which would be included in our LMZs) versus nontidal wetlands above tide range (which would not be included in our LMZs). Because of these classification and methods discrepancies, we were unable to proceed further in our comparison of the Coquille SLAMM run to our LMZ results.

USAGE NOTES

This report and accompanying maps are intended to be tools for use by local and regional groups, to inform their estuary conservation and restoration planning work. We hope this report will help groups learn about the parts of the estuary where tidal wetlands may be in the future. They can then gather the site-specific information needed for more detailed planning.

Specific usage notes for the products are listed below.

LMZ maps

Mapping is not intended for site-specific planning. This project is a broad analysis for landscape-scale planning. Site-specific planning requires site-scale review and correction of source data errors; and should take into account local knowledge of land ownership, land use patterns (e.g. areas of low and high value farm and ranch use), and landowner desires.

Even if SLR doesn't occur, LMZ maps are useful. LMZs are important ecosystem gradients providing connectivity and buffers. Even if SLR doesn't occur or accretion offsets SLR, these topographic gradients (indicated by the LMZs on the maps) form connections between tidal wetlands, adjacent nontidal wetlands, and uplands. These gradients are ecologically important, and are important areas for conservation action.

Current tidal wetland area from the baseline LMZ (0 ft SLR) differs somewhat from other mapping of current tidal wetlands such as OCMP's estuary habitat mapping (Lanier et al. 2104). The primary difference is that the LMZ excludes areas that would probably be non-vegetated due to their low elevations, if tides were reintroduced. Thus, the baseline LMZs can be thought of as "potential vegetated tidal wetlands at current tide range *if dikes were removed*." This baseline mapping is based on elevations that would be vegetated tidal wetlands if tides were reintroduced. By contrast, the OCMP products map vegetated diked, subsided wetlands as "emergent wetlands," reflecting their current vegetated state. The OCMP products don't exclude areas that would be too low to be vegetated if tides were reintroduced (i.e. areas below MTL).

Prioritization

In the prioritization, the structure of the underlying analysis units (NHDD Coastal Catchments) can lead to unexpected results in some cases. For example, several industrial areas in Coos Bay rank high in the prioritization despite their developed land use zoning, because they are located in very large catchments, leading to high scores for the "LMZ area" and "further LMZ area" prioritization criteria, in turn leading to a high ranking in the prioritization. To help understand the prioritization, we recommend users view the NHDPlus V2 as an overlay above the prioritization, and check the scoring for each individual criterion to see why an area is prioritized.

RECOMMENDED ACTIONS

Landowner outreach. Coastal groups involved with tidal wetland conservation and restoration are continually engaged in landowner outreach. The LMZ maps may help these groups identify additional landowners who own land within the LMZs just above current tidal areas. Landowners in these areas might be willing and interested in working with community groups to restore native habitats, including tidal-nontidal wetland connectivity; or may simply agree to keep these areas in non-developed uses through easements or other agreements. "Working lands" agreements, in which agricultural use are maintained for some time into the future while enhancing wetland functions, may be a useful tool for keeping LMZs available for future tidal wetlands.

Using the LMZ maps, coastal groups can also work with the local agricultural community to identify less-productive agricultural lands within LMZs that are suitable for current or future wetland (or upland) restoration of native ecosystems. For low-elevation, subsided diked lands, removing flow barriers to restore sediment inputs could help reduce future impacts of SLR (see "**Sediment accretion**" above). Creative solutions, such as deliberate winter flooding to enhance sediment inputs outside the period of agricultural use, will be needed.

Land use planning. To reduce future land use conflicts between developed uses and tidal wetland resources, and to help ensure valued tidal wetland functions are retained under SLR conditions, coastal communities and planners can work to avoid new development within LMZs. This effort would help avoid cumulative impacts to potential future tidal wetland resources as sea level rises. A change in land use planning approach may be needed; instead of considering land use permit applications on a site-by-site basis using primarily current conditions for decision support, future conditions and landscape patterns of LMZs could also be considered. This might be considered "planning in 4 dimensions" – considering topography and time as well as 2-dimensional map locations for land use decision-making.

The big picture. Of course, tidal wetlands are just part of the coastal conversation about potential SLR impacts. Risks to health and safety, buildings and roads, and peoples' livelihoods must be prominent in this conversation. Still, it is important to maintain the visibility of tidal wetlands in this dialogue, to prevent avoidable wetland losses that could have cascading effects on coastal fisheries, wildlife, tourism and quality of life.

DATA GAPS AND RECOMMENDATIONS FOR FURTHER ANALYSES

Catchments (prioritization analysis units). This study's prioritization could be refined by considering more detailed analysis units. In some estuaries (e.g. the Coos Bay estuary), the lower bay contained some very large catchments. These large analysis units limited our ability to distinguish between areas of greater and lesser opportunity. Subdivision of these units into smaller basins could help generate more useful prioritization rankings.

Land ownership patterns, relationships, and economics. Analysis of land ownership patterns within the LMZs will be useful in determining next steps. Coastal groups are likely to find good opportunities for conservation and restoration within middle to high-ranked LMZs where they have existing positive landowner relationships. Analysis of areas of lower and higher agricultural value within middle to high-ranked LMZs can help identify areas for landowner outreach and discussion with the agricultural community.

Salinity. Many coastal groups are interested in learning where they might be able to restore specific, high-priority tidal wetland types ("classes") such as shrub or forested tidal swamp, as opposed to the more prevalent tidal marsh. They are also interested in where specific habitat types might be located under future climate change and SLR scenarios. However, to determine current and future locations of specific tidal wetland classes, detailed salinity data are required, because salinity (along with elevation) is a key controlling factor in determining the distribution of these wetland classes (Brophy 2009, Brophy et al. 2011). Unfortunately, salinity data for the Oregon coast are very sparse: data on projected future salinity regimes are lacking, and even current salinity regimes are poorly understood for most Oregon estuaries. Examples of needed data include landscape patterns of salinity, particularly variability in surface water salinity across spring/neap tide cycles, across seasons, and across years; and relationships between surface water salinity and soil porewater salinity (because soil salinity is likely to correlate most closely to vegetation type). Along with data on salinity regimes, we need data on salinity thresholds for emergent, shrub and forested vegetation in tidal wetlands. Basic monitoring comparing surface water and soil porewater salinity in different tidal wetland classes has only recently been initiated (e.g. Brophy 2009, Brophy et al. 2011, Brophy et al. 2017, Cornu 2017), so these thresholds are not yet established.

Although some models (e.g. SLAMM) include predictions of spatial distribution of these vegetation classes, the SLAMM model runs to date in Oregon have not used salinity subroutines or locally-determined salinity thresholds (e.g. Warren Pinnacle Consulting, Inc., 2012, 2014). Since salinity (independent of elevation) is a very important controlling factor for vegetation type in Oregon, models that fail to account for salinity are unlikely to be accurate. In addition, the available salinity and vegetation transition routines within SLAMM are not yet calibrated or validated for the Pacific Northwest. Appropriate calibration and validation should be conducted before applying these types of models in our area.

PRODUCTS

Products from this study are listed below and may be obtained from the project sponsor (MidCoast Watersheds Council, 541-265-9195, http://www.midcoastwatersheds.org):

- This report
- Presentation (slideshow) summarizing the project
- 24 PDF maps of "Current vs. 4.7 ft SLR LMZs". These maps overlay "baseline" LMZs (areas within vegetated tidal wetland elevation range at current sea level) and LMZs at 4.7 ft SLR; they also show areas that convert to mudflat. 1 map for each estuary, 2 for the Coos Bay estuary.
- 24 PDF maps of the LMZ prioritization based on the 4.7 ft SLR scenario (1 map for each estuary, 2 for the Coos Bay estuary).
- Geospatial data (shapefiles) of LMZs for all SLR scenarios (including "baseline" or initial condition):
    - Each shapefile is specific to a single SLR scenario and includes all 23 estuaries.
    - There are 7 shapefiles: 0.0 ft SLR (initial condition), 0.8 ft SLR, 1.6 ft SLR, 2.5 ft SLR, 4.7 ft SLR, 8.2 ft SLR, and 11.5 ft SLR.
    - Each shapefile's filename indicates SLR scenario. For example, the baseline shapefile is "Oregon_LMZs_SLR_0pt0ft_20170824" and the shapefile for 4.7 ft SLR is "Oregon_LMZs_SLR_4pt7ft_20170824".
- Geospatial data (shapefile) of the prioritization
    - Shapefile includes all 23 estuaries
    - The shapefile's filename indicates the SLR scenario ("Oregon_LMZs_prioritiz_SLR_4pt7ft_20170824")
- Excel workbook (including tables and bar charts) of tidal wetland area under each scenario (includes all 23 estuaries). Filename: Oregon_LMZ_area_by_estuary_imperv_20171121.xlsx
- Excel workbook containing the attribute table for the prioritization shapefile. Filename: Oregon_LMZs_prioritiz_SLR_4pt7ft_20170824.xlsx

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Appendix A. Maps

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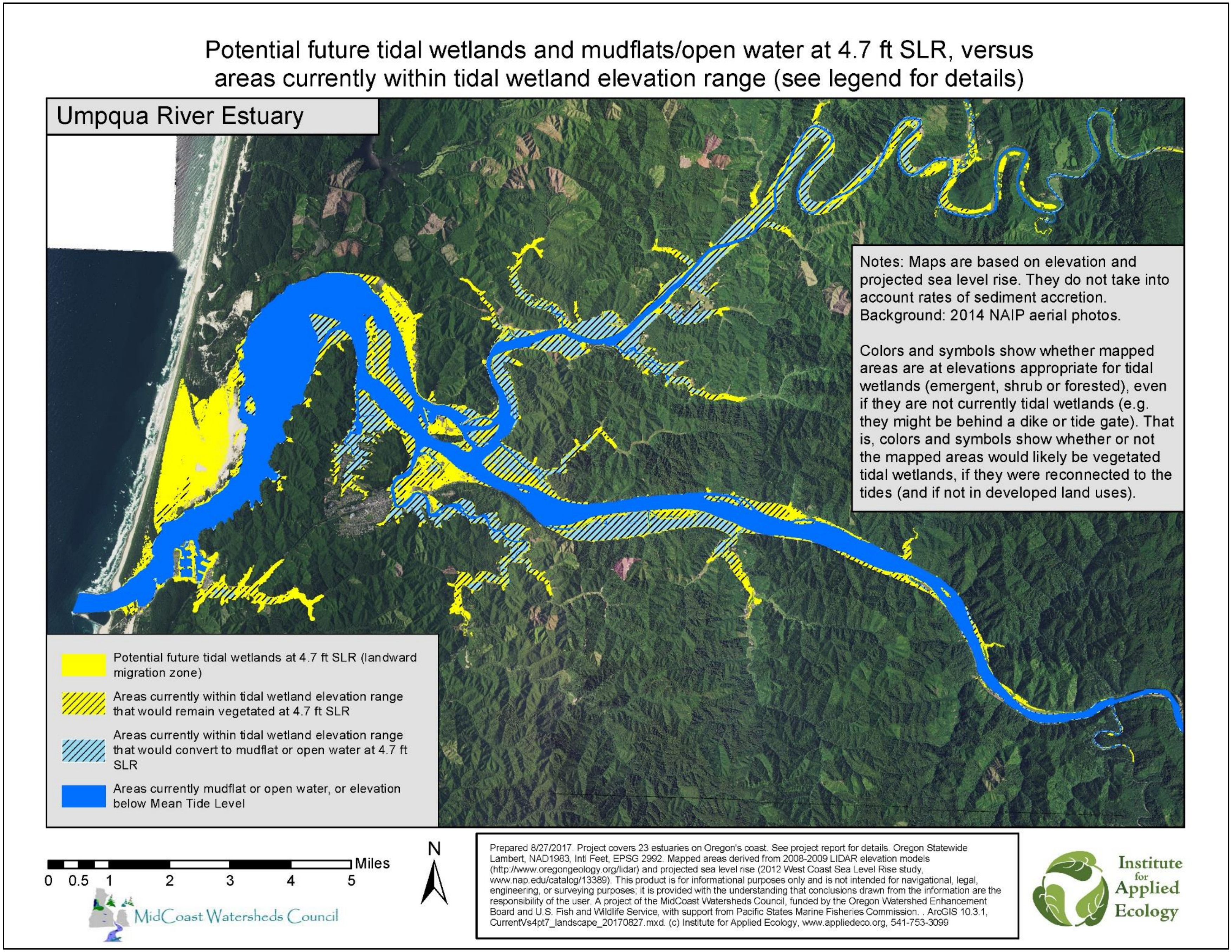
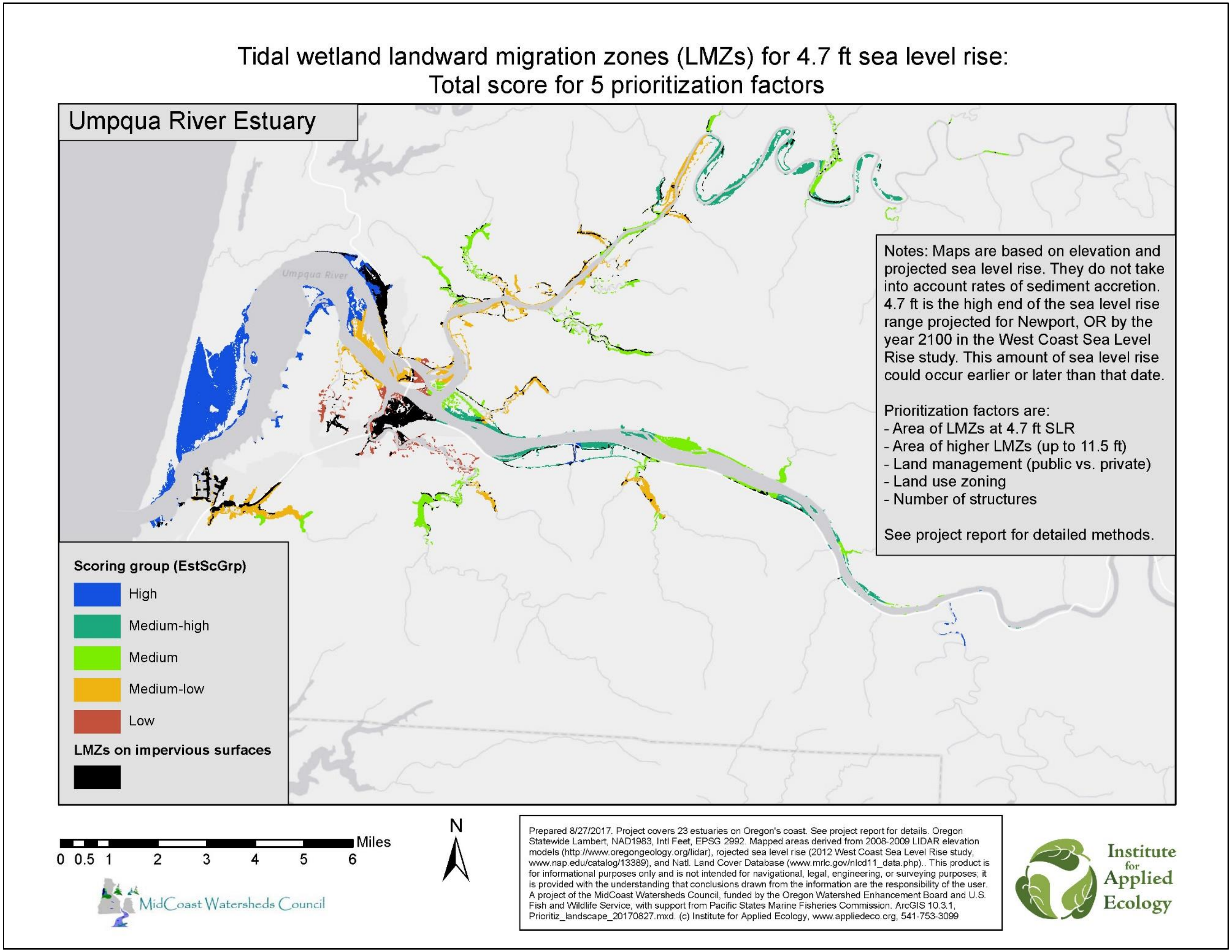
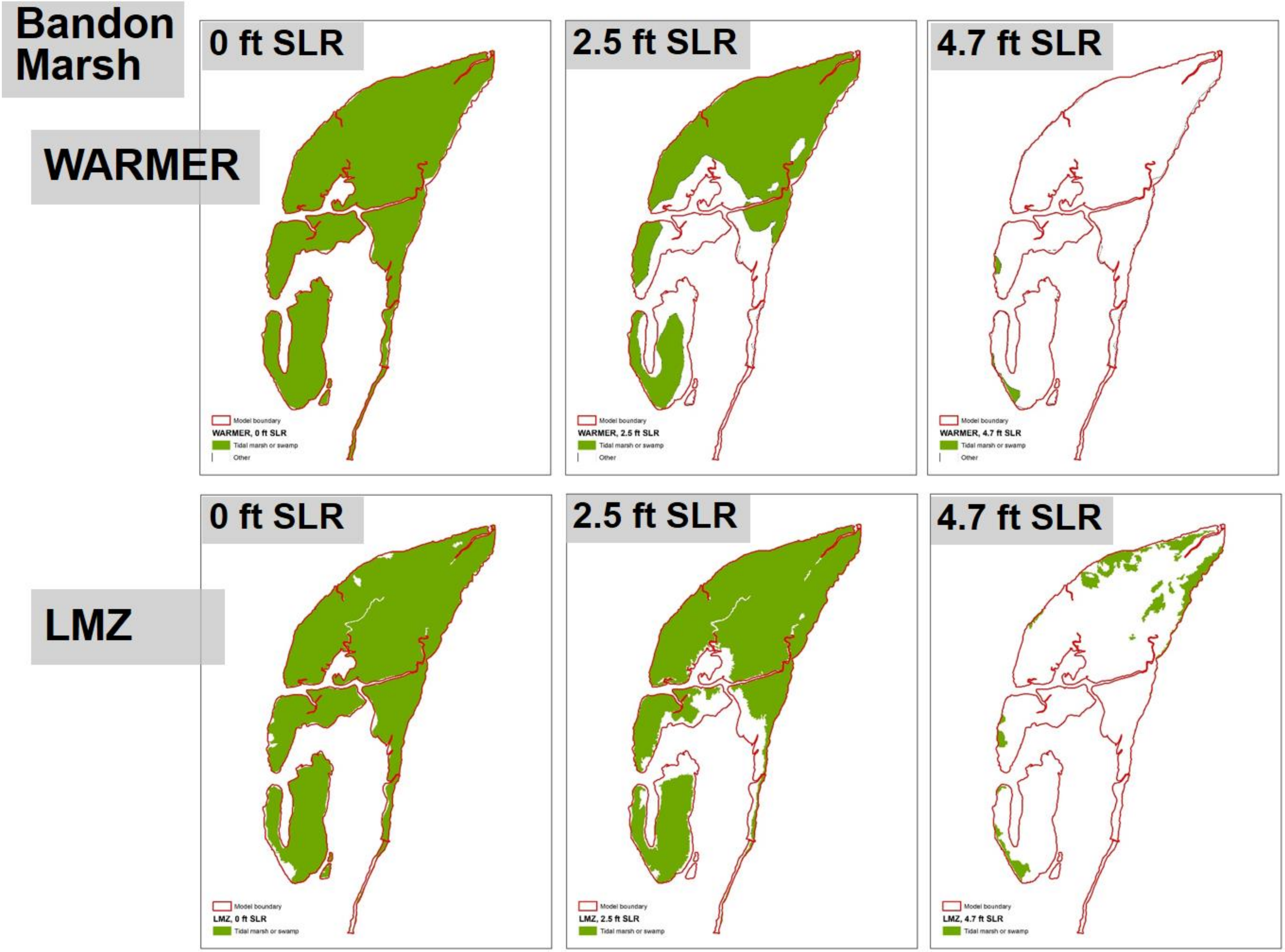
Map A1. Example map for the Umpqua River Estuary showing baseline LMZs, LMZs at 4.7 ft SLR, and areas that convert to mudflat



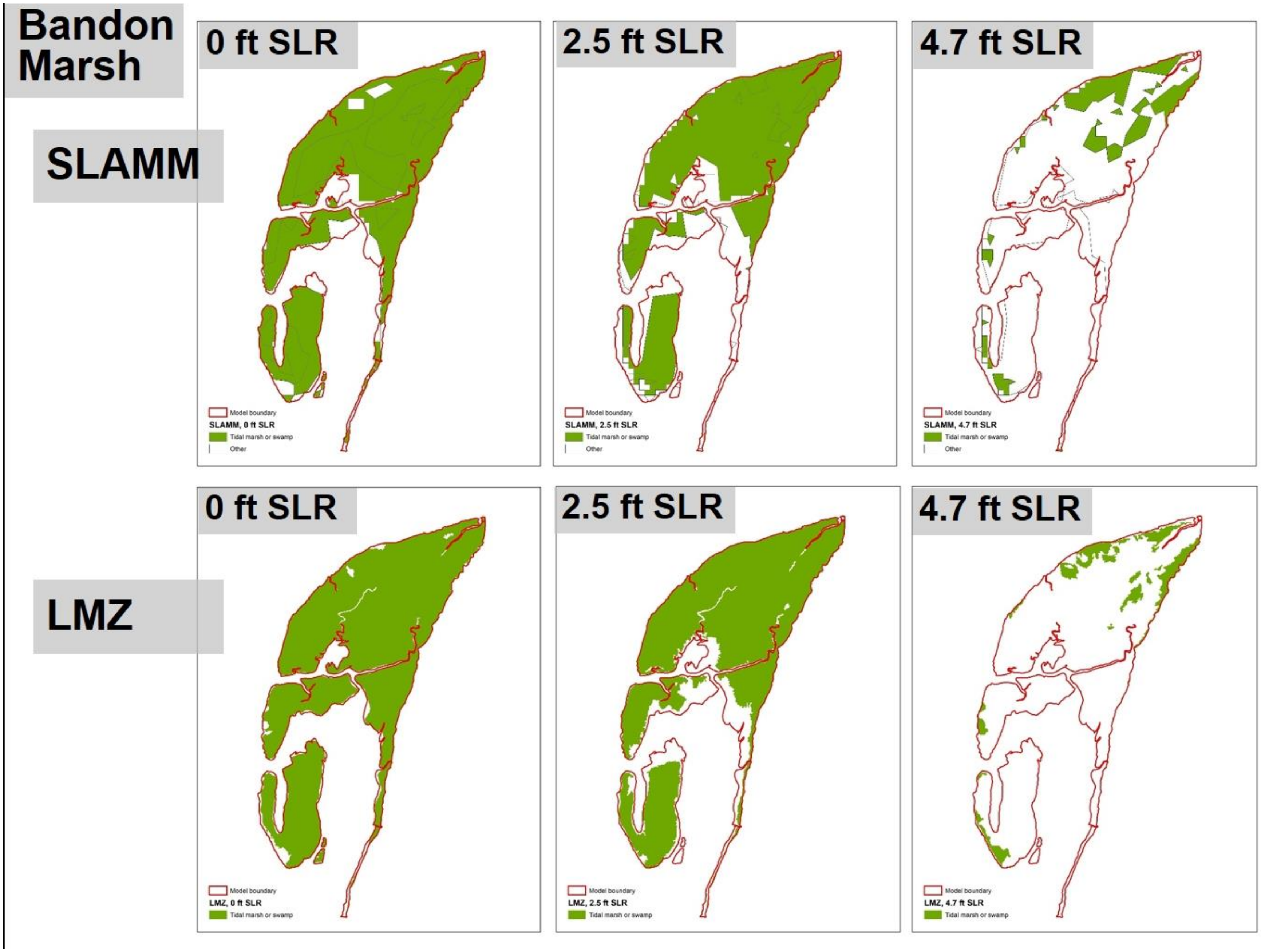
Map A2. Example prioritization map for the Umpqua River Estuary



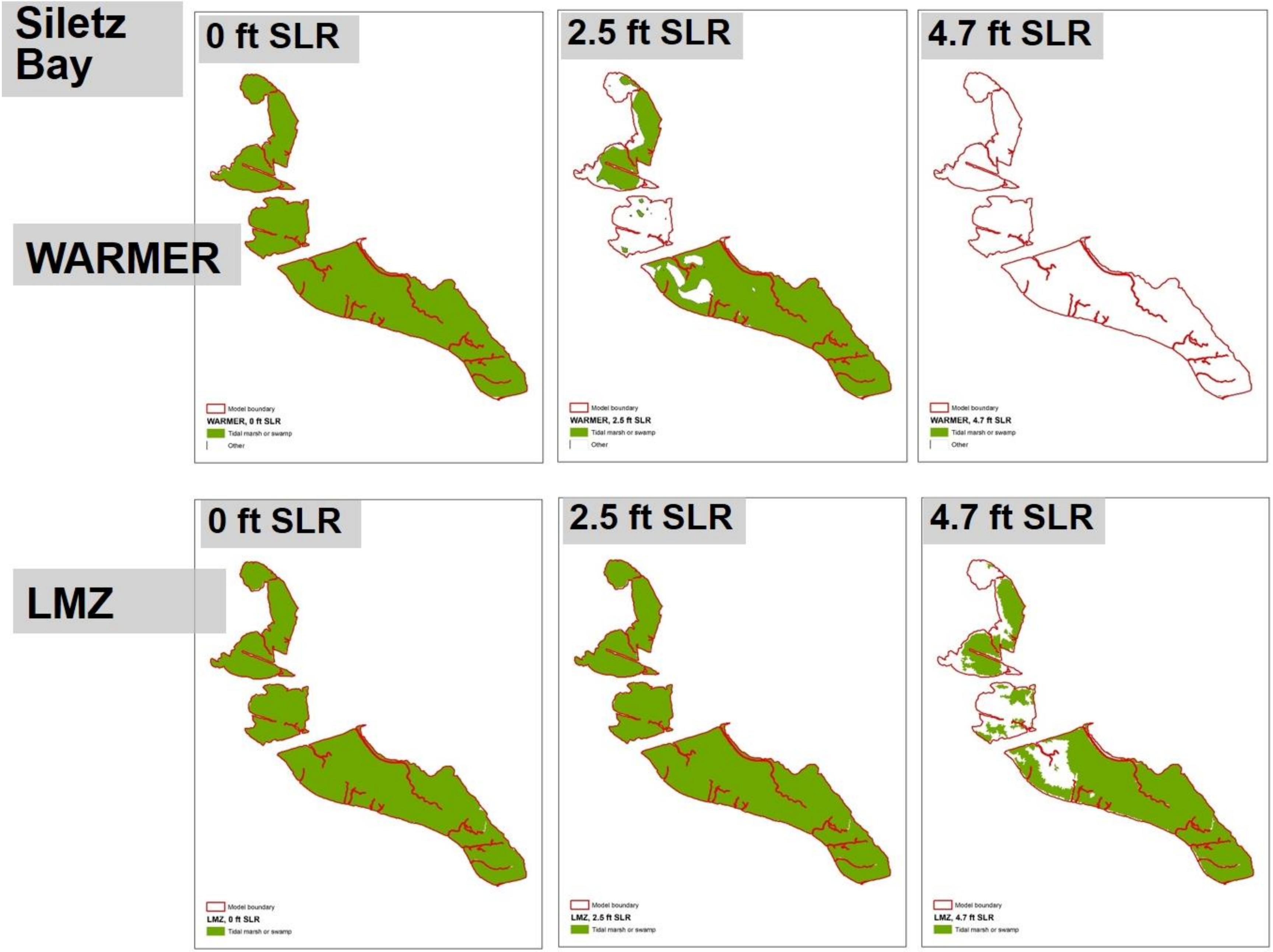
Map A3. Comparison of WARMER and LMZ model results for Bandon Marsh Unit, Bandon Marsh NWR



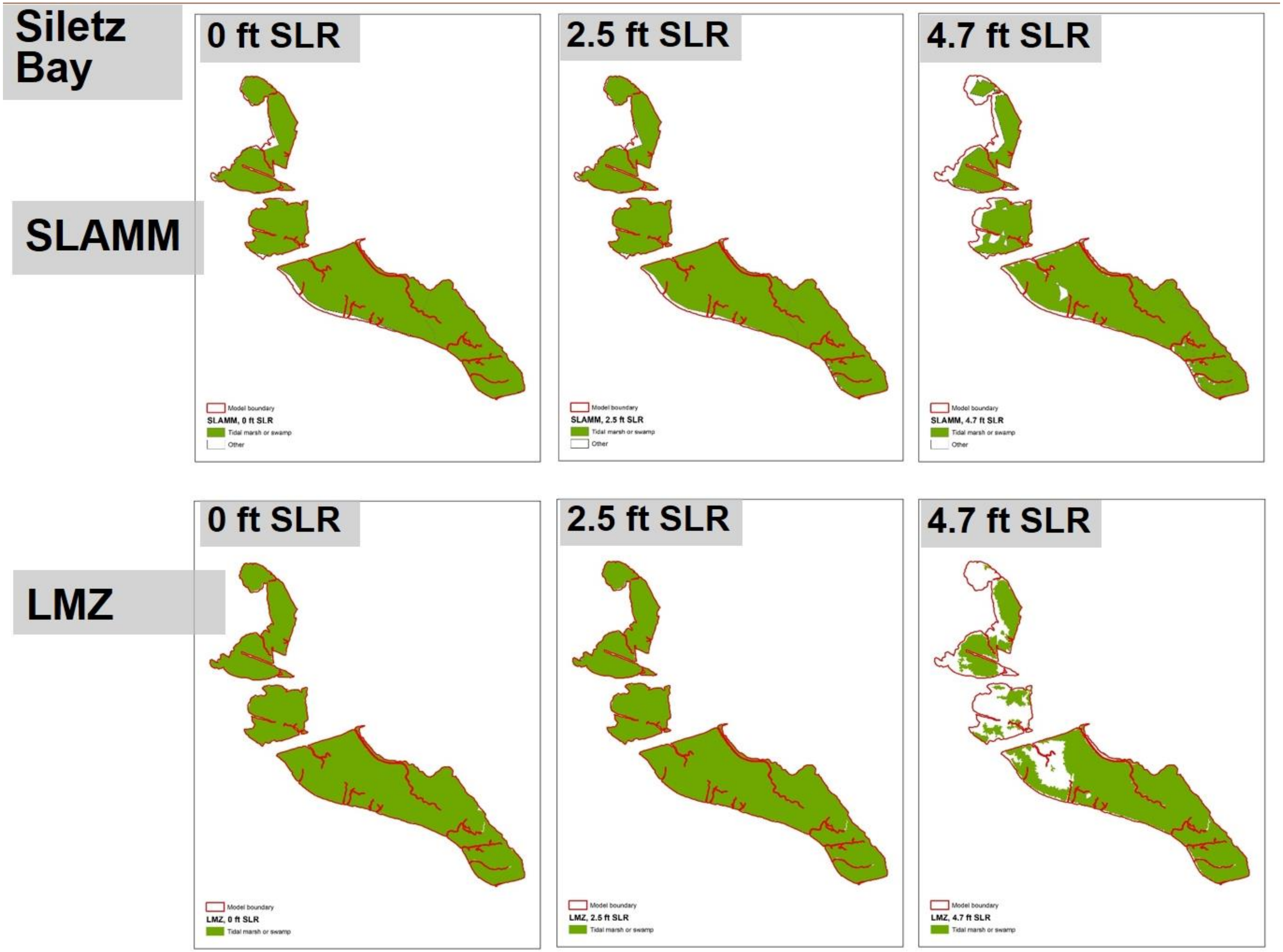
Map A4. Comparison of SLAMM and LMZ model results for Bandon Marsh Unit, Bandon Marsh NWR



Map A5. Comparison of WARMER and LMZ results for Siletz Bay NWR

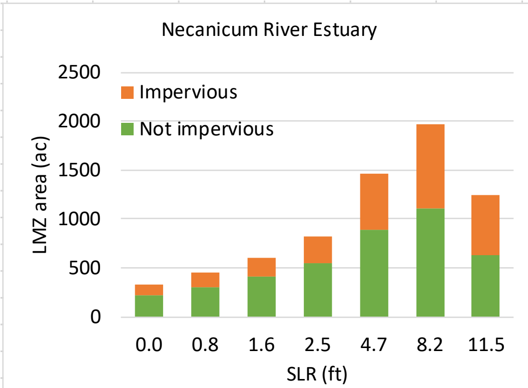


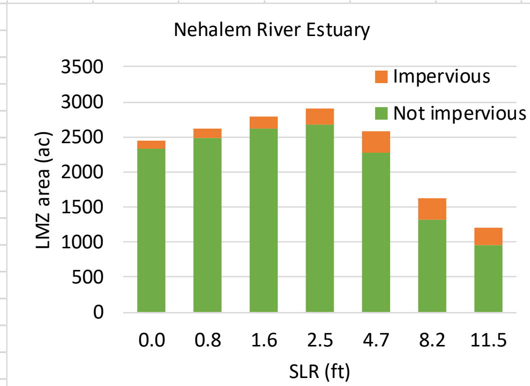
Map A6. Comparison of SLAMM and LMZ results for Siletz Bay NWR

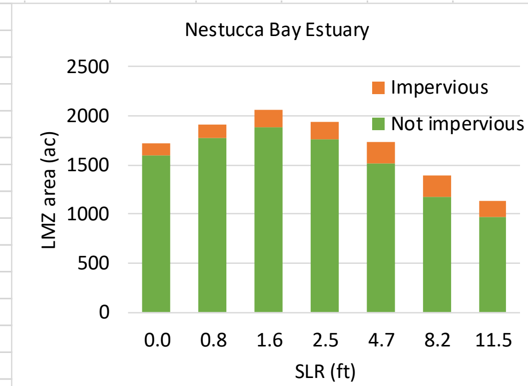


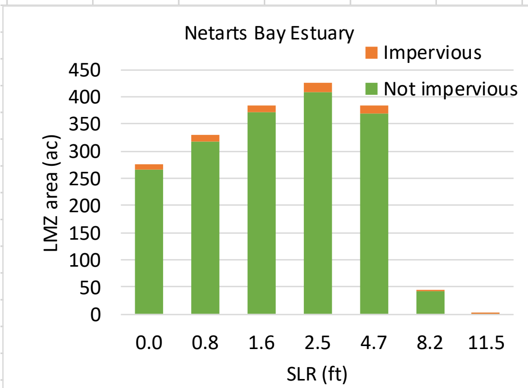
APPENDIX B. BAR CHARTS OF LMZ AREA BY ESTUARY AND SLR SCENARIO

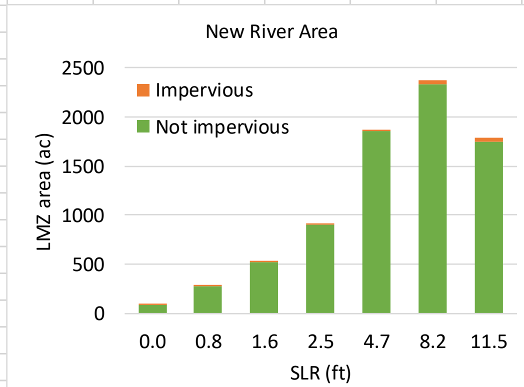
Figure B1. LMZ area by SLR scenario for each estuary. These charts are presented in alphabetical order by estuary; LMZ area is divided into impervious surfaces (orange) and non-impervious surfaces (green).

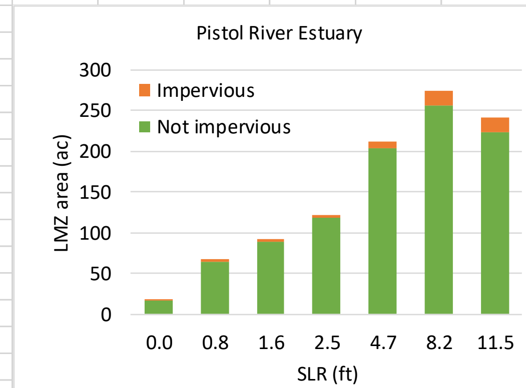

Necanicum River Estuary
Impervious
Not impervious
LMZ area (ac)
2500
2000
1500
1000
500
0
0.0 0.8 1.6 2.5 4.7 8.2 11.5
SLR (ft)

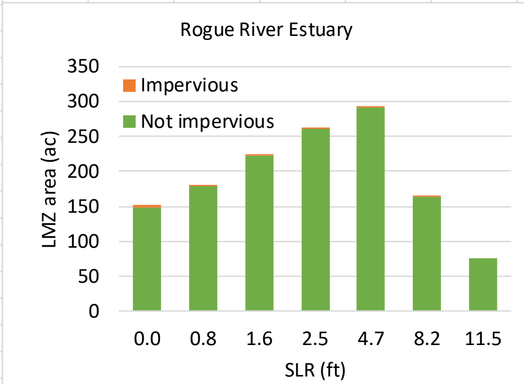

Nehalem River Estuary
Impervious
Not impervious
LMZ area (ac)
3500
3000
2500
2000
1500
1000
500
0
0.0 0.8 1.6 2.5 4.7 8.2 11.5
SLR (ft)

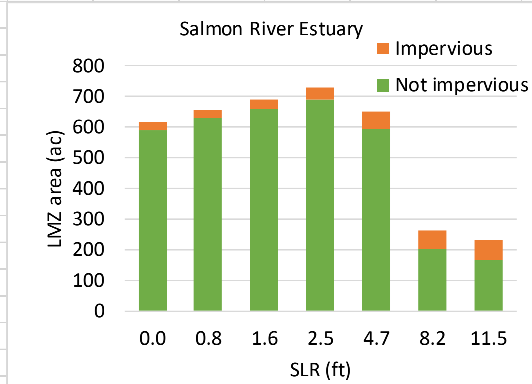

Nestucca Bay Estuary
Impervious
Not impervious
LMZ area (ac)
2500
2000
1500
1000
500
0
0.0 0.8 1.6 2.5 4.7 8.2 11.5
SLR (ft)

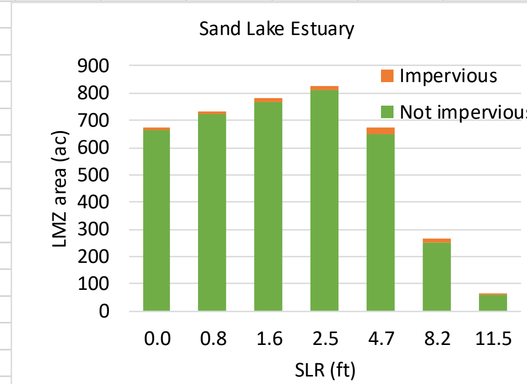

Netarts Bay Estuary
Impervious
Not impervious
LMZ area (ac)
450
400
350
300
250
200
150
100
50
0
0.0 0.8 1.6 2.5 4.7 8.2 11.5
SLR (ft)

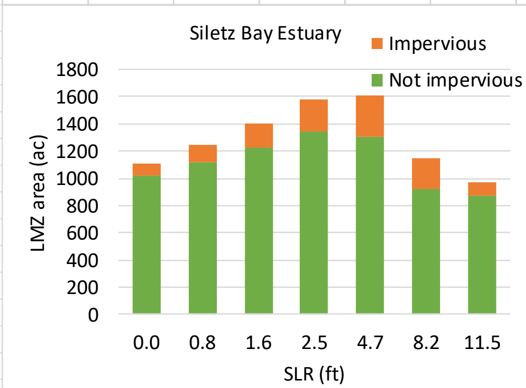

New River Area
Impervious
Not impervious
LMZ area (ac)
2500
2000
1500
1000
500
0
0.0 0.8 1.6 2.5 4.7 8.2 11.5
SLR (ft)

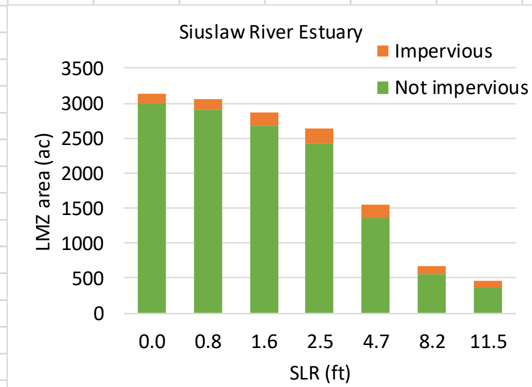

Pistol River Estuary
Impervious
Not impervious
LMZ area (ac)
300
250
200
150
100
50
0
0.0 0.8 1.6 2.5 4.7 8.2 11.5
SLR (ft)

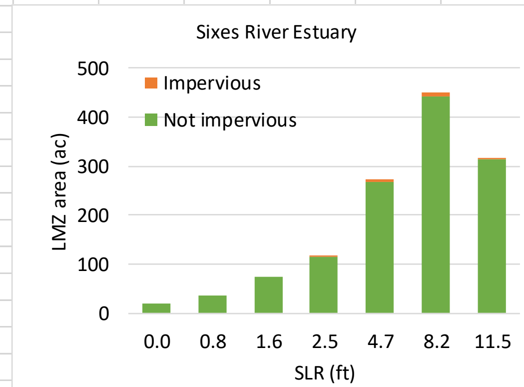

Rogue River Estuary
Impervious
Not impervious
LMZ area (ac)
350
300
250
200
150
100
50
0
0.0 0.8 1.6 2.5 4.7 8.2 11.5
SLR (ft)

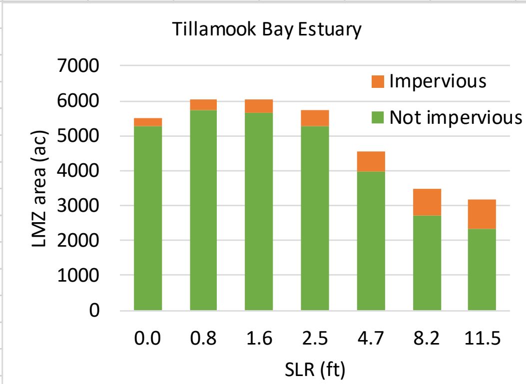

Salmon River Estuary
Impervious
Not impervious
LMZ area (ac)
800
700
600
500
400
300
200
100
0
0.0 0.8 1.6 2.5 4.7 8.2 11.5
SLR (ft)

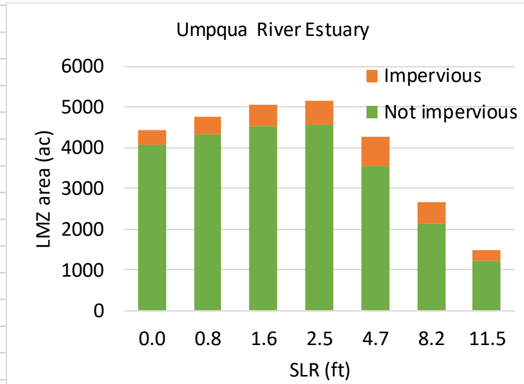

Sand Lake Estuary
Impervious
Not impervious
LMZ area (ac)
900
800
700
600
500
400
300
200
100
0
0.0 0.8 1.6 2.5 4.7 8.2 11.5
SLR (ft)

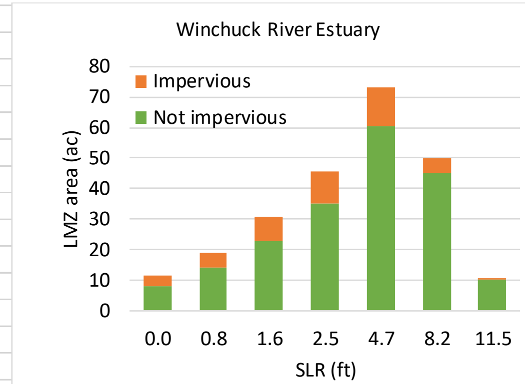

Siletz Bay Estuary
Impervious
Not impervious
LMZ area (ac)
1800
1600
1400
1200
1000
800
600
400
200
0
0.0 0.8 1.6 2.5 4.7 8.2 11.5
SLR (ft)

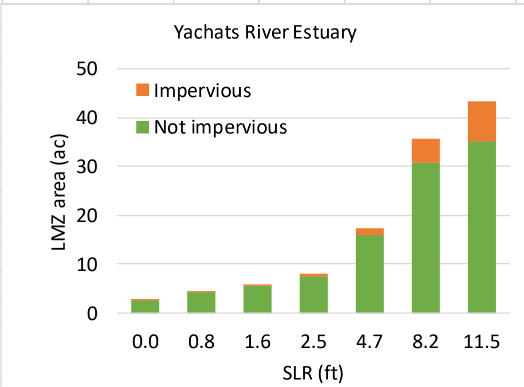

Siuslaw River Estuary
Impervious
Not impervious
LMZ area (ac)
3500
3000
2500
2000
1500
1000
500
0
0.0 0.8 1.6 2.5 4.7 8.2 11.5
SLR (ft)


Sixes River Estuary
Impervious
Not impervious
LMZ area (ac)
500
400
300
200
100
0
0.0 0.8 1.6 2.5 4.7 8.2 11.5
SLR (ft)


Tillamook Bay Estuary
Impervious
Not impervious
LMZ area (ac)
7000
6000
5000
4000
3000
2000
1000
0
0.0
0.8
1.6
2.5
4.7
8.2
11.5
SLR (ft)


Umpqua River Estuary
Impervious
Not impervious
LMZ area (ac)
6000
5000
4000
3000
2000
1000
0
0.0
0.8
1.6
2.5
4.7
8.2
11.5
SLR (ft)


Winchuck River Estuary
Impervious
Not impervious
LMZ area (ac)
80
70
60
50
40
30
20
10
0
0.0
0.8
1.6
2.5
4.7
8.2
11.5
SLR (ft)


Yachats River Estuary
Impervious
Not impervious
LMZ area (ac)
50
40
30
20
10
0
0.0
0.8
1.6
2.5
4.7
8.2
11.5
SLR (ft)

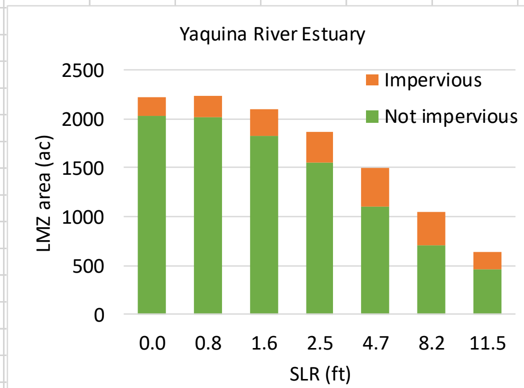
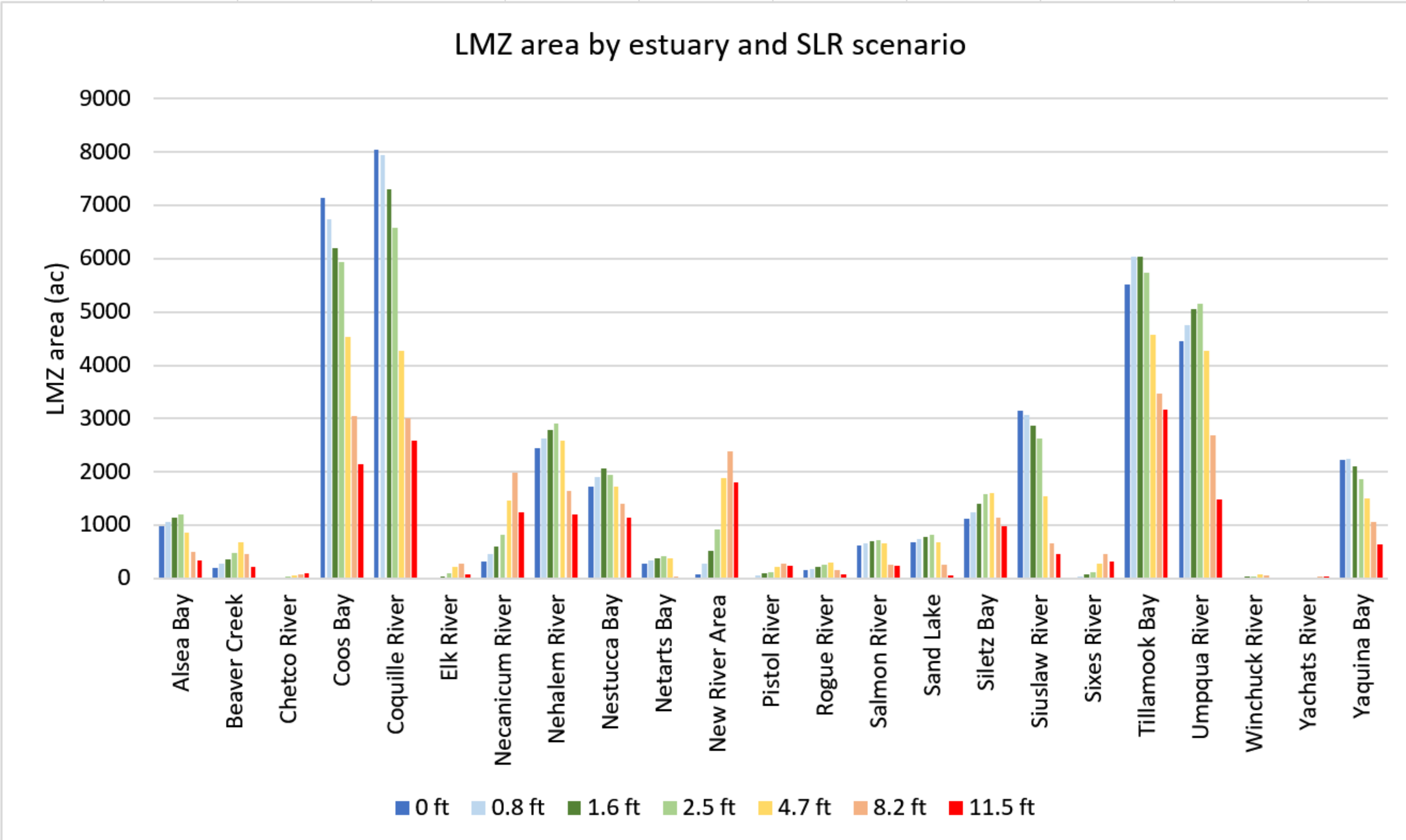

Yaquina River Estuary
Impervious
Not impervious
LMZ area (ac)
2500
2000
1500
1000
500
0
0.0
0.8
1.6
2.5
4.7
8.2
11.5
SLR (ft)

Figure B2. LMZ area by SLR scenario for all estuaries. LMZ area includes both impervious and non-impervious surfaces.



APPENDIX C. TABLES

Table C1. LMZ area (ac) by estuary and SLR scenario. Estuaries are listed in alphabetical order.

	SLR scenario (ft)						
Estuary	0.0	0.8	1.6	2.5	4.7	8.2	11.5
Alsea Bay	939	1004	1051	1086	678	331	237
Beaver Creek	182	256	343	441	619	413	197
Chetco River	10	15	25	32	52	63	66
Coos Bay	6422	5887	5171	4740	3103	1937	1542
Coquille River	7758	7623	6985	6251	3946	2633	2227
Elk River	7	18	42	86	212	263	70
Necanicum River	217	307	412	550	883	1109	633
Nehalem River	2328	2480	2613	2681	2284	1325	958
Nestucca Bay	1601	1769	1891	1766	1520	1179	967
Netarts Bay	266	319	371	409	369	43	1
New River Area	81	271	514	907	1861	2340	1747
Pistol River	16	65	89	118	203	255	224
Rogue River	148	178	222	261	291	163	75
Salmon River	592	628	660	690	597	200	165
Sand Lake	666	721	767	812	649	249	60
Siletz Bay	1017	1120	1224	1349	1301	923	874
Siuslaw River	2996	2899	2685	2435	1365	557	356
Sixes River	19	35	73	114	269	443	314
Tillamook Bay	5262	5727	5673	5291	3985	2721	2334
Umpqua River	4084	4334	4530	4553	3558	2149	1214
Winchuck River	8	14	23	35	60	45	10
Yachats River	3	4	6	8	16	31	35
Yaquina Bay	2037	2018	1827	1549	1101	702	463
Grand Total	36657	37694	37197	36164	28922	20074	14768

Table C2. LMZ loss or gain compared to baseline (% change) by estuary and SLR scenario. Estuaries are listed in alphabetical order. Negative numbers indicate loss of LMZ area, positive numbers indicate gain. ***Results must be interpreted in light of the absolute areas shown in Table C1.***

	SLR scenario (ft)						
Estuary	0.0	0.8	1.6	2.5	4.7	8.2	11.5
Alsea Bay	0%	7%	12%	16%	-28%	-65%	-75%
Beaver Creek	0%	40%	88%	142%	240%	127%	8%
Chetco River	0%	60%	158%	239%	446%	563%	590%
Coos Bay	0%	-8%	-19%	-26%	-52%	-70%	-76%
Coquille River	0%	-2%	-10%	-19%	-49%	-66%	-71%
Elk River	0%	183%	542%	1211%	3148%	3934%	971%
Necanicum River	0%	41%	90%	154%	307%	411%	192%
Nehalem River	0%	7%	12%	15%	-2%	-43%	-59%
Nestucca Bay	0%	11%	18%	10%	-5%	-26%	-40%
Netarts Bay	0%	20%	39%	54%	39%	-84%	-100%
New River Area	0%	235%	534%	1019%	2196%	2786%	2055%
Pistol River	0%	300%	453%	628%	1159%	1481%	1286%
Rogue River	0%	21%	51%	77%	97%	10%	-49%
Salmon River	0%	6%	11%	17%	1%	-66%	-72%
Sand Lake	0%	8%	15%	22%	-3%	-63%	-91%
Siletz Bay	0%	10%	20%	33%	28%	-9%	-14%
Siuslaw River	0%	-3%	-10%	-19%	-54%	-81%	-88%
Sixes River	0%	89%	292%	515%	1345%	2284%	1587%
Tillamook Bay	0%	9%	8%	1%	-24%	-48%	-56%
Umpqua River	0%	6%	11%	11%	-13%	-47%	-70%
Winchuck River	0%	74%	185%	337%	647%	456%	26%
Yachats River	0%	62%	121%	198%	529%	1108%	1285%
Yaquina Bay	0%	-1%	-10%	-24%	-46%	-66%	-77%
Grand Total	0%	3%	1%	-1%	-21%	-45%	-60%

Table C3. LMZ area (ac) by estuary and SLR scenario. Estuaries are listed in decreasing order of size (size = area of potential vegetated tidal wetlands in the baseline scenario, 0 ft SLR)

	SLR scenario (ft)						
Estuary	0.0	0.8	1.6	2.5	4.7	8.2	11.5
Coquille River	7758	7623	6985	6251	3946	2633	2227
Coos Bay	6422	5887	5171	4740	3103	1937	1542
Tillamook Bay	5262	5727	5673	5291	3985	2721	2334
Umpqua River	4084	4334	4530	4553	3558	2149	1214
Siuslaw River	2996	2899	2685	2435	1365	557	356
Nehalem River	2328	2480	2613	2681	2284	1325	958
Yaquina Bay	2037	2018	1827	1549	1101	702	463
Nestucca Bay	1601	1769	1891	1766	1520	1179	967
Siletz Bay	1017	1120	1224	1349	1301	923	874
Alsea Bay	939	1004	1051	1086	678	331	237
Sand Lake	666	721	767	812	649	249	60
Salmon River	592	628	660	690	597	200	165
Netarts Bay	266	319	371	409	369	43	1
Necanicum River	217	307	412	550	883	1109	633
Beaver Creek	182	256	343	441	619	413	197
Rogue River	148	178	222	261	291	163	75
New River Area	81	271	514	907	1861	2340	1747
Sixes River	19	35	73	114	269	443	314
Pistol River	16	65	89	118	203	255	224
Chetco River	10	15	25	32	52	63	66
Winchuck River	8	14	23	35	60	45	10
Elk River	7	18	42	86	212	263	70
Yachats River	3	4	6	8	16	31	35
Grand Total	36657	37694	37197	36164	28922	20074	14768

Table C4. LMZ loss or gain compared to baseline (%) by estuary and SLR scenario. Estuaries are listed in the same order as Table C3. ***Results must be interpreted in light of the absolute areas shown in Table C3.***

	SLR scenario (ft)						
Estuary	0.0	0.8	1.6	2.5	4.7	8.2	11.5
Coquille River	0%	-2%	-10%	-19%	-49%	-66%	-71%
Coos Bay	0%	-8%	-19%	-26%	-52%	-70%	-76%
Tillamook Bay	0%	9%	8%	1%	-24%	-48%	-56%
Umpqua River	0%	6%	11%	11%	-13%	-47%	-70%
Siuslaw River	0%	-3%	-10%	-19%	-54%	-81%	-88%
Nehalem River	0%	7%	12%	15%	-2%	-43%	-59%
Yaquina Bay	0%	-1%	-10%	-24%	-46%	-66%	-77%
Nestucca Bay	0%	11%	18%	10%	-5%	-26%	-40%
Siletz Bay	0%	10%	20%	33%	28%	-9%	-14%
Alsea Bay	0%	7%	12%	16%	-28%	-65%	-75%
Sand Lake	0%	8%	15%	22%	-3%	-63%	-91%
Salmon River	0%	6%	11%	17%	1%	-66%	-72%
Netarts Bay	0%	20%	39%	54%	39%	-84%	-100%
Necanicum River	0%	41%	90%	154%	307%	411%	192%
Beaver Creek	0%	40%	88%	142%	240%	127%	8%
Rogue River	0%	21%	51%	77%	97%	10%	-49%
New River Area	0%	235%	534%	1019%	2196%	2786%	2055%
Sixes River	0%	89%	292%	515%	1345%	2284%	1587%
Pistol River	0%	300%	453%	628%	1159%	1481%	1286%
Chetco River	0%	60%	158%	239%	446%	563%	590%
Winchuck River	0%	74%	185%	337%	647%	456%	26%
Elk River	0%	183%	542%	1211%	3148%	3934%	971%
Yachats River	0%	62%	121%	198%	529%	1108%	1285%
Grand Total	0%	3%	1%	-1%	-21%	-45%	-60%

Appendix D. Land management scoring

Within this project's prioritization for LMZs at the 4.7 ft SLR scenario, one of the prioritization criteria is land management (best available proxy for land ownership). The underlying data for this criterion is the Oregon Land Management 2015 layer (an element of the Oregon GIS Framework). In this land management geodatabase (2015_LandManagementDraft.gdb), there is an attribute called "LM_class" which indicates the land management type. Based on the Fee Title Holders listed, the classes are:

- 0 = federal
- 1 = private industrial (timber lands)
- 2 = local government (city/county)
- 3 = private non-industrial
- 4 = state (or private with state land management)
- 5 = tribal
- 6 = no records within our study area
- 7 = water

We lumped these classes into public versus private ownership as follows:

Public ownership: LM_Class = 0, 2, 4, 5, 7
Private ownership: LM_Class = 1, 3

Scoring: Raw score = % of LMZ Unit in public land management (LM_Classes 0, 2, 4, 5, 7)

The raw score is then normalized following the same process as for other criteria.

APPENDIX E. ZONING ANALYSIS AND SCORING

The goal of this step of the prioritization is to prioritize lands zoned for conservation or natural resource uses, and deprioritize lands zoned for development.

The analysis starts from the following statewide generalized land use zoning layer: http://navigator.state.or.us/sdl/data/shapefile/k100/zoning.zip. Although this layer is old (1986), the OR Spatial Data Library says this is the "best available statewide zoning layer." The only other zoning layer provided at the Spatial Data Library (http://oe.oregonexplorer.info/ExternalContent/SpatialDataforDownload/OregonZoning_09_24_2014.zip) has no data for many coastal cities, so it cannot be used for our analysis.

Within the statewide layer, we used the general zoning ("General_zo") attribute for scoring. Scores were assigned to zoning categories based on the degree of development that zoning category would allow, as follows:

General_zo value	Description	Score	Notes
A/F	Agriculture/Forestry	4	
Ag	Agriculture	4	
Airport	Airport	1	
Estuary	Estuary	5	
For	Forestry	5	
Min/Agg	Mining/Aggregate	n/a	None on the coast*
Mixed Use	Mixed	n/a	None on the coast*
Nat Res	Natural Resource	5	Open Space, Lakes and Wetlands, Natural Uplands
Non Res	(not present)	n/a	None on the coast*
Park	Park	5	
Public	Public	n/a	None on the coast*
Range	Range	n/a	None on the coast*
RCom	Rural Commercial	2	
Refuge	Refuge	5	
Reserve	Reserve	5	Spits and/or jetties**
RInd	Rural Industrial	2	
RR	Rural Residential	2	
RSC	Rural Service Center	2	Dense rural residential
Shore	Shore	5	
Urban	Urban	1	
Water	Water	5	

* This generalized land use zoning category is not present within our prioritization layer (4.7 ft SLR LMZ)
** Only two areas with this zoning category exist on the coast: Kincheloe Pt. Military Res. on BayOcean Peninsula and Coos Head US Naval Facility. Both are undeveloped sand spits and are very unlikely to be the subject of development, so they were scored at the highest level.

Method for calculating the zoning score:

We calculated an area-weighted score for zoning, based on the percentage of the LMZ Unit in each zoning category. (Percentage was used because the prioritization also has an area criterion; using percentage avoids double-counting "area" as a prioritization criterion.)

The formula for the "raw area-weighted zoning score" is:

((% of LMZ Unit's area with a zoning score of 1)*1))
+ ((% of LMZ Unit's area with a zoning score of 2)*2))
+ ((% of LMZ Unit's area with a zoning score of 3)*3))
+ ((% of LMZ Unit's area with a zoning score of 4)*4))
+ ((% of LMZ Unit's area with a zoning score of 5)*5))

The range of possible values for this raw score is 100 to 500.

These raw area-weighted scores were then normalized following the same score normalization methods used for all criteria (see Score normalization above).

APPENDIX F. SPATIAL REFERENCE

This project uses the Oregon Lambert projection, which is endorsed by the Oregon Geographic Information Council and is the State of Oregon's Coordinate Reference System Standard (http://www.oregon.gov/geo/pages/projections.aspx). Details of this spatial reference system are shown below.

Oregon Lambert
EPSG spatial reference ID: 2992
Projection: LAMBERT CONIC CONFORMAL
Datum: NAD83
Units: INTERNATIONAL FEET, 3.28084 (.3048 METERS)
Spheroid: GRS1980

Parameters
1st Standard Parallel: 43 00 0.000
2nd Standard Parallel: 45 30 0.000
Central Meridian: -120 30 0.000
Latitude of Projection's Origin: 41 45 0.000
False Easting: 1,312,335.958 Feet
False Northing: 0.00000 Feet

** Notes: US Survey foot = 1200/3937 meters (0.3048006096 m). International foot = 0.3048 m exactly, 1 meter = 3.28084 Intl. feet

APPENDIX G. INFORMATION SHARING AND OUTREACH

This section was contributed by Fran Recht, Pacific States Marine Fisheries Commission, Habitat Program, frecht@psmfc.org.

An important component of this project involved sharing results with coastal planners and legislators, watershed councils, soil and water conservation districts, scientists, the general public and agencies (e.g. Natural Resource Conservation Service, Oregon Department of Fish and Wildlife, and the Department of Land Conservation and Development). The project leaders (Brophy, Recht) gave numerous presentations up and down the Oregon coast (and elsewhere) in order to increase the understanding of the project and the likelihood that the information would be used to help in future planning and assessment efforts. (In turn, by listening to the comments and questions and concerns of the groups, we were able to refine our work to make the material more understandable.) A table of the outreach efforts is below. We presented this information to 735 people in total.

Outreach to Watershed Councils, Coastal Planners and Legislators, and Scientists			
2/5/2016	Planner	Lincoln County Planning Department meeting, Newport, Oregon (Planning Director Husing, 2 staff, Matt Spangler,	4 attendees
3/1/2016	wsh council*	Pacific City, Tillamook County, Science Pub presentation (hosted by Nestucca, Neskowin, Sand Lake Watershed Council)	60 attendees
10/6/2016	Planner	Coastal Planners Network meeting, Newport, Oregon	40 attendees
2/23/2016	scientific	Newport, Lincoln County, presentation to Oregon Central Coast Estuary Collabor	13 attendees
10/20/2016	scientific	Lincoln City, Tech Team Mtg (MCWC, SDCWC) input on prioritization	12 attendees
11/16/2016	scientific	Skamania, WA, Northwest Climate Conference	50 attendees
12/1/2016	wsh council	Mapleton, OR	15 attendees
12/2/2016	wsh council	Coquiile, OR	19 attendees
12/2/2016	wsh council	Charleston, OR	16 attendees
12/14/2016	wsh council	Reedsport, OR	23 attendees
12/14/2016	wsh council	Goldbeach, OR	23 attendees
12/15/2016	wsh council	Newport, OR	19 attendees
1/9/2017	wsh council	Tillamook	23 attendees
3/17/2017	scientific	Coos Ba Pacific Estuarine Research Society	30 attendees
3/22/2017	legislators	Coastal Caucus, Salem, OR	15 attendees
5/22/2017	city, county, port	OR Coastal Zone Mngmt Assoc, Salem	23 attendees
6/8/2017	scientific	Habitat Com,Pac Fishery Mng Council	11 attendees
9/29/2017	wsh council	Rogue Basin Partnership	11 attendees
10/5/2017	scientific	Oregon Coastal and Marine Data Network - Oregon Ocean Info	18 attendees
10/11/2017	scientific	Tacoma, WA NW Climate Change Conference	74 attendees
10/18/2017	scientific	Oregon Climate Change Research Institute	40 attendees
12/7/2017	wsh council	Newport, OR	34 attendees
		Total	**573 attendees**
Other-- Public Outreach			
1/15/2016	public	Otter Rock, Lincoln County (presentation hosted by Oregon Shores, Surfrider, DLCD, Otter Crest lodge)	35 attendees
2/4/2016	public	Newport, Lincoln County, Science on Tap presentation (hosted by MidCoast WC, Hatfield Marine Science Center)	50 attendees
10/31/2016	public	Salishan, Lincoln County, State of the Coast Conference, hosted by Oregon Sea	30 attendees
1/7/2017	public	Cannon Beach (hosted by CoastWatch)	12 attendees
11/16/2017	public	Yaquina Birders and Naturalists, Newport,OR	35 attendees
		Total	**162 attendees**
*** NOTE: presentations labeled wsh councils had broad attendance from outreach to watershed council mailing lists, including landowners; additionally, NRCS, ODFW and City and County Planners were called directly and invited to attend.**			
		TOTAL	**735 attendees**

Appendix H. King tide photos

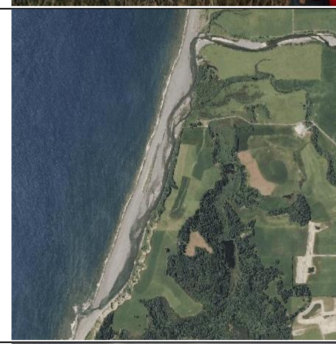
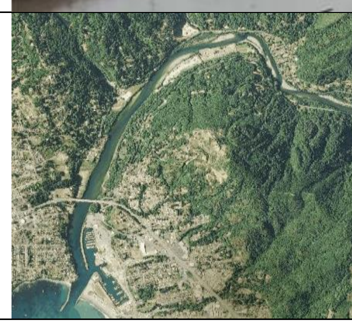
This section was contributed by Fran Recht, Pacific States Marine Fisheries Commission, Habitat Program, frecht@psmfc.org.

"King Tides" are the highest tides of the year, when the moon's gravitational pull is the greatest (see Oregon's king tide website for more information and photographs: http://www.oregonkingtides.net/) Comparison photographs, such as the one of the cover, taken during average tides and king tides can help people visualize clearly how sea level rise can affect our tidal marshes. We don't have many of these comparison photos. While these tides are the "normal" highest tides now, that level of inundation is likely to be more frequent in the future. More frequent inundation means that the plants that are there now (our tidal wetland plants) may not be able to survive, and must move, if they can, to higher elevations (e.g. through seed dispersal).

	Necanicum Estuary Nehalem Bay Necanicum Estuary, Seaside. Nehalem Bay on right. Photos courtesy of The Wetlands Conservancy and Lighthawk, January 30, 2014	
	Tillamook Estuary On left, Miami Cove; flown by Lighthawk for The Wetlands Conservancy. Jan 30, 2014. On right, Dougherty Slough; during King Tide Dec 22, 2014, after a "two year" flood event Dec 20-21. Photo by Outlier Solutions, Inc., and Lighthawk.	
	Netarts Estuary Sand Lake On left—Netarts Bay. On Right Sand Lake. Photos taken during the King Tide Dec 22, 2014, after a "two year" flood event Dec 20-21). Photo by Outlier Solutions, Inc., and Lighthawk.	

	**Nestucca Estuary** Photos taken during King Tide Dec 22, 2014, after a "two year" flood event Dec 20-21). On right, Horn Creek, Nestucca Valley. Photos by Outlier Solutions, Inc., and Lighthawk.	
	**Salmon River** Salmon River. Photos taken during King Tide Dec 22, 2014, after a "two year" flood event Dec 20-21). Photo by Outlier Solutions, Inc., and Lighthawk.	
	**Siletz River Estuary** King tide photos. On left, Drift Creek; on right, Siletz River at Hwy 101 and Hwy 229, Kernville, during the King Tide Dec 22, 2014,after a "two year" flood event Dec 20-21). Photo by Outlier Solutions, Inc., and Lighthawk.	
	**Yaquina Estuary** Low tide on left; King Tide on right. In the Poole Slough in the Yaquina estuary. Photo on left Dave Pitkin, USFWS; photo on right flown by Lighthawk for The Wetlands Conservancy. Jan 30,2014. Notice all the tidal marshes are submerged	
	**Beaver Creek Estuary** On left—low tide; photo by OR Parks and Recreation; on right king tide, photo by Fran Recht courtesy of Lighthawk, January 2017	

	Alsea Estuary King tide photos. On left Drift Creek Wetlands, on right Lower section Bayview Oxbow. Photos flown by Light Hawk for The Wetlands Conservancy (Jan 30, 2014, January 2016.)	
	Yachats River Estuary King tide photos. November 2016, photos by Paul Engelmeyer.	
	Siuslaw Estuary King Tide in the Siuslaw Estuary.. Waite Ranch on left; N. Fork Siuslaw on the right, Jan 30,2014. The Wetlands Conservancy, flown by LightHawk	
	Umpqua Estuary At left, Reedsport, Confluence of Smith and Umpqua Rivers; at right Dean Creek wetlands, Feb 2011, Partnership for the Umpqua Rivers	
	Coos Estuary On left, Shinglehouse Slough, west of Hwy 101, photo by Roy Lowe, December 2013; On right, south edge of Millicoma Slough, photo by Robert More, December 2013	

	**Coquille Estuary** Saw mill Coquille on right; residential property Bandon, looking west, photo by Jens Anderson, November 2016	
	**New River Estuary** Left, at low tide; right at high tide, May 2015, photos by Leslie Peters	
	**Sixes River Estuary** **Elk River Estuary** Average tide images, not king tides. On left, Sixes River; on right Elk River. King Tide images not found. Photographs from Oregon Coastal Atlas, Estuary viewer	
	**Rogue River estuary** Average tide on left; photo Wild River Coast Alliance; On right 8.5' king tide, on the lower river, December 2014. Photo by Lower Rogue Watershed Council	
	**Pistol River Estuary** On left, Pistol River estuary, **Chetco Estuary** On right, Chetco Estuary Photographs taken at average tides; no king tide images available. Photos from Oregon Coastal Atlas, Estuary viewer	

	**Winchuck Estuary** On left, Winchuck estuary, average tide. From Oregon Coastal Atlas, Esutary viewer. On right Winchuck River. King Tides 2015, Kelly Timchack	

APPENDIX I. ECOLOGICAL AND ECONOMIC IMPORTANCE OF ESTUARIES AND THEIR TIDAL WETLANDS

This section was contributed by Fran Recht, Pacific States Marine Fisheries Commission, Habitat Program, frecht@psmfc.org.

Estuaries are "partially enclosed tidal inlets of the sea in which sea water and river water mix to some degree" (Little 2000). They serve as a transitional area between freshwater and marine ecosystems. They receive nutrients, sediment, and water inputs (of various salinities) from both the river and the ocean.

Within estuaries, there are many different types of habitats, including open water, mudflats, eelgrass beds, marshes (low and high marshes), and swamps (scrub shrub and spruce swamps). Because of this diversity, estuaries are biological hotspots that provide important habitat for a great diversity of fish and wildlife (Thom 1987). This diversity includes numerous insects and amphibians, migratory and resident shorebirds and waterfowl, including black brant, a sensitive species; marine mammals including Stellar sea lions, elk, bear and small rodents, and many important fish and shellfish species including Dungeness crab, bay clams, English sole, brown rockfish, herring, green sturgeon and salmon (both juveniles and adults). This diversity – of habitats and species, also make them wonderful places for humans to enjoy and benefit from, in active and passive ways. People raise oysters here; they also fish, hunt, bird watch, kayak and enjoy its scenic qualities.

For those interested in bird use of estuaries, the Portland Audubon Society has documented bird numbers in many of Oregon's estuaries, designating many as Important Bird Areas. (See http://www.audubon.org/important-bird-areas/state/oregon).

The value of estuaries for many fish species has also been assessed. The role of estuaries for fish support, particularly juvenile fish, is documented in Pacific Marine and Estuarine Fish Habitat Partnership publications, http://www.pacificfishhabitat.org/ (see Nursery Functions of U.S. West Coast Estuaries, Hughes et.al 2014). The use of 8 Oregon estuaries by various fish and at various life stages is documented in Monaco, et. al. 1990. The value of estuaries in the production of commercial and recreational fish and shellfish is very high. Of all the commercial landings of fish and shellfish in the Pacific Northwest, 76% of commercial fish landings by weight and 73% of commercial landings by volume are from fish that are estuarine dependent. The percentage of the harvest (by weight) of recreational fish that are estuarine dependent is 74% (Lellis-Dibble, et.al 2008).

Tidal wetlands (i.e. vegetated wetlands) are highly productive parts of the estuary. That is, they produce a large amount of organic material through photosynthesis, that in turn feeds the complex food web of the estuary, including phytoplankton, micro-organisms on and below the soil, and the many species of insects, amphibians, reptiles, fish, birds, and mammals that live or visit here. The plants and bacteria of the tidal wetlands and soils process nutrients, the plants use photosynthesis and uptake nutrients to grow their visible stems and leaves as well as their roots, accumulating organic carbon both above ground and in the soils. These systems also provide physical structure that traps sediments, as well as nutrients and contaminants, improving water quality. The vegetation also helps stabilize sediments, and dampens waves and currents. The physical canopy structure provides cover for fish and other organisms and the channels provide refuge from swift currents.

Sediment trapping rates depend on the watershed and its geology and land-use patterns. In the Salmon River estuary, 10 years after a marsh was restored by dike breaching, the marsh surface was found to be 1.2-2.75 inches higher in elevation due to a combination of sediment accretion and soil swelling (Frenkel & Morlan 1991). (Lower elevation marsh areas accumulated the most sediment (1.97-2.76 inches (5-7cm) per decade; at the highest elevation marsh areas it was 1.18-1.57 inches (3-4 cm) per decade). A study of other sites in the Pacific Northwest (Thom 1992) found sedimentation could range from .94-1.89 inches per decade (2.4-4.8 cm). A study by Thorne et.al (2015) found that most tidal marshes studied were resilient to sea-level rise over the next 50-70 years, but that sea-level rise would eventually outpace marsh accretion and drown most habitats of high and middle marshes by 2110. Knowing this, some restoration groups are experimenting with more active restoration, such as adding dredged sediments to the wetland surface. (See case study of Kunz marsh: http://www.oregon.gov/DSL/SS/Documents/WTRPkunzpart1.pdf.)

Of particular interest currently is the role of tidal wetlands in salmon recovery, particularly for the listed coho salmon. Coho may utilize estuaries and their tidal marsh channels more extensively and for longer periods in their life history than previously thought. This is a life history strategy which seems to confer a survival benefit. This bump in survival for those using estuaries was already known for chinook salmon. Tidal marshes and other parts of the estuary provide rich, diverse feeding grounds for out-migrating smolts and over-wintering habitat for young coho salmon. Increased feeding by salmon and steelhead in the estuary can fuel rapid growth, in some cases exceeding one millimeter per day, as fish gain size quickly before entering the ocean (Bottom et al. 2011). The larger the fish are when entering the ocean, the faster they can swim and the stronger they are, conveying a survival benefit. In fact, relatively new information from Oregon's Salmon River shows that, similar to the survival bump known for chinook salmon, those coho whose life stages include a longer estuarine residence time, return at disproportionately higher rates as adults (25-40% higher for chinook, 20-35 % higher for coho) (Jones et al. 2014). The marsh and its associated tidal channels support juvenile salmon by providing foraging areas (they eat both terrestrial and aquatic insects and other organisms in and around the marsh), protection from predators and resting areas. While not technically "tidal wetlands" the subtidal and intertidal channels (non-vegetated) within the wetlands allow fish to access the marsh. Subtidal channels maintain connection with the estuary during low tide and are corridors between the different habitats in the estuary. Because tidal marshes provide many functions valued by society (support for salmon, maintaining estuarine water quality, supporting complex food webs, recreation and beauty) and because there have been significant losses of tidal wetland habitats in most Oregon estuaries (often 60-70% or more) these habitats are being prioritized for restoration.

The loss of these valuable habitats is due primarily to past diking, road building and tide gating which blocks off tidal flow into the wetlands, as well as to direct filling. For additional information about tidal wetland loss see the PMEP link above and the Oregon Coastal Atlas Estuary Data Viewer http://www.coastalatlas.net/index.php/tools/planners/63-estuary-data-viewer).

With sea level rise, it is especially important that tidal wetland restoration work proceed where it can. Surface elevation is the principal control of marsh hydrology and vegetation because the height of the land affects tidal flooding and the presence of water. Where tidal waters have been restricted for many decades, the land subsides, often two-three feet, compared to natural marshes. Subsidence is due to buoyancy loss, compaction, and organic soil oxidation. The sooner tides and sediments can re-enter these areas, the more chance that sediment and organic material accretion can help re-build the soil elevation and help these wetlands keep pace with the rise of sea level.

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