Habitat change in the Lower Columbia River and Estuary, 1870 - 2011

Keith Marcoe, Steve Pilson. Lower Columbia Estuary Partnership
kmarcoe@lcrep.org

Summary

Change in land cover over roughly the past 140 years was evaluated for the Lower Columbia River and Estuary by comparing digital GIS representations of late 1800's maps (Office of Coast topographic sheets, and General Land Office survey maps) with recent land cover data that was generated by the Lower Columbia Estuary Partnership as part of the Columbia River Estuary Ecosystem Classification. The evaluation was conducted for the historical floodplain of the tidally influenced, lower 146 miles of river. The data derived from this analysis constitutes one level of a multiple lines of evidence habitat restoration prioritization tool being developed by the Estuary Partnership to help inform its restoration and conservation practices in the Lower Columbia River floodplain. Losses of 68 – 70% were noted for vegetated tidal wetlands, which are critical habitats for juvenile salmonids that utilize the lower river and estuary. These values are consistent with those derived from previous studies. A loss of 55% of forested uplands was also noted. The majority of loss of these habitats was due to conversion of land for agriculture, as well as significant loss to urban development. Also significant was conversion of tidal wetlands to non-tidal wetlands. Tidal flats have changed more with respect to location than overall areal coverage, which seems consistent with this high energy environment as well as sediment manipulation practices throughout the past several decades. We noted spatial patterns of change in these habitats which varied over the course of the lower river. These changes may have practical implications for guiding restoration and conservation practices. In interpreting the results of this analysis, it is important to keep in mind that the historical and current data sets were developed very differently, and several assumptions were made in aggregating a wide variety of cover classes into a normalized set of classes which could effectively be used for comparison. Thus, some classes may be better represented than others, and a significant range of uncertainty is likely for some of the change scenarios. We found that the largest source of uncertainty in this analysis was contributed by the historical data, both in the unknown accuracy of the maps themselves relative to the scales of interest, as well as the ability of the analysts to effectively interpret the symbols used, which were often ambiguous or inconsistent from map to map. Despite these uncertainties, the results provide useful insight into the extent of change which has occurred in the Lower Columbia River Estuary and the significant declines in vegetated tidal wetlands that have occurred.

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Contents

Introduction

Background

As part of the US Environmental Protection Agency's National Estuary Program, the Lower Columbia Estuary Partnership is tasked with creating and implementing a Comprehensive Conservation and Management Plan for the lower Columbia River and estuary (LCRE). Through actions outlined in this plan, the Estuary Partnership seeks to preserve and, where possible, restore the natural ecological habitats of the Lower Columbia River, in order to protect the diverse array of fish and wildlife which they support. Among these species are 13 salmonid populations which are currently listed as threatened or endangered under the Endangered Species Act. To assist in implementing its habitat restoration and protection actions, the Estuary Partnership is developing a comprehensive, GIS based Habitat Restoration Prioritization Strategy. This framework will provide a basis for strategically restoring and protecting critical habitats throughout the LCRE. An important component of this framework is to inventory the current quality and distribution of these habitats, and to look at how these parameters have changed relative to a baseline 'historical' condition. Such information is useful in understanding how to effectively manage fish and wildlife populations which rely on these habitats.

The objective of this study was to quantify changes in habitats that have occurred in the LCRE, from a historical state which predated most human impacts, to its present day state. The analysis was conducted by comparing spatial data sets representative of the 'historical' and 'current' habitat conditions, in a digitized GIS format. A GIS framework allows for a straightforward quantitative comparison of this type of data. For the purpose of this study, the spatial extent of interest included the main stem lower Columbia River and Estuary and its floodplain, as shown in Figure 1. This comprises an area of approximately 463,000 acres (including water), extending from the confluence with the Pacific Ocean 146 miles upstream (RM 146) to Bonneville Dam, the first of several dams along the Columbia River and the upstream extent of tidal influence within the estuary. The LCRE has become a focal point for research due to its significance with respect to juvenile salmonid rearing. The role of the estuary in the development of juvenile Columbia River salmon has been well documented (e.g. Bottom et al., 2005; Fresh, Casillas, Johnson, & Bottom, 2005; Roegner et al., 2008). As a result of its importance, the floodplain has seen increased data development throughout the past decade, allowing for an analysis of this scope to be undertaken.

Our baseline 'historical' condition for this study dates back to the late 19th century, a period covering approximately 1870 to 1890. These decades are representative of 'relatively undisturbed' ecological conditions with respect to human impacts. Despite a limited amount of impact at the time, the actions which have been most closely tied to significant habitat loss and degradation in the LCRE primarily occurred later, during the early to mid-20th century (Bottom et al., 2005). These activities include: hydropower generation, dredging, forestry, agriculture, channel alteration, diking, and urban/industrial development. Two major survey efforts during this time produced the historical source data that was used for this study. The US Coast and Geodetic Survey (Coast Survey) conducted its early navigation charting efforts of the lower Columbia, while the General Land Office (GLO) was conducting detailed land surveys. Both of these surveys provided detailed vegetation information and spatially accurate maps which could be reliably digitized. Thus, they constitute the earliest known sources from which a comprehensive habitat survey of the entire estuary can be conducted. Digital representations of both of these data sets currently exist: the University of Washington School of Aquatic & Fishery Sciences Wetlands Ecosystem Team (WET lab) has recently completed a GIS representation of the Coast Survey historical maps, while GLO maps have been digitized in previous years by the Oregon Natural Heritage Information Center (ONHIC).

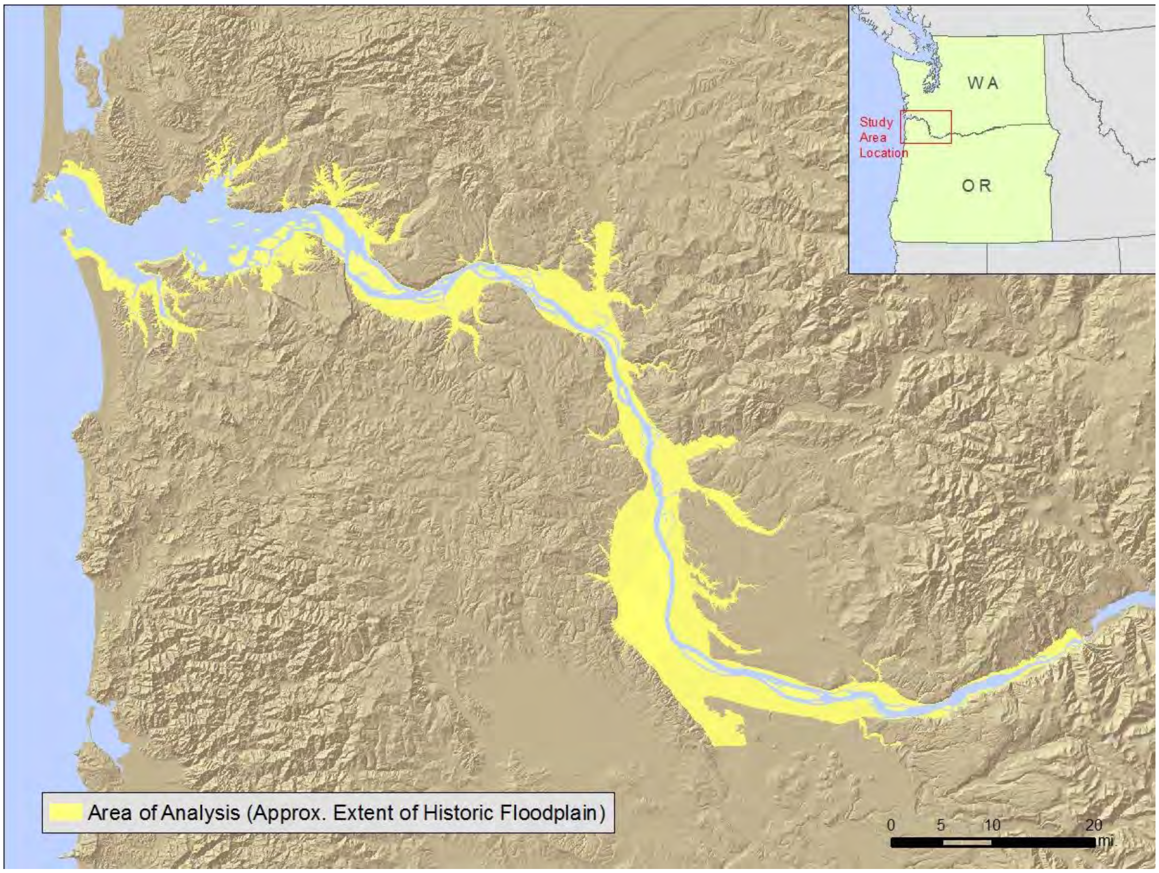

Figure 1: *Geographical location of the Lower Columbia River Estuary, and the approximate extent of its historical floodplain, which comprised the study area.*

To represent current conditions, the Estuary Partnership utilized its recently completed 2010 land cover classification. This data set was created as part of the Columbia River Estuarine Ecosystem Classification (CREEC). The CREEC is a separate GIS based management tool that the Estuary Partnership has been developing over the past several years in conjunction with USGS and the University of Washington, with funding from the Bonneville Power Administration. The land cover data created for this study was derived from the most recent aerial imagery. The data were classified using a recent approach that has been adopted by the National Oceanic and Atmospheric Administration's Coastal Change Analysis Program (NOAA-CCAP) for generating their high resolution habitat change analysis surveys along coastal margins. We believe that it is the best available data representing comprehensive, current land cover conditions for the LCRE.

In order to characterize habitat in this study, we considered vegetation cover type, hydrology (wetland vs. upland), and tidal inundation. These are the relevant metrics that, in most cases, could be obtained from both the current and baseline data sets. A particular habitat type that has been identified as a critical component for supporting many species, juvenile salmonids in particular, is tidally influenced wetlands. These are floodplain areas which receive hydrologic inundation from the main stem Columbia river (or its tributaries), through a combination of two factors: 1) tidal forcing from the Pacific Ocean, and 2) fluvial discharge as a result of controlled releases at the Bonneville Dam. Contributions from each process vary based on river location, with tidal forcing being more dominant in the lower estuary, and fluvial effects from river discharge beginning at approximately River Mile 22, and increasing non-linearly with distance upstream. More detailed descriptions of the hydrological characteristics of the LCRE can be found in Kukulka and Jay (2003) and Bottom et al. (2005). Discharge becomes most pronounced during the spring freshet period, as a result of runoff from snow melt. During this time, access to habitat for juvenile fish increases, as areas of floodplain become inundated due to the increased discharge. For the purpose of this study, we consider 'tidal' areas to be those habitats which receive adequate inundation to support juvenile fish during some time period of the year under a typical annual flow regime (mean river discharge as measured at Bonneville Dam) resulting from current Federal Columbia River Hydropower System management. With both water surface elevation from various gauges, as well as topographical elevations from recent LidAR data readily available, a general approximation of 'tidally influenced' areas could be obtained for current conditions. It should be noted that the exact criteria that were used to map historical 'tidally influenced' areas are not well documented, and thus the general approximation for this metric in the current data set, as described above, was considered acceptable for this analysis.

Numerous land cover change analyses have been performed for the LCRE in recent years (Garano, Anderson, & Robinson, 2003a; Thomas, 1983; Allen, 1995), with most driven by the common goals of understanding how much habitat is currently available for species relative to what was available historically, and how these habitats have been changing throughout time. The Estuary Partnership's decision to perform an additional analysis, in light of these existing studies, was motivated by the significant improvements in available land cover data that have occurred over the past 5-6 years. These include improvements with respect to accuracy, as well as spatial and temporal extent of data. In reviewing existing habitat change studies, we found that each utilized baseline data which was limited with respect to one or both of these factors. By utilizing recently available data, we were able to generate a comprehensive change analysis for the entire historical floodplain, dating back to the late 1800s. This combination of spatial and temporal extent had not been achieved in previous analyses. Our approach provides a useful supplement to studies by Allen, Garano, and C-CAP, which provide detailed focus on changes that have occurred over more recent decades. Appendix A provides a summary of the previous habitat change analyses of the LCRE, and what we perceived as the associated limitations with respect to our intended purposes.

Although the goal of this study was to characterize the changes in habitat which have occurred throughout the LCRE over approximately the past 140 years, we did not attempt to link these changes to the underlying processes. Because the baseline data sets include various components of land use as categories, some of the change scenarios can be directly inferred to result from anthropogenic activities (for example, natural vegetation changing to developed or agricultural land). However, as with other estuaries, the lower Columbia is a highly dynamic system, subject to a variety of natural as well as anthropogenic influences. Both types of processes are capable of gradual or sudden impacts on the landscape which can alter the existing habitat types dramatically.

Approach

The approach utilized by any landscape change analysis is typically guided by the format of the available baseline data, as well as the specific aspects of change that are being analyzed. For example, a change analysis can be performed to examine alterations in individual land cover classes of interest, or to detect changes between multiple land cover types. Existing studies for the LCRE have analyzed changes between multiple land cover types. The techniques for doing this have varied, based on available data formats. A summary of previous land cover efforts follows:

Thomas (1983) analyzed changes using the same baseline historical data source (Coast Survey Maps from the late 1800s) as we have chosen for this study. Working before the advent of GIS and other relevant computer software, the comparisons between historical and current data were made by analyzing hard copy maps. This approach provided an effective means for comparing overall acreages of various land cover types for the baseline data sets, however it was not practical for illustrating spatial patterns of change. The analysis was limited to the lower 46 miles of river floodplain. Graves, Christy, Clinton & Britz. (1995) subsequently extended Thomas's work up river to approximately mile 105, but did not perform a detailed change assessment. They did, however, generate a digital, GIS representation of the historical habitats which they interpreted from the Coast Survey maps.

Allen (1999) used aerial photography taken at 5 different time periods in order to identify changes in wetland habitats from 1948 to 1991. Photo interpretation to classify habitat types was conducted using a GIS. Vector based polygons representing on the ground habitat conditions were digitized and attributed. These layers were then overlain in the GIS, and spatial analysis was performed in order to examine detailed patterns of change. Using this approach, the specific type of land cover change is recorded at every spatial location, and overall changes between all habitat types are easily quantified. The analysis extended over the full 146 miles of the LCRE, but was limited to an approximately 3km swath on either side of the river, due to limitations in the extent of the aerial photography. As a result, extensive floodplain areas were omitted from the analysis, including many of the major tributary floodplain areas. The date of the earliest images analyzed (1948) is subsequent to major anthropogenic impacts to the river (dam construction, diking, etc.), and so was a limiting factor with respect to the temporal extent that we were looking for.

As satellite based land cover data and image processing software became more readily available in recent decades, pixel based analyses of raster data sets have become more common place. This approach allows for detailed change detection over very large spatial areas, with resolutions on the order of meters. Garano et al. (2003a), as well as C-CAP, have generated pixel based change analyses for the LCRE. While informative, these analyses are limited, with respect to our objectives, in their temporal extent of baseline historical data, with baseline conditions extending back only as far as the 1990's. A straightforward method of summarizing results of pixel based change analyses is to use a cross-tabulation matrix. With this method, information about how each pixel changes from its historical state to its current state is tracked using software. For each particular change scenario, the number of pixels exhibiting that change is summed. Since the pixel area is known, a final acreage for every particular change scenario is obtained. This information is then tabulated, with the rows representing the historical, or 'from' categories, and the columns representing the current, or 'to', categories. This provides a convenient display of how much each cover class changes, which classes it changes to, and how much of that class remains unchanged. Garano et al. (2003a) used this method to present results. We present our results in the same manner, based on acreages of GIS polygons rather than pixel counts.

Our approach utilized aspects of each of the analyses described above. Our historical and current data sets both existed in vector based GIS format, allowing for a straightforward change analysis to be performed through a basic 'union' overlay, a common geoprocessing task. We were interested in examining various types of change, and thus attributed the data such that results could be presented in a cross-tabulation matrix.

A potential challenge for any change analysis is presented by variations in cover classes between the source data sets. Often, the analyst is faced with trying to compare data sets that were created with differing land cover classifications. In order to make meaningful interpretations in these situations, some manipulation of one or both of the data sets may be required prior to the analysis. Our baseline historical data set for this study was created from a number of different data sources, in order to obtain the desired spatial coverage. Each of these sources utilized its own unique land cover classification, and in turn each of these differed from the classification used by the 'current' data set. In order to account for these differences and obtain meaningful results, we aggregated all classes from each data source into a normalized set of land cover classes. In doing so, we lost some of the detail provided by the more specific existing classes, but at the same time reduced the number of possible change possibilities, and simplified the interpretation of results.

Materials & Methods

Source Data

The objective of the study was to conduct a landscape change analysis using source data which offered the greatest spatial and temporal extent possible, and at the same time met reasonable quality and accuracy standards. The latter criteria were particularly relevant to the historical data, when considering its age, the processes used to derive it, and the availability of metadata describing it. A description of the data sources selected for use in this study follows:

'Current' Data Set

The data set representing current conditions was created by the Sanborn Map Company for the Estuary Partnership in 2010, as part of the CREEC. The report describing this data set (Lower Columbia Estuary Partnership, Sanborn Map Company, 2011) can be currently obtained from the Estuary Partnership, and will be available online in 2012. Sanborn used an object based classification approach and image segmentation to derive a high resolution, vector based land cover map based primarily on 4 band aerial imagery collected by the National Agriculture Inventory Program (NAIP). NAIP is administered by the US Department of Agriculture, and acquires 1-meter resolution imagery during leaf-on seasons, on a 3–5 year cycle. The default spectral bands are the red, blue and green visible bands (RGB). A fourth, near-infrared band was added in 2007, allowing image processing techniques similar to those used for land cover classification of satellite imagery to be applied to NAIP imagery. In addition to NAIP, archived LandSAT imagery from multiple dates was incorporated into the analysis, creating an 'image stack' that provided information covering multiple growing seasons and years (2007 – 2009). Recently acquired LiDAR data was also used in the analysis. This high quality elevation data is useful for deriving numerous aspects of habitat quality, including vegetation heights, slopes, and land elevations relative to tidal heights.

The classification method utilized an initial software based segmentation process to generate vector (polygon) based land unit segments. These segments were derived from texture and color of the source imagery, in combination with elevation breaks obtained from supporting LiDAR data. The boundaries between resulting segments tend to fall along natural breaks in land cover classes, which differ from the fixed, square pixel boundaries created in a raster based analysis. Once the imagery was segmented, spectral analysis was then applied to classify the segments. The final result was a vector based land cover data set, with more uniform boundaries between adjacent cover types compared to a raster data set. In addition, habitat patches generated by the segmentation method tend to be more contiguous compared to raster based analyses, which can produce highly pixelated data. Figure 2 provides a comparison of the final data sets generated by the different methods (segments vs. raster pixels). It is important to note that the spatial resolutions are not the same for the two data sets that are shown (30 meters for the raster versus 1-meter for the vector), however the pixelated nature of the raster (isolated, differently classed pixels within more homogenous groupings), is still apparent.

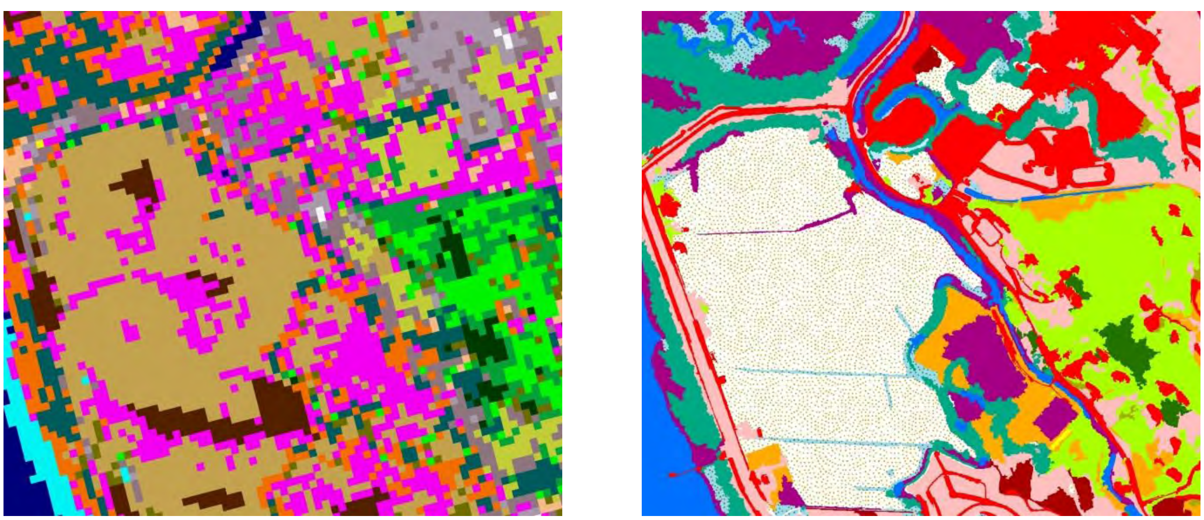

Figure 2: *Comparison of traditional pixel based land cover data classification (shown on left. Source is NOAA C-CAP 2006, 30 meter resolution), and high resolution, segment based land cover classification (shown on right. Source is 2010 Estuary Partnership data set, 1 meter resolution) shown for the same location.*

The land cover classes selected for this map were identical to those used by Garano et al. (2003a, 2003b). This classification scheme was developed with input from a diverse group of stakeholders and was tailored to the land cover classes of the LCRE. Cover classes were chosen with specific focus on estuarine and tidal freshwater habitats. We were also interested in differentiating between tidal and non-tidal wetlands, including areas that are isolated from tide due to the presence of artificial flow barriers. This information was derived independently from, and later merged with, the spectral land cover classification. Ancillary data used to derive this information included LiDAR, water surface elevation data, and locations of hydrologic barriers (levees, tidegates, roads, etc). Table 1 lists the land cover classes, and their associated areal extents calculated for the LCRE, that were used in the 2010 LCEP land cover data set.

A standard accuracy assessment was performed on the data set. Results are provided in the final report. This assessment accuracy analysis excluded information related to tidal inundation, and was relevant only to the vegetation classes.

Table 1: *Land cover classes used in the 2010 Lower Columbia Estuary Partnership land cover data set, and their calculated areal extents in acres.*

Class #	Habitat Class	Area (acres)
10	Coniferous Upland Forest	30,672
11	Deciduous Upland Forest	48,049
23	Coniferous Wetland Forest – Non tidal	3,092
24	Coniferous Wetland Forest – Tidal	1,569
25	Coniferous Wetland Forest – Diked	1,067
26	Deciduous Wetland Forest – Non tidal	12,356
27	Deciduous Wetland Forest – Tidal	6,319
28	Deciduous Wetland Forest – Diked	3,737
40	Upland Shrub/Scrub	4,747
42	Wetland Shrub/Scrub – Non tidal	3,866
43	Wetland Shrub/Scrub – Tidal	4,957
44	Wetland Shrub/Scrub – Diked	1,692
50	Upland Herbaceous	10,188
52	Wetland Herbaceous – Non tidal	7,299
53	Wetland Herbaceous – Tidal	11,838
54	Wetland Herbaceous – Diked	10,406
60	Aquatic Beds	1,370
70	Agriculture	71,358
71	Tree Farm	4,117
80	Barren	2,427
81	Mud	7,808
82	Sand	7,722
84	Rock	35
90	Urban – Impervious	52,243
91	Urban - Open Space Developed	23,648
93	Water	147,576

Historical Data Set

The Estuary Partnership utilized the following four existing sources to generate the baseline historical data set: 1) University of Washington's WET lab interpretation of the late 1800s Coast Survey topographic charts; 2) ONHIC interpretation of the late 1800s GLO survey maps; 3) Estuary Partnership's interpretation of late 1800s GLO survey maps for gap areas not covered by the OHNIC data (this data, limited to the Columbia River Gorge, was created for the Estuary Partnership by John Christy, one of the primary authors of the OHNIC data set); 4) Thomas (1983)/Graves et al. (1995) interpretations of the late 1800s Office of Coast Survey topographic charts. Because no single data source provided spatial coverage of the entire floodplain, segments of each were incorporated as necessary to provide maximum coverage.

The late 1800's Coast Survey topographic charts (commonly referred to as T-sheets) were an obvious choice for a baseline historical data source. These maps have been used in previous Lower Columbia River studies (Thomas, 1983; Graves et al., 1995) to characterize historical vegetation patterns within the floodplain. Shalowitz (1964) provides a description of the processes that were used to generate these maps, as well as the land cover classes and associated map symbology that were used. Because the charts were intended for navigational purposes, particular attention was paid to near shore areas, and as a result tidal/fluvial influenced wetland areas were well mapped.

Thomas (1983) performed one of the first habitat change assessments for the LCRE, based on his interpretation of the T-sheets, as part of the Columbia River Estuary Data Development Program (CREDDP) in the late 1970s. The analysis was limited to the lower 46 miles of the LCRE. The report provides excellent background on historical data sources for the Lower Columbia, and a rationale for selecting the T-sheets as the preferred source. Graves et al. (1995) expanded on the work of Thomas, creating a digital GIS database of the habitat types that they could interpret from the T-sheets. The dataset extends upriver as far as Portland (RM 105). They also refined the land cover classes, subdividing Thomas' original 7 classes into 18 categories, based on the appearance of additional symbology upriver from Puget Island and supporting field work along the river (Graves et al. (1995), pg. 6). Both of these authors took steps to verify the accuracy of the data included on the original charts, and concluded that they are reliable representations of the floodplain vegetation.

In recent years, additional work has been done by the UW WET lab to delineate the information contained in the T-sheets, using a revised land cover classification with additional detail not included in the Graves et al. (1995) data set. Working with georeferenced versions of the T-sheets provided by NOAA, the WET lab in 2010 generated a vector based interpretation of the complete set of T-sheets that exist for the estuary, from RM 0 to approximately RM 120, based on their revised land cover classification (https://catalyst.uw.edu/workspace/wet/14965/82926). Figure 3 shows an example of a georeferenced T-Sheet for the Columbia River and the resulting GIS polygons generated by the WET lab, delineating the various vegetation types. We felt that this interpretation of the historical T-sheets provided the best baseline historical data for this analysis. It covered a larger spatial extent than the Graves et al. (1995) data set, and the land cover classes were more compatible with the classes contained in the baseline 'current' data set, relative to both the Graves et al. (1995) and Christy et al. (2012) data sets.

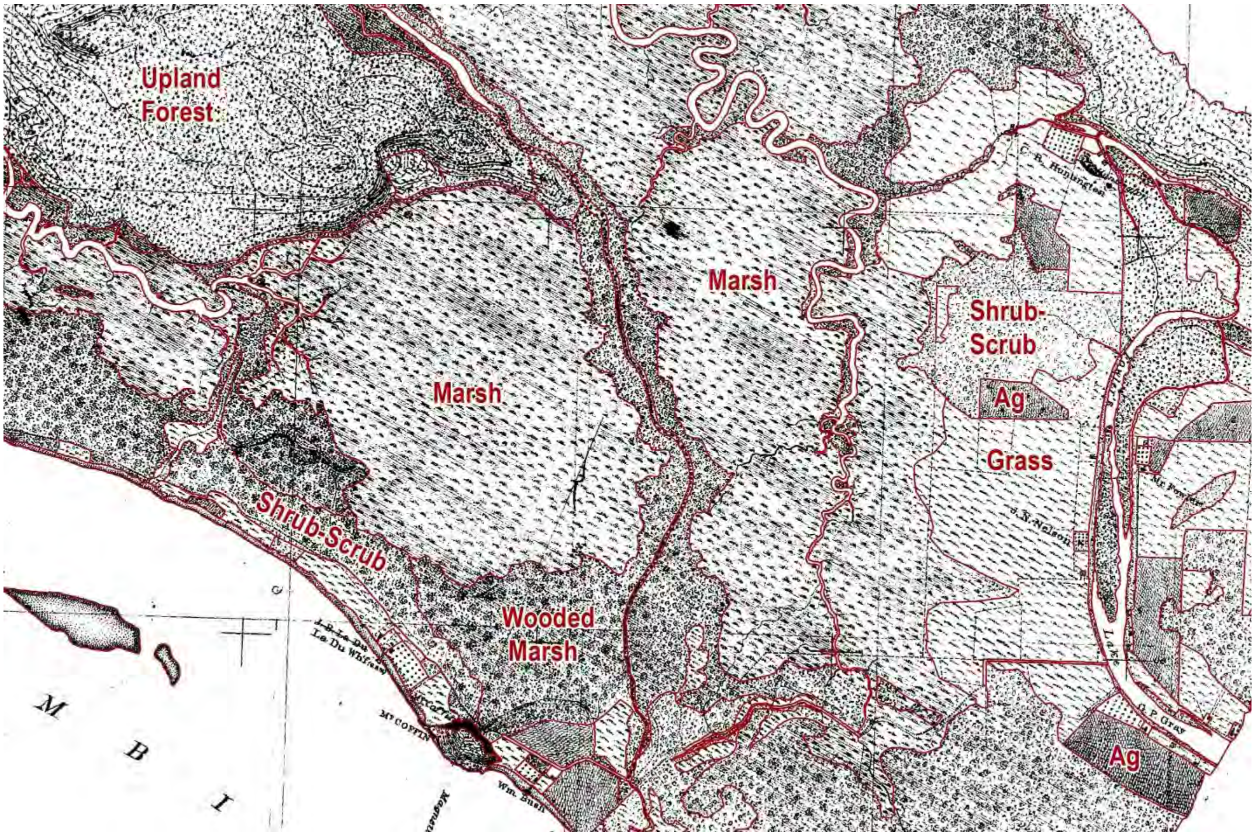

Figure 3: *Example of baseline historical data used for the land cover change analysis. Georeferenced version of a late 1800s Office of Coast Survey T-sheet, with outlines of polygons delineated by the WET lab (based on the T-sheet vegetation symbols). Labels indicate the cover classes assigned to the polygons by WET lab staff.*

The WET lab data exists as a set of files for each individual T-sheet, of which there are a total of 27 covering the LCRE. Spatial overlap exists between each sheet at the boundaries, and upon inspection of the map symbols it became evident that in several areas smooth transitions do not exist between sheets. Furthermore, the symbology in spatial areas where the overlaps occur is often considerably different between any two overlapping sheets. We could not find an explanation for these inconsistencies in Shalowitz, but assume that they are a result of the maps being created at different points in time, and possibly by different surveyors. Either or both of these factors could likely result in the same area being interpreted in slightly different ways. For our analysis, a single, seamless coverage was needed. This required an additional pre-processing step, consisting of edge matching each of the WET lab polygon segments in the areas of overlap. In order to resolve discrepancies in the differing map symbols for overlapping T-sheet segments, we were able to use as reference an alternate version of the historical maps, available at the NOAA Office of Coast Survey online historical map & chart collection. These provide coverage of the LCRE in a series of three or four maps, thus eliminating the areas of overlap between the

27 larger scale T-sheets. These maps were not available in GIS format, but were still quite useful as a visual aid. Figure 4 illustrates the overlap issue that we encountered.

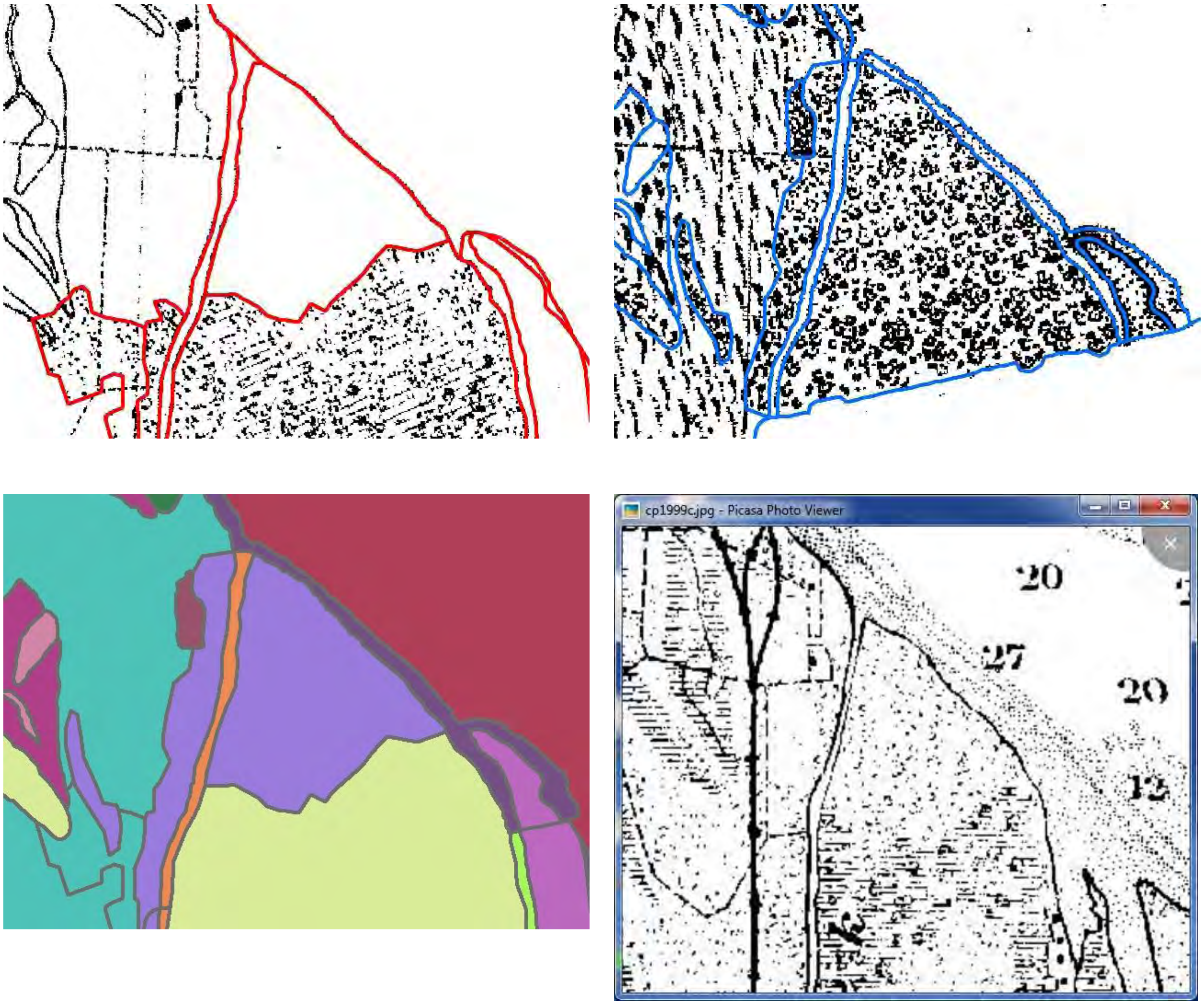

Figure 4: *Example of edge matching process for WET labs polygons of 1880s T-sheet maps. <u>Upper left</u>: T-sheet 1455b with corresponding WET labs polygons overlain. <u>Upper right</u>: T-sheet 1495 with corresponding WET labs polygons overlain. Note differences in symbols between T-sheets 1455b and 1495, for the same spatial area. <u>Lower left</u>: Resulting Estuary Partnership edge matched polygon boundaries generated for the baseline historical data set for change analysis. <u>Lower Right</u>: Reference map obtained from Office of Coast Survey online historical chart archives, used to resolve differences in T-sheets for the edge matching process.*

During approximately the same time period that the Coast Survey was surveying the river for navigation purposes, the GLO was conducting cadastral surveys of township and range properties in this area. The surveys and resulting maps provided detailed vegetation information. In recent years, Christy et al. (2012) have digitized historical vegetation patterns throughout Oregon and Washington, based on the maps and notes generated from the GLO surveys. This information exists in various vector based GIS data sets, and the methods used to create it are well documented. Figure 5 shows an example of a GLO survey map for the Columbia River and the resulting GIS polygons generated by Christy et al. (2012), delineating the various vegetation types.

Figure 5: *Example of baseline historical data source used for the land cover change analysis. Image on left shows a digital version of a late 1800s GLO survey map. Map symbols depicting various land use/land cover types is evident. Image on right shows GIS polygons delineated by Christy et al. (2012), based on the GLO map vegetation symbology.*

Of the available data sources, WET labs T-sheet interpretation was chosen as the primary data source due to its favorable spatial extent, spatial accuracy, and similarity of cover classes relative to the current data set. This data was supplemented with the Christy et al. (2012) GLO interpretation for areas not covered by the Wet labs data. For regions where neither of these data sets provided coverage, portions of the Graves et al. (1995) T-sheet interpretation were utilized. These were limited to very small areas in the lower estuary. Figure 6 shows the coverage extents utilized for each of the data sets. In total, we were able to obtain baseline historical coverage for 401,400 acres of the possible 462,000 acres of historic floodplain (87% of floodplain). Because the 'current' data set provided complete floodplain coverage, the historical data set was the limiting factor spatially.

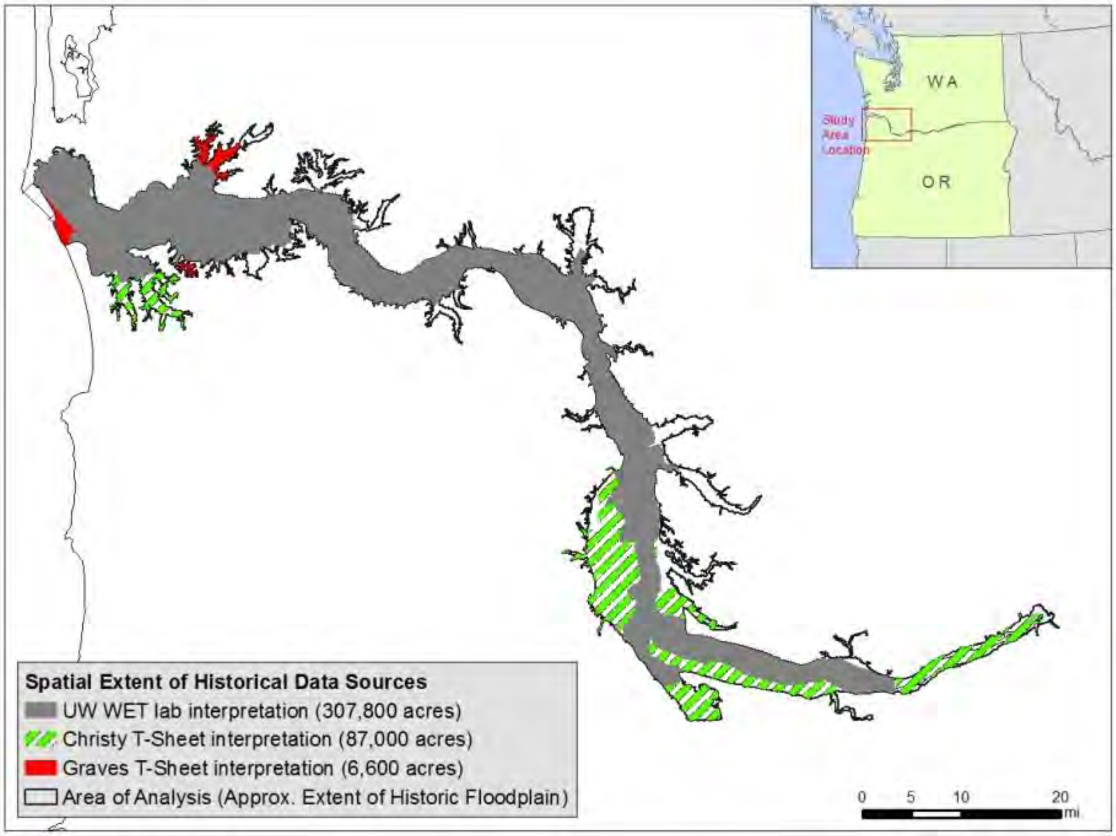

Figure 6: *Map showing spatial extent of coverage from each of the historical data sources that was used in the final baseline data set for land cover change analysis. WET labs data constituted 77% of the total area analyzed, Christy GLO data 24%, and Graves/CREST data the remaining 1%. Note areas within the historical floodplain which were not analyzed, due to a lack of historical data. These were primarily limited to tributary valleys.*

Aggregation of Land Cover Classes

The greatest challenge in incorporating data from three historical sources was in deriving a set of normalized cover classes which would adequately represent the classes from all of these sources, in addition to the classes used in the 'current' data set. The set of normalized classes was developed using input from local plant biologists, and represents our best attempt to aggregate existing classes into representative categories. In aggregating some of the more uncertain categories, we used ancillary data where possible to help determine the appropriate assignments. For example, based on LiDAR elevations it seemed most appropriate to assign several of the forested riparian classes in the GLO data to a 'non-tidal' wetland category, rather than a 'tidal' wetland. Table 2 lists the different cover classes from each of the historical sources. Table 3 lists the normalized classes, and the classes from each source data set that were aggregated into each normalized class.

Table 2: *Land cover classes used in the data sources chosen for the baseline historical data set. Note: several more classes exist in both the Graves/CREST T Sheet and Christy GLO classifications. Classes shown are the ones included in segments of each data set which were used in our analysis.*

WET lab T Sheet Analysis	**Graves/CREST T Sheet Analysis**	**Christy GLO Analysis** General Category	 Detailed Cover Classes
Marsh: upland, floodplain, tidal Submerged Marsh: floodplain, tidal Wooded Marsh: upland, floodplain, tidal Shrub Scrub Marsh: floodplain, tidal	Marsh: tidal Willow Swamp: tidal Spruce Swamp: tidal Cottonwood Swamp: tidal Deep Water Medium-Shallow Water Tidal Flats, Shallow	Closed Forest; Riparian & Wetland	Black Cottonwood Riparian Red Alder - mixed conifer riparian forest Red Alder swamp Southern mixed riparian Riparian Sitka Spruce Forest Sitka Spruce Swamp Ash swamp Swamp, composition unknown
Submerged Marsh: floodplain, tidal Wooded Marsh: upland, floodplain, tidal Shrub Scrub Marsh: floodplain, tidal		Closed Forest; Upland	Doug Fir Doug Fir - White Oak White Oak Sitka Spruce
Mixed Forest: upland, floodplain Pine: upland, floodplain Woodland: upland, floodplain Shrubs: upland, floodplain		Emergent Wetland	Marsh or wet meadow, composition unknown Tidal marsh, salinity undifferentiated Wetland, composition unknown Marsh, composition unknown Wapato Marsh
Grass: upland, floodplain		Prairie	Prairie, wet and dry undifferentiated Seasonally or perennially wet prairie Upland and xeric prairie
Orchard: upland, floodplain Cultivated: upland, floodplain		Savanna	Doug Fir
Barren: upland, floodplain Sand: floodplain Sand Flat: floodplain, tidal Rocky bluff: upland Eroded Bank: upland		Shrubland	Brush fields or thickets on slopes and ridges Brush, composition unknown Willow swamp or riparian stands Brush fields or thickets on bottoms or wet terraces Rose or briar thickets
Riverine/Estuarine: tidal Open Water: upland, floodplain Stream/river, upland, floodplain		Un-vegetated	Rock Outcrops, talus, exposed bedrock, scree, etc. Gravel bar
Dwellings: upland, floodplain Road: upland, floodplain Levee: upland, floodplain Overwater Structure: floodplain		Water and Wetlands	Water Bodies > 1 chain across Seasonally flooded lake or pond > 1 chain
Unclassified		Woodland	Doug Fir - White Oak Doug Fir

Table 3: *Normalized land cover classes used for change detection analysis (left hand column), with assigned source data cover classes. Columns 3 – 5 are the historical data sources. Column 6 is the 'current' data source.*

Normalized Class	**Code**	**Classes from WET lab T-Sheet Analysis**	**Classes from Graves/CREST T-Sheet Analysis**	**Classes from Christy GLO Analysis**	**Classes from Estuary Partnership 2010 'Current' Data Set**
Herbaceous Wetland: tidal	HWT	Marsh: tidal Submerged Marsh: tidal	Marsh: tidal	Tidal marsh, salinity undifferentiated Marsh, unknown Wapato Marsh	Wetland Herbaceous – Tidal
Herbaceous Wetland: non-tidal	HWNT	Marsh: floodplain, upland Submerged Marsh: floodplain		Seasonally or perennially wet prairie Marsh/Wet Meadow, unknown	Wetland Herbaceous – Non tidal Wetland Herbaceous – Diked
Shrub-Scrub Wetland: tidal	SWT	Shrub-Scrub Marsh: tidal	Willow Swamp: Tidal	Willow Swamp Swamp: unknown	Wetland Shrub/Scrub – Tidal
Shrub Scrub Wetland: non-tidal	SWNT	Shrub Scrub Marsh: floodplain		Wetland: unknown	Wetland Shrub/Scrub – Non tidal Wetland Shrub/Scrub – Diked
Forested Wetland: tidal	FWT	Wooded Marsh: tidal	Spruce Swamp: Tidal Cottonwood Swamp: Tidal	Sitka Spruce Swamp Ash Swamp	Coniferous Wetland Forest – Tidal Deciduous Wetland Forest – Tidal
Forested Wetland: non-tidal	FWNT	Wooded Marsh: floodplain, upland		Black Cottonwood Riparian Red Alder – Mixed Conifer Riparian Red Alder swamp Mixed Riparian Riparian Sitka Spruce Forest Mixed Riparian Black Cottonwood Riparian Red	Coniferous Wetland Forest – Non tidal Coniferous Wetland Forest – Diked Deciduous Wetland Forest – Non tidal Deciduous Wetland Forest – Diked
Herbaceous non-wetland	H	Grass: upland, floodplain		Prairie, wet and dry undifferentiated Upland and xeric prairie	Upland Herbaceous
Shrub-Scrub non-wetland	S	Shrubs: upland, floodplain		Doug Fir (Savannah) Rose or briar thickets Brush fields or thickets on slopes and ridges Brush, composition unknown Brush fields or thickets on bottoms or wet terraces	Upland Shrub/Scrub
Forested non-wetland	F	Mixed Forest: upland, floodplain Pine: upland, floodplain Woodland: upland, floodplain		Doug Fir Doug Fir - White Oak White Oak Sitka Spruce Doug Fir - White Oak (Woodland) Doug Fir (Woodland)	Coniferous Upland Forest Deciduous Upland Forest
Tidal Sand/Mud Flats	TF	Sand flat, tidal	Tidal Flats, Shallows		Sand Mud

Agriculture	AG	Orchard: upland, floodplain Cultivated: upland, floodplain			Agriculture Tree Farms
Developed	D	Dwellings: upland, floodplain Road: upland, floodplain Levee: upland, floodplain Overwater Structure: floodplain			Urban, Impervious Urban, Open Space Developed
Water	W	Riverine/Estuarine: tidal Open Water: upland, floodplain Stream/river, upland, floodplain	Deep Water Medium-Shallow Water	Water Bodies Seasonally Flooded Lake	Aquatic Beds Water
Other	O	Barren: upland, floodplain Sand: floodplain Sand Flat: floodplain Rocky bluff: upland Eroded Bank: upland		Rock Outcrops, talus, exposed bedrock, scree etc. Gravel bar	Barren Rock
Unclassified	UNC	Unclassified			

Once a normalized set of cover classes was chosen and each of the historical and current baseline data sets was converted to these classes, an overlay analysis was performed in ArcGIS, using the 'Union' geoprocessing task. The resulting output was a GIS data set representing habitat change, with attribute fields representing the original historic class, the current class, and the type of change.

Results

Table 4 shows total acreages of all normalized land cover classes (columns 2 and 3), for both the historical and current data sets. Also shown is each class' percent composition of the total acreage (columns 4 and 5). It is also informative to examine changes between vegetated (non-water) classes only, and thus each class' percent contribution relative to other non-water classes is also shown (columns 6 and 7).

Upon close inspection of the symbols used throughout the historical T-Sheets, it became clear that there was significant uncertainty in the interpreters' ability to distinguish between a 'shrub-scrub' and 'forested' class in the GIS representations, particularly in the wetland areas. This was confirmed in speaking with WET labs staff, who acknowledged the difficulties. In light of this we felt it would be informative to combine these classes as an additional part of our analysis. Table 5 presents the results with the forested and shrub-scrub wetland classes combined into 'wooded wetland' classes, for both the tidal and non-tidal wetlands.

Table 4: *Areas (in acres) of normalized land cover classes for the historic and current data sets (columns 2 and 3). Relative percent coverages for each class with respect to total area analyzed (columns4 and 5), and relative to total land (non-water) area (columns 6 and 7).*

Normalized Land Cover Class	Historic Data Set (acres)	Current Data Set (acres)	Overall Change (acres)	% of Overall Area (Historic)	% of Overall Area (Current)	% of Overall Land Area (Historic)	% of Overall Land Area (Current)
Agriculture	2,267	61,849	59,582	0.6	15.4	1.0	24.4
Developed	1,724	65,751	64,027	0.4	16.4	0.8	26.0
Forested non-wetland	82,969	36,989	-45,980	20.7	9.2	36.1	14.6
Forested Wetland: non-tidal	8,162	17,451	9,289	2.0	4.3	3.6	6.9
Forested Wetland: tidal	30,565	7,516	-23,049	7.6	1.9	13.3	3.0
Herbaceous non-wetland	26,739	7,221	-19,518	6.7	1.8	11.6	2.9
Herbaceous Wetland: non-tidal	11,236	15,623	4,387	2.8	3.9	4.9	6.2
Herbaceous Wetland: tidal	35,466	11,381	-24,085	8.8	2.8	15.4	4.5
Other	1,632	2,354	722	0.4	0.6	0.7	0.9
Shrub-Scrub non-wetland	5,262	2,549	-2,713	1.3	0.6	2.3	1.0
Shrub Scrub Wetland: non-tidal	2,359	4,576	2,217	0.5	1.1	1.0	1.8
Shrub-Scrub Wetland: tidal	8,875	4,773	-4,102	2.2	1.2	3.9	1.9
Tidal Sand/Mud Flats	12,448	15,187	2,739	3.1	3.8	5.4	6.0
Unclassified	1,583	0		0.4	0	0.7	0
Water	170,114	146,598	-23,516	42.4	36.5	N/A	N/A

Table 5: *Identical results as presented in Table 4 but with the 'forested' and' shrub scrub' wetland classes combined into 'wooded' wetlands classes.*

Normalized Land Cover Class	Historic Data Set (acres)	Current Data Set (acres)	Overall Change (acres)	% of Overall Area (Historic)	% of Overall Area (Current)	% of Overall Land Area (Historic)	% of Overall Land Area (Current)
Agriculture	2,267	61,849	59,582	0.6	15.4	1.0	24.4
Developed	1,724	65,751	64,027	0.4	16.4	0.8	26.0
Forested non-wetland	82,969	36,989	-45,980	20.7	9.2	36.1	14.6
Herbaceous non-wetland	26,739	7,221	-19,518	6.7	1.8	11.6	2.9
Herbaceous Wetland: non-tidal	11,236	15,623	4,387	2.8	3.9	4.9	6.2
Herbaceous Wetland: tidal	35,466	11,381	-24,085	8.8	2.8	15.4	4.5

Other	1,632	2,354	722	0.4	0.6	0.7	0.9
Shrub-Scrub non-wetland	5,262	2,549	-2,713	1.3	0.6	2.3	1.0
Tidal Sand/Mud Flats	12,448	15,187	2,739	3.1	3.8	5.4	6.0
Unclassified	1,583	0		0.4	0	0.7	0
Water	170,114	146,598	-23,516	42.4	36.5	N/A	N/A
Wooded Wetland: non-tidal (includes Forested and Shrub-Scrub non-tidal wetlands)	10,522	22,027	11,505	2.5	5.4	4.6	8.7
Wooded Wetland: tidal (includes Forested and Shrub-Scrub tidal wetlands)	39,439	12,289	-27,150	9.8	3.1	17.2	4.9

As expected, both land use classes (Agriculture, Developed) showed sharp increases in extent from the historical period to present day. Agriculture comprised only 1% of historical land area, compared to 24.4 % of current land area (increasing from 2,267 acres to 61,849 acres). Developed land showed a similar trend, changing from 0.8% of total historical area to 26% today (increasing from 1,724 acres to 65,751 acres). Most vegetation classes showed decreases in total area over time, with the largest changes occurring in forested non-wetlands as well as all tidal wetlands classes. Forested non-wetlands decreased from 36.1% of total land area to 14.6% of total land area (decreasing from 82,969 acres to 36,989 acres, a 55% decrease). Herbaceous tidal wetland decreased from 15.4% of total land area to 4.5% currently (decreasing from 35,466 acres to 11,381 acres, a 68% decrease). Wooded tidal wetlands (forested + shrub scrub) decreased from 17.2% of total land area to 4.9% currently (decreasing from 39,439 acres to 12,289 acres, a 69% decrease). Non-tidal wetlands classes showed slight increases in percent cover, with herbaceous increasing from 4.9% to 6.2% total land area and wooded increasing from 4.6% to 8.7% total land area. Water showed a slight decrease in total area, decreasing from 42.4% to 36.5%. Tidal flats (sand and mud) remained relatively unchanged with respect to total percent area (3.1% historic versus 3.8% current). We expected to see larger changes in this class, considering the highly dynamic sediment processes in the estuary as well as the manipulation of dredged material throughout the LCRE that has occurred.

As part of our analysis, we constructed a change matrix to illustrate the specific changes that occurred for each class, measured in acres. The matrix also shows how much of each class remained unchanged. Results are shown in Table 6. By reading across rows, the user can see the quantity of that cover class (indicated by the class at the start of the row) which changed to each other class. The value at the end of the row is the sum total of acres that existed historically for that class. The value at the bottom of each column equals the total acres of the class indicated at the top of the column that exists presently. For example, examining the 'Forested non-wetland' row, we see that 11,559 acres of this class changed to Agriculture, 31,482 acres changed to Developed, and 25355 acres remained unchanged. Looking at the end of the row, we see that a total of 82,969 acres existed historically. Looking at the 'Forested non-wetland' column, the bottom column shows a total of 36,989 of this class existing presently.

Table 6: *Matrix showing change (in acres) between normalized land cover classes from 'Historical' to 'Current' time period. Wooded wetland categories include the summed forested and shrub-scrub wetland categories (i.e. WWNT = FWNT + SWNT). 'Unclassified values (shown in parentheses) are not included in the summed 'Historic total' and "Current total' calculations. Classes are listed using code values. Classes associated with each code value can be found in Table 3. Grey shaded boxes show the amount of 'unchanged' area for each class.*

TO CLASS: / FROM CLASS:	A	D	F	FWNT	FWT	H	HWNT	HWT	O	S	SWNT	SWT	TF	UNC	W		WWNT	WWT	Historical acres, total
Agriculture (A)	323	1411	265	54	5	28	42	3	47	25	14	2	7	(0)	44		67	7	2267
Developed (D)	216	1023	237	54	5	38	33	7	27	16	6	0	6	(0)	55		60	5	1724
Forested non-wetland (F)	11559	31482	25355	3864	578	2449	1552	319	983	1430	517	152	289	(0)	2441		4381	730	82969
Forested wetland: non-tidal (FWNT)	1123	1837	1305	1092	407	615	510	258	57	87	176	86	53	(0)	558		1268	493	8162
forested wetland: tidal (FWT)	9579	4769	1291	3297	1886	509	3172	1182	223	108	1039	1170	209	(0)	2131		4336	3056	30565
Herbaceous non-wetland (H)	9229	9706	2432	1044	305	1046	1207	337	323	245	153	19	59	(0)	635		1197	324	26739
Herbaceous wetland: non-tidal (HWNT)	6393	1670	450	576	288	240	749	313	37	49	105	13	8	(0)	342		681	301	11236
Herbaceous wetland: tidal (HWT)	12521	4859	826	2201	824	646	3472	3877	128	126	980	1145	902	(0)	2959		3181	1969	35466
Other (O)	20	298	304	146	11	12	39	76	5	31	33	19	50	(0)	589		179	30	1632
Shrub scrub non-wetland (S)	1296	2367	870	208	16	108	117	12	34	21	21	4	22	(0)	166		229	20	5262
Shrub scrub wetland: non-tidal (SWNT)	671	196	235	261	221	57	203	161	21	12	28	34	24	(0)	237		288	255	2359
Shrub scrub wetland: tidal (SWT)	3883	531	230	912	427	29	1027	124	29	15	620	701	61	(0)	287		1531	1128	8875
Tidal flats (TF)	155	722	581	571	277	129	389	1326	81	67	175	155	2588	(0)	5231		746	432	12448
Unclassified (UNC)	(361)	(497)	(360)	(92)	(28)	(46)	(45)	(17)	(6)	(28)	(18)	(2)	(13)	(0)	(70)		(110)	('30)	0
Water (W)	4883	4881	2608	3173	2265	1316	3111	3386	359	317	710	1274	10910	(0)	130921		3883	3539	170114
Wooded wetland: non-tidal (WWNT)	1794	2033	1540	1352	628	671	712	419	78	99	204	119	77	(0)	795		1556	748	10522
Wooded wetland: tidal (WWT)	13462	5300	1521	4208	2313	538	4198	1306	251	123	1658	1871	270	(0)	2419		5867	4184	39439
Current Acres, total	61849	65751	36989	17451	7516	7221	15623	11381	2354	2549	4576	4773	15187	(0)	146598		22027	12289	399817

Similar patterns of natural vegetation loss to Agriculture and Development are seen for the vegetated tidal wetlands as well. For sand flats we saw relatively little change in total acreage from the historical to current condition (Figure 5, total percent area historic = 3.1%, versus total percent area current = 3.8%). Examination of the matrix, however, shows that out of 12,448 total historical acres, only 2,588 of these original acres currently remain within this category, while an additional 12,599 acres from a combination of other classes changed into tidal flats, for a current total of 15,187 acres. Most of this contribution was a result of water changing to tidal flats (10,910 acres). This suggests a highly dynamic state for this class (as well as for water), which would be expected in such a highly energetic and highly manipulated system.

We were also interested in looking at where different change scenarios have occurred throughout the LCRE, to determine if there were any patterns which might help inform restoration and conservation efforts. In order to do this, we used the set of eight hydrogeomorphic reaches that have been developed as part of the CREEC (Figure 7). These reach boundaries represent significant breaks in the estuary with respect to a combination of hydrologic and geologic influences, and have been widely adopted as spatial management units by various agencies and organizations working in the LCRE. We developed separate change matrices for each of the reaches, as well as a set of maps highlighting patterns of change. Table 9 shows the matrices for each of the hydrogeomorphic reaches from Reach A, the furthest downstream reach, to Reach H, in the Columbia River Gorge, the furthest upstream reach. In addition, graphs showing total historic acreages versus total current acres (Figure 8) are included to help visualize the differences between reaches.

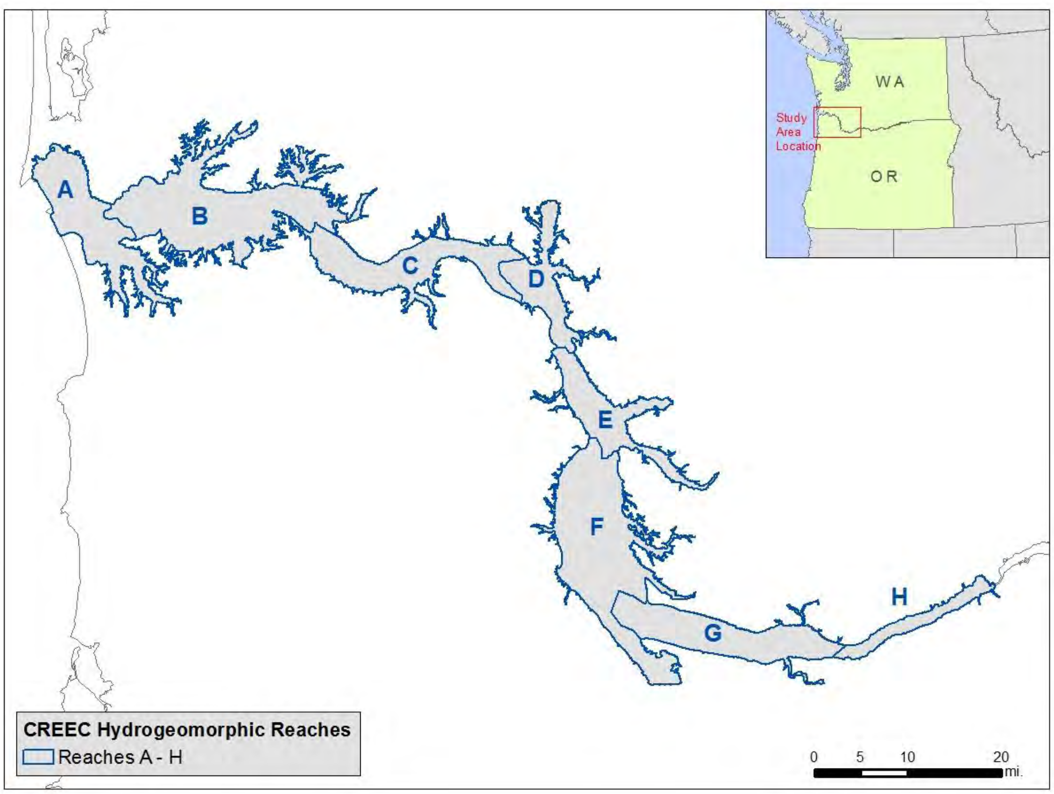

Figure 7: *Columbia River Estuarine Ecosystem Classification (CREEC) Level 3 hydrogeomorphic reaches. The reach boundaries comprise the approximate historic floodplain of the LCRE.*

Table 9a: *Matrix showing change (In acres) between normalized land cover classes from 'Historical' to 'Current' time period for hydrogeomorphic* ***Reach A*** *of the LCRE.*

TO: / FROM:	A	D	F	FWNT	FWT	H	HWNT	HWT	O	S	SWNT	SWT	TF	UNC	W		WWNT	WWT	Historic acres
A	0	43	10	4	0	4	0	1	0	1	0	0	0	(0)	0		4	0	65
D	0	88	11	1	0	0	1	0	0	0	0	0	1	(0)	5		1	0	107
F	1188	981	2517	1017	37	182	201	63	25	175	169	15	29	(0)	188		1186	51	6786
FWNT	0	0	0	0	0	0	0	0	0	0	0	0	0	(0)	0		0	0	0
FWT	445	39	114	81	16	5	47	55	2	6	41	31	24	(0)	15		121	46	921
H	9	132	76	55	0	10	17	9	6	9	4	0	0	(0)	0		59	0	327
HWNT	0	13	7	8	0	0	0	0	1	0	5	0	0	(0)	0		13	0	34
HWT	2904	950	271	1335	26	45	1211	357	18	57	622	31	81	(0)	121		1958	57	8031
O	8	187	113	120	3	1	28	54	5	24	26	1	22	(0)	359		146	4	952
S	0	2	0	0	0	0	0	0	0	0	0	0	0	(0)	0		0	0	2
SWNT	0	0	0	0	0	0	0	0	0	0	0	0	0	(0)	0		0	0	0
SWT	1090	367	102	312	3	17	446	36	21	9	179	7	16	(0)	52		490	10	2657
TF	2	166	219	178	3	65	143	296	20	39	92	7	1028	(0)	1149		270	10	3407
UNC	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(6)	(0)	(0)	(0)	(0)	(7)	(0)	(0)		(0)	(0)	14
W	140	367	231	410	23	109	368	609	28	99	173	18	2134	(0)	26138		583	41	30847
WWNT	0	0	0	0	0	0	0	0	0	0	0	0	0	(0)	0		0	0	0
WWT	1536	406	216	392	18	22	494	91	23	15	219	38	41	(0)	67		612	56	3578
Current Acres	5787	3336	3671	3521	110	439	2464	1480	125	419	1311	109	3336	0	28028		4832	219	54136
% overall area (excluding Water) historical:	0.3%	0.5%	29.1%	0.0%	4.0%	1.4%	0.1%	34.5%	4.1%	0.0%	0.0%	11.4%	14.6%				0.0%	15.4%	
% overall area (excluding Water) current:	22.2%	12.8%	14.1%	13.5%	0.4%	1.7%	9.4%	5.7%	0.5%	1.6%	5.0%	0.4%	12.8%				18.5%	0.8%	

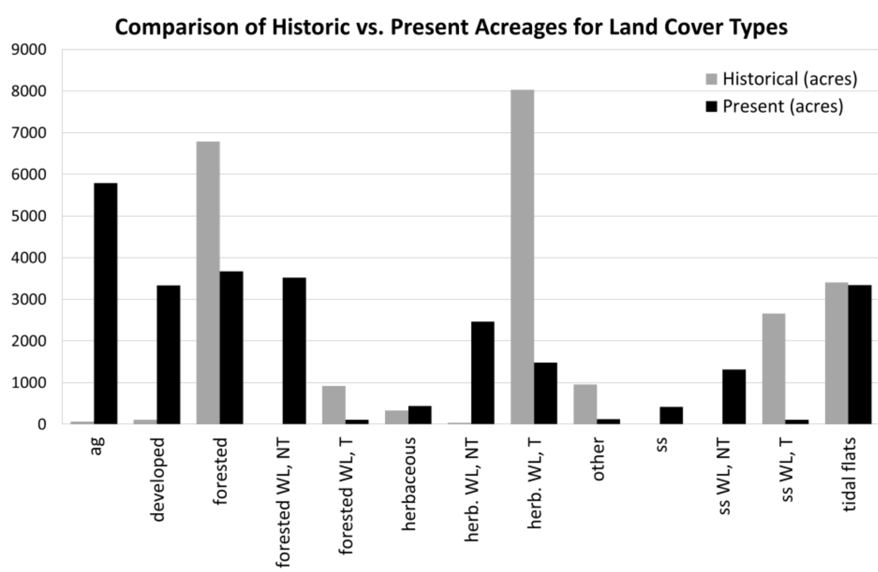

Figure 8a: *Comparison of historic versus current acreages for normalized land cover types for hydrogeomorphic* ***Reach A*** *of the LCRE. Note: the combined 'wooded' wetland categories are not shown.*

Table 9b: *Matrix showing change (In acres) between normalized land cover classes from 'Historical' to 'Current' time period for hydrogeomorphic* ***Reach B*** *of the LCRE.*

TO: / FROM:	A	D	F	FWNT	FWT	H	HWNT	HWT	O	S	SWNT	SWT	TF	UNC	W		WWNT	WWT	Historic acres
A	5	12	2	0	0	0	0	0	0	1	0	0	0	(0)	0		0	0	20
D	0	27	6	0	0	0	0	0	0	0	0	0	0	(0)	1		0	0	35
F	347	292	2377	361	94	90	156	34	9	128	63	16	3	(0)	24		424	110	3993
FWNT	0	0	0	0	0	0	0	0	0	0	0	0	0	(0)	0		0	0	0
FWT	1834	311	459	1484	927	41	1737	761	36	31	585	930	80	(0)	952		2069	1857	10168
H	49	119	85	4	1	4	20	2	0	10	4	0	0	(0)	2		7	2	299
HWNT	0	0	0	0	0	0	0	0	0	0	0	0	0	(0)	0		0	0	0
HWT	363	45	57	256	82	2	737	2628	2	20	188	875	801	(0)	1927		443	957	7983
O	0	6	25	3	1	0	2	4	0	1	2	1	0	(0)	0		5	2	46
S	0	4	7	0	0	0	0	0	0	0	0	0	0	(0)	0		0	0	11
SWNT	0	0	0	0	0	0	0	0	0	0	0	0	0	(0)	0		0	0	0
SWT	1164	101	124	532	418	2	513	87	6	5	404	677	45	(0)	212		937	1095	4291
TF	127	89	144	195	144	14	104	943	8	21	57	107	1433	(0)	2946		252	251	6332
UNC	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(1)		(0)	(0)	1
W	92	263	202	305	133	89	199	1074	12	56	116	183	6369	(0)	46131		421	316	55225
WWNT	0	0	0	0	0	0	0	0	0	0	0	0	0	(0)	0		0	0	0
WWT	2998	412	583	2016	1345	44	2250	848	42	35	989	1607	124	(0)	1165		3005	2952	14459
Current Acres	3982	1269	3487	3141	1800	244	3469	5533	73	273	1418	2790	8730	0	52196		4559	4589	88403
% overall area (excluding Water) historical:	0.1%	0.1%	12.0%	0.0%	30.6%	0.9%	0.0%	24.1%	0.1%	0.0%	0.0%	12.9%	19.1%				0.0%	43.6%	
% overall area (excluding Water) current:	11.0%	3.5%	9.6%	8.7%	5.0%	0.7%	9.6%	15.3%	0.2%	0.8%	3.9%	7.7%	24.1%				12.6%	12.7%	

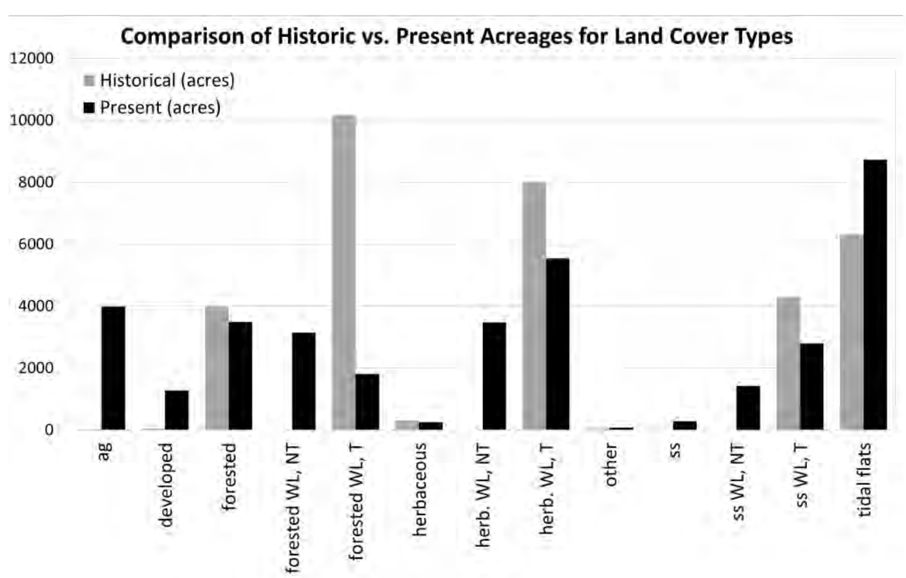

Figure 8b: *Comparison of historic versus current acreages for normalized land cover types for hydrogeomorphic* ***Reach B*** *of the LCRE. Note: the combined 'wooded' wetland categories are not shown.*

Table 9c: Matrix showing change (In acres) between normalized land cover classes from 'Historical' to 'Current' time period for hydrogeomorphic **Reach C** of the LCRE.																			
TO: / FROM:	A	D	F	FWNT	FWT	H	HWNT	HWT	O	S	SWNT	SWT	TF	UNC	W		WWNT	WWT	Historic acres
A	94	100	31	31	1	5	23	1	1	1	5	0	0	(0)	4		36	2	298
D	25	21	5	1	0	0	5	3	4	0	0	0	1	(0)	11		1	1	77
F	226	760	3561	105	39	146	63	20	61	136	22	21	7	(0)	59		127	60	5225
FWNT	0	0	6	0	0	1	0	0	0	0	0	0	0	(0)	0		0	0	7
FWT	5396	1528	375	1300	548	208	852	194	65	37	357	195	87	(0)	853		1656	743	11994
H	117	113	103	26	2	16	13	4	4	3	4	1	2	(0)	17		30	3	423
HWNT	0	0	0	0	0	0	0	0	0	0	0	0	0	(0)	0		0	0	0
HWT	7873	1345	158	225	114	132	840	362	36	8	112	208	12	(0)	329		337	322	11753
O	0	6	33	1	1	4	0	1	0	0	0	0	0	(0)	16		1	1	63
S	16	47	64	55	15	2	14	19	4	6	2	6	3	(0)	0	9	57	21	253
SWNT	0	0	0	0	0	0	0	0	0	0	0	0	0	(0)	0		0	0	0
SWT	1609	62	4	60	4	9	53	1	1	1	37	17	0	(0)	23		97	21	1881
TF	2	34	27	40	61	6	13	36	1	0	6	16	39	(0)	376		46	77	657
UNC	(80)	(72)	(58)	(24)	(2)	(4)	(8)	(2)	(0)	(10)	(7)	(1)	(0)	(0)	(11)		(0)	(0)	278
W	270	355	227	732	665	168	226	713	32	12	88	310	333	(0)	14527		820	976	18658
WWNT	0	0	6	0	0	1	0	0	0	0	0	0	0	(0)	0		0	0	7
WWT	7005	1590	379	1360	552	217	905	195	66	38	393	212	87	(0)	876		1753	764	13876
Current Acres	15627	4371	4593	2578	1451	696	2103	1353	209	204	632	775	483	0	16215		3210	2226	51289
% overall area (excluding Water) historical:	0.9%	0.2%	16.0%	0.0%	36.8%	1.3%	0.0%	36.0%	0.2%	0.8%	0.0%	5.8%	2.0%				0.0%	42.5%	
% overall area (excluding Water) current:	44.6%	12.5%	13.1%	7.3%	4.1%	2.0%	6.0%	3.9%	0.6%	0.6%	1.8%	2.2%	1.4%				9.2%	6.3%	

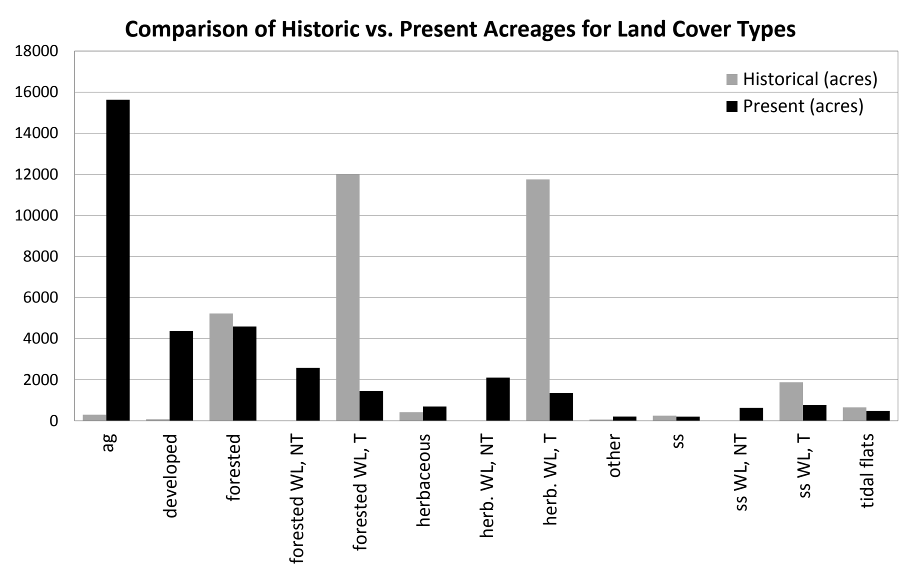

Figure 8c: *Comparison of historic versus current acreages for normalized land cover types for hydrogeomorphic* ***Reach C*** *of the LCRE. Note: the combined 'wooded' wetland categories are not shown.*

Table 9d: *Matrix showing change (In acres) between normalized land cover classes from 'Historical' to 'Current' time period for hydrogeomorphic* ***Reach D*** *of the LCRE.*

TO: / FROM:	A	D	F	FWNT	FWT	H	HWNT	HWT	O	S	SWNT	SWT	TF	UNC	W		WWNT	WWT	Historic acres
A	13	574	78	4	1	6	7	0	28	2	2	0	0	(0)	7		6	1	722
D	5	150	36	8	1	6	5	0	7	1	1	0	0	(0)	5		10	1	226
F	185	3742	2346	397	24	293	219	10	379	106	39	7	29	(0)	388		436	31	8164
FWNT	0	6	3	2	0	0	0	0	0	0	0	0	0	(0)	0		2	0	11
FWT	22	1901	153	124	49	181	93	15	75	26	22	1	4	(0)	74		146	50	2738
H	129	2264	354	79	6	40	100	2	77	18	15	0	1	(0)	51		95	6	3135
HWNT	0	0	0	0	0	0	0	0	0	0	0	0	0	(0)	0		0	0	0
HWT	91	1251	122	82	22	393	302	9	39	27	24	3	2	(0)	203		106	25	2570
O	0	13	17	4	1	3	0	0	0	0	0	0	1	(0)	5		4	1	44
S	1	204	56	5	1	4	2	1	0	1	0	0	0	(0)	1		6	1	276
SWNT	0	0	0	0	0	0	0	0	0	0	0	0	0	(0)	0		0	0	0
SWT	0	0	0	0	0	1	0	0	0	0	0	0	0	(0)	0		0	0	1
TF	0	47	27	22	7	14	11	4	13	3	3	3	10	(0)	53		25	10	216
UNC	(0)	(1)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)		(0)	(0)	1
W	6	429	207	185	138	353	83	92	149	54	18	20	125	(0)	4258		202	157	6115
WWNT	0	6	3	2	0	0	0	0	0	0	0	0	0	(0)	0		2	0	11
WWT	22	1901	153	124	49	182	93	15	75	26	22	1	4	(0)	74		146	50	2740
Current Acres	451	10581	3399	913	249	1293	822	133	766	238	124	34	172	(0)	5044		1037	283	24220
% overall area (excluding Water) historical:	4.0%	1.3%	45.1%	0.1%	15.1%	17.3%	0.0%	14.2%	0.2%	1.5%	0.0%	0.0%	1.2%				0.1%	15.1%	
% overall area (excluding Water) current:	2.4%	55.2%	17.7%	4.8%	1.3%	6.7%	4.3%	0.7%	4.0%	1.2%	0.6%	0.2%	0.9%				5.4%	1.5%	

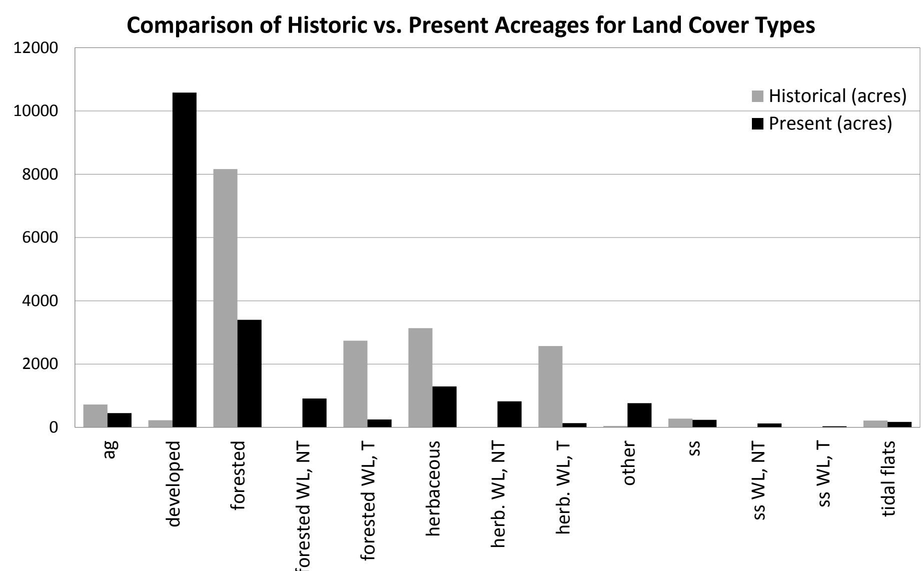

Figure 8d: *Comparison of historic versus current acreages for normalized land cover types for hydrogeomorphic* ***Reach D*** *of the LCRE. Note: the combined 'wooded' wetland categories are not shown.*

Table 9e: *Matrix showing change (In acres) between normalized land cover classes from 'Historical' to 'Current' time period for hydrogeomorphic* ***Reach E*** *of the LCRE.*

TO: / FROM:	A	D	F	FWNT	FWT	H	HWNT	HWT	O	S	SWNT	SWT	TF	UNC	W		WWNT	WWT	Historic acres
A	61	55	18	0	0	3	5	0	5	2	0	0	0	(0)	11		1	0	161
D	59	110	53	4	0	7	4	0	2	5	0	0	0	(0)	8		4	0	252
F	2419	1446	2132	451	61	193	139	38	112	117	22	5	31	(0)	307		472	67	7473
FWNT	2	2	1	2	0	1	8	0	0	0	0	0	0	(0)	0		2	0	16
FWT	514	62	38	74	37	5	40	7	3	1	0	3	6	(0)	44		74	40	833
H	3709	660	298	150	9	55	160	4	54	18	18	0	10	(0)	99		168	9	5243
HWNT	2	17	13	4	0	1	3	0	0	0	5	0	0	(0)	0		9	0	44
HWT	674	51	99	170	18	18	168	6	8	3	8	4	4	(0)	59		179	22	1290
O	7	2	3	1	0	0	0	0	0	0	0	0	0	(0)	1		1	0	14
S	974	229	188	128	2	30	36	1	13	6	3	0	6	(0)	64		131	2	1680
SWNT	0	0	0	0	0	0	0	0	0	0	0	0	0	(0)	0		0	0	0
SWT	6	0	0	0	0	0	0	0	0	0	0	0	0	(0)	0		0	0	6
TF	10	28	40	48	17	8	11	14	26	0	1	7	12	(0)	96		49	24	318
UNC	(110)	(91)	(232)	(29)	(2)	(26)	(9)	(2)	(1)	(15)	(2)	(1)	(2)	(0)	(16)		(0)	(0)	(538)
W	277	90	346	377	192	94	237	122	49	13	25	45	175	(0)	5171		402	237	7213
WWNT	2	2	1	2	0	1	8	0	0	0	0	0	0	(0)	0		2	0	16
WWT	520	62	38	74	37	5	40	7	3	1	0	3	6	(0)	44		74	40	839
Current Acres	8712	2752	3269	1407	337	416	809	192	272	166	83	65	244	(0)	5860		1490	401	24583
% overall area (excluding Water) historical:	0.9%	1.5%	43.0%	0.1%	4.8%	30.2%	0.3%	7.4%	0.1%	9.7%	0.0%	0.0%	1.8%				0.1%	4.8%	
% overall area (excluding Water) current:	46.5%	14.7%	17.5%	7.5%	1.8%	2.2%	4.3%	1.0%	1.5%	0.9%	0.4%	0.3%	1.3%				8.0%	2.1%	

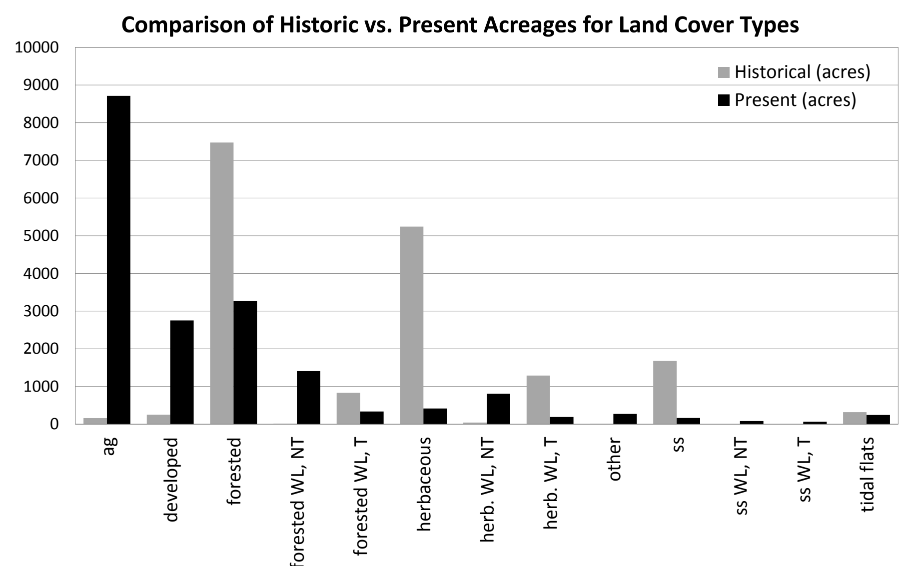

Figure 8e: *Comparison of historic versus current acreages for normalized land cover types for hydrogeomorphic* ***Reach E*** *of the LCRE. Note: the combined 'wooded' wetland categories are not shown.*

Table 9f: *Matrix showing change (In acres) between normalized land cover classes from 'Historical' to 'Current' time period for hydrogeomorphic **Reach F** of the LCRE.*

TO: / FROM:	A	D	F	FWNT	FWT	H	HWNT	HWT	O	S	SWNT	SWT	TF	UNC	W		WWNT	WWT	Historic acres
A	100	293	53	14	2	2	7	1	1	3	5	1	5	(0)	10		19	3	498
D	115	247	63	37	3	22	16	4	13	4	3	0	2	(0)	20		40	3	549
F	6248	12405	6580	1135	291	604	432	120	241	347	95	9	68	(0)	677		1230	301	29253
FWNT	1007	433	331	604	366	170	310	211	14	22	54	10	1	(0)	335		658	376	3867
FWT	1362	744	147	221	310	60	397	149	38	8	34	11	9	(0)	188		255	321	3677
H	4138	2110	618	531	268	652	552	296	78	61	53	7	33	(0)	290		584	275	9688
HWNT	6330	422	302	481	288	229	713	313	25	43	76	13	8	(0)	309		557	300	9552
HWT	414	125	46	98	494	35	157	371	5	6	11	13	2	(0)	273		110	508	2052
O	11	160	61	18	18	1	7	10	7	0	10	4	2	(0)	125		28	22	434
S	199	1293	356	50	9	46	48	5	0	1	11	1	5	(0)	45		60	10	2069
SWNT	635	99	29	78	217	22	56	134	19	1	8	18	19	(0)	126		85	235	1461
SWT	14	0	0	7	2	0	14	0	0	0	0	0	0	(0)	0		7	2	39
TF	13	214	29	35	19	1	8	11	8	0	10	6	13	(0)	215		45	25	582
UNC	(170)	(317)	(70)	(38)	(23)	(16)	(28)	(7)	(4)	(2)	(8)	(1)	(3)	(0)	(42)		(0)	(0)	729
W	3980	1822	481	769	930	227	1347	500	47	22	86	130	405	(0)	16030		855	1060	26778
WWNT	1642	532	360	682	583	192	366	345	33	22	61	28	20	(0)	461		743	611	5328
WWT	1376	744	147	228	312	60	411	149	38	8	34	11	9	(0)	188		263	323	3716
Current Acres	24567	20370	9095	4079	3218	2070	4064	2125	496	518	456	223	574	(0)	18644		4535	3441	90499
% overall area (excluding Water) historical:	0.8%	0.9%	45.9%	6.1%	5.8%	15.2%	15.0%	3.2%	0.7%	3.2%	2.3%	0.1%	0.9%				8.4%	5.8%	
% overall area (excluding Water) present:	34.2%	28.3%	12.7%	5.7%	4.5%	2.9%	5.7%	3.0%	0.7%	0.7%	0.6%	0.3%	0.8%				6.3%	4.8%	

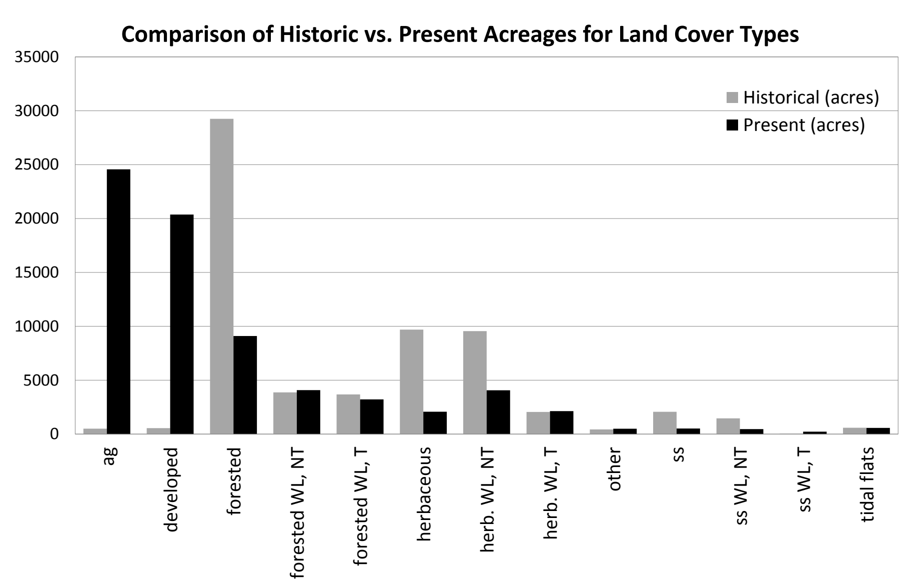

Figure 8f: *Comparison of historic versus current acreages for normalized land cover types for hydrogeomorphic **Reach F** of the LCRE. Note: the combined 'wooded' wetland categories are not shown.*

Table 9g: *Matrix showing change (In acres) between normalized land cover classes from 'Historical' to 'Current' time period for hydrogeomorphic* ***Reach G*** *of the LCRE.*

TO: / FROM:	A	D	F	FWNT	FWT	H	HWNT	HWT	O	S	SWNT	SWT	TF	UNC	W		WWNT	WWT	Historic acres
A	49	335	72	0	0	8	1	0	11	14	0	0	1	0	11		1	0	503
D	12	379	64	3	0	2	2	0	1	5	2	0	1	0	5		5	0	477
F	884	11070	3868	358	29	870	333	33	139	297	91	65	98	0	652		449	95	18790
FWNT	27	1043	157	164	23	86	30	4	42	11	25	4	2	0	76		189	27	1694
FWT	6	184	5	13	0	9	6	0	4	0	1	0	0	0	4		14	0	232
H	1058	4280	882	196	18	269	333	21	105	123	55	10	12	0	176		250	28	7537
HWNT	61	1217	129	82	1	11	33	0	12	6	20	0	0	0	33		102	1	1606
HWT	202	1091	72	34	69	21	57	144	20	5	14	10	1	0	47		47	79	1786
O	3	45	58	14	3	3	8	10	0	6	4	13	14	0	145		18	15	325
S	76	570	203	8	1	13	13	2	15	11	2	0	6	0	47		10	1	967
SWNT	18	20	38	6	0	13	17	0	1	4	2	0	0	0	6		8	0	125
SWT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0
TF	0	144	95	53	27	22	98	23	5	3	6	9	53	0	397		59	36	936
UNC	0	16	1	1	0	0	0	0	0	0	1	0	0	0	0		(0)	(0)	24
W	113	1472	785	352	173	250	609	189	38	47	136	365	890	0	11932		487	537	17350
WWNT	45	1062	195	170	23	99	47	4	43	14	27	4	2	(0)	82		197	27	1818
WWT	6	184	5	13	0	9	6	0	4	0	1	0	0	(0)	4		14	0	232
Current Acres	2510	21866	6429	1286	343	1578	1540	427	394	533	357	475	1078	0	13532		1640	818	52347
% overall area (excluding Water) historical:	1.4%	1.4%	53.7%	4.8%	0.7%	21.5%	4.6%	5.1%	0.9%	2.8%	0.4%	0.0%	2.7%				5.2%	0.7%	
% overall area (excluding Water) present:	6.5%	56.3%	16.6%	3.3%	0.9%	4.1%	4.0%	1.1%	1.0%	1.4%	0.9%	1.2%	2.8%				4.2%	2.1%	

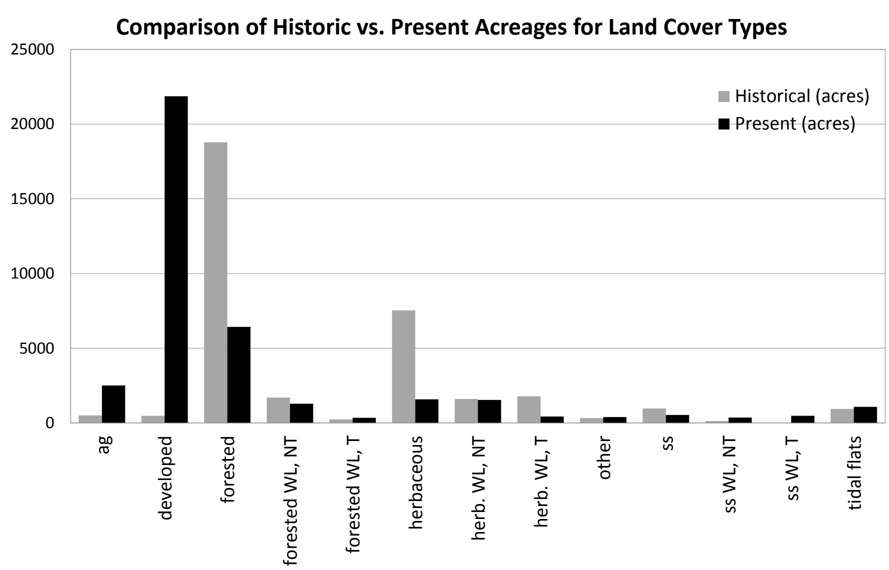

Figure 8g: *Comparison of historic versus current acreages for normalized land cover types for hydrogeomorphic* ***Reach G*** *of the LCRE. Note: the combined 'wooded' wetland categories are not shown.*

Table 9h: *Matrix showing change (In acres) between normalized land cover classes from 'Historical' to 'Current' time period for hydrogeomorphic **Reach H** of the LCRE.*

FROM: / TO:	A	D	F	FWNT	FWT	H	HWNT	HWT	O	S	SWNT	SWT	TF	UNC	W		WWNT	WWT	Historic acres
A	0	0	0	0	0	0	0	0	0	0	0	0	0	(0)	0		0	0	0
D	0	0	0	0	0	0	0	0	0	0	0	0	0	(0)	0		0	0	0
F	61	786	1974	40	2	71	8	1	18	123	17	14	24	(0)	148		57	16	3286
FWNT	87	353	807	320	18	356	162	43	1	55	97	72	50	(0)	147		417	90	2568
FWT	0	0	0	0	0	0	0	0	0	0	0	0	0	(0)	0		0	0	0
H	20	28	16	3	0	0	12	0	0	4	1	0	0	(0)	0		3	0	85
HWNT	0	0	0	0	0	0	0	0	0	0	0	0	0	(0)	0		0	0	0
HWT	0	0	0	0	0	0	0	0	0	0	0	0	0	(0)	0		0	0	0
O	0	1	9	0	1	0	0	2	0	0	0	4	12	(0)	35		0	5	65
S	0	0	6	0	0	0	0	0	0	0	0	0	0	(0)	0		0	0	7
SWNT	18	77	168	177	5	22	129	27	0	8	18	15	5	(0)	105		195	20	774
SWT	0	0	0	0	0	0	0	0	0	0	0	0	0	(0)	0		0	0	0
TF	0	0	0	0	0	0	0	0	0	0	0	0	0	(0)	0		0	0	0
UNC	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)		(0)	(0)	(0)
W	6	82	130	44	12	24	42	87	4	14	69	203	478	(0)	6735		112	215	7929
WWNT	104	430	975	496	23	378	291	70	2	63	115	87	55	(0)	252		612	110	3342
WWT	0	0	0	0	0	0	0	0	0	0	0	0	0	(0)	0		0	0	0
Current Acres	192	1328	3111	583	38	473	354	160	23	203	202	309	569	(0)	7170		785	347	14714
% overall area (excluding Water) historical:	0.0%	0.0%	48.4%	37.8%	0.0%	1.3%	0.0%	0.0%	1.0%	0.1%	11.4%	0.0%	0.0%				49.3%	0.0%	
% overall area (excluding Water) present:	2.5%	17.6%	41.2%	7.7%	0.5%	6.3%	4.7%	2.1%	0.3%	2.7%	2.7%	4.1%	7.5%				10.4%	4.6%	

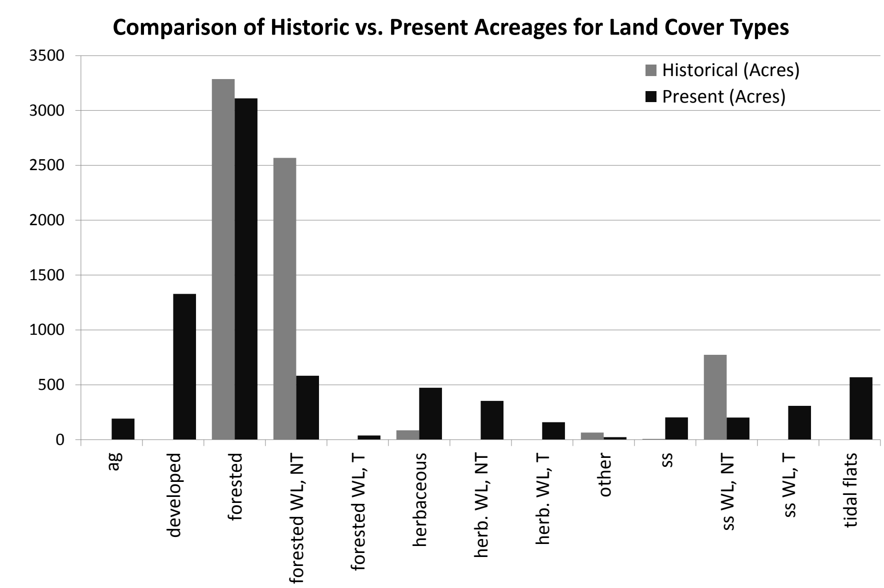

Figure 8h: *Comparison of historic versus current acreages for normalized land cover types for hydrogeomorphic **Reach H** of the LCRE. Note: the combined 'wooded' wetland categories are not shown.*

A comparison of reaches confirmed some expected patterns of change, as well as others which were less apparent before analysis. In the tables above, changes in percent overall area from historical to current are highlighted as either green (indicating an increase) or red (indicating a decrease) where significant (greater than 10%) changes have occurred. Examination of these rows shows significant increases in either the Agriculture or Developed classes, or both, for every reach. The downriver reaches (A – C) showed the largest losses in tidal wetlands (converting primarily to Agriculture or Developed), as expected based on the land use patterns in this region. Significant losses in non-tidal wetlands were seen in Reach H, the furthest upriver reach. Most of this change was a result of conversion to Forested non-wetland. The middle to upper reaches (D – G), as well as Reach A, showed the greatest losses in Forested non-wetland. Reach B showed the least amount of overall disturbance relative to other reaches. With the exception of a large decrease in wooded tidal wetlands (converting primarily to Agriculture), many of the vegetated classes remained at or close to their respective historical percent cover. There was also very little loss to developed land within this reach (0.1% historical, 3.5% current). An interesting pattern in the loss of tidal wetland types was seen between the lower reaches. Reach A was historically dominated by herbaceous tidal wetlands, and thus this class exhibited the sharpest overall areal decline, while the wooded wetlands classes showed significant declines as well relative to their initial extents. Reach B was historically dominated by forested tidal wetlands (Sitka spruce swamps), which exhibited sharp losses. Declines in herbaceous and shrub-scrub tidal wetlands were less significant. In Reach C, historical distributions of wooded and herbaceous wetlands were large and of similar extent. Sharp declines were seen for both of these classes.

Discussion

Comparison With Previous Studies

Our analysis proved consistent with previous habitat change analyses for the LCRE, in detecting sharp overall losses in vegetated wetlands throughout the past century. The analysis by Graves et al. (1995) was most similar to this analysis with respect to temporal and spatial coverage. Graves et al. (1995) reported a decrease in wetland marsh area of approximately 71%. Assuming these marshes to be tidal (based on the assumption that, before the advent of widespread diking activity, most of the floodplain wetlands were connected to the lower Columbia main-stem either tidally, or fluvially during high water periods), this is comparable to our observed 68% decrease in herbaceous tidal wetlands. Graves et al. (1995) did not provide specific information about the nature of the changes between classes, although they did show significant increases in both agricultural and developed land. The primary loss of herbaceous tidal wetland in our data was attributed to gains in agriculture (40% of total loss) and development (15%); however, we also saw significant conversion to non-tidal wetlands (herbaceous (11%) and wooded (10%)), as well as conversion to other tidal wetlands categories (6%), and water (9%). Graves et al. (1995) showed an approximate 70% decrease in forested wetlands. We noted a similar loss of 75% of forested tidal wetlands (and a slightly smaller 69% loss of 'wooded' tidal wetlands, if the shrub-scrub category is included). Considering the 'wooded' tidal wetland category, again, the primary loss factors here were Agriculture (38% of total loss), and Developed (15%). We also noted significant conversion to non-tidal wetlands vegetation (herbaceous (12%) and wooded (17%)), with lesser conversion to water (7%) and other tidal wetlands categories (herbaceous, 4%).

It is likely that a portion of the losses attributed to conversion to non-tidal wetlands are also a result of agricultural activity, on land that is no longer being actively farmed but is still cut off from the lower Columbia main-stem by levees constructed several years ago. This land would likely be classified as vegetated non-wetland, rather than Agriculture, in the current classification (which reserves Agriculture for lands where active farming is occurring). However, another contributing factor with respect to this change scenario may be the significant hydrological changes that have occurred in the Columbia River since the mid-19th century. These changes have occurred as a result of several factors, but have been predominantly attributed to flow regulation and to a lesser extent water withdrawal. These have resulted in both decreased annual average flow and an even larger decrease in the seasonal duration and timing of the spring freshet, a critical time period for migrating juvenile salmonids (Bottom et al., 2005). Bottom et al. (2005) noted a 16.9% decrease in average annual flow, from the late 19th century to the present period (defined as 1970 – 1999 in the study), a 57% reduction in total freshet-season mean flow, and a 44% reduction in observed maximum annual daily spring-freshet flow. These reduced flow factors would be expected to result in overall reduced area of wetted lands, as well as reduced duration of inundation periods.

It should be noted that although many vegetation classes exhibited net losses (tidal wetlands in particular) there was significant spatial variability, with many of these same classes exhibiting gains in particular areas. In order to make sense of this shifting mosaic of land cover types, it is useful to visualize the patterns using maps. The two sets of maps included in Appendix B (as well as the GIS output files used to create them) are useful for examining the spatial distribution of change, and prioritizing areas for restoration and conservation. The Reach maps highlight patterns of loss for key habitat types that have occurred within each reach. The Regional maps highlight various patterns of change for some of the key habitat types. These illustrate not only where losses have occurred, but also where these habitats have shown gains, or have remained intact. The key habitats considered include Forested non-wetland, as well as the vegetated tidal wetlands (Herbaceous and Wooded).

Uncertainties in Analysis

The most significant uncertainty that we have noted in interpreting results from this analysis is the quality of the baseline historical data. In using these data sources, both the interpreted Coast Survey data as well as the interpreted GLO data, we have made many assumptions, as follows: 1) the field surveyors were mapping vegetation patterns with high spatial accuracy and consistency; 2) the cartographers who were creating the T-sheets and GLO maps from the field data were doing so with good spatial accuracy; 3) the cartographers were also using map symbols in a consistent and repeatable manner as they proceeded throughout the LCRE; 4) the original T-sheets and GLO maps were georeferenced (converted to a digital version that could be used in a GIS) properly to ensure precise overlays with current data 4) the data interpreters (WET lab; Christy et al., (2012)) working with the georeferenced maps were interpreting the map symbols in a consistent and repeatable manner.

A review of Shalowitz (1964) provides some confirmation of assumptions 1-3 above. The report provides extremely detailed explanations of the survey and cartographic processes, including technical details regarding tidal information, survey control, charting procedures, geographic datums, and basic accuracy assessments for the charts. Graves et al. (1995) noted the quality of the T-sheet surveys, and devised methods of testing the accuracy of the information. Thomas (1983), in his research, concluded that 'the charts are an accurate representation of the floodplain vegetation, at least for distinguishing emergent marshes from forested and tall-shrub dominated swamps'.

Despite these assurances we still have concerns about the original map information. As discussed in the Methods section above, we noted several areas where vegetation was mapped differently for the same spatial area covered by overlapping T-sheets. This could be a result of many factors including inconsistencies in both surveying and mapping, or both. Whatever the reason, it provides a level of doubt as to the overall reliability of the map interpretations. We also noted variability in the quality and the choice of map symbology from map to map. For certain areas, symbols were difficult to interpret, or non-existent in the digital versions. This may be an artifact of the georeferencing process. The online historical maps available through the Office of Coast Survey website assisted us in resolving both of these issues, in several locations. In discussions with WET lab staff that derived this product, they acknowledged difficulties in ascertaining some of the map symbology. This was particularly true for distinguishing between forested and shrub-scrub wetlands, and thus we created the combined 'wooded' wetland classes to eliminate some of this uncertainty.

Having copies of the georeferenced T-sheets and GLO maps provided confidence in regard to assumption 4. The maps showed excellent alignment with current data sources in GIS, when examining static features such has hardened shorelines, floodplain lakes and channels, or anthropogenic features, which can be reasonably assumed to have remained in the same place over time. This also provides confirmation that the surveyors were paying close attention to detail with regard to control and accuracy, and that the boundaries between various features are in the correct locations. We did not have georeferenced versions of GLO maps, and thus did not do any evaluation of the interpreted GLO data created by Christy et al. As this data comprised a small portion of our overall source data set and only represented a small relative source of error, we used the data as is.

Despite the shortcomings we have identified, the historical data set that we have compiled from these data sources provides an excellent overall representation of the historical vegetation of the LCRE, and we feel it provides a reasonable basis for a change analysis of this type.

In performing this analysis, it was necessary to aggregate classes, in order to perform a meaningful comparison. This was not always straightforward, particulary in assigning some historical classes to a 'tidal' or 'non-tidal' category. Based on discussions with WET lab staff, we had reasonable confidence in aggregating the Office of Coast Survey classes. Some of the GLO cover classes could possibly have been assigned to other normalized classes than what was chosen. For example, we placed the riparian forest categories into the 'Forested wetland, non-tidal' category. This was a best guess, based on comparison of the elevations at which the majority of these areas are located (using recent LidAR), to the hydrograph data extending back several decades. However, without having actual hydrograph data from the historical period, it is difficult to say whether or not these classes would have been better described as 'Forested wetland, tidal'. For these uncertain categories, we placed them as we saw most appropriate based on the particular region of the river where we were utilizing this data.

The definition of 'tidal' wetlands presents another uncertainty in itself. This term, as applied to this study, refers to areas of the floodplain which wet as a result of inundation from the main-stem Lower Columbia. The inundation may occur daily throughout the year, as a result of the influence of ocean tides, or seasonally, as a result of fluvial processes (in particular, during the spring freshet period). For much of the LCRE, it is a combination of both processes, with ocean tides dominating in the lower river, and increasing fluvial effects proceeding upriver. In assigning the term 'tidal', we were trying to capture areas that would likely be useable for juvenile fish for at least some portion of the year. In order to compare what we believe were 'tidal' wetlands historically to what we classify as 'tidal' wetlands today, it was necessary to make some assumptions. We assumed that all wetlands categories in the historical Coast Survey data were 'tidal'. This decision was based on descriptions in Shalowitz (1964), and discussions with WET lab staff (personal communication). Furthermore, it seems reasonable to assume that historically, with higher annual flows and higher mean peak flows during the freshet, most of the historic floodplain was inundated on a regular basis. For the current data set, we used a GIS based elevation model to delineate 'tidal', 'diked', and 'non-tidal' wetlands. 'Diked' areas are areas that likely would be 'tidal', if not for the presence of hydrologic barriers impeding flow from the main-stem. 'Non-tidal' areas are areas which are likely at too high an elevation to be even seasonally inundated, based on the current hydrograph (except during less frequent flood events). Some of these areas may well have flooded under a historical flow regime. For this study, 'diked' and 'non-tidal' areas were grouped into 'non-tidal' wetlands. The uncertainty applies mainly to areas further upriver, where fluvial process become more dominant. We are considering areas that are affected by the spring-freshet to be 'tidal', however depending on the time of year surveyed, these areas may or may not have been mapped as wetlands (and by our definition, tidal) in the historical data.

As mentioned above, the primary goal of this study was to quantify changes in land cover that have occurred in the LCRE since the late 19th century. We did not attempt to directly attribute changes to any particular process, except in cases where these processes be inferred from the land cover classes involved (i.e., Agriculture, Development). The data set generated from this analysis will be incorporated into the larger Habitat Restoration Prioritization Strategy being developed by the Estuary Partnership. This framework incorporates additional GIS layers describing in-water conditions, and their suitability for juvenile salmonids. This in-water information, combined with the land cover change information derived here, should provide an effective management tool for restoring and conserving key patches of habitat for various species. By analyzing the data on a reach basis, we noted significant spatial variation in the types of change occurring throughout the river. These patterns can be used to set restoration and conservation targets for each reach. The analysis provides a good baseline assessment of habitat changes that have occurred over the last century, dating back to a time where the lower Columbia River was in a relatively pristine state and unaffected by the vast majority of anthropogenic impacts. Looking forward, the Estuary Partnership 2010 land cover data set (the 'current' data set for this analysis) will also serve as a good baseline for change detection over the next several years, in an attempt to track future trends in habitat change.

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Appendix A. Summary of Previous Land Cover Change Analyses for the LCRE

Authors/ Study Year	Project Final Report Sources	Spatial Extent	Historical Data Source	Current Data Source	Limitations (relative to LCEP objectives)
Thomas (CREDDP) 1983	Online (CREST/LCEP)	RM 0 – RM 46	Late 1800s OCS T-and hydro sheets. Interpreted and digitized by Thomas	1980 Source: CREDDP/CREST	Spatial – limited to lower 46 miles Temporal – 1980 latest
Graves et al. 1995	Online (CREST/LCEP)	RM 0 – RM 102 Incomplete floodplain coverage in many areas	Late 1800s OCS T-and hydro sheets. Lower 43 miles digitized and interpreted by Thomas, upper 60 miles digitized and interpreted by Graves et al.	1991 USACE aerial photos. Classified by Allen/USACOE	Spatial – limited to lower 103 miles, with additional gaps within the coverage area
Allen/ USACOE 1991	Oregon State University, LCEP	RM 0 – RM 146 limited to immediate shoreline in many areas	1948, 1961, 1973, 1983 USACE aerial photos. Classified by Allen/USACOE	1991 USACE aerial photos. Classified by Allen/USACOE	Temporal – does not extend back to pre-disturbance period
NOAA-CCAP 1994	Online (NOAA)	RM 0 – RM 146 extends outside floodplain	1989 LandSAT TM. Classified by NOAA CCAP	1993 LandSAT TM. Classified by NOAA CCAP	Temporal – analysis covers last 20 years
Garano 2003	Online (LCEP)	RM 0 – RM 146 extends outside floodplain	1992 LandSAT TM. Classified by Garano	2000 LandSAT TM. Classified by Garano	Temporal – analysis covers last 20 years
Burke (UW WET Lab) 2006	No	RM 0 – RM 43	Late 1800s OCS T-and hydro sheets. Interpreted and digitized by Burke	2000 LandSAT TM. Classified by Garano	Spatial Extent – limited to lower 43 miles

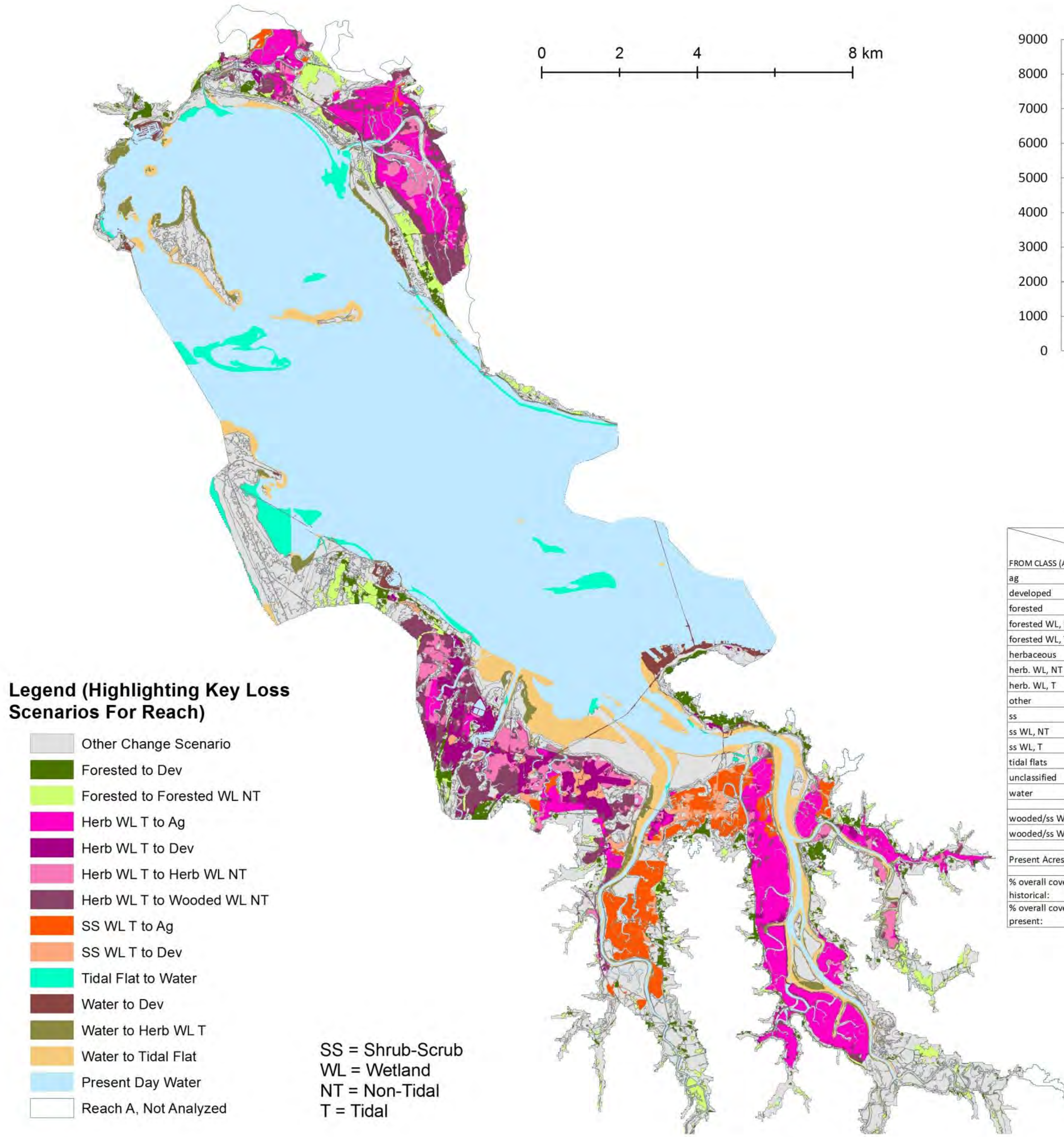
USACOE: United States Army Corps of Engineers

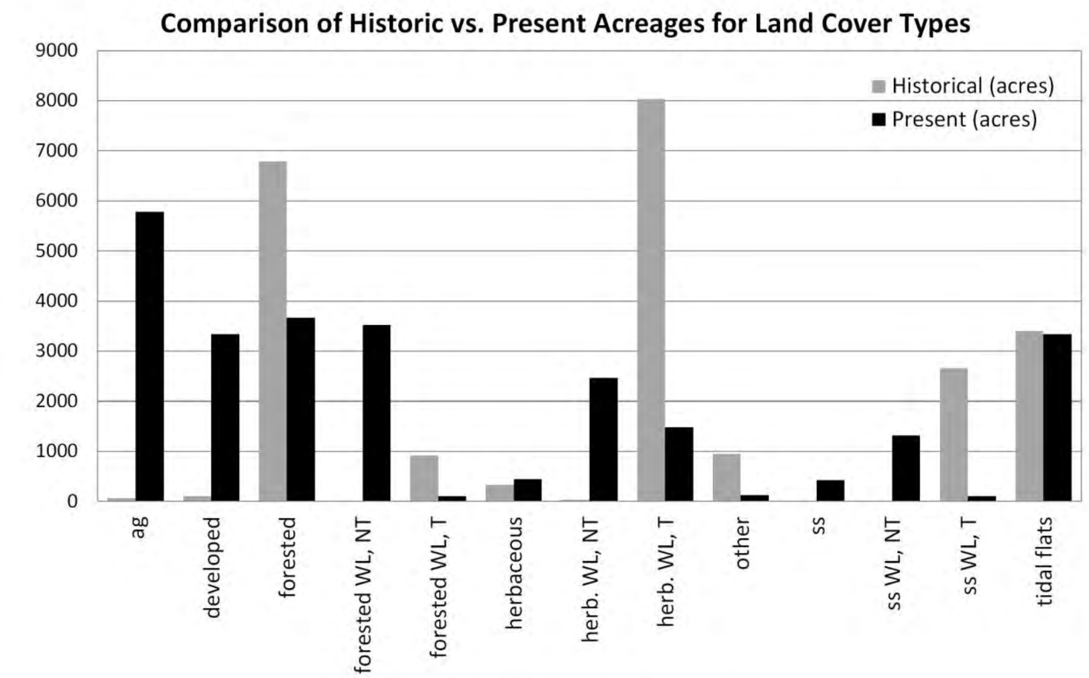
Appendix B. Habitat Change Maps Created From LCEP Habitat Change Analysis

The maps on the following pages illustrate some of the significant changes in habitat that were noted in this analysis. There are two basic sets of maps as follows:

1) Reach Maps (Figures 9 – 16) - These maps highlight the key habitat *loss* scenarios for each reach. The key habitats mapped include all of the vegetated tidal wetlands (herbaceous, forested, and shrub-scrub), forested non-wetland, tidal flats, and water. For the purpose of keeping the maps as simple as possible, we did not include the non-tidal wetlands here. This is because for most reaches, non-tidal wetlands actually showed increases in overall acreage, and also because much of this land may actually be diked, non-active farmland or pasture that is not accessible to juvenile salmonids (but potentially beneficial to other species). Patterns of loss for various vegetation types are grouped by color, with green/yellow shades denoting losses in upland forests, purple shades denoting losses in forested wetland, pink shades denoting losses in herbaceous wetlands, and orange/brown shades denoting losses in shrub-scrub wetlands. Blue and tan shades represent transitions between water and unvegetated tidal flats. As can be seen in the map legends, transition between vegetated tidal wetlands are not illustrated here, only losses.

2) Regional Maps (Figures 17 – 24) – These maps highlight habitat *change* scenarios for three particular key habitat types: Forested uplands, herbaceous tidal wetlands, and wooded tidal wetlands. Relative to the Reach maps, they provide a better idea of current and historic distributions of each habitat type, and how they have changed, including losses, gains, and areas where these habitat types have remained intact. For simplicity, specific change scenarios are not shown separately, with the exception of changes involving these 3 habitat types. All others are combined into a simple gained, lost, or intact category for display.





Land Cover Change Matrix

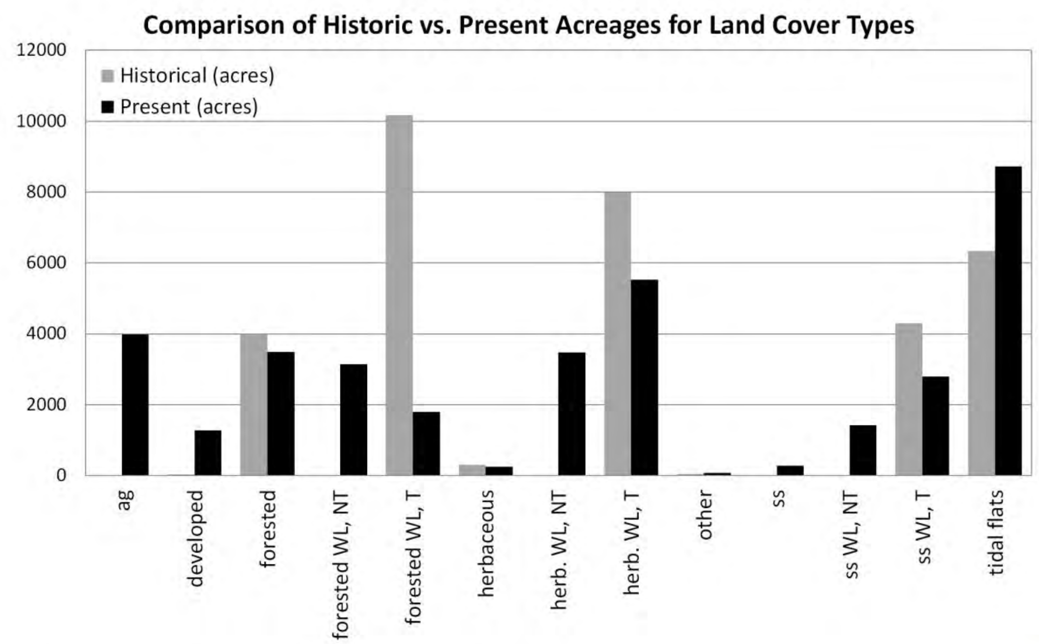
TO CLASS (Acres): / FROM CLASS (Acres):	ag	dev	forest	forest WL, NT	forest WL, T	herb.	herb. WL, NT	herb. WL, T	other	shrub-scrub	ss WL, NT	ss WL, T	tidal flats	unc.	water	wooded / ss WL, NT	wooded/ ss WL, T	Hist-orical Acres
ag	0	43	10	4	0	4	0	1	0	1	0	0	0	(0)	0	4	0	65
developed	0	88	11	1	0	0	1	0	0	0	0	0	1	(0)	5	1	0	107
forested	1188	981	2517	1017	37	182	201	63	25	175	169	15	29	(0)	188	1186	51	6786
forested WL, NT	0	0	0	0	0	0	0	0	0	0	0	0	0	(0)	0	0	0	0
forested WL, T	445	39	114	81	16	5	47	55	2	6	41	31	24	(0)	15	121	46	921
herbaceous	9	132	76	55	0	10	17	9	6	9	4	0	0	(0)	0	59	0	327
herb. WL, NT	0	13	7	8	0	0	0	0	1	0	5	0	0	(0)	0	13	0	34
herb. WL, T	2904	950	271	1335	26	45	1211	357	18	57	622	31	81	(0)	121	1958	57	8031
other	8	187	113	120	3	1	28	54	5	24	26	1	22	(0)	359	146	4	952
ss	0	2	0	0	0	0	0	0	0	0	0	0	0	(0)	0	0	0	2
ss WL, NT	0	0	0	0	0	0	0	0	0	0	0	0	0	(0)	0	0	0	0
ss WL, T	1090	367	102	312	3	17	446	36	21	9	179	7	16	(0)	52	490	10	2657
tidal flats	2	166	219	178	3	65	143	296	20	39	92	7	1028	(0)	1149	270	10	3407
unclassified	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(6)	(0)	(0)	(0)	(0)	(7)	(0)	(0)	(0)	(0)	14
water	140	367	231	410	23	109	368	609	28	99	173	18	2134	(0)	26138	583	41	30847
wooded/ss WL, NT	0	0	0	0	0	0	0	0	0	0	0	0	0	(0)	0	0	0	0
wooded/ss WL, T	1536	406	216	392	18	22	494	91	23	15	219	38	41	(0)	67	612	56	3578
Present Acres	5787	3336	3671	3521	110	439	2464	1480	125	419	1311	109	3336	0	28028	4832	219	54136
% overall cover (excluding Water) historical:	0.3%	0.5%	29.1%	0.0%	4.0%	1.4%	0.1%	34.5%	4.1%	0.0%	0.0%	11.4%	14.6%			0.0%	15.4%	
% overall cover (excluding Water) present:	22.2%	12.8%	14.1%	13.5%	0.4%	1.7%	9.4%	5.7%	0.5%	1.6%	5.0%	0.4%	12.8%			18.5%	0.8%	

Total Acres in Reach (Water + Floodplain): 55,023
Total Acres Covered by Analysis: 54,136 (98% of Total)

Historical Land Cover Change, 1880s to 2010: Lower Columbia River, Reach A

Lower Columbia River Estuary Partnership

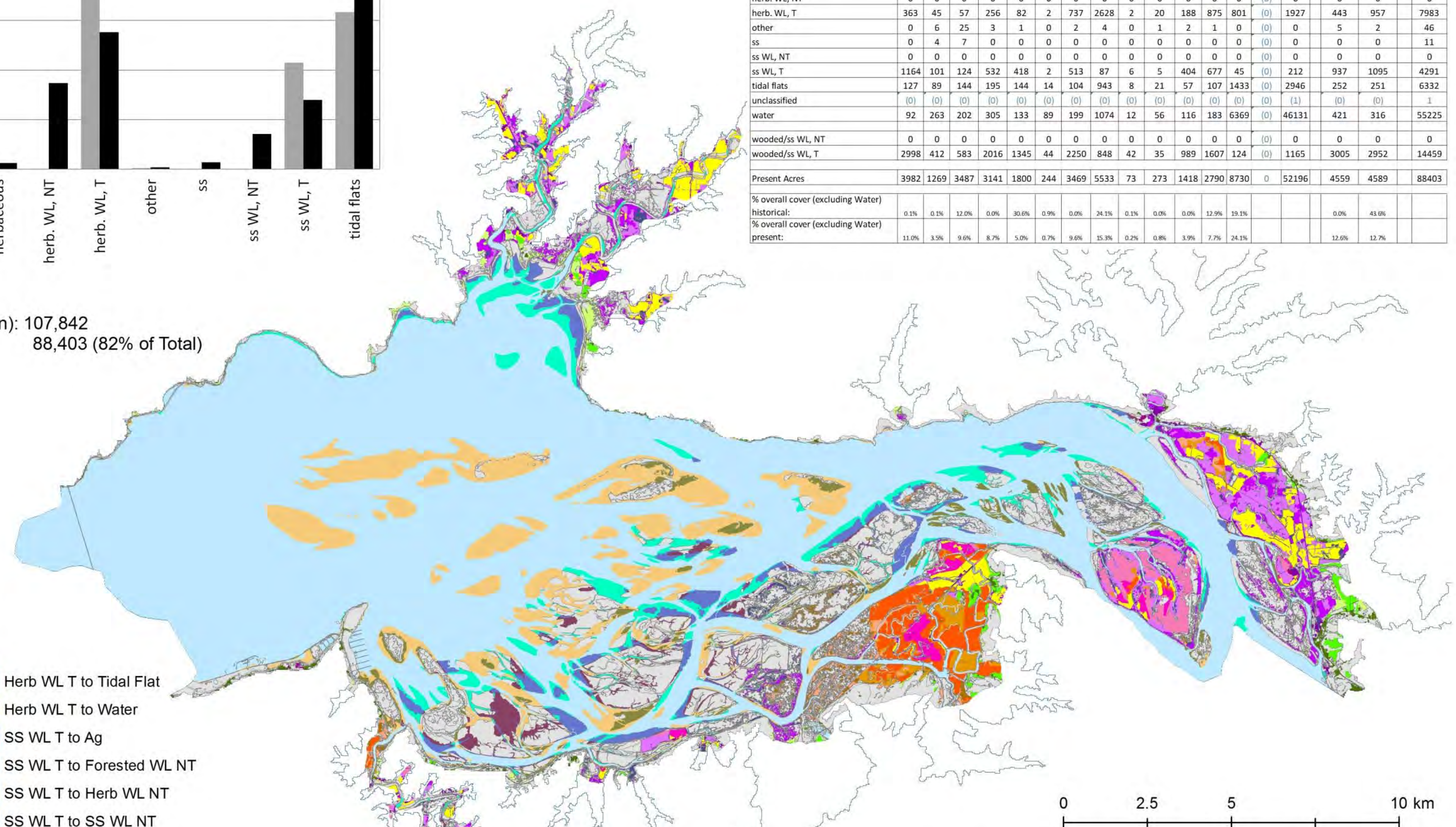
Figure 9: Reach Map, LCRE Reach A



Total Acres in Reach (Water + Floodplain): 107,842
Total Acres Covered by Analysis: 88,403 (82% of Total)

Land Cover Change Matrix

FROM CLASS (Acres): \ TO CLASS (Acres):	ag	dev	forest	forest WL, NT	forest WL, T	herb.	herb. WL, NT	herb. WL, T	other	shrub-scrub	ss WL, NT	ss WL, T	tidal flats	unc.	water	wooded / ss WL, NT	wooded/ ss WL, T	Hist-orical Acres
ag	5	12	2	0	0	0	0	0	0	1	0	0	0	(0)	0	0	0	20
developed	0	27	6	0	0	0	0	0	0	0	0	0	0	(0)	1	0	0	35
forested	347	292	2377	361	94	90	156	34	9	128	63	16	3	(0)	24	424	110	3993
forested WL, NT	0	0	0	0	0	0	0	0	0	0	0	0	0	(0)	0	0	0	0
forested WL, T	1834	311	459	1484	927	41	1737	761	36	31	585	930	80	(0)	952	2069	1857	10168
herbaceous	49	119	85	4	1	4	20	2	0	10	4	0	0	(0)	2	7	2	299
herb. WL, NT	0	0	0	0	0	0	0	0	0	0	0	0	0	(0)	0	0	0	0
herb. WL, T	363	45	57	256	82	2	737	2628	2	20	188	875	801	(0)	1927	443	957	7983
other	0	6	25	3	1	0	2	4	0	1	2	1	0	(0)	0	5	2	46
ss	0	4	7	0	0	0	0	0	0	0	0	0	0	(0)	0	0	0	11
ss WL, NT	0	0	0	0	0	0	0	0	0	0	0	0	0	(0)	0	0	0	0
ss WL, T	1164	101	124	532	418	2	513	87	6	5	404	677	45	(0)	212	937	1095	4291
tidal flats	127	89	144	195	144	14	104	943	8	21	57	107	1433	(0)	2946	252	251	6332
unclassified	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(1)	(0)	(0)	1
water	92	263	202	305	133	89	199	1074	12	56	116	183	6369	(0)	46131	421	316	55225
wooded/ss WL, NT	0	0	0	0	0	0	0	0	0	0	0	0	0	(0)	0	0	0	0
wooded/ss WL, T	2998	412	583	2016	1345	44	2250	848	42	35	989	1607	124	(0)	1165	3005	2952	14459
Present Acres	3982	1269	3487	3141	1800	244	3469	5533	73	273	1418	2790	8730	0	52196	4559	4589	88403
% overall cover (excluding Water) historical:	0.1%	0.1%	12.0%	0.0%	30.6%	0.9%	0.0%	24.1%	0.1%	0.0%	0.0%	12.9%	19.1%			0.0%	43.6%	
% overall cover (excluding Water) present:	11.0%	3.5%	9.6%	8.7%	5.0%	0.7%	9.6%	15.3%	0.2%	0.8%	3.9%	7.7%	24.1%			12.6%	12.7%	



Legend (Highlighting Key Loss Scenarios For Reach)

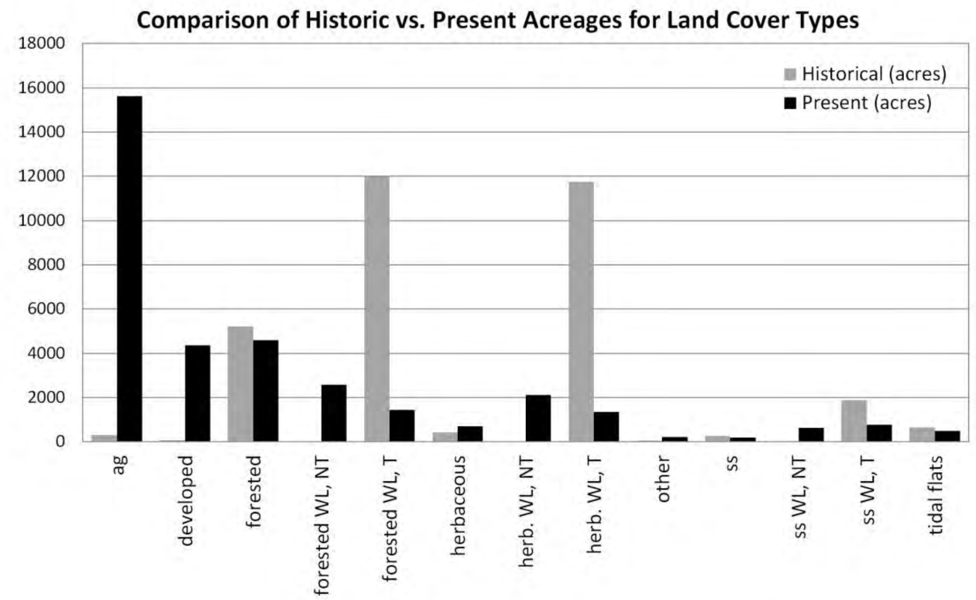
- Other Change Scenario
- Forested to Ag
- Forested to Dev
- Forested to Forested WL NT
- Forested WL T to Ag
- Forested WL T to Dev
- Forested WL T to Forested WL NT
- Forested WL T to Herb WL NT
- Forested WL T to SS WL NT
- Herb WL T to Ag
- Herb WL T to Dev
- Herb WL T to Herb WL NT
- Herb WL T to Tidal Flat
- Herb WL T to Water
- SS WL T to Ag
- SS WL T to Forested WL NT
- SS WL T to Herb WL NT
- SS WL T to SS WL NT
- Tidal Flat to Water
- Water to Herb WL T
- Water to Tidal Flat
- Present Day Water
- Reach B, Not Analyzed

SS = Shrub-Scrub
WL = Wetland
NT = Non-Tidal
T = Tidal

Historical Land Cover Change, 1880s to 2010: Lower Columbia River, Reach B

Lower Columbia River Estuary Partnership

Figure 10: Reach Map, LCRE Reach B



Land Cover Change Matrix

TO CLASS (Acres): / FROM CLASS (Acres):	ag	dev	forest	forest WL, NT	forest WL, T	herb.	herb. WL, NT	herb. WL, T	other	shrub-scrub	ss WL, NT	ss WL, T	tidal flats	unc.	water		wooded / ss WL, NT	wooded/ ss WL, T		Hist-orical Acres
ag	94	100	31	31	1	5	23	1	1	1	5	0	0	(0)	4		36	2		298
developed	25	21	5	1	0	0	5	3	4	0	0	0	1	(0)	11		1	1		77
forested	226	760	3561	105	39	146	63	20	61	136	22	21	7	(0)	59		127	60		5225
forested WL, NT	0	0	6	0	0	1	0	0	0	0	0	0	0	(0)	0		0	0		7
forested WL, T	5396	1528	375	1300	548	208	852	194	65	37	357	195	87	(0)	853		1656	743		11994
herbaceous	117	113	103	26	2	16	13	4	4	3	4	1	2	(0)	17		30	3		423
herb. WL, NT	0	0	0	0	0	0	0	0	0	0	0	0	0	(0)	0		0	0		0
herb. WL, T	7873	1345	158	225	114	132	840	362	36	8	112	208	12	(0)	329		337	322		11753
other	0	6	33	1	1	4	0	1	0	0	0	0	0	(0)	16		1	1		63
ss	16	47	64	55	15	2	14	19	4	6	2	6	3	(0)	0	9	57	21		253
ss WL, NT	0	0	0	0	0	0	0	0	0	0	0	0	0	(0)	0		0	0		0
ss WL, T	1609	62	4	60	4	9	53	1	1	1	37	17	0	(0)	23		97	21		1881
tidal flats	2	34	27	40	61	6	13	36	1	0	6	16	39	(0)	376		46	77		657
unclassified	(80)	(72)	(58)	(24)	(2)	(4)	(8)	(2)	(0)	(10)	(7)	(1)	(0)	(0)	(11)		(0)	(0)		278
water	270	355	227	732	665	168	226	713	32	12	88	310	333	(0)	14527		820	976		18658
wooded/ss WL, NT	0	0	6	0	0	1	0	0	0	0	0	0	0	(0)	0		0	0		7
wooded/ss WL, T	7005	1590	379	1360	552	217	905	195	66	38	393	212	87	(0)	876		1753	764		13876
Present Acres	15627	4371	4593	2578	1451	696	2103	1353	209	204	632	775	483	0	16215		3210	2226		51289
% overall cover (excluding Water) historical:	0.9%	0.2%	16.0%	0.0%	36.8%	1.3%	0.0%	36.0%	0.2%	0.8%	0.0%	5.8%	2.0%				0.0%	42.5%		
% overall cover (excluding Water) present:	44.6%	12.5%	13.1%	7.3%	4.1%	2.0%	6.0%	3.9%	0.6%	0.6%	1.8%	2.2%	1.4%				9.2%	6.3%		

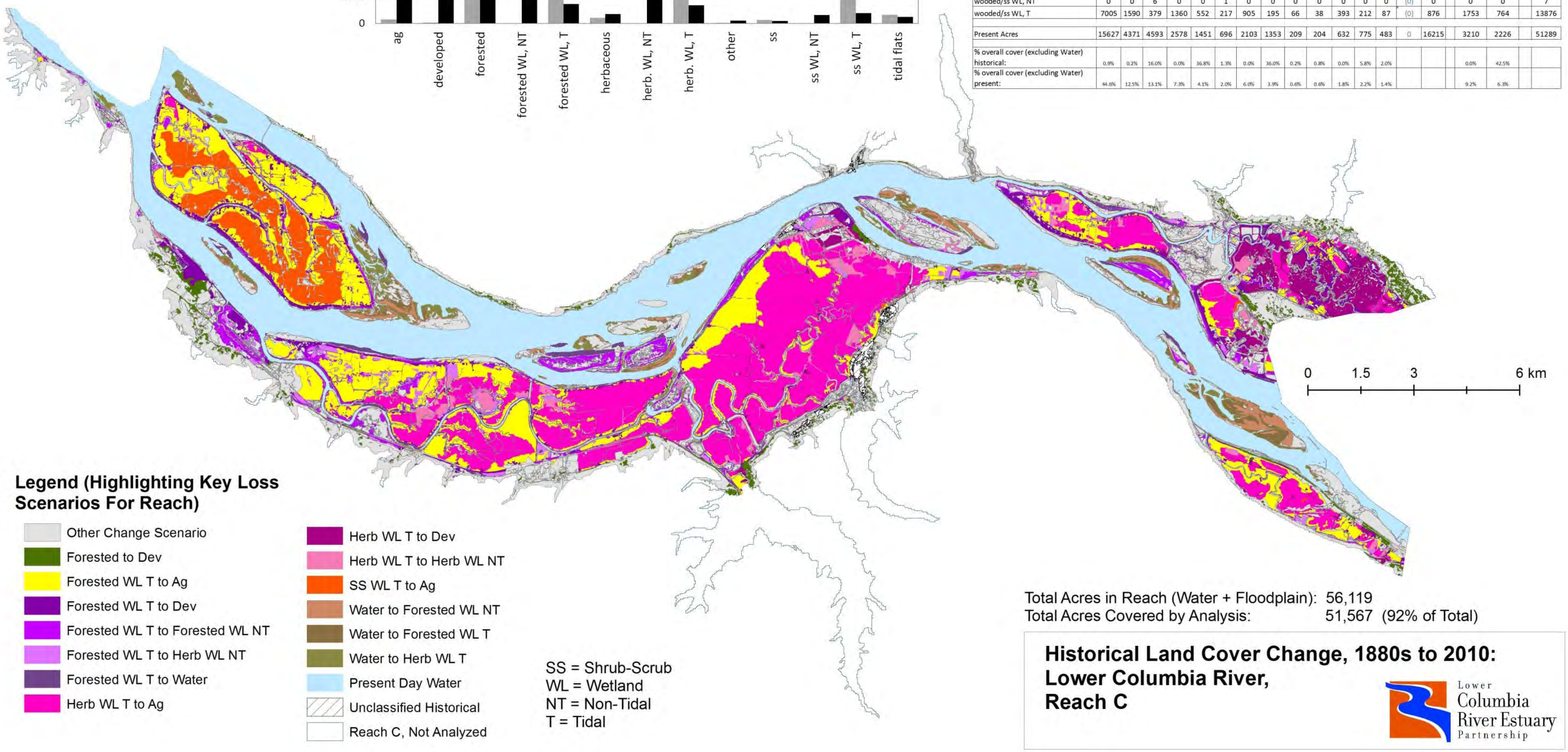
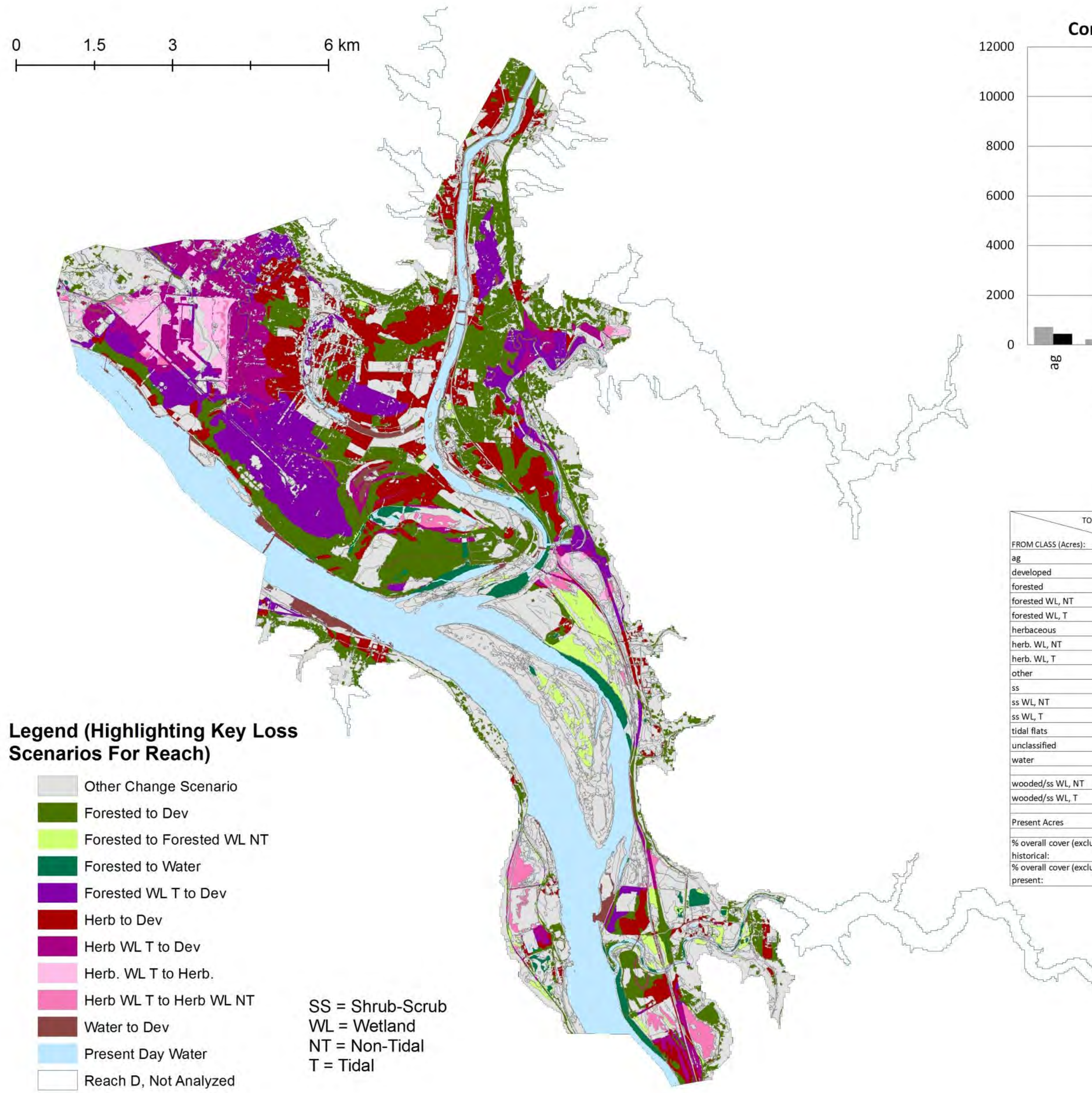
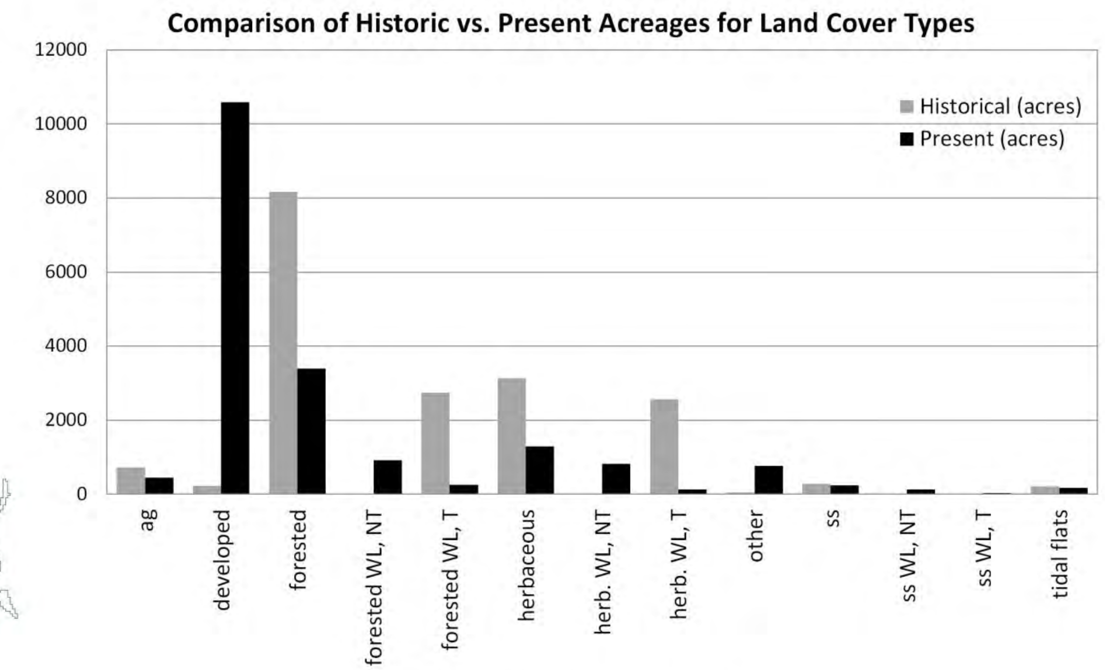


Figure 11: *Reach Map, LCRE Reach C*





Land Cover Change Matrix

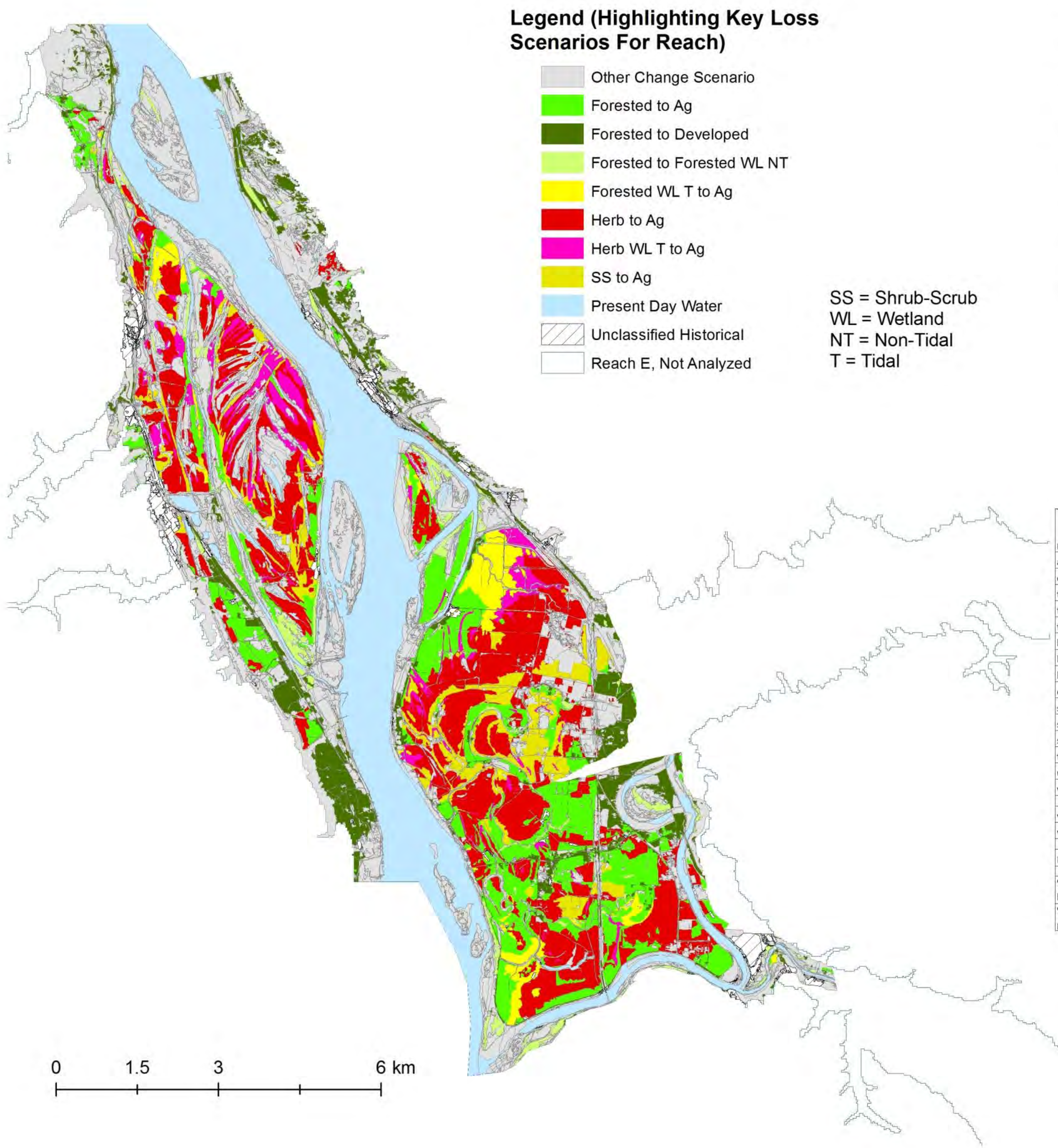
TO CLASS (Acres): / FROM CLASS (Acres):	ag	dev	forest	forest WL, NT	forest WL, T	herb.	herb. WL, NT	herb. WL, T	other	shrub-scrub	ss WL, NT	ss WL, T	tidal flats	unc.	water	wooded / ss WL, NT	wooded/ ss WL, T	Hist-orical Acres
ag	13	574	78	4	1	6	7	0	28	2	2	0	0	(0)	7	6	1	722
developed	5	150	36	8	1	6	5	0	7	1	1	0	0	(0)	5	10	1	226
forested	185	3742	2346	397	24	293	219	10	379	106	39	7	29	(0)	388	436	31	8164
forested WL, NT	0	6	3	2	0	0	0	0	0	0	0	0	0	(0)	0	2	0	11
forested WL, T	22	1901	153	124	49	181	93	15	75	26	22	1	4	(0)	74	146	50	2738
herbaceous	129	2264	354	79	6	40	100	2	77	18	15	0	1	(0)	51	95	6	3135
herb. WL, NT	0	0	0	0	0	0	0	0	0	0	0	0	0	(0)	0	0	0	0
herb. WL, T	91	1251	122	82	22	393	302	9	39	27	24	3	2	(0)	203	106	25	2570
other	0	13	17	4	1	3	0	0	0	0	0	0	1	(0)	5	4	1	44
ss	1	204	56	5	1	4	2	1	0	1	0	0	0	(0)	1	6	1	276
ss WL, NT	0	0	0	0	0	0	0	0	0	0	0	0	0	(0)	0	0	0	0
ss WL, T	0	0	0	0	0	1	0	0	0	0	0	0	0	(0)	0	0	0	1
tidal flats	0	47	27	22	7	14	11	4	13	3	3	3	10	(0)	53	25	10	216
unclassified	(0)	(1)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	1
water	6	429	207	185	138	353	83	92	149	54	18	20	125	(0)	4258	202	157	6115
wooded/ss WL, NT	0	6	3	2	0	0	0	0	0	0	0	0	0	(0)	0	2	0	11
wooded/ss WL, T	22	1901	153	124	49	182	93	15	75	26	22	1	4	(0)	74	146	50	2740
Present Acres	451	10581	3399	913	249	1293	822	133	766	238	124	34	172	(0)	5044	1037	283	24220
% overall cover (excluding Water) historical:	4.0%	1.3%	45.1%	0.1%	15.1%	17.3%	0.0%	14.2%	0.2%	1.5%	0.0%	0.0%	1.2%			0.1%	15.1%	
% overall cover (excluding Water) present:	2.4%	55.2%	17.7%	4.8%	1.3%	6.7%	4.3%	0.7%	4.0%	1.2%	0.6%	0.2%	0.9%			5.4%	1.5%	

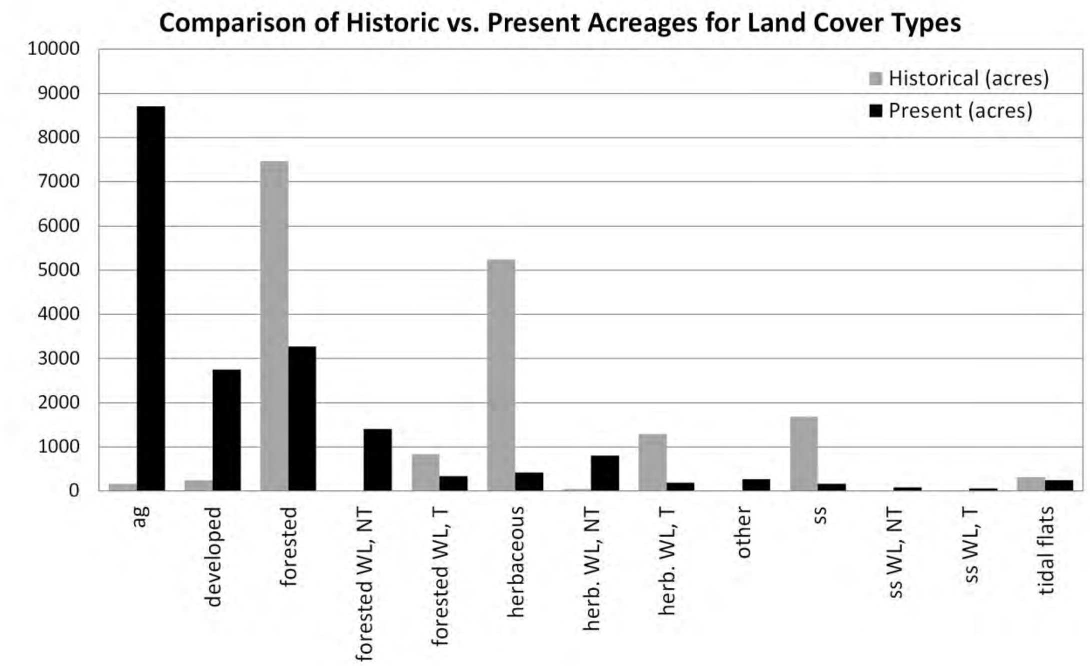
Total Acres in Reach (Water + Floodplain): 32,602
Total Acres Covered by Analysis: 24,220 (74% of Total)

Historical Land Cover Change, 1880s to 2010: Lower Columbia River, Reach D

Lower Columbia River Estuary Partnership

Figure 12: *Reach Map, LCRE Reach D*





Land Cover Change Matrix

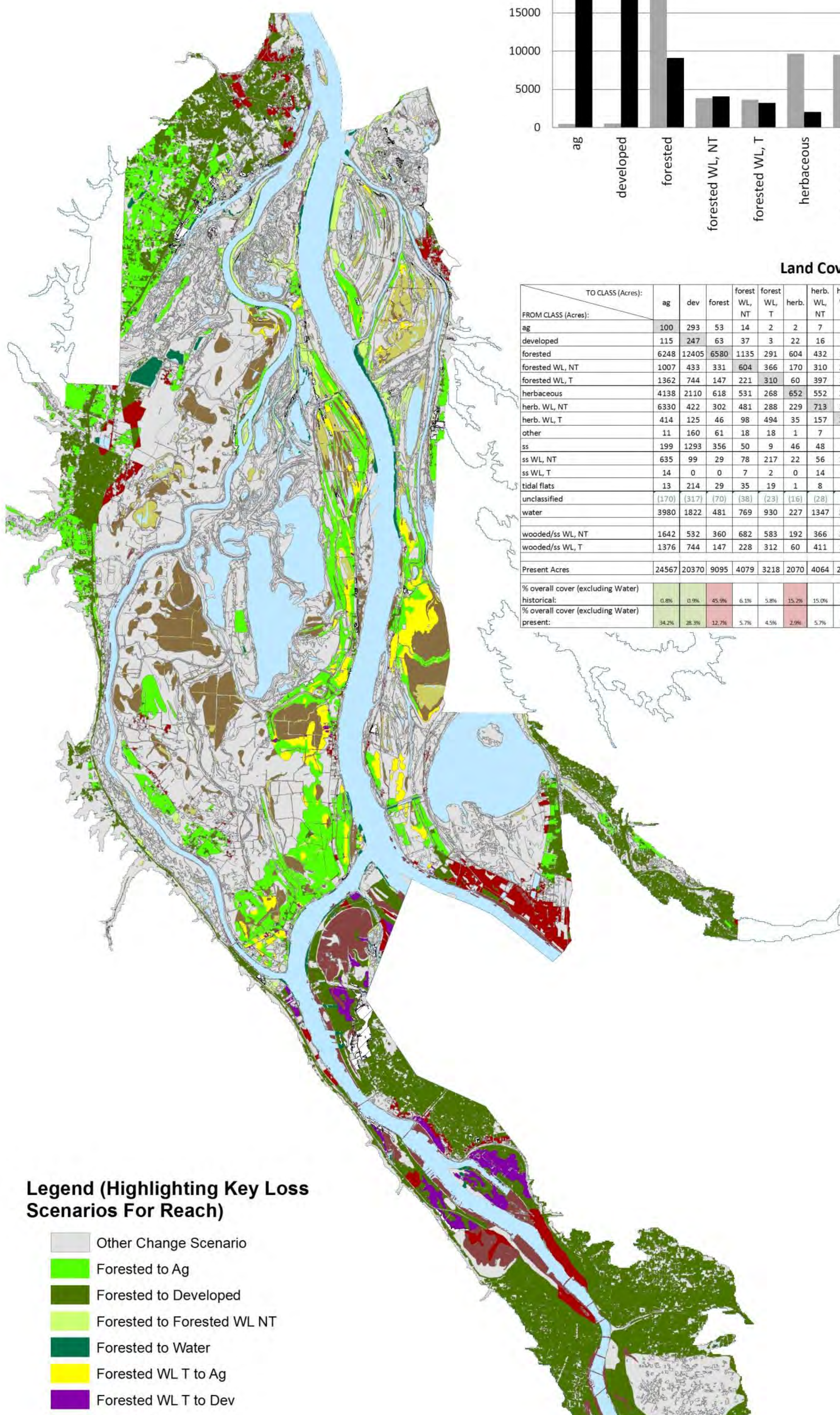
TO CLASS (Acres): / FROM CLASS (Acres):	ag	dev	forest	forest WL, NT	forest WL, T	herb.	herb. WL, NT	herb. WL, T	other	shrub-scrub	ss WL, NT	ss WL, T	tidal flats	unc.	water	wooded / ss WL, NT	wooded/ ss WL, T	Hist-orical Acres
ag	61	55	18	0	0	3	5	0	5	2	0	0	0	(0)	11	1	0	161
developed	59	110	53	4	0	7	4	0	2	5	0	0	0	(0)	8	4	0	252
forested	2419	1446	2132	451	61	193	139	38	112	117	22	5	31	(0)	307	472	67	7473
forested WL, NT	2	2	1	2	0	1	8	0	0	0	0	0	0	(0)	0	2	0	16
forested WL, T	514	62	38	74	37	5	40	7	3	1	0	3	6	(0)	44	74	40	833
herbaceous	3709	660	298	150	9	55	160	4	54	18	18	0	10	(0)	99	168	9	5243
herb. WL, NT	2	17	13	4	0	1	3	0	0	0	5	0	0	(0)	0	9	0	44
herb. WL, T	674	51	99	170	18	18	168	6	8	3	8	4	4	(0)	59	179	22	1290
other	7	2	3	1	0	0	0	0	0	0	0	0	0	(0)	1	1	0	14
ss	974	229	188	128	2	30	36	1	13	6	3	0	6	(0)	64	131	2	1680
ss WL, NT	0	0	0	0	0	0	0	0	0	0	0	0	0	(0)	0	0	0	0
ss WL, T	6	0	0	0	0	0	0	0	0	0	0	0	0	(0)	0	0	0	6
tidal flats	10	28	40	48	17	8	11	14	26	0	1	7	12	(0)	96	49	24	318
unclassified	(110)	(91)	(232)	(29)	(2)	(26)	(9)	(2)	(1)	(15)	(2)	(1)	(2)	(0)	(16)	(0)	(0)	(538)
water	277	90	346	377	192	94	237	122	49	13	25	45	175	(0)	5171	402	237	7213
wooded/ss WL, NT	2	2	1	2	0	1	8	0	0	0	0	0	0	(0)	0	2	0	16
wooded/ss WL, T	520	62	38	74	37	5	40	7	3	1	0	3	6	(0)	44	74	40	839
Present Acres	8712	2752	3230	1407	337	416	809	192	272	166	83	65	244	(0)	5860	1490	401	24544
% overall cover (excluding Water) historical:	0.9%	1.5%	43.1%	0.1%	4.8%	30.3%	0.3%	7.4%	0.1%	9.7%	0.0%	0.0%	1.8%			0.1%	4.8%	
% overall cover (excluding Water) present:	46.6%	14.7%	17.3%	7.5%	1.8%	2.2%	4.3%	1.0%	1.5%	0.9%	0.4%	0.3%	1.3%			8.0%	2.1%	

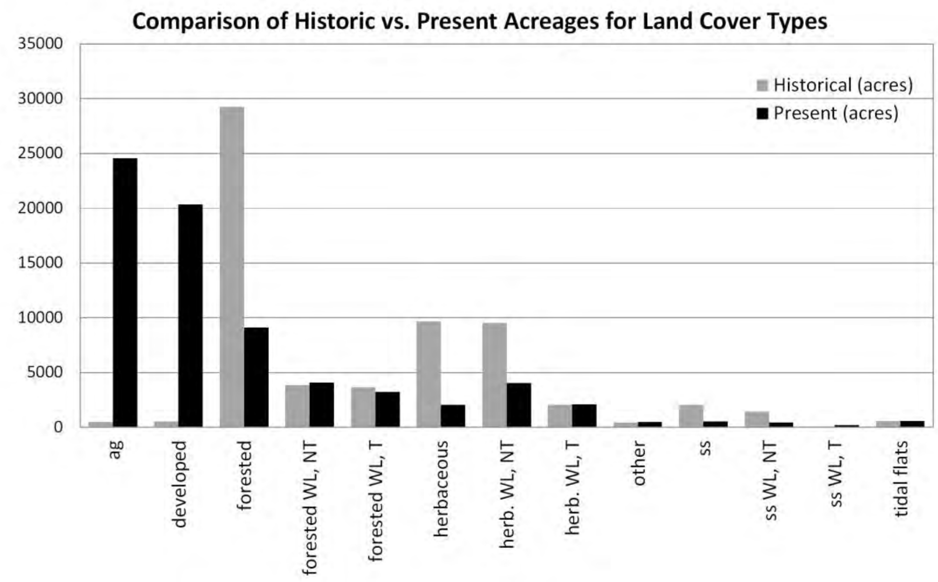
Total Acres in Reach (Water + Floodplain): 38,015
Total Acres Covered by Analysis: 25,121 (66% of Total)

Historical Land Cover Change, 1880s to 2010: Lower Columbia River, Reach E

Lower Columbia River Estuary Partnership

Figure 13: *Reach Map, LCRE Reach E*





Land Cover Change Matrix

FROM CLASS (Acres): / TO CLASS (Acres):	ag	dev	forest	forest WL, NT	forest WL, T	herb.	herb. WL, NT	herb. WL, T	other	shrub-scrub	ss WL, NT	ss WL, T	tidal flats	unc.	water	wooded / ss WL, NT	wooded/ ss WL, T	Hist-orical Acres
ag	100	293	53	14	2	2	7	1	1	3	5	1	5	(0)	10	19	3	498
developed	115	247	63	37	3	22	16	4	13	4	3	0	2	(0)	20	40	3	549
forested	6248	12405	6580	1135	291	604	432	120	241	347	95	9	68	(0)	677	1230	301	29253
forested WL, NT	1007	433	331	604	366	170	310	211	14	22	54	10	1	(0)	335	658	376	3867
forested WL, T	1362	744	147	221	310	60	397	149	38	8	34	11	9	(0)	188	255	321	3677
herbaceous	4138	2110	618	531	268	652	552	296	78	61	53	7	33	(0)	290	584	275	9688
herb. WL, NT	6330	422	302	481	288	229	713	313	25	43	76	13	8	(0)	309	557	300	9552
herb. WL, T	414	125	46	98	494	35	157	371	5	6	11	13	2	(0)	273	110	508	2052
other	11	160	61	18	18	1	7	10	7	0	10	4	2	(0)	125	28	22	434
ss	199	1293	356	50	9	46	48	5	0	1	11	1	5	(0)	45	60	10	2069
ss WL, NT	635	99	29	78	217	22	56	134	19	1	8	18	19	(0)	126	85	235	1461
ss WL, T	14	0	0	7	2	0	14	0	0	0	0	0	0	(0)	0	7	2	39
tidal flats	13	214	29	35	19	1	8	11	8	0	10	6	13	(0)	215	45	25	582
unclassified	(170)	(317)	(70)	(38)	(23)	(16)	(28)	(7)	(4)	(2)	(8)	(1)	(3)	(0)	(42)	(0)	(0)	729
water	3980	1822	481	769	930	227	1347	500	47	22	86	130	405	(0)	16030	855	1060	26778
wooded/ss WL, NT	1642	532	360	682	583	192	366	345	33	22	61	28	20	(0)	461	743	611	5328
wooded/ss WL, T	1376	744	147	228	312	60	411	149	38	8	34	11	9	(0)	188	263	323	3716
Present Acres	24567	20370	9095	4079	3218	2070	4064	2125	496	518	456	223	574	(0)	18644	4535	3441	90499
% overall cover (excluding Water) historical:	0.8%	0.9%	45.9%	6.1%	5.8%	15.2%	15.0%	3.2%	0.7%	3.2%	2.3%	0.1%	0.9%			8.4%	5.8%	
% overall cover (excluding Water) present:	34.2%	28.3%	12.7%	5.7%	4.5%	2.9%	5.7%	3.0%	0.7%	0.7%	0.6%	0.3%	0.8%			6.3%	4.8%	

Legend (Highlighting Key Loss Scenarios For Reach)

- Other Change Scenario
- Forested to Ag
- Forested to Developed
- Forested to Forested WL NT
- Forested to Water
- Forested WL T to Ag
- Forested WL T to Dev
- Herb to Dev
- Herb WL T to Wooded WL NT
- Water to Ag
- Water to Dev
- Water to Herb WL NT
- Present Day Water
- Unclassified Historical
- Reach F, Not Analyzed

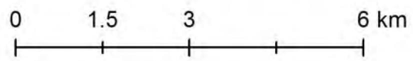
SS = Shrub-Scrub
WL = Wetland
NT = Non-Tidal
T = Tidal

Total Acres in Reach (Water + Floodplain): 101,728
Total Acres Covered by Analysis: 91,228 (90% of Total)

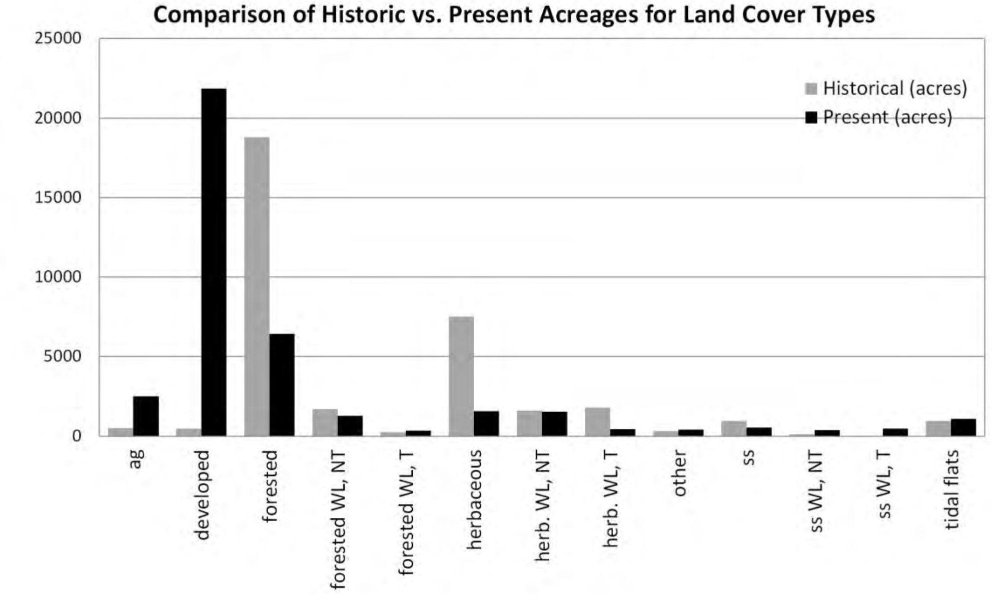
Historical Land Cover Change, 1880s to 2010: Lower Columbia River, Reach F

Lower Columbia River Estuary Partnership

Figure 14: Reach Map, LCRE Reach F

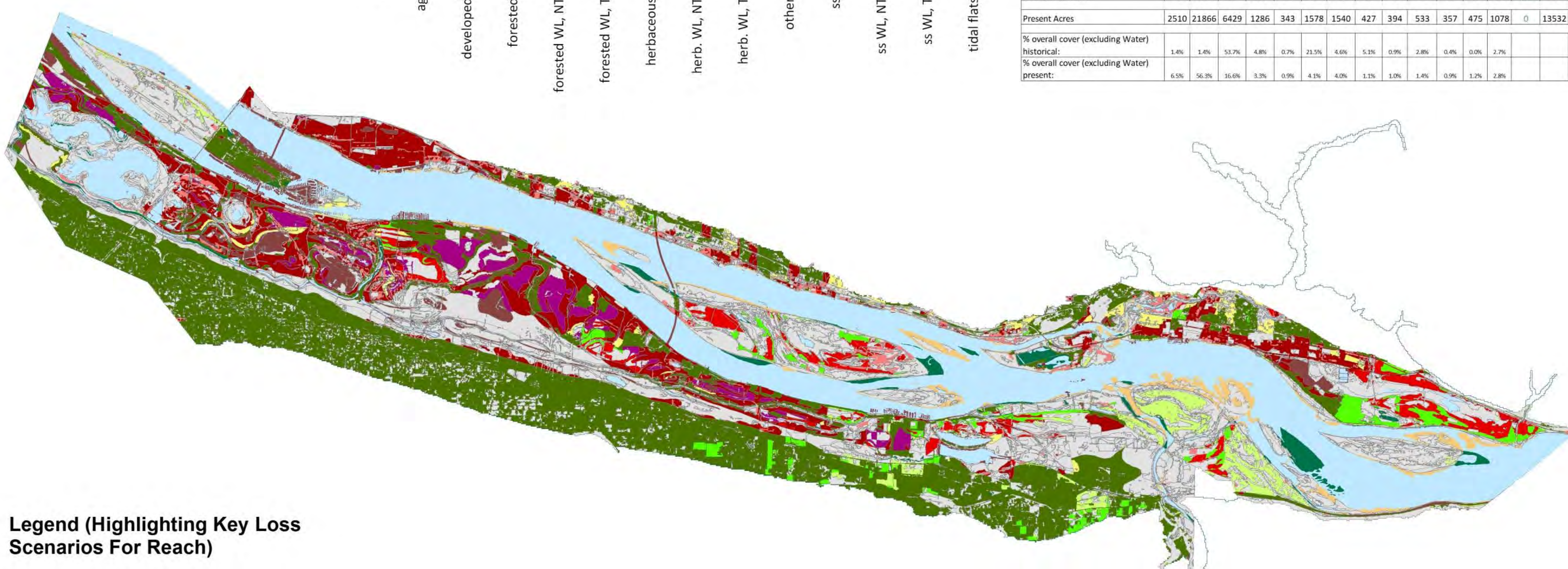


Comparison of Historic vs. Present Acreages for Land Cover Types



Land Cover Change Matrix

FROM CLASS (Acres) \ TO CLASS (Acres):	ag	dev	forest	forest WL, NT	forest WL, T	herb.	herb. WL, NT	herb. WL, T	other	shrub-scrub	ss WL, NT	ss WL, T	tidal flats	unc.	water	wooded / ss WL, NT	wooded/ ss WL, T	Hist-orical Acres
ag	49	335	72	0	0	8	1	0	11	14	0	0	1	0	11	1	0	503
developed	12	379	64	3	0	2	2	0	1	5	2	0	1	0	5	5	0	477
forested	884	11070	3868	358	29	870	333	33	139	297	91	65	98	0	652	449	95	18790
forested WL, NT	27	1043	157	164	23	86	30	4	42	11	25	4	2	0	76	189	27	1694
forested WL, T	6	184	5	13	0	9	6	0	4	0	1	0	0	0	4	14	0	232
herbaceous	1058	4280	882	196	18	269	333	21	105	123	55	10	12	0	176	250	28	7537
herb. WL, NT	61	1217	129	82	1	11	33	0	12	6	20	0	0	0	33	102	1	1606
herb. WL, T	202	1091	72	34	69	21	57	144	20	5	14	10	1	0	47	47	79	1786
other	3	45	58	14	3	3	8	10	0	6	4	13	14	0	145	18	15	325
ss	76	570	203	8	1	13	13	2	15	11	2	0	6	0	47	10	1	967
ss WL, NT	18	20	38	6	0	13	17	0	1	4	2	0	0	0	6	8	0	125
ss WL, T	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
tidal flats	0	144	95	53	27	22	98	23	5	3	6	9	53	0	397	59	36	936
unclassified	0	16	1	1	0	0	0	0	0	0	1	0	0	0	0	(0)	(0)	24
water	113	1472	785	352	173	250	609	189	38	47	136	365	890	0	11932	487	537	17350
wooded/ss WL, NT	45	1062	195	170	23	99	47	4	43	14	27	4	2	(0)	82	197	27	1818
wooded/ss WL, T	6	184	5	13	0	9	6	0	4	0	1	0	0	(0)	4	14	0	232
Present Acres	2510	21866	6429	1286	343	1578	1540	427	394	533	357	475	1078	0	13532	1640	818	52347
% overall cover (excluding Water) historical:	1.4%	1.4%	53.7%	4.8%	0.7%	21.5%	4.6%	5.1%	0.9%	2.8%	0.4%	0.0%	2.7%			5.2%	0.7%	
% overall cover (excluding Water) present:	6.5%	56.3%	16.6%	3.3%	0.9%	4.1%	4.0%	1.1%	1.0%	1.4%	0.9%	1.2%	2.8%			4.2%	2.1%	



Legend (Highlighting Key Loss Scenarios For Reach)

- Other Change Scenario
- Forested to Ag
- Forested to Developed
- Forested to Herbaceous
- Forested to Water
- Herbaceous to Ag
- Herb to Dev
- Herb to Forested
- Herb WL T to Dev
- SS to Dev
- Water to Developed
- Water to Tidal Flats
- Present Day Water
- Reach G, Not Analyzed

SS = Shrub-Scrub
WL = Wetland
NT = Non-Tidal
T = Tidal

Total Acres in Reach (Water + Floodplain): 55,293
Total Acres Covered by Analysis: 52,347 (95% of Total)

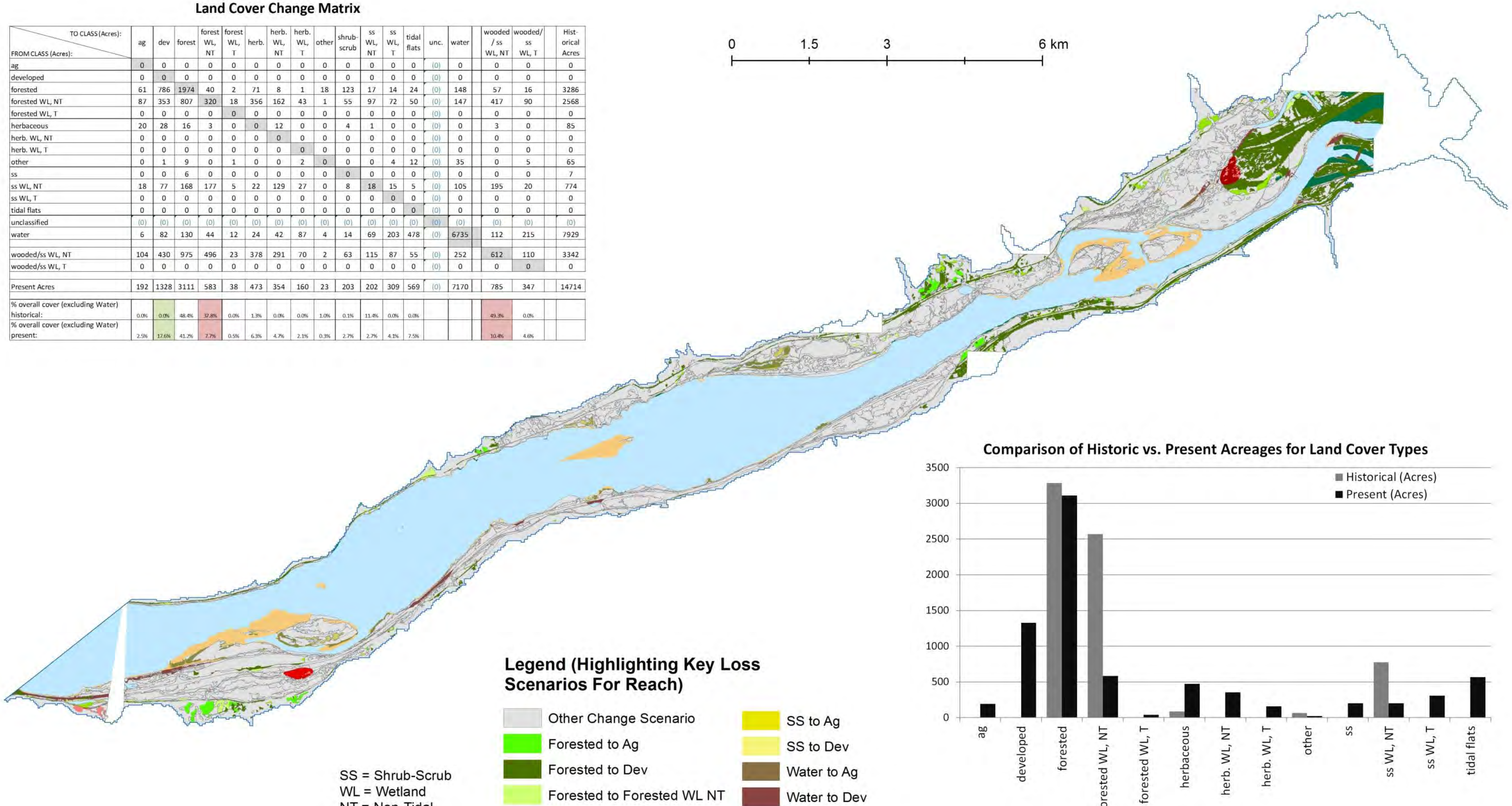
Historical Land Cover Change, 1880s to 2010: Lower Columbia River, Reach G

Lower Columbia River Estuary Partnership

Figure 15: *Reach Map, LCRE Reach G*

Land Cover Change Matrix

TO CLASS (Acres): / FROM CLASS (Acres):	ag	dev	forest	forest WL, NT	forest WL, T	herb.	herb. WL, NT	herb. WL, T	other	shrub-scrub	ss WL, NT	ss WL, T	tidal flats	unc.	water	wooded / ss WL, NT	wooded/ ss WL, T	Hist-orical Acres
ag	0	0	0	0	0	0	0	0	0	0	0	0	0	(0)	0	0	0	0
developed	0	0	0	0	0	0	0	0	0	0	0	0	0	(0)	0	0	0	0
forested	61	786	1974	40	2	71	8	1	18	123	17	14	24	(0)	148	57	16	3286
forested WL, NT	87	353	807	320	18	356	162	43	1	55	97	72	50	(0)	147	417	90	2568
forested WL, T	0	0	0	0	0	0	0	0	0	0	0	0	0	(0)	0	0	0	0
herbaceous	20	28	16	3	0	0	12	0	0	4	1	0	0	(0)	0	3	0	85
herb. WL, NT	0	0	0	0	0	0	0	0	0	0	0	0	0	(0)	0	0	0	0
herb. WL, T	0	0	0	0	0	0	0	0	0	0	0	0	0	(0)	0	0	0	0
other	0	1	9	0	1	0	0	2	0	0	0	4	12	(0)	35	0	5	65
ss	0	0	6	0	0	0	0	0	0	0	0	0	0	(0)	0	0	0	7
ss WL, NT	18	77	168	177	5	22	129	27	0	8	18	15	5	(0)	105	195	20	774
ss WL, T	0	0	0	0	0	0	0	0	0	0	0	0	0	(0)	0	0	0	0
tidal flats	0	0	0	0	0	0	0	0	0	0	0	0	0	(0)	0	0	0	0
unclassified	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
water	6	82	130	44	12	24	42	87	4	14	69	203	478	(0)	6735	112	215	7929
wooded/ss WL, NT	104	430	975	496	23	378	291	70	2	63	115	87	55	(0)	252	612	110	3342
wooded/ss WL, T	0	0	0	0	0	0	0	0	0	0	0	0	0	(0)	0	0	0	0
Present Acres	192	1328	3111	583	38	473	354	160	23	203	202	309	569	(0)	7170	785	347	14714
% overall cover (excluding Water) historical:	0.0%	0.0%	48.4%	37.8%	0.0%	1.3%	0.0%	0.0%	1.0%	0.1%	11.4%	0.0%	0.0%			49.3%	0.0%	
% overall cover (excluding Water) present:	2.5%	17.6%	41.2%	7.7%	0.5%	6.3%	4.7%	2.1%	0.3%	2.7%	2.7%	4.1%	7.5%			10.4%	4.6%	



Legend (Highlighting Key Loss Scenarios For Reach)

- Other Change Scenario
- Forested to Ag
- Forested to Dev
- Forested to Forested WL NT
- Forested to Herb.
- Forested to Water
- Herb. to Ag
- Herb. to Dev
- Herb. to Forested
- SS to Ag
- SS to Dev
- Water to Ag
- Water to Dev
- Water to Herb WL T
- Water to Herb WL NT
- Water to Tidal Flat
- Present Day Water
- Reach H, Not Analyzed

SS = Shrub-Scrub
WL = Wetland
NT = Non-Tidal
T = Tidal

Total Acres in Reach (Water + Floodplain): 16,337
Total Acres Covered by Analysis: 14,714 (90% of Total)

Historical Land Cover Change, 1880s to 2010: Lower Columbia River, Reach H

Lower Columbia River Estuary Partnership

Figure 16: *Reach Map, LCRE Reach H*

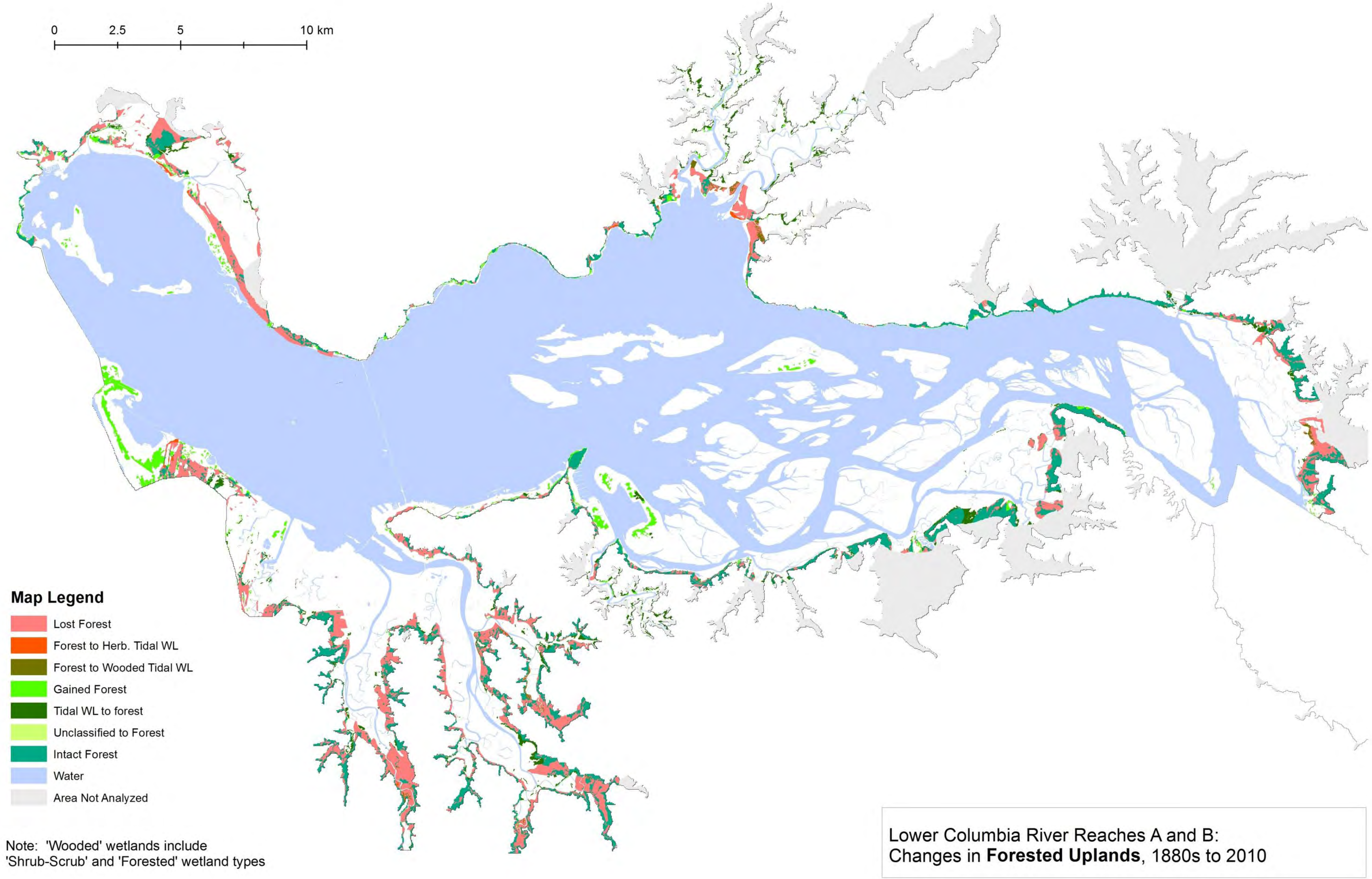


Figure 17: *Regional Map – Changes in Forested Uplands, Lower Estuary*

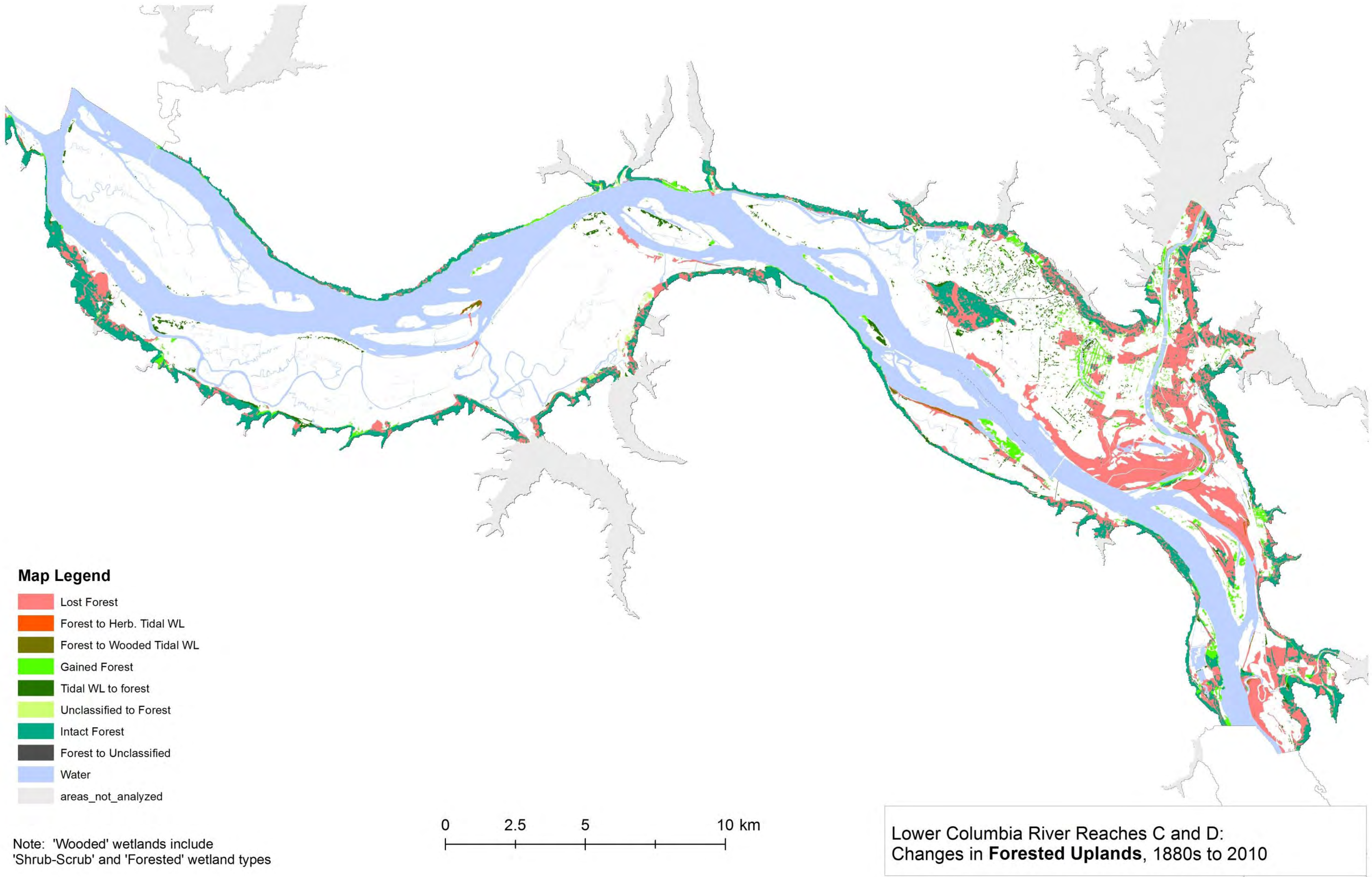


Figure 18: *Regional Map – Changes in Forested Uplands, Mid-Lower Estuary*

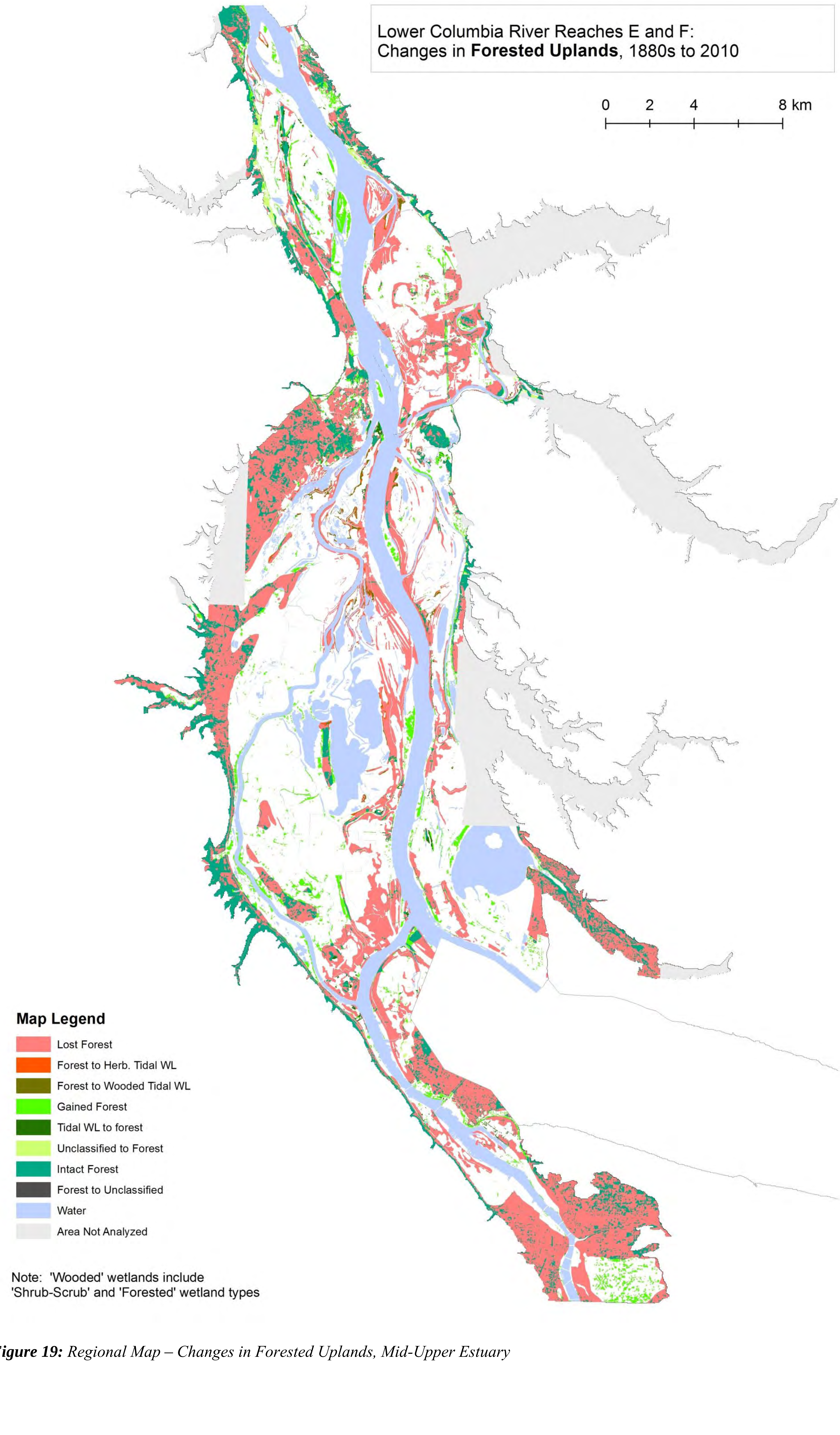


Figure 19: *Regional Map – Changes in Forested Uplands, Mid-Upper Estuary*

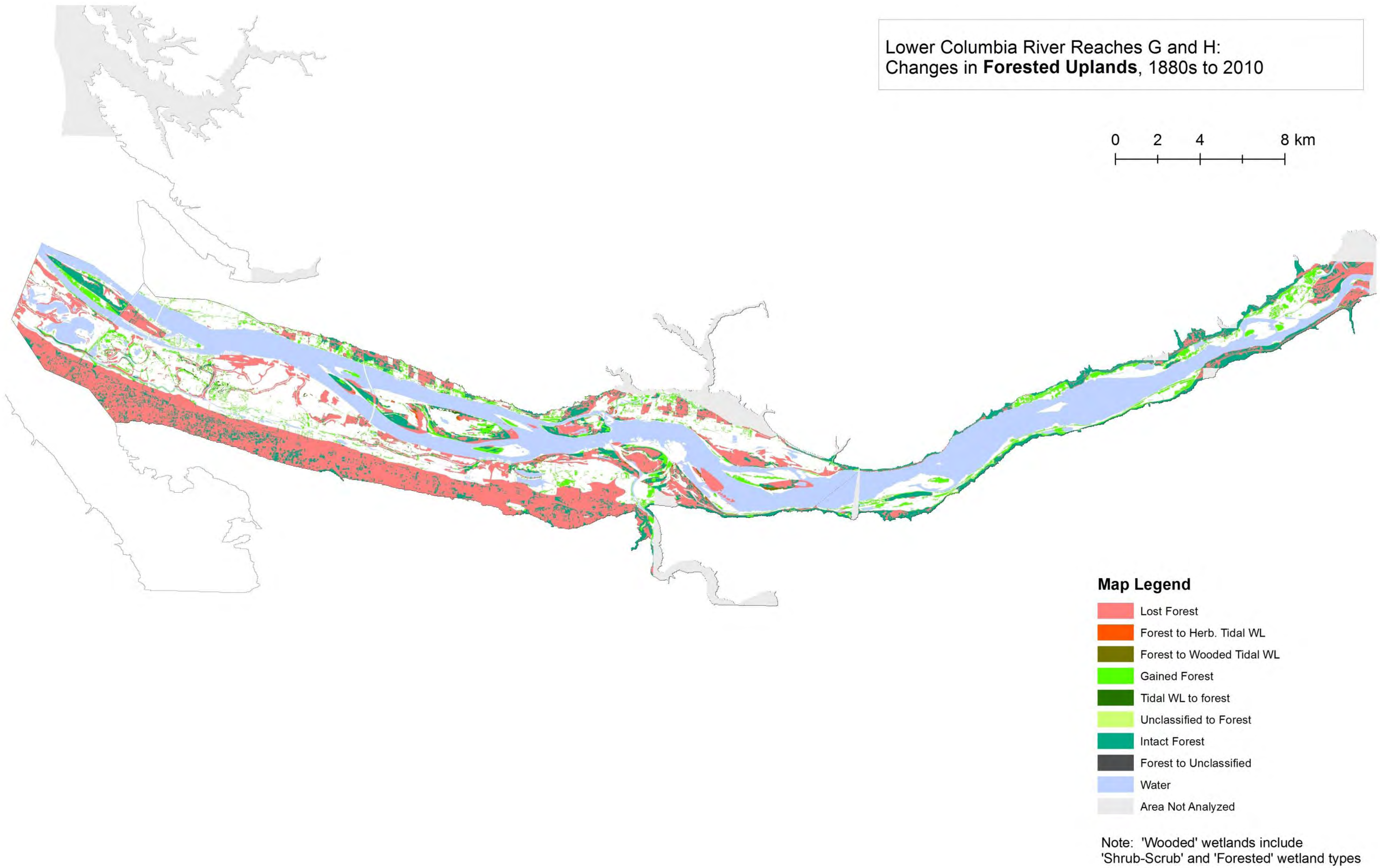


Figure 20: *Regional Map – Changes in Forested Uplands, Upper Estuary*

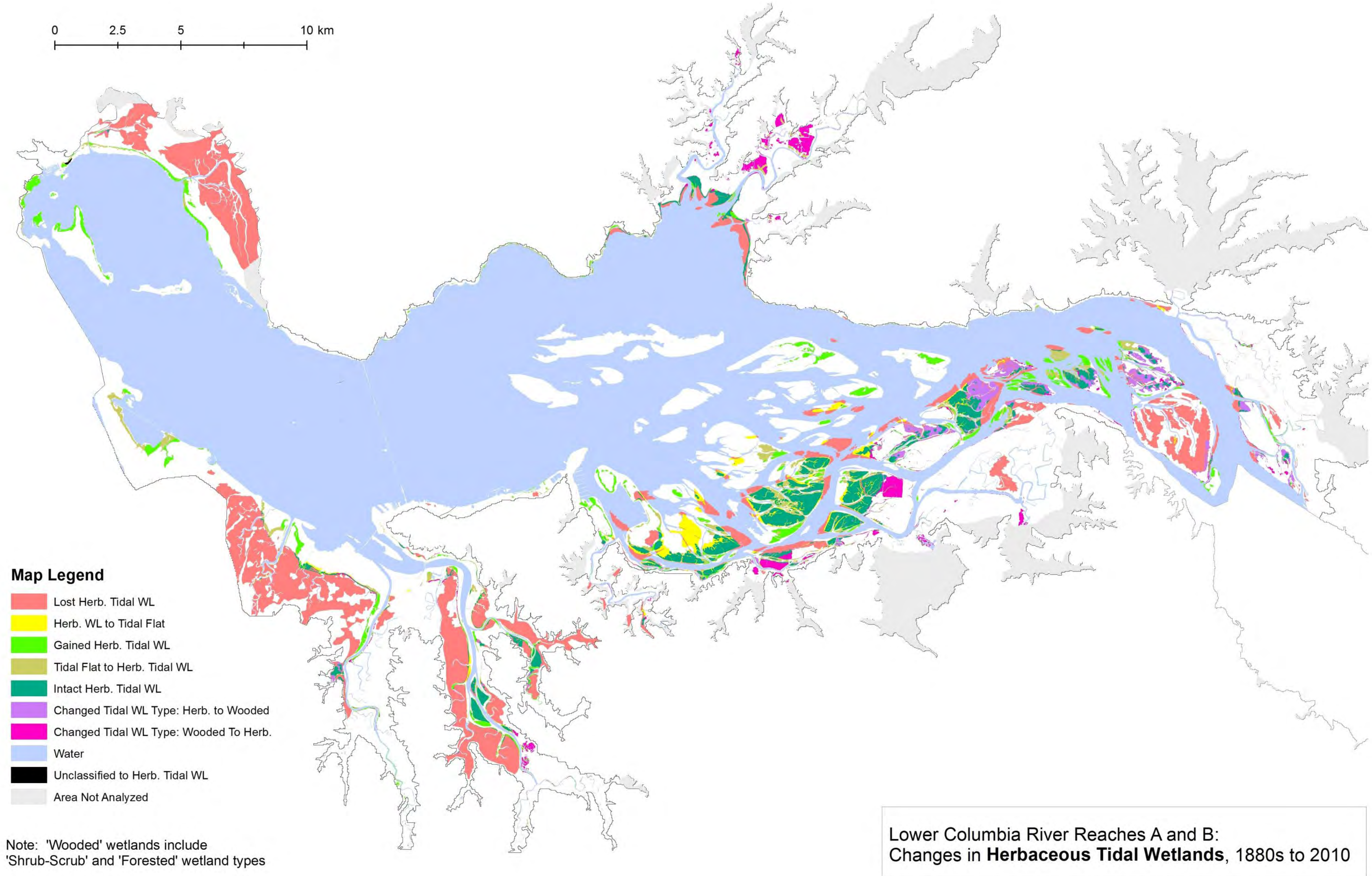


Figure 21: *Regional Map – Changes in Herbaceous Tidal Wetlands, Lower Estuary*

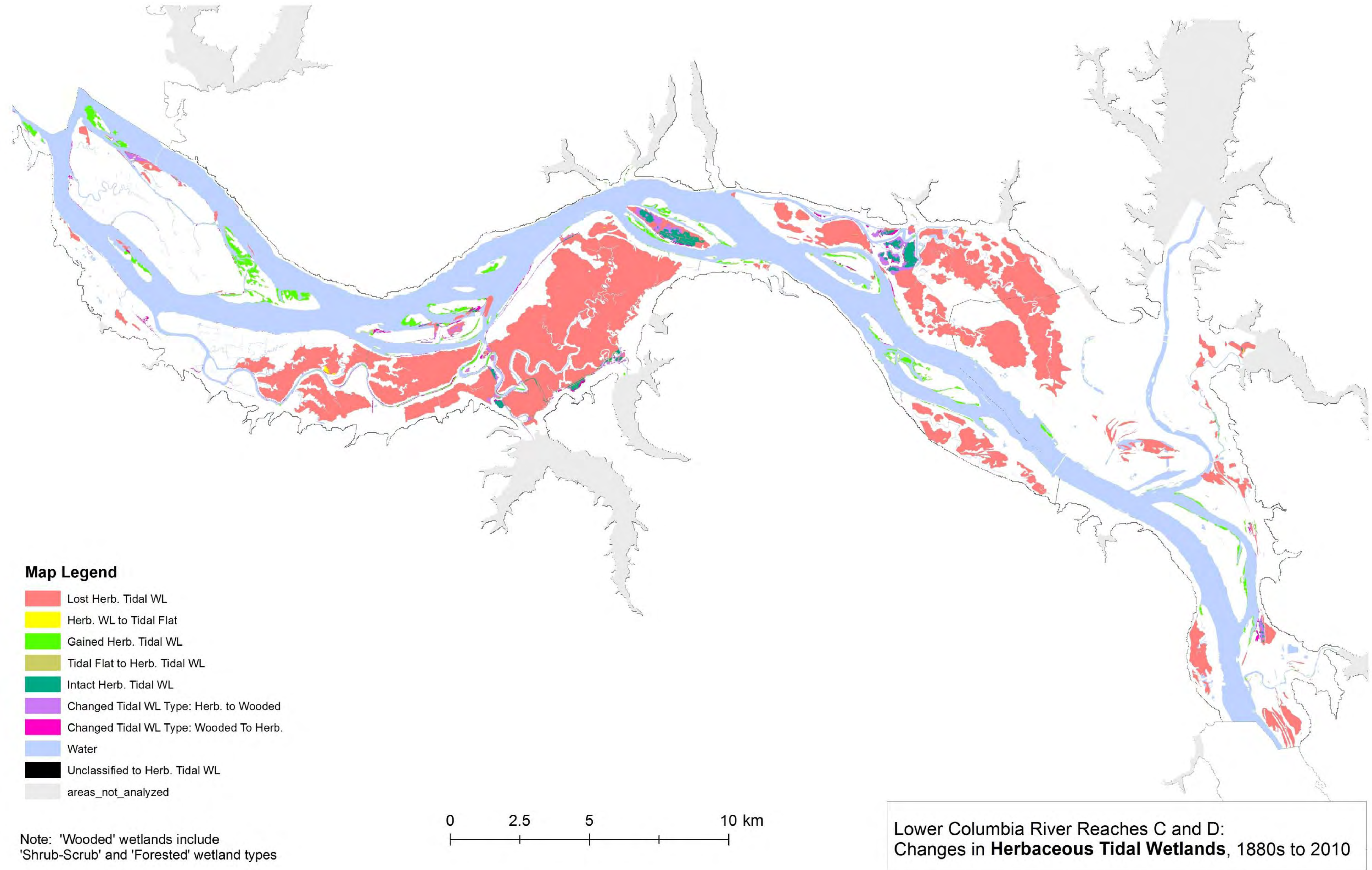


Figure 22: *Regional Map – Changes in Herbaceous Tidal Wetlands, Mid-Lower Estuary*

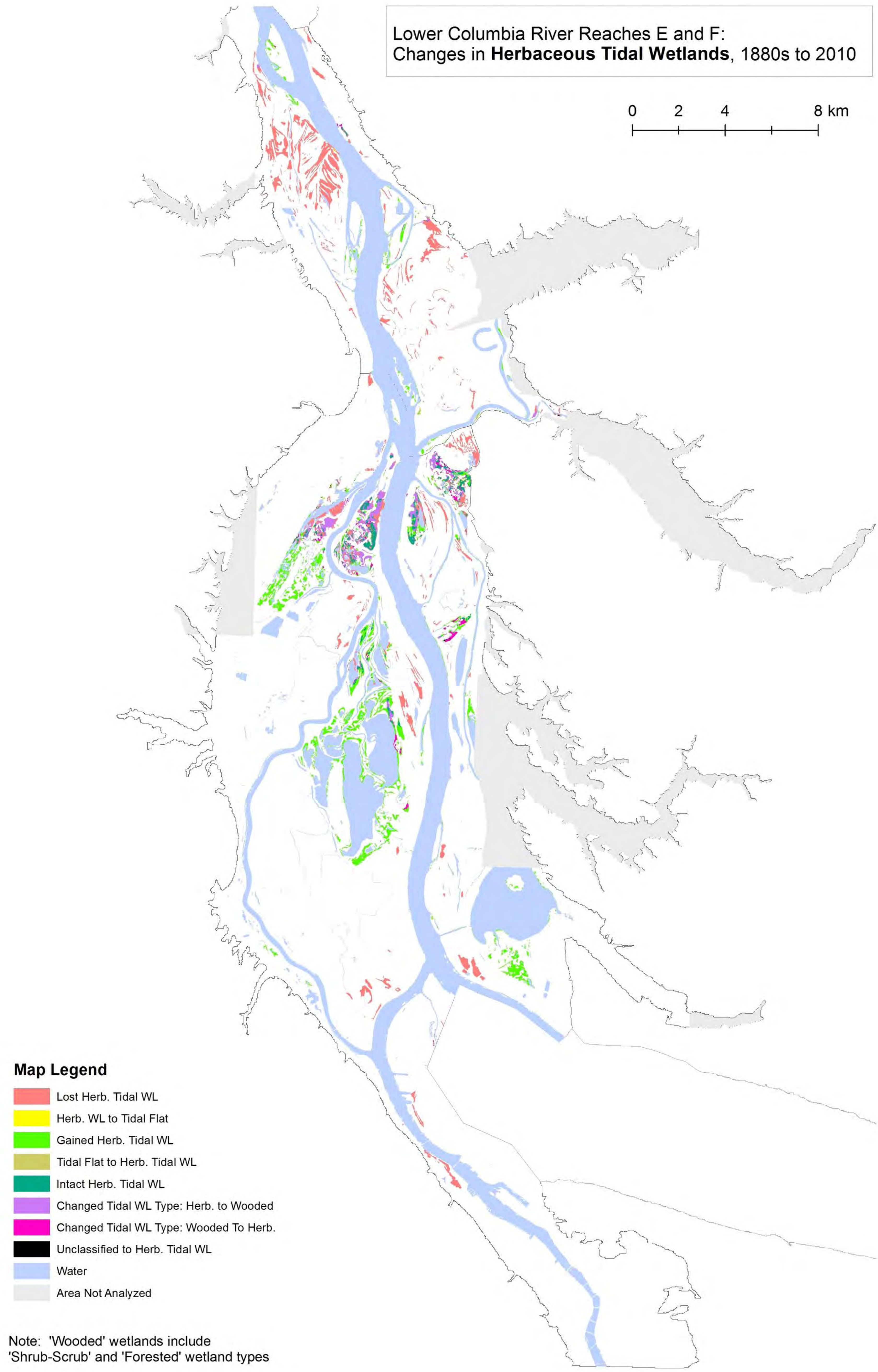


Figure 23: *Regional Map – Changes in Herbaceous Tidal Wetlands, Mid-Upper Estuary*

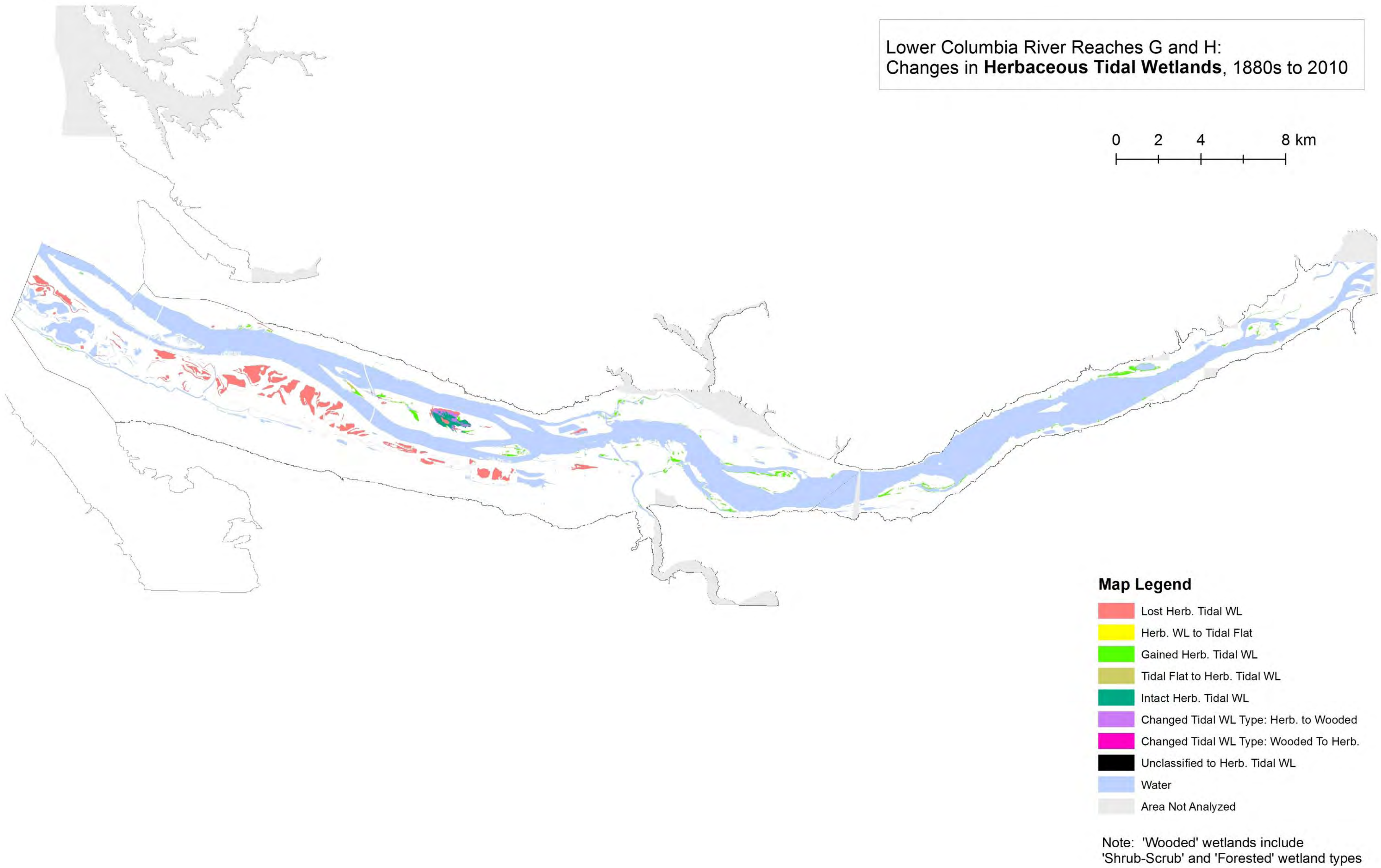


Figure 24: *Regional Map – Changes in Herbaceous Tidal Wetlands, Upper Estuary*

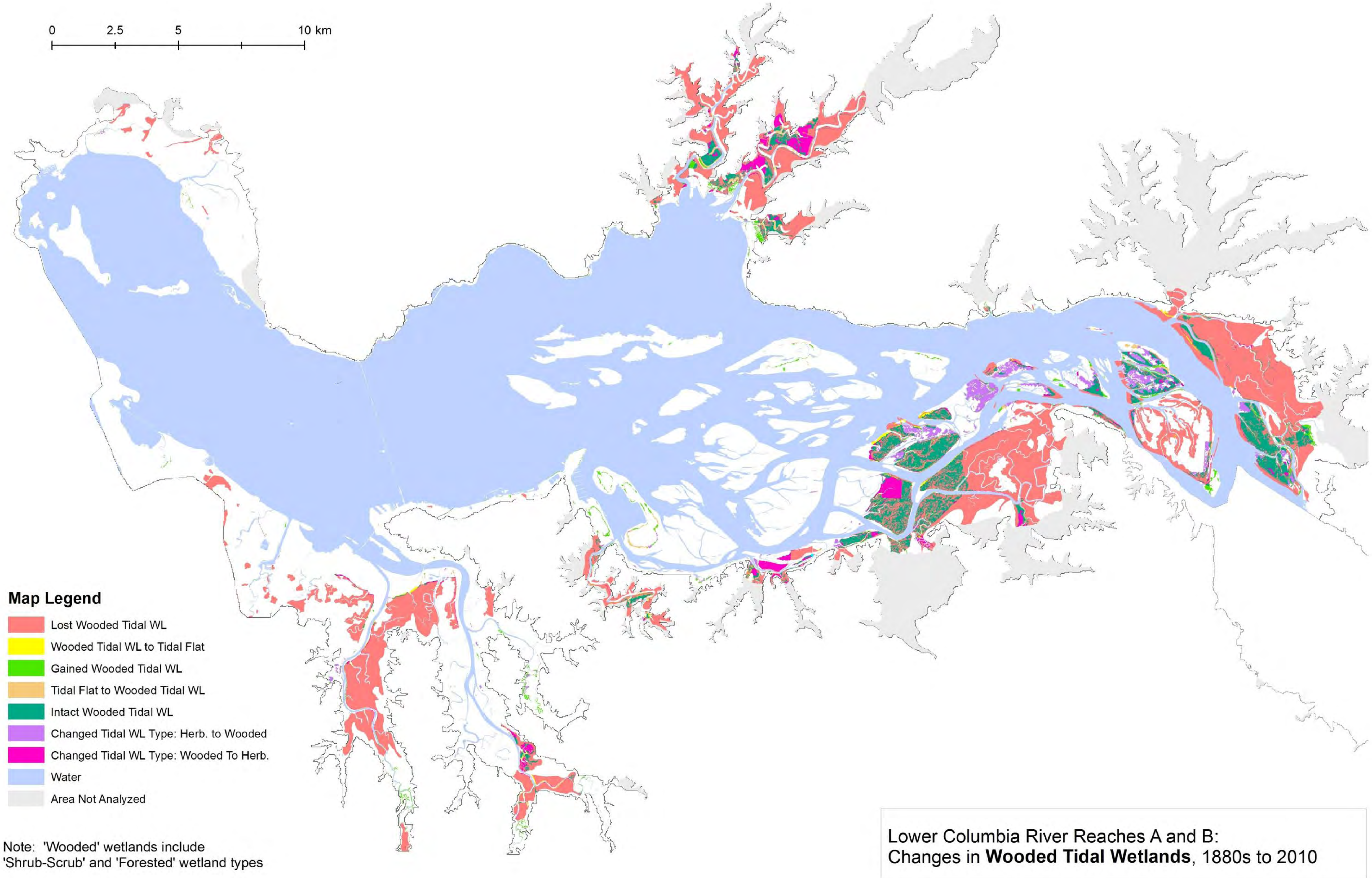


Figure 25: *Regional Map – Changes in Wooded Tidal Wetlands, Lower Estuary*

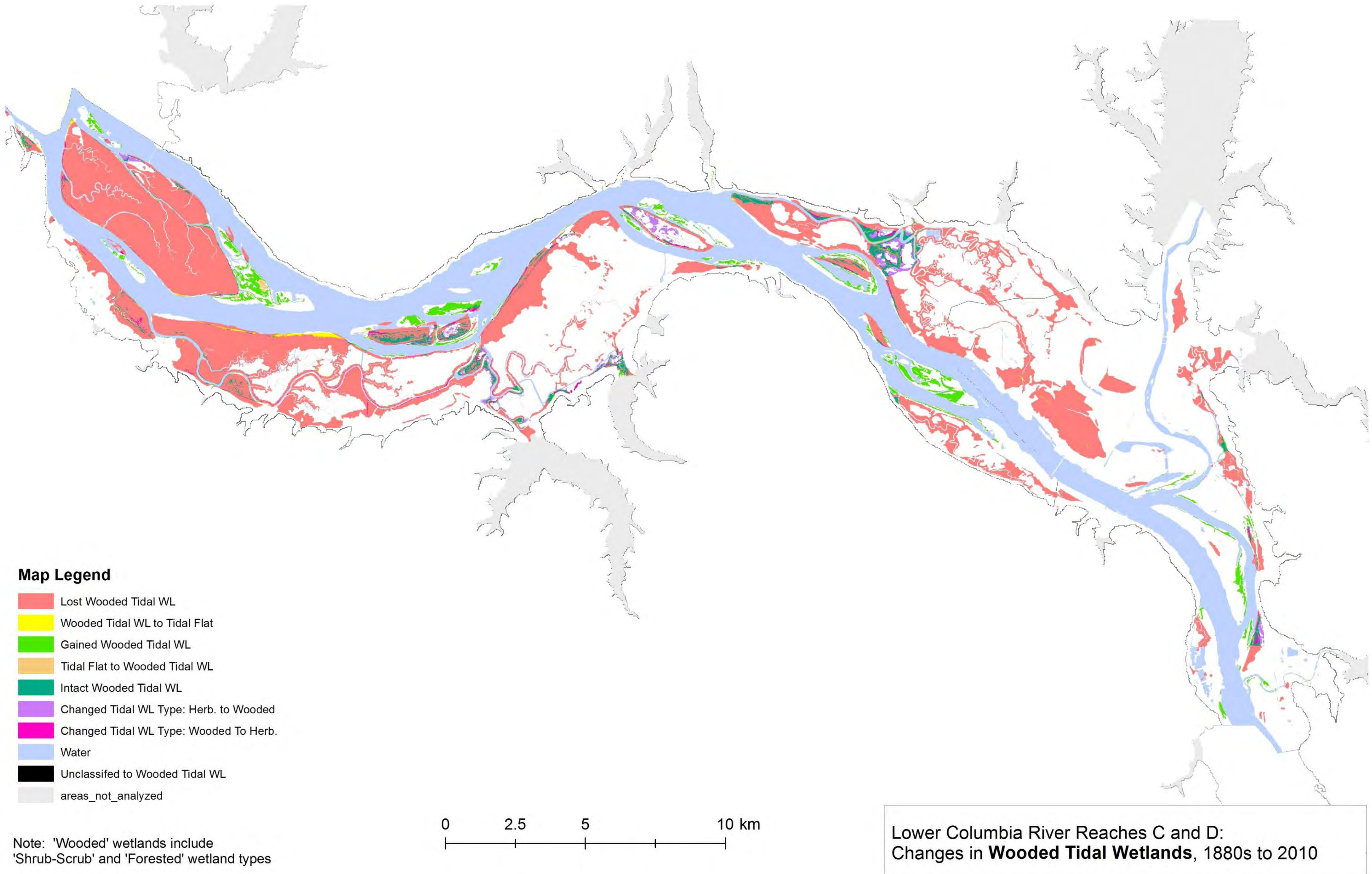


Figure 26: *Regional Map – Changes in Wooded Tidal Wetlands, Mid-Lower Estuary*

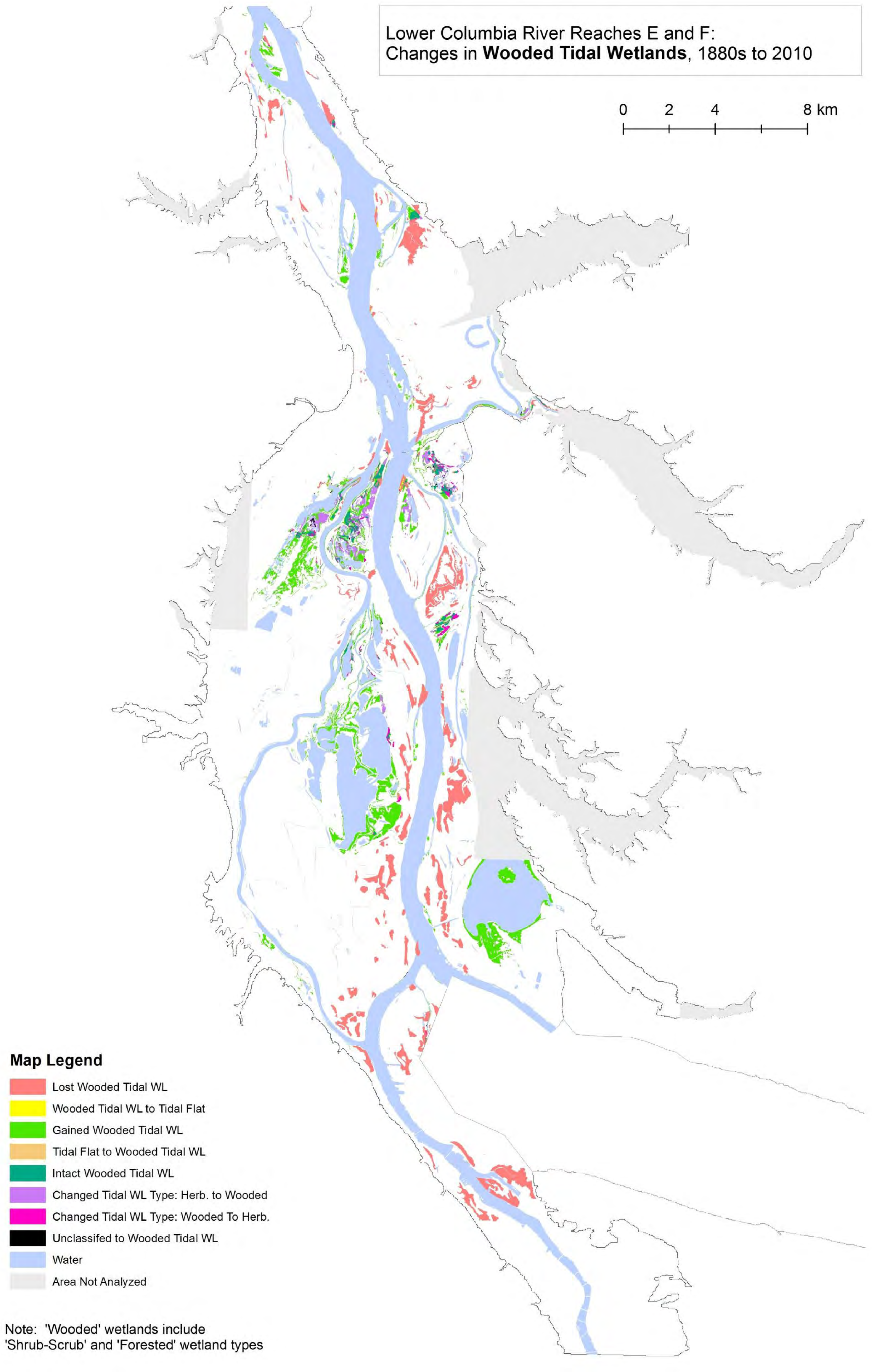


Figure 27: *Regional Map – Changes in Wooded Tidal Wetlands, Mid-Upper Estuary*

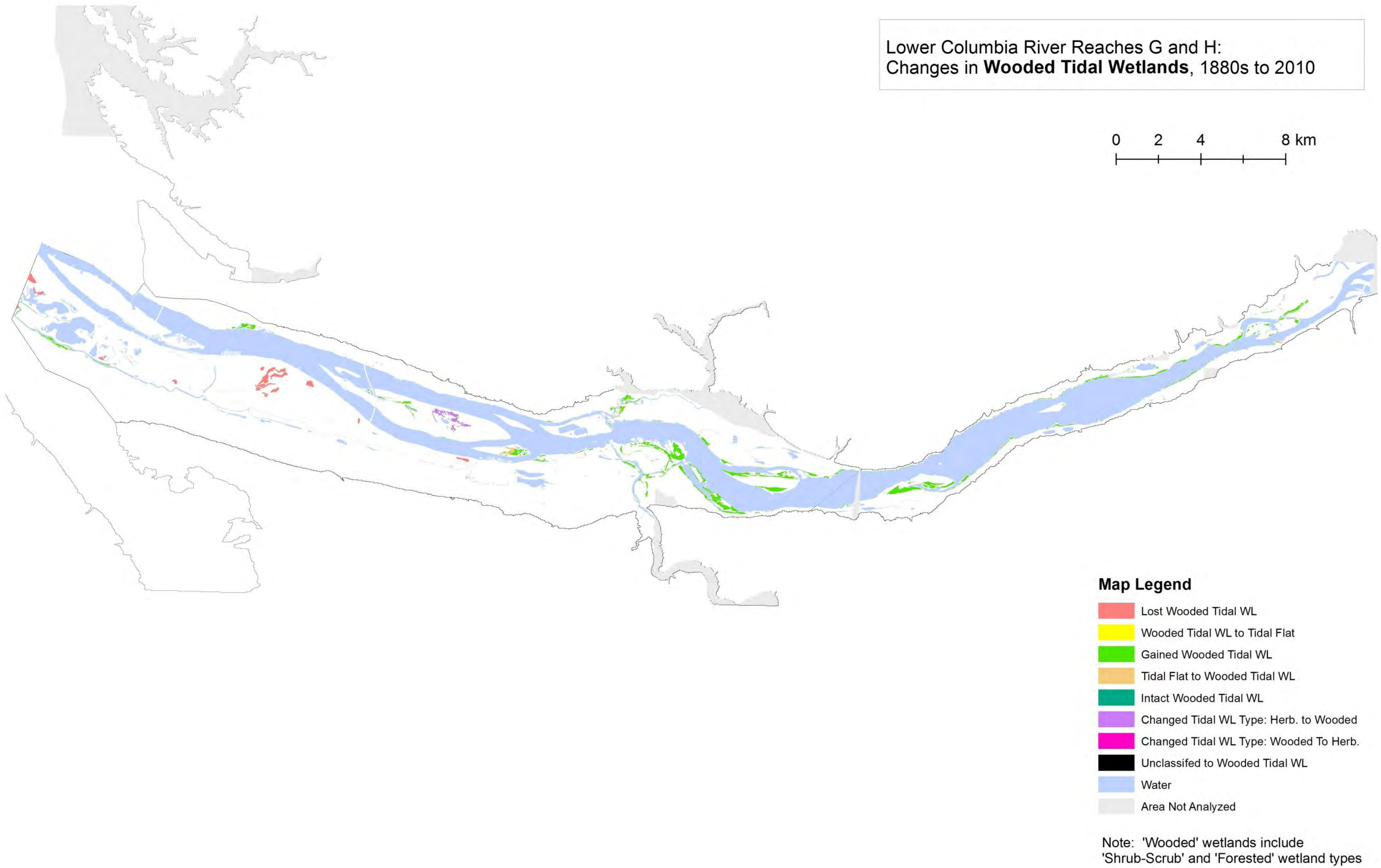


Figure 27: *Regional Map – Changes in Wooded Tidal Wetlands, Upper Estuary*