A Guide to the

Lower Columbia River

Ecosystem Restoration Program

Prepared by the

Lower Columbia Estuary Partnership

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Preface

This guide to the Lower Columbia River Ecosystem Restoration Program provides a description of the Lower Columbia Estuary Partnership's Restoration Prioritization Strategy and ways to apply the Restoration Prioritization Strategy to enhance restoration in the lower river. Like the Restoration Prioritization Strategy, this guide includes goals and objectives of key partners within the Lower Columbia Estuary Partnership (Estuary Partnership) umbrella. The Estuary Partnership includes local, state, federal and tribal government agencies; private sector interests; not-for-profit organizations and academia, as well as the general public. The Restoration Prioritization Strategy was developed within the framework of the Estuary Partnership Comprehensive Conservation and Management Plan (Management Plan).[1] Like the Management Plan, this guide is a living document and will be updated as new information, research and results of monitoring emerge. The guide focuses on the mainstem and historic floodplain as well as tidally influenced portions of the tributaries from Bonneville Dam to the plume.

The Estuary Partnership was created in 1995 by the governors of Washington and Oregon and the US Environmental Protection Agency (USEPA) when USEPA designated the lower Columbia River 'an estuary of national significance.' The National Estuary Program (NEP) was created by the US Congress in 1987 amendments to the Clean Water Act to create collaborative, locally driven programs to address the physical, chemical, social, biological, economic and cultural considerations for conserving and restoring our nation's estuaries. The Estuary Partnership is scientifically based to ensure we make decisions with the best available information; we use an ecosystem-based approach to transcend political or human imposed boundaries; we provide a regional focus to unify, collaborate and build on existing efforts, create partnerships and fill gaps on this shared waterway. The Estuary Partnership is accountable to the US Congress, USEPA and the States. The governing board of directors and our work groups represents the diverse public and private interests and geography of the lower river and include government, private sector and academia partners to ensure comprehensive assessment of issues, leverage resources and target local priorities.

The Lower Columbia Estuary Partnership is one of 28 NEPs. A NEP facilitates and coordinates the collaborative network of partners to implement the actions and meet the goals within the Management Plan, and each NEP relies very heavily on its partners for Management Plan implementation. The major roles of the NEP staff are to ensure coordination, use of best available science, provide a central clearinghouse of information on the estuary, to identify gaps

[1] The Estuary Partnership Management Plan was developed from 1996 to 1999 using results of an extensive review of scientific research and analysis. The Management Committee that developed the Management Plan was composed of 34 representatives of various river interests and incorporated broad constituent and public input to ensure that the Management Plan met local needs, represented local and regional values, and was supported by local communities and citizens. The 1999 Management Plan identified 43 actions, including environmental goals and objectives, to address *seven priority issues*: biological integrity; habitat loss and modification; impacts from human activity; conventional pollutants; toxic contaminants; institutional constraints; and public awareness and stewardship. The Estuary Partnership Board of Directors updated the actions in 2011 to present progress since 1999, add climate change issues, set new targets and streamline actions, resulting in 17 actions that give concise direction for the region. The Management Plan is a long range regional plan, and many actions need to be sustained for years to ensure the long term health of the ecosystem.

in implementation and work to find ways to fill them. In referring to the Estuary Partnership, this guide makes no attempt to separate accomplishments or roles of the Estuary Partnership staff versus those of the regional partners. In general, when referring to the Estuary Partnership, this guide assumes the broader regional partnership.

Acknowledgements

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Section 2, Line of Evidence 1 – Historical Habitat Changes 1870-2010, we would like to thank the following, for their roles:

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Amy Borde, Heida Diefenderfer and Chaeli Judd of the Pacific Northwest National Laboratory, for valuable assistance in interpreting vegetation types and selecting a set of aggregated land cover classes with which to perform the analysis.

Members of the Estuary Partnership Science Work Group, for refinement of the methods and review of the results. In particular, thanks to Jim Brick, Steve Caicco, Bernadette Graham Hudson, Paul Meyers, Tom Murtagh, Kathy Roberts, Dan Roix, Dan Shively, Cindy Studebaker, Ron Thom, and Yvonne Vallette.

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Members of the Estuary Partnership Science Work Group, for refinement of the methods and review and application of the results. In particular, thanks to Alex Uber, Jim Brick, Bernadette Graham Hudson, Regan McNatt, Tom Murtagh, Kathy Roberts, Cindy Studebaker, Ron Thom, Yvonne Vallette and Steve Vigg.

Section 6

Members of the Estuary Partnership Science Work Group. In particular, thanks to Alex Uber, Jim Brick, Bernadette Graham Hudson, Regan McNatt, Tom Murtagh, Cindy Studebaker and Ron Thom.

Executive Summary

Background

The study area of the Lower Columbia River Ecosystem Restoration Program encompasses the study area of the Lower Columbia Estuary Partnership (Estuary Partnership) and includes all tidally influenced areas of the mainstem and tributaries from Bonneville Dam to the plume. The Columbia River historically supported diverse and abundant populations of fish and wildlife and is thought to have been one of the largest historical producers of Pacific salmonids in the world. Additionally, the lower Columbia River is one of the most important areas in the Pacific Flyway providing migrating, overwintering and/or breeding habitats for shorebirds, waterfowl and neotropical bird species. Anthropogenic changes since the 1860s have significantly reduced the quantity and quality of habitat available to fish and wildlife species. Contributing factors include altered timing, magnitude, duration, frequency, and rate of change in river flows; degraded water quality and increased toxic, chemical contaminants; introduction of invasive exotic species and altered food web dynamics. Ecosystem-based restoration of the lower Columbia River and estuary has become a regional priority in order to recover its historic productivity and diversity of fish and wildlife.

In 1995 the Estuary Partnership was established by the governors of Washington and Oregon and the US Environmental Protection Agency (USEPA) when USEPA designated the lower Columbia River 'an estuary of national significance.' The National Estuary Program (NEP) was established by the US Congress in 1987 amendments to the Clean Water Act to create collaborative, locally driven programs to conserve and restore the nation's estuaries. The Estuary Partnership is one of the 28 NEPs, and each NEP facilitates and coordinates a collaborative network of partners to implement the actions and meet the goals within its Comprehensive Conservation and Management Plan (Management Plan). Each NEP relies very heavily on its collaborative network of partners for implementation of the Management Plan.

The lower Columbia River region identified *biological integrity* and *habitat loss and modification* as two significant issues to be addressed through the Estuary Partnership's Management Plan. The vision or goals for these are as follows:

- *Integrated, resilient, and diverse biological communities are restored and maintained in the lower Columbia River and estuary* and

- *Habitat in the lower Columbia River and estuary supports self-sustaining populations of plants, fish, and wildlife*.

These goals overlap well with the Northwest Power Conservation Council's (NPCC) Columbia River Fish and Wildlife Program objectives for the entire Columbia Basin, which include the following, amongst others:

- A Columbia River ecosystem that sustains an abundant, productive, and diverse community of fish and wildlife

- Recovery of the fish and wildlife that are affected by the development and operation of the hydrosystem and are listed under the ESA.

The Estuary Partnership's objectives for these issues are then to restore the lower river's biological integrity and ecosystem structure and function. The Management Plan lists multiple actions to meet these goals and objectives, including the following actions, amongst others:

- Inventory habitat types and attributes in the lower Columbia River and estuary and prioritize those that need protection and conservation; identify habitats and environmentally sensitive lands that should not be altered.

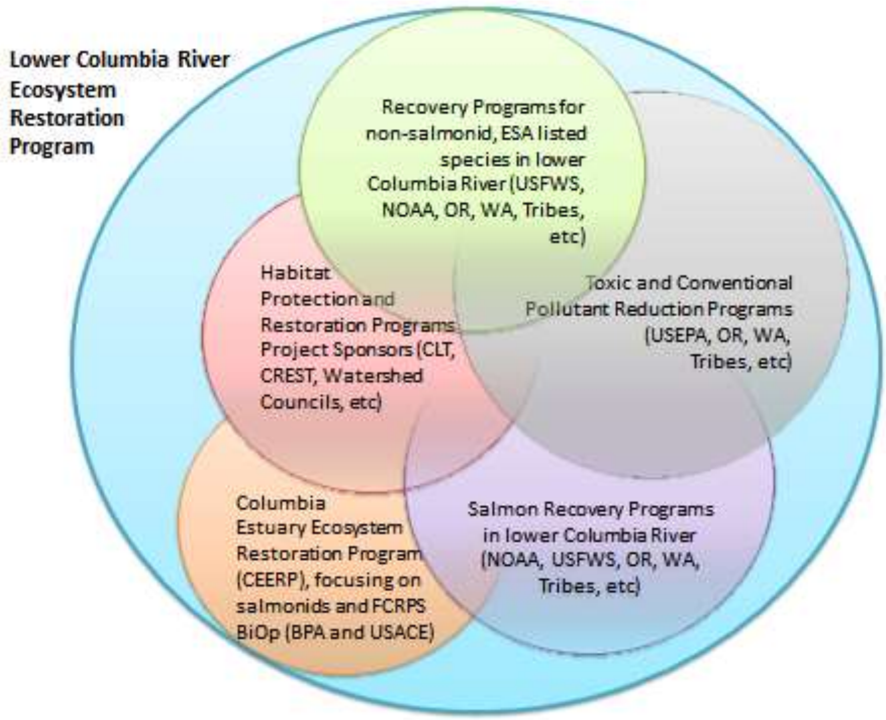
- Protect, conserve, and enhance priority habitats, particularly wetlands, on the mainstem of the lower Columbia River and in the estuary.

- Monitor status and trends of ecosystem conditions.

Included within the Management Plan is the Estuary Partnership's goal of restoring ecosystem structure and function through the protection and restoration of 19,000 acres of habitat by 2014. This goal was adopted by USEPA in their 2009-2014 Strategic Plan. Large scale habitat restoration and protection actions are also included in NOAA, Oregon, and Washington salmonid recovery plans; the Pacific Joint Venture implementation plan for migratory and overwintering birds; the Northwest Power and Conservation Council (NPCC) Sub-basin Plan and the 2008 Federal Columbia River Power System Biological Opinion (2008 BiOp).

Ecosystem-based Restoration of the lower Columbia

Clearly defined goals and objectives are key requirements for all ecosystem-based management approaches. The vision and objectives within the Estuary Partnership's Management Plan addresses this component. The other three components are: 1) well informed stakeholders, 2) delegation of authority and 3) financial resources to sustain implementation and capacity within implementing institutions. These four components are fully integrated within the Lower Columbia River Ecosystem Restoration Program, the umbrella restoration program for the lower river that encompasses the programs described above.



In 2003, the region developed a series of science-based steps to use in an ecosystem-based approach to restoration for the lower Columbia River. The approach calls for seven steps, one of which is focused on salmon recovery. We expand this step to other focal species, and slightly modified several others (*text in italics denote modifications added by authors of this document*):

1. Describe the fundamentals of restoration science and assess disturbance across landscape and at individual site scales…The usefulness of a given restoration technique depends on the level of disturbance at the landscape and local scales.
2. Determine usage of habitats by salmonid life history type, i.e., determine which habitats are most important and why…Ensure adequate habitat needs are met to ensure diversity in life history strategies. *Apply similar prioritization approaches to Columbia White-tailed deer; overwintering, migratory or breeding waterfowl and other focal species.*
3. Determine what habitats have been lost relative to historical conditions... *Prioritize the remaining stands of habitats where large losses have occurred, for future protection.*
4. Identify and prioritize restoration actions…and establish a reasonable future condition, given constraints on the system (e.g., flow regulation). Optimal habitat conditions for a site under present-day conditions may differ from optimal historical conditions.
5. Determine what specific habitats can be restored and where, i.e., develop an inventory of possible actions. Develop an inventory of priority actions at site, landscape scales and ensure project sponsors and funding agencies support and use in funding priorities
6. Implement locally supported and scientifically based restoration projects. *Support capacity of restoration partners to develop scientifically based and collaborative projects that are supported by landowners, local community, funders and relevant agencies.*
7. Monitor actions using standardized protocols and apply the results to adaptively manage future restoration actions. .. A process to coordinate, monitor performance, collect and disseminate data, and adaptively manage multiple projects should be used (Johnson et al. 2003)

The Estuary Partnership and partners have been working towards implementation of the steps outlined in this approach within the Lower Columbia River Ecosystem Restoration Program.

Step 1 was accomplished through the creation of the Estuary Partnership's Restoration Prioritization Framework in 2006 in collaboration with the Pacific Northwest National Laboratory (PNNL) with funding by Bonneville Power Administration (BPA). The Restoration Prioritization Framework is broken into two tiers: Tier 1- disturbance model and Tier 2 – project evaluation. Tier 1 uses existing data for a series of stressors such as diking, toxic contaminants, roads, population, flow restrictions, etc. to model disturbances on individual site and landscape scales (i.e., Step 1). Management areas (HUC 6 watersheds) and individual sites (on average 130 acre parcels) are assigned rankings of "low", "moderate", or "high" disturbance based on results of this model. This evaluation is useful in determining the types of restoration (preservation, conservation, enhancement, restoration or creation) that is appropriate for each location. Tier 2 of the Restoration Prioritization Framework provides a scientific framework for comparing identified projects using predicted changes in ecosystem function, likelihood of success, size of project and cost.

Restoration Prioritization Strategy

The Restoration Prioritization Strategy is the major focus of this Guide, and it is focused on addressing steps 2-4 in Johnson et al. 2003, as modified herein. It uses a "multiple-lines-of-evidence" approach to identify priority areas for habitat protection and restoration. This approach allows the user to make a decision using one or multiple selection factors, each with a set of criteria and predefined thresholds. In this case, the selection factors include the following:

1) natural habitat diversity
2) suitable migratory and rearing habitat for juvenile "ocean-type" Chinook salmonids
3) important rearing habitats for lower Columbia River (LCR) "ocean-type" salmonids
4) potential Columbia White-tailed deer habitat
5) potential overwintering, migratory or breeding waterfowl habitat
6) toxic contaminant cleanup sites or other hot spots and
7) low production agricultural lands.

To define the areas in the lower river that we wish to target in our restoration program, we used the results from the following analyses, respectively:

1) a habitat change analysis, which compares historical land cover conditions (derived from late 1800s topographical survey maps), to current land cover conditions (derived from 2010 remotely sensed imagery),
2) a Habitat Suitability Index Model for juvenile Chinook salmon, which uses model outputs from an Oregon Health and Science University (OHSU) hydrodynamic model to predict times and locations that meet suitable water temperature, depth and velocity criteria (as identified in Bottom et al. 2005) for juvenile salmon and
3) tidally influenced reaches of tributaries designated in Oregon and Washington salmon and steelhead recovery plans as priorities for LCR fall and late fall Chinook and chum populations. Also included here are segments of the mainstem Columbia that are within twenty five kilometers downstream of priority tributaries supporting fall Chinook populations (see NOAA "Tule" Harvest BiOp method in Cooney and Holzer 2011).

Lines of Evidence 4 -7 are incomplete at the time of this version but are expected to be added to the report in winter 2013.

Overlaying the results of these seven analyses will allow managers to identify on a map of the lower river, those critical areas for restoration and protection. Each line of evidence included in the Restoration Prioritization Strategy can be used in combination with the others or be the sole selection factor, depending on the focus and goals of the user. For example, recovery planners in Oregon and Washington may be mainly focused on priority tributaries and mainstem areas for the lower Columbia River salmonid populations (Line of Evidence 3) in combination with historic habitat changes (Line of Evidence 1), while BPA and the US Army Corps of Engineers (USACE) may be interested in historic habitat changes and the availability of juvenile Chinook rearing and migratory habitat (Line of Evidence 2). Furthermore, USFWS managers may wish to identify specific types of riparian habitats that have been lost since the 1870s (Line of Evidence 1) to use in prioritizing overwintering and migratory bird habitats (Line of Evidence 5).

The Restoration Prioritization Strategy is GIS map/inventory of identified critical areas that can be overlain with the results of landscape assessment tools such as the landscape disturbance analyses (Framework's Tier 1) and parcel ownership datasets to identify appropriate techniques and levels of effort needed to restore individual sites or to combine multiple projects to restore larger areas. Additionally, the Restoration Inventory, a geodatabase of identified restoration and protection actions can be overlain on the priority areas to highlight gaps in restoration actions in priority areas. Finally, the Strategy is a GIS-based model that is not static; it was constructed to be easily updated or combined with additional datasets as they become available.

Applying the Restoration Prioritization Strategy to Identify Priority Areas for Protection and Restoration

Results from the multiple lines of evidence were applied to identify priority areas for protection or restoration that will provide the greatest ecological uplift:

- Results from Line of Evidence 1 – Historical Habitat Change 1870 – 2010, demonstrated large losses of tidal herbaceous wetlands, tidal wooded wetlands, forested, herbaceous and other classes since historic conditions. To recover historic habitat diversity, the following habitats were prioritized for protection by river reach:

River Reach	Priority Habitats
A	1. Tidal herbaceous wetland, 2. Tidal wooded wetland
B	1. Tidal wooded wetland, 2. Tidal herbaceous wetland
C	1. Tidal wooded wetland, 2. Tidal herbaceous wetland
D	1. Tidal herbaceous wetland, 2. Tidal wooded wetland, 3. Forested, 4. Herbaceous
E	1. Herbaceous, 2. Forested, 3. Shrub scrub, 4. Tidal herbaceous wetland
F	1. Forested, 2. Herbaceous, 3. Non-tidal herbaceous wetland, 4. Shrub scrub
G	1. Forested, 2. Herbaceous, 3. Tidal herbaceous wetland
H	Non-tidal wooded wetland

  Numeric targets by region will be created in summer 2012 and added to future versions of this document.

- Results of Line of Evidence 2 – Habitat Suitability Index Model, demonstrated spatial and temporal trends in areas or "patches" suitable for juvenile "ocean-type" Chinook salmon. Under all flow conditions, the quantity of suitable habitat patches and size of patches increased moving downstream from Bonneville Dam to the mouth. The opposite trend was seen in the variability of suitable habitat patch size and location as one went upstream. We found river reaches A, B and C as having rather stable suitable habitat patches that remained under different flows and months, while upriver, in reaches F, G and H, the opposite was true. The upriver river reaches are characterized by a high variability in suitable habitat patch location and size. Gaps in habitat generally occurred near armored areas, such as around Swan Island, the city of Portland and near Kelso. These results imply that different restoration techniques are needed in order to restore or protect suitable juvenile salmon habitat for upstream versus downstream areas.

  One result of this analysis is that inundation of habitats, while valuable in assessing habitat opportunity for juvenile salmon, if used alone in assessing the value of habitats will result in higher prioritization for habitats within the lower river reaches. This is because these areas are more stable and less influenced by dam discharge than upstream areas. On the one hand, flow and river stage conditions within the upper reaches will yield less time for access of habitats by juvenile salmon, but on the other, the amount of habitats in this area is greatly minimized and therefore highly valuable. Because of these considerations, we separate out the concept of protecting habitat patches from protecting matrices of patches.

- Results of Line of Evidence 3 – Lower Columbia River Salmonid Recovery Plan Priorities identified the tidal portions of the tributaries Skamakowa Creek; Elochoman River; Mill, Abernathy and Germany Creeks; Lewis (both North and East Forks) and Washougal Rivers in Washington and Clatskanie, Scappoose and Sandy Rivers in Oregon as the highest priority for protection and restoration actions. The tidal tributaries of Chinook, Deep, Wallacut, Grays and Cowlitz Rivers in Washington and the lower gorge tributaries in both states are high priority for protection and restoration, whereas the remaining tributaries are considered medium priority. Immediately at the confluence and up to 25km downstream of the tributaries along the mainstem lower Columbia River are also priority areas for protection and restoration activities.

Finally, the other lines of evidence, priority areas for Columbia white-tailed deer, Pacific Northwest flyway, toxic contaminant hot spots and agricultural areas will be added to this report in future versions as they become available.

Implementation of the Restoration Prioritization Strategy

Integral to the Lower Columbia River Ecosystem Restoration Program is on-the-ground restoration and protection activities. A "typical" restoration project includes multiple phases: 1) landowner outreach to identify potential projects, including parcel acquisition (fee or less than fee simple); 2) baseline data collection (usually assessing topography, hydraulics and hydrology, water temperature and other site characteristics); 3) feasibility and alternatives analysis; 4) design; 5) permitting, often requiring additional data collection (e.g., listed species presence/absence, wetland delineation); 6) contracting and construction; 7) post construction action effectiveness monitoring; 8) reporting and 9) long term operation and maintenance. Predictive modeling to determine project alternatives and feasibility (phase 3), inform engineering designs and permits (phases 4 and 5) and evaluate project success (phase 7), requires additional data (water stage, tributary discharge, topography, bathymetry) and resources such as the specific technical expertise to develop, run and interpret model results. Each of these phases requires staffing, time, and technical and financial resources from the project sponsor. Additionally, to incorporate best available science and fill gaps in restoration actions, project sponsors require opportunities to learn from lessons gained by other restoration practitioners, incorporate latest findings from scientific studies contributing to the understanding of the lower river, and collaborate on individual projects. At the same time, funding entities like NPCC/BPA, US Fish and Wildlife Service, Oregon Watershed Enhancement Board and Lower Columbia Fish Recovery Board want to ensure they are funding technically sound and strategically placed projects.

The Lower Columbia River Ecosystem Restoration Program includes six major components that are designed to address the needs of natural resource protection program managers, project funders as well as restoration practitioners:

1) a restoration prioritization strategy that identifies priority areas for protection and restoration;
2) a technical assistance program that provides capacity and support for restoration partners' efforts in working with landowners to identify, develop, manage and monitor landscape scale or complex projects;
3) a scientific review and competitive bid process to evaluate and prioritize individual restoration projects;
4) a restoration inventory database that tracks identified actions and their status in a GIS-based system;
5) outreach and coordination efforts designed to ensure communication and coordination amongst partners, integration of restoration and protection priorities within regulatory and planning activities of agencies, use of best available science throughout the lower river, and identification of issues and gaps; and
6) an adaptive management framework that includes
    a) an ecosystem monitoring program to track trends in the overall condition of the lower river, provide a suite of reference sites for use as end points in our restoration actions and place results of our findings into the context with the larger ecosystem;
    b) an action effectiveness monitoring program that tracks whether restoration actions are meeting partners' goals or whether future actions are necessary, identifies which actions are working best and informs how we can improve efficacy of our actions;
    c) critical uncertainties research designed to address specific questions (e.g., contribution of salmon use of estuarine habitats to adult returns) and
    d) implementation monitoring.

Funding assistance for Phase 1, landowner outreach, and parts of Phase 6, extensive action effectiveness monitoring, is not addressed specifically through this Program, although these phases are inherently key for Program implementation. At this time, funding issues are partly addressed for intertidal reconnection or passage improvement actions benefiting juvenile salmon, through direct contracts with the NPCC/BPA and a subset of project sponsors (e.g., the Estuary Partnership, CREST, CLT, Cowlitz Indian Tribe and WADFW). At the time of writing this report, we did not have a more holistic resolution to resource capacity issues of sponsors or funding agencies outside this focused area.

Finally, the Estuary Partnership strongly believes that for ecosystem restoration and species recovery actions to be successful, it is imperative that the region address toxic contaminants, by knowing and reducing sources of historic, current and emerging chemicals, understanding their pathways and encouraging safer alternatives (i.e., green chemistry) *within our restoration, species recovery and RME activities*.

The next steps for the Lower Columbia River Ecosystem Restoration Program are to integrate the identified priority areas into existing regulatory and resource management frameworks. This will include efforts by the Estuary Partnership to engage state, tribal, federal and local government agencies to adopt the target priority areas within this guide as funding priorities and within land use planning and zoning practices. This will allow implementers security over the long term to use limited resources to pursue these sites, working with landowners and agencies to develop mutually beneficial activities. The tools within this guide will also resource management agencies to assess the habitat value of specific areas and coordinate recovery and management actions for multiple species simultaneously.

Acronyms and Abbreviations

AEM	action effectiveness monitoring
AEMR	action effectiveness monitoring and research
AER	action effectiveness research
AFEP	Anadromous Fish Evaluation Program
BiOp	Biological Opinion
BPA	Bonneville Power Administration
CEERP	Columbia Estuary Ecosystem Restoration Program
CLT	Columbia Land Trust
CREEC	Columbia River Estuary Ecosystem Classification
CREST	Columbia River Estuary Study Taskforce
CUR	critical uncertainties research
CWTD	Columbian white-tailed deer
Estuary Partnership	Lower Columbia Estuary Partnership (formerly LCREP/ Lower Columbia River Estuary Partnership)
ERTG	Expert Regional Technical Group
ESA	Endangered Species Act
ESU	evolutionarily significant unit
FCRPS	Federal Columbia River Power System
GIS	Geographic Information Systems
ICM	implementation and compliance monitoring
ISAB	Independent Scientific Advisory Board
ISRP	Independent Scientific Review Panel
LCFRB	Lower Columbia Fish Recovery Board
LCRE	lower Columbia River and estuary
LWG	Portland Harbor Lower Willamette Group
NANOOS	Northwest Association of Networked Ocean Observation Systems
NAWCA	North American Wetlands Conservation Act
NEP	National Estuary Program
NFWF	National Fish and Wildlife Foundation
NOAA	National Oceanic and Atmospheric Administration
NPCC	Northwest Power and Conservation Council
NMFS	NOAA National Marine Fisheries Service
NWFSC	NOAA Northwest Fisheries Science Center
NWR	National Wildlife Refuge

PCJV	Pacific Coast Joint Venture
PNAMP	Pacific Northwest Aquatic Monitoring Partnership
ODEQ	Oregon Department of Environmental Quality
ODFW	Oregon Department of Fish and Wildlife
OHSU	Oregon Health Sciences University
OSU	Oregon State University
OWEB	Oregon Watershed Enhancement Board
PNNL	Pacific Northwest National Laboratory
PSU	Portland State University
RM	river mile
RME	research, monitoring, and evaluation
RPA	Reasonable and Prudent Alternative
SBU	survival benefit unit
STM	status and trends monitoring
SWG	Science Work Group
USACE	U.S. Army Corps of Engineers
USEPA	U.S. Environmental Protection Agency
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
UW	University of Washington
WDFW	Washington Department of Fish and Wildlife
WDOE	Washington Department of Ecology

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1. Introduction and Background

Summary

The study area of the Lower Columbia River Ecosystem Restoration Program encompasses the study area of the Lower Columbia Estuary Partnership and includes all tidally influenced areas of the mainstem and tributaries from Bonneville Dam to the plume. The lower Columbia River historically supported diverse and abundant populations of fish and wildlife. The lower Columbia River is one of the most important areas in the Pacific Flyway providing migrating, overwintering and/or breeding habitats for shorebirds, waterfowl and neotropical bird species, and the Columbia Basin is thought to have been one of the largest producers of Pacific salmonids in the world. Anthropogenic changes since the 1880s have significantly reduced the quantity and quality of habitat available to fish and wildlife species; altered timing, magnitude, duration, frequency, and rate of change in river flows; degraded water quality and increased toxic, chemical contaminants; introduced invasive exotic species and altered food web dynamics. Ecosystem-based restoration of the lower Columbia River and estuary has become a regional priority.

Ecosystem-based Management requires four components: unambiguous goals, well informed stakeholders, delegation of authority and financial resources to sustain implementation and capacity within implementing institutions. This document describes the Lower Columbia River Ecosystem Restoration Program, which focuses on restoration of ecosystem structure and function and fish and wildlife species recovery. These four components are fully integrated within the Program and have been weaved into the description within this document. Section 1 provides background information for the Program, the vision/goals for the Program, an approach for achieving the vision/goals, previous accomplishments in addressing steps within the approach and a description of the remainder of this document.

Background

Description of Program Area

The geographic scope of the Lower Columbia River Ecosystem Restoration Program study area includes the mainstem from Bonneville Dam (River Mile [RM] 146) to the mouth of the Columbia River and tidally influenced portions of the tributaries below Bonneville Dam (**Error! Reference source not found.**). The study area includes the lower portion of the Willamette River up to Willamette Falls (RM 26.6), and tidal influence is defined as historic tidal, relative to post dam construction in the 1930s.

Figure 1. Study area for the Lower Columbia River Estuary Restoration Program.

Estuaries are semi-enclosed embayments where freshwater transitions to salt water. Estuarine environments are among the most productive on earth, creating more organic matter each year than comparably-sized areas of forest, grassland or agricultural land. The tidal, sheltered waters of estuaries also support unique communities of plants and animals especially adapted for life in these transition areas; thousands of species of birds, mammals, fish and other wildlife depend on estuarine habitats at some point in their lives, including most commercially-important species of fish.

The lower Columbia River is a drowned river estuary, formed by the river valley flooding during sea level rise after the last ice age, and differs from the fjord-type estuaries formed through glaciation (e.g., Puget Sound), lagoonal estuaries resulting from flat topography and low freshwater inflows (e.g., Humboldt Bay) or rare, bar-built (Tillamook Bay) estuaries found along the Pacific coast (Emmett et al. 2000). The area has a Mediterranean climate (i.e., wet, cool winters and warm, dry summers) whereby most precipitation falls from October thru May and June thru September months are dry. Mountain and glacier snow melt from interior B.C. and U.S. cause high freshwater inflows to the estuary in May and June and moderately high flows can also occur between November and March, caused by heavy winter precipitation. Much of the local geomorphology results from the North American Plate moving north-northwest against Juan De Fuca and other Plates, producing a subduction zone and the rugged topography including the Olympic, Coast Range, Klamath and volcanically active Cascade Mountains (Emmett et al. 2000). This rugged topography then creates the orographic precipitation patterns of a relatively wet coastal region and dry, desert conditions east of the mountain ranges. Finally, the California Current is a slow moving southerly current off the Pacific coast that is most dominant in summer when northwest winds are typical, whereas in winter, southwesterly winds cause an inshore counter-current to develop. The summer ocean upwelling carries cool, deep, nutrient-rich water to the surface, and with the addition of sunlight, these nutrient-rich waters stimulate growth of phytoplankton populations (primarily diatoms). Tidal exchange transports the associated flora and fauna into the lower Columbia River where organisms such as Dungeness crab and salmonids take advantage of these conditions. For example, Dungeness crab spawn in the winter, larvae are retained nearshore, and juveniles move into the estuary to mature. Many salmonid stocks spawn in the tributaries during fall or winter, and juveniles migrate to sea in spring/summer just before or during the productive upwelling period (Emmett et al. 2000).

Importance of Lower Columbia River as a National Resource

The lower Columbia River is designated an "estuary of national significance" by the US Environmental Protection Agency (USEPA), making it one of 28 National Estuary Programs (NEPs) under Section 320 of the Clean Water Act. USEPA has also designated it as one of ten "Large Aquatic Ecosystems". The lower river is one of the most important areas within the Pacific Flyway for migrating shorebirds and neotropical bird species, and it provides key wintering waterfowl habitat (PCJV 1994). Additionally, the Columbia Basin is thought to have been one of the largest producers of Pacific salmonids in the world. Finally, the upper portion of the lower river is included within the Columbia River Gorge National Scenic Area.

The lower Columbia River historically supported diverse and abundant populations of fish and wildlife because of its moderate climate, abundant food resources, ample water and diverse array of habitats. Most of the streams support anadromous fish, more than 250 species of birds use the area on a regular basis and a variety of mammals including elk, bear, black-tailed deer, beaver, river otter, mink, raccoon and coyote are common (PCJV 1994).

The lower Columbia River is one of the most important areas in the Pacific Flyway for migrating shorebirds, with peak counts in the estuary of almost 150,000 birds and substantial numbers using other areas along the river up to Sauvie Island and the Willamette Valley (PCJV1994). Wintering waterfowl populations in the lower Columbia area reach peaks of more than 200,000 birds; the most abundant species are mallard, northern shoveler, American wigeon, green-winged teal, canvasbacks, lesser scaup, and northern pintail ducks; the dusky, cackler, western, Vancouver, lesser, and Taverner's subspecies of Canada geese; and tundra and trumpeter swans (PCJV 1994). The area is particularly important for the dusky Canada goose, a large, dark-breasted subspecies that winters only along the lower Columbia, in the Willamette Valley, and at a few locations on the Oregon coast (PCJV 1994). Lowland areas are heavily used as resting and staging areas for migratory waterfowl and shorebirds of the Pacific Flyway. Finally, the lower Columbia River area also provides important migratory and breeding habitat for a variety of other neotropical migrant bird species. One survey of a bottomland forest during peak migration recorded some of the highest concentrations of neotropical migrants ever reported.

The Columbia River Basin is thought to have been the largest historic producer of Chinook salmon (*Oncorhynchus tshawytscha*) and steelhead (*O. mykiss*) in the world (Netboy 1980). Researchers estimate that 8 to 16 million wild Pacific salmon migrated up the Columbia

River System each year to spawn in the mid 1870s (Netboy 1980; Cone 1995). In comparison, total current returns of wild fish number less than 1 million annually. All anadromous salmon and steelhead populations within the Columbia River Basin utilize the estuary as a critical migration corridor. The estuary is thought to offer three advantages to juvenile salmon in their transition from freshwater to saltwater environments: 1) a productive feeding area capable of sustaining increased growth rates; 2) a temporary refuge from marine predators; and 3) a physiological transition zone where fish can gradually acclimate to saltwater (Simenstad et al. 1982; Thorpe 1994). Additionally, recent research has well documented that Chinook salmon, especially subyearlings, and other salmon such as chum (*O. keta*) and lower Columbia coho (*O. kisutch*), to a lesser degree, can rear extensively in shallow water and vegetated habitats within the estuary, including tidal channels, tributary confluence and nearshore areas (e.g., Bottom et al. 2005; Fresh et al. 2005; Good et al. 2005; Fresh et al. 2006; Bottom et al. 2007; Roegner et al. 2008; Casillas 2009). In 2012, research under the Estuary Partnership's Ecosystem Monitoring Program documented upriver sockeye (*O. nerka*) use of a backwater slough system for 12 days (Sagar et al. 2012). Subyearling migrants that enter the estuary as fry or fingerlings, or "ocean-type" salmon, exhibit a wide range of residence periods depending on the species, from days to weeks (chum) to several months (Chinook) (Thorpe 1994). Juvenile salmon may occur in the estuary all year, as different species, size classes, and life history types continually move downstream and enter tidal waters from multiple upstream sources (Bottom et al. 2005). Peak estuarine migration periods vary among and within species, suggesting that different life history strategies may provide a mechanism for partitioning limited estuarine habitats (Myers and Horton 1982 as cited in Bottom et al. 2005). In the Columbia River estuary, subyearling Chinook salmon are most abundant from May through September but are present all year (Rich 1920 and McCabe et al. 1986 as cited in Bottom et al. 2005). The recent USACE Synthesis Memo (Thom et al. 2012) provides a great synopsis of current salmonid migratory and habitat use patterns:

1. Six species of salmonids use shallow-water and wetland habitats within the lower river, including peripheral bays and backwater sloughs: Chinook salmon, coho salmon (*O. kisutch*), chum salmon (*O. keta*), sockeye salmon (*O. nerka*), steelhead and coastal cutthroat trout (*O. clarkii*) with Chinook, chum and coho found in higher abundances.
2. The various (ESUs) display variations in juvenile life history characteristics, including in the timing and pathways of their migrations.
3. Chinook and coho salmon exhibit yearling and subyearling life-history types, while chum are primarily captured as fry migrants.
4. Yearling Chinook and coho salmon and steelhead primarily use main channel migratory pathways during spring (as cited in Thom et al. 2012: Dawley et al. 1986; Magie et al. 2008; Weitkamp et al. 2012), and larger smolted subyearling Chinook salmon also tend to migrate rapidly through the lower river (as cited in Thom et al. 2012: Dawley et al. 1986; Harnish et al. 2012). However, a portion of these larger fish are also found in shallow-water habitats (as cited in Thom et al. 2012: Poirier et al. 2009a, b; Bottom et al. 2011; Sather et al. 2011; Roegner et al. 2012).
5. Smaller subyearling Chinook and chum salmon make substantial use of shallow tidal habitats, and subyearling coho are often abundant in the lower sections of

tributaries (as cited in Thom et al. 2012: Poirier et al. 2009a, b; Roegner et al. 2010; Sagar et al. 2011; Sagar et al. 2012a, b).

Historical Changes to the Lower Columbia River

Since the 1880s, anthropogenic impacts to the lower river include diking and conversion of habitat for agriculture, industry and urban development. Several studies (Thomas 1983; Allen 1999; Garano 2003; Estuary Partnership 2012) noted losses of approximately 70% of vegetated tidal wetlands and 55% of forested uplands for the project area since this era. Other important anthropogenic impacts to the Basin include the construction of >30 dams and dozens of smaller flow control structures on the mainstem and tributaries for hydropower, flood control, irrigation and transportation. Freshwater from above Bonneville is also diverted to irrigate arid lands in eastern Washington and Oregon for large-scale agricultural production. Water management through dams and maintenance of the navigation channel through dredging and pile dike construction allow deep-water ports to exist as far inland as Lewiston, Idaho.

River flow, a primary factor affecting habitat and food web patterns in the estuary and plume, has been significantly modified by operations of this hydropower system. Changes include a reduction in the mean annual flow, reduced magnitude of spring freshets, an almost complete elimination of overbank flows, and altered timing of ecologically important flow events as well as habitat forming processes (Bottom et al. 2005a; Fresh et al. 2005). These hydrological changes, along with floodplain diking, conversion of habitats and navigation channel maintenance, represent a fundamental shift in the physical state of the lower Columbia River ecosystem, and have resulted not only in a loss of vegetated and shallow water habitats but also a change in the size, seasonality, and behavior of the river plume (Bottom et al. 2005a; Fresh et al. 2005). Kukulka and Jay (2003) suggested that the annual Columbia River flow cycle has been dampened and spring freshet flows has been reduced by >40% due to flow regulation by the hydropower system, water withdrawal for agriculture and climate change, and that during the spring freshet, floodplain diking and flow alteration together reduced average shallow water habitat within their study area (rkm-50 to rkm-90) by 62%. They hypothesized that taken individually, floodplain diking has reduced average shallow water habitat coverage during the spring freshet by 52% and flow alterations by 29% (Kukulka and Jay 2003).

The historic spring freshet aided in juvenile salmon migrations and transported large quantities of sediments, nutrients, cold water and associated organic matter downstream (Naiman et al. 2012). Large scale floodplain diking has severed the historic connection of habitat with the river, eliminating any direct use ("habitat opportunity") and reducing indirect (e.g., export of organic matter for food webs) benefits to aquatic species, which over time acclimated to the historic conditions (Fresh et al. 2005). Low velocity, peripheral bay habitats and the mid-estuary estuarine turbidity maximum are locations in the lower river where organic matter is concentrated and where invertebrate prey production and fish and macroinvertebrate feeding are higher than many other locations (Bottom and Jones 1990; Jones et al. 1990; Simenstad et al. 1990). Researchers hypothesize that the loss of these historic wetlands and macro-algal habitats (e.g., mud and sand flats) within the estuary may have shifted the estuarine food chains from macrodetrital to microdetrital sources (Sherwood et al. 1990). Such a shift would likely benefit food chains supporting pelagic-feeding fishes such as American shad (*Alosa sapidissima*) with corresponding loss of food webs supporting epibenthic-feeding fishes such as juvenile salmon (Bottom et al. 2005a).

Introduction and wide-spread expansion of non-native, invasive species such as the noxious reed canary grass (*Phalaris arundinacea*) or American shad results in altered food webs and increased competition for limited resources by native plant, fish and wildlife species. Similar problems result from wide-spread Columbia Basin hatchery releases. Approximately 130-150 million hatchery salmonids are added to the river annually, significantly impacting the capacity of the lower river to sustain both these artificially produced as well as native fishes over time (Naiman et al. 2012).

Additionally, toxic contaminants from industry, agriculture and urban development have been introduced throughout the Basin, and these contaminants have been well documented to pose a threat to fish and wildlife species. Exposure to waterborne and sediment-associated chemical contaminants has the potential to affect survival and productivity of all anadromous fish species as well as predator species that prey upon them in the lower river (Fresh et al. 2005; Estuary Partnership 2007; Johnson et al. 2007). While improving since the 1990s, USFWS researchers are still finding lower nesting success in bald eagles in the lower Columbia River than elsewhere in Washington and Oregon, a result of DDT/DDE, PCBs and dioxins in this region (cited in NPCC 2004; Estuary Partnership 2010). Also, USGS has consistently found DDE and other chemical contaminants (cited in NPCC 2004) in osprey and their food web along the mainstem lower Columbia. The type and extent of exposure may vary with timing and length of use. For those organisms that move through the estuary quickly, short-term exposure to waterborne contaminants such as current use pesticides and dissolved metals may be the greatest threat, as these chemicals can disrupt olfactory function and interfere with behavior such as capturing prey, avoiding predators, imprinting, and homing (for stream-type ESUs) (Fresh et al. 2005). Organisms that use the estuary more extensively (e.g., ocean-type salmonids) are exposed to these types of contaminants as well as persistent, bioaccumulative toxicants such as polychlorinated biphenyls (PCBs), polybrominated diphenyl ethers (PBDEs), and DDTs that they may absorb through feeding and rearing (in the case of ocean-type salmonids) in the estuary (Fresh et al. 2005; Estuary Partnership 2007; Johnson et al. 2007; Sloan et al. 2010). Chronic exposure to and accumulation of these chemicals in tissues can lead to effects such as reduced growth, immune dysfunction, and metabolic disorders that may lessen their chance of survival (for salmonids, see Arkoosh et al. 2001; Arkoosh and Collier 2002; Meador et al. 2002; Arkoosh et al. 2010).

Additionally, chemical habitat quality can have a significant impact on survival and recovery of endangered salmon stocks and those chemical contaminants can contribute to salmon mortality, prey base reduction and sublethal health effects. Multiple studies, including the Estuary Partnership's Ecosystem Monitoring (Estuary Partnership 2007; project #2003-007-00), suggest salmon are exposed to toxic contaminants in the lower Columbia River and are experiencing sublethal health effects from this exposure (e.g., Johnson et al. 2005; Johnson et al. 2007). Substantial proportions of specimens caught in the lower river have exposure levels to one or more contaminants, such as organic contaminants, polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), dichlorodiphenyltrichloroethanes (DDTs) and polybrominated diphenyl ethers (PBDEs), exceeding values thought to cause health risks (Estuary Partnership

2007; Johnson et al. 2007, 2012; Sloan et al. 2010; Yanagida et al. 2012). Concentrations of PAH metabolites were above estimated effect thresholds (Meador et al. 2008) in over 40% of juvenile Chinook salmon bile samples from the lower Columbia River (Yanagida et al. 2012). Moreover, ~50% of subyearling fall Chinook samples from tidal freshwater sites (Johnson et al. 2012) and ~66% of Chinook smolts from the lower estuary (Johnson et al. 2007) had PCB concentrations exceeding the 2400 ng/g lipid threshold estimated by Meador et al. (2002). Maximum concentrations of PCBs, DDTs, and PBDEs in juvenile salmon from the lower Columbia were all within the upper range of juvenile salmon sampled in the Pacific Northwest, and the condition and lipid content of a number of these fish, especially smolts, was also reduced. Body lipid content can influence an organisms' tolerance of bioaccumulative contaminants, with individuals with lower lipid content typically showing a greater toxic response to comparable exposure (Lassiter and Hallam 1990). Consequently, Johnson et al. (2007, 2012) and Arkoosh et al. (2010) suspect the decline in lipid content described above could increase the sensitivity of fish to the effects of bioaccumulative contaminants, such as PCBs, DDTs and PBDEs. The health of juvenile salmon may also be affected by exposure to other classes of contaminants present in the lower Columbia River, including pharmaceuticals and personal care products in wastewater (Estuary Partnership 2007; Morace et al. 2012); current use pesticides (NMFS 2008) and toxic metals such as copper (Hecht et al. 2007).

Finally, warming water temperatures and changing precipitation patterns resulting from climate change are expected to have a deleterious impact on Pacific salmonid populations throughout the Columbia Basin, including approximately 40% salmon habitat loss in Oregon and Idaho and 22% loss in Washington by 2090 (ISAB 2007). Several studies predict sea level rise within the lowest downstream areas of the river, inundating present floodplain wetland habitats and causing coastal migration inland (NWF 2007; Duck Unlimited *In Review*). There are additional concerns regarding climate changes specific to the estuary and plume regions. Low oxygen conditions that occur deep in the continental shelves of Oregon and Washington during sustained periods of coastal upwelling are increasing. When combined with low river discharges, those conditions may also lead to oxygen depletion in the Columbia River estuary (Roegner et al. 2011). Upwelled waters have a direct impact on the Columbia River estuary through tidal exchange and entrainment by estuarine circulation. Implications of these low oxygen conditions are significant as these hypoxic episodes may lead to displacement or death by suffocation of marine organisms. Recent research has also documented increased acidification in upwelling waters along the coast of the Pacific Northwest (Feely et al. 2008) and decreasing pH levels in the Columbia River estuary at Beaver Army Terminal (J. Morace, pers. comm. USGS). The low dissolved oxygen levels, increasing acidification and increasing water temperatures that accompany climate change have the potential to alter fish behavior and survival (Roegner at al. 2011) and have significant deleterious impacts on the estuarine food web (Feely et al. 2008).

Role of the Estuary in Salmon Recovery

NMFS uses 4 viable salmonid population (VSP) performance criteria to define the viability status of salmonids: abundance, productivity, spatial structure, and diversity; all 4 of these VSP criteria are critical to salmon recovery and are interrelated (Fresh et al. 2005). NMFS recommends that the lower Columbia River contributes to the viability and persistence of all anadromous salmonid populations within the Columbia River Basin in the following ways: 1) the amount of estuarine habitat that is accessible affects the abundance and productivity of a population; 2) the distribution, connectivity, number, sizes, and shapes of estuarine habitats affect both the life history diversity and the spatial structure of a population; and 3) attributes of estuarine habitats (e.g., temperature and salinity regimes, food web interactions) affect diversity and productivity of populations (Fresh et al. 2005). Diverse habitats and the expression of life history strategies based on use of these habitats are directly linked to salmon population viability (i.e., persistence) over long time scales (McElhany et al. 2000). The Independent Scientific Review Panel (ISRP) for the Northwest Power Conservation Council (NPCC) concluded that estuary and ocean dynamics help control salmon productivity (Beamish and Bouillon 1993; Beamish et al. 1999) and salmon biodiversity (including the diversity of life history strategies) helps reduce impacts from changing ocean and other conditions (ISG 2000). Hence, changes to the estuarine ecosystem such as degradation and loss of estuarine habitat, can directly alter salmonid population viability.

Because of the importance of the lower Columbia River within salmonid life cycles, protection and restoration of important salmonid habitats within it has been identified as a priority for salmon recovery. In addition, in life stage risk and sensitivity modeling, Kareiva et al. (2000) and McClure et al. (2003) found that to recover salmonid populations in the Columbia River Basin additional actions above and beyond passage improvements at the Federal Hydropower System dams were needed and that the life stages for rearing in the river, estuary and ocean were sensitive to disturbances (cited in Fresh et al. 2005). Kareiva et al. (2000) concluded that the maximum potential to contribute to anadromous salmonid recovery was associated with these life stages but could not discriminate between these life stages nor determine how much of a change in survival was possible (Fresh et al. 2005). The questions of how much restoration will be necessary, which locations are most beneficial for individual life history strategies and the contribution of individual or cumulative restoration actions within the estuary to salmon adult returns still exist.

In developing ecological assessment criteria to identify and evaluate salmon habitat restoration actions, Simenstad and Cordell (2000) advocated the use of measures directly relatable to the ecological and physiological responses of juvenile salmonids to restored habitats. Three criteria suggested by Simenstad and Cordell (2000) are now routinely used within the lower Columbia to plan and assess restoration actions for improving juvenile salmon habitat: 1) “opportunity”, 2) “capacity” and 3) “realized function”. These are function-based, rather than structure-based, criteria to accommodate the highly dynamic and evolutionary nature of estuarine habitats and the relatively episodic occurrence of salmonids within them (Simenstad and Cordell 2000). Structure-based endpoints depend on reference sites, arguably difficult to find and subject to evolution and disturbance, and do not account for the changing role that habitats may provide salmonids through different successional stages. The authors defined habitat opportunity as the capability of juvenile salmon to access and benefit from occupying a habitat (Table 1 lists factors encompassing habitat opportunity). The capacity criteria is an extension of the ecological concept of carrying capacity and is defined as those habitat qualities that promote juvenile salmon production, including characteristics promoting feeding, growth, growth efficiency and eluding predators. These include, amongst others:

- productivity of preferred invertebrate prey
- ecological conditions that maintain quality and availability of preferred prey
- salinities and temperatures that promote high assimilation efficiencies

- low predation and competition levels.

Realized function includes those physiological or behavioral responses within salmonids attributable to occupation of the habitat that promote fitness and survival. These include survival, habitat-specific residence time, foraging success and growth. An overarching regional goal then is to ensure adequate coverage of diverse habitats with these qualities throughout the lower river to aid in the recovery of juvenile salmonid natural life history diversities.

Table 1. Factors affecting estuarine-habitat opportunity for juvenile salmon (from Bottom et al. 2005a)

Physical	Physiological/ behavioral	Water characteristics and quality	Ecological
Tidal flooding Depth Duration Fluvial flooding Frequency Depth Duration Timing Distributary and tidal channel structure	Water velocity Turbidity	Temperature Salinity Dissolved oxygen Turbidity Toxic contaminants	Proximity to disturbance (e.g., noise, movement, etc.) Refugia from predation (e.g., extent of overhanging vegetation, marsh vegetation height, proximity to deep water habitats)

These three criteria were integrated into two key subsequent assessments of the lower Columbia and its role in salmon recovery (i.e., Bottom et al. 2005a; Fresh et al. 2005). In turn, NMFS relied heavily on these efforts when it developed the *Columbia River Estuary ESA Recovery Plan Module for Salmon and Steelhead* (Estuary Recovery Plan Module) (NMFS 2011b). The Estuary Recovery Plan Module lists the following as limiting factors for juvenile salmon performance within the lower Columbia River:

1. **Habitat-Related Limiting Factors**
    - Reduced in-channel habitat opportunity
        - Flow-related estuary habitat changes
        - Sediment/nutrient-related estuary habitat changes
    - Reduced off-channel habitat opportunity
        - Flow-related changes in access to off-channel habitat
        - Bankfull elevation changes
    - Reduced plume habitat opportunity
        - Flow-related plume changes
        - Sediment/nutrient-related plume changes
    - Water temperature
    - Stranding
2. **Food Web-Related Limiting Factors**
    - Food Source Changes
        - Reduced macrodetrital inputs

- Increased microdetrital inputs
- Competition and Predation
  - Native fish
  - Native birds
  - Native pinnipeds
  - Exotic fish
  - Introduced invertebrates
  - Exotic plants

3. **Toxic Contaminants**
   - Bioaccumulation toxicity
   - Non-bioaccumulative toxicity

Within the Recovery Module, NMFS then linked the limiting factors to 23 specific management actions recommended for implementation in order to meet salmon recovery throughout the Basin (see NMFS 2011b, Section 5).

Habitat Restoration as Regional Goal
As a result of changes described above, thirty two species of fish and wildlife residing in the lower Columbia River study area have been listed as threatened or endangered under the Endangered Species Act (ESA) as of the year 2010. Protection and restoration of those habitats identified as critical for those species is key for protecting and recovering remaining populations.

In the lower Columbia River, ecosystem restoration has become a regional priority in the last decade or so. The Estuary Partnership set a goal of restoring ecosystem structure and function through the protection and restoration of 19,000 acres of habitat by 2014 and 25,000 acres by 2025. This goal was adopted by USEPA in their 2009-2014 Strategic Plan. Large scale habitat restoration and protection actions are included in NOAA, Oregon, and Washington salmonid recovery plans; the Pacific Coast Joint Venture (PCJV) implementation plan for migratory, nesting and overwintering birds; the Northwest Power and Conservation Council (NPCC) Sub-basin Plan and the 2008/2010 Federal Columbia River Power System Biological Opinion (2008 BiOp).

Between1999 -2012 regional partners have protected and/or restored at least 18,433 acres of habitat. Despite this incredible amount of work and investment in ecosystem restoration, much still remains to be accomplished. The focus of efforts in the past has largely been opportunistic restoration and protection activities with an emphasis on a limited set of focal species (e.g., waterfowl, Pacific salmonids). The next phase of restoration in the lower river requires resource managers to review what has been accomplished on an ecosystem and landscape scale, assess benefits on a cumulative basis, identify gaps and strategically plan restoration activities to allow for more integrated multi-species protection and recovery over the long term. This next phase will demand a more focused, scientifically-based, regional habitat restoration strategy and increased regional collaboration and communication. This report describes the ecosystem-based restoration strategy developed by the broader Estuary Partnership with the support of state and federal partnering agencies. The next steps of ensuring regional implementation of this strategy are to incorporate key components of the strategy into funding entities' (e.g., LCFRB, OWEB, NOAA, USFWS) priorities, and to coordinate with partners to ensure the region is developing projects in key spatial locations identified within the strategy.

Ecosystem Based Restoration for the lower Columbia River

Ecosystem-based management is a place-based approach to natural resource management that aims to restore and protect the health, function and resilience of entire ecosystems for the benefit of all organisms. It includes a comprehensive and integrated approach that recognizes humans as part of and having significant influences on their environments. This represents a shift from conventional management strategies that are often jurisdictional and consider humans to be independent of nature (from Seaweb 2012).

Ecosystem-based management includes the following attributes: it is place based, it is focused on sustaining valued ecosystem services by protecting ecosystem structure and function, it recognizes internal and external linkages of the whole system and specifically considers economic, social and institutional aspects of the system. The United Nations Environmental Program (UNEP) recommends four conditions *essential* for effective ecosystem-based management, including:

1. unambiguous goals
2. well informed stakeholders
3. delegation of authority and financial resources to sustain implementation and
4. capacity within implementing institutions (UNEP 2006).

To create these four conditions UNEP recommends the following essential elements for implementing Ecosystem-based management:

- **holistic vision/plan** - comprehensive description of system, articulation of multiple management objectives
- **community** - effective engagement of policy makers, managers, stakeholders, scientists
- **foundation** - legal framework, management institutions, financial resources, effective communications
- **process** - effective adaptive management (UNEP 2006)

Inherent within this framework is an explicit governance and/or organizational support structure to encourage progress, track compliance/implementation, resolve disputes, provide coordination and ensure adaptive management.

The National Estuary Program (NEP) was established by USEPA to provide this coordination and support structure for estuaries designated of national importance. Each NEP is required to work with regional stakeholders, such as local, state, tribal and federal governments, industry, citizens, non-profit organizations and academia, to 1) identify issues facing that estuary, 2) to determine goals and quantifiable objectives to address the issue, 3) create a Comprehensive Conservation and Management Plan (CCMP) outlining these as well as specific steps to reach the goals and objectives, 4) develop a long-term monitoring plan to track progress and ecosystem condition, 5) develop a long-term financial strategy to support actions within the CCMP and 6) maintain a “management conference” of stakeholders. This last item is a key facet of NEPs that allows each NEP to facilitate partners’ CCMP implementation, to ensure communication and coordination across partners as well as track progress and identify gaps and emerging issues. The management conference of the NEP then works together to fill identified gaps and integrate emerging issues and “lessons learned” with CCMP implementation into future actions.

For three years beginning in 1995, Estuary Partnership staff facilitated a management conference that included a Policy (9 representatives) and a Management Committee (31 representatives) to set policy and provide overall direction in the development of the CCMP. Multiple work groups were also established to develop the CCMP, including:

- Finance
- Science and technology
- Public involvement
- Action now
- Local government

Participants on the committees and work group included representatives from government agencies, environmental groups, agriculture, commercial fishing, industry (e.g., timber and paper), ports, recreation, and citizens. After the CCMP was approved and adopted by USEPA and the governors of Oregon and Washington in 1999, the Estuary Partnership modified this management conference structure to include a Board of Directors and a Science Work Group, which both meet regularly to provide policy and technical guidance respectively as well as increased coordination and communication.

The Estuary Partnership regularly facilitates the following forums to provide increased communication and coordination amongst partners towards implementing the CCMP:

- **Estuary Partnership's Board of Directors** - 21 members that set policy direction of the Estuary Partnership. Representatives rotate through the following organizations amongst others: agricultural and citizen community, Beaverton School District, Cannery Pier Hotel, City of Portland Bureau of Environmental Services, Clark County Environmental Services, Columbia River Inter-Tribal Fish Commission, Cowlitz-Wahkiakum Council of Governments, National Marine Fisheries Service, Northwest Pulp and Paper Association, Oregon Department of Environmental Quality, Oregon House of Representatives, Oregon State Senate, Oregon Watershed Enhancement Board, Port of Portland, Smith Root, Inc., US Army Corps of Engineers, US Environmental Protection Agency, US Geological Survey, Washington Department of Ecology and Washington State House of Representatives. The membership represents the diverse public and private interests and geography of the lower river to ensure a comprehensive assessment of issues, leverage resources and set target priorities. This forum not only influences what the Estuary Partnership works on but also allows members to learn from each other and take what they learn back to their organizations.
- **Science Work Group** – members meet monthly and work to ensure a consistent and cooperative approach to solving regional scientific issues. In 2011, the Science Work Group focused on refining the methods and applying the results of this Restoration Prioritization Strategy, developing an estuarine indicator system for the lower Columbia River, and reviewing results of the comprehensive status and trends analysis of the Ecosystem Monitoring Program. This group is open to anyone with technical knowledge and working towards implementing the actions of the Estuary Partnership's CCMP.
- **Estuary RME Coordination** – members meet annually to provide updates on their research, monitoring and evaluation (RME) activities and their plans for the upcoming sampling season. This meeting is coordinated by the Estuary Partnership with USACE, BPA, LCFRB and ODFW input and support. Membership includes principal investigators of RME projects funded through the USACE's AFEP, BPA's Fish and

Wildlife Program and states' salmon recovery programs. The meetings have been held since 2009.

- **Quarterly Project Development Coordination** – members meet quarterly at rotating locations to provide an update on projects they have recently identified, begun developing and/or are underway. Members also discuss larger issues holding up or of concern to restoration activities, identify knowledge gaps or critical uncertainties and help to identify ways to resolve these issues. These meetings have been held since 2010, and membership is open to government agencies and not-for-profit entities working on habitat restoration in the lower river.
- **Science to Policy Summit –** these are annual workshops to bring those involved with emerging science together with policy makers and people working on the ground. Community leaders from tribal government, academia and applied science, agriculture, transportation, fisheries, recreation, elected officials, and local, regional, state and federal government agencies participate in each summit. Scientists with expertise in habitat restoration, ecosystem function, toxics contaminants, climate change and many other disciplines contribute regularly as speakers and participants.
- **Columbia River Estuary Conference** – these are biennial conferences that allow technical exchange on a large scale amongst researchers, scientists, resource managers and planners. These conferences have been held in Astoria since 1999 and are open to any who wish to attend. Topics of the conferences include the following:
    - 1999 - Biological Integrity
    - 2001 - Habitat Conservation and Restoration
    - 2003 - Research Needs
    - 2006 - Estuarine and Ocean Ecology of Juvenile Salmonids
    - 2008 - Ecosystem Restoration
    - 2010 - Adaptive Management
    - 2012 - New Scientific Findings and their Management Implications

  The conferences are organized by a Steering Committee composed of representatives from the Columbia River Estuary Study Taskforce (CREST), USACE, BPA, Lower Columbia Fish Recovery Board (LCFRB), NPCC, US Geologic Survey (USGS), USFWS, NOAA, ODFW and Columbia Land Trust (CLT).

In addition to these regular occurring coordination activities, the Estuary Partnership convenes topical workshops and conferences, such as the two-day April 2012 Estuarine Indicators Workshop. Previous workshops have focused on issues facing habitat restoration, water quality and toxic contaminants, bathymetry data gaps and updating the 2001 land cover dataset. Finally, the Estuary Partnership participates in regional efforts such as the USEPA Toxics Reduction Working Group, Northwest Association of Networked Ocean Observation Systems (NANOOS), Pacific Coast Joint Venture, and Pacific Estuarine Research Federation to provide regional representation and input as well as bring back information gleaned from these groups to share with regional partners.

The remainder of this section describes past accomplishments for addressing the holistic vision/plan element including the overall approach the region is using within the Lower Columbia River Ecosystem Restoration Program for an ecosystem-based approach. This document serves as the description of the Program's management objectives and prioritization strategies for meeting them, including stakeholder and resource management community engagement as well as assisting in addressing capacity issues with implementing partners.

Holistic Vision for the Lower Columbia River Ecosystem Restoration Program

The region identified *biological integrity*[2] and *habitat loss and modification* as two significant issues to be addressed through the Estuary Partnership's CCMP. The vision or goals for these are as follows:

- *Integrated, resilient, and diverse biological communities are restored and maintained in the lower Columbia River and estuary* and
- *Habitat in the lower Columbia River and estuary supports self-sustaining populations of plants, fish, and wildlife* (Estuary Partnership 1999; Estuary Partnership 2011).

These goals overlap well with the NPCC's Columbia River Fish and Wildlife Program objectives for the entire Columbia Basin, which include the following:

- A Columbia River ecosystem that sustains an abundant, productive, and diverse community of fish and wildlife
- Mitigation across the Columbia River Basin for the adverse effects to fish and wildlife caused by the development and operation of the hydrosystem
- Sufficient populations of fish and wildlife for abundant opportunities for tribal trust and treaty rights harvest and for non-tribal harvest
- Recovery of the fish and wildlife that are affected by the development and operation of the hydrosystem and are listed under the ESA (NPCC 2004).

The Estuary Partnership's objectives for these issues are then to restore the lower river's biological integrity and structure and function of the estuary ecosystem. The CCMP lists multiple actions to meet these goals and objectives, including the following actions, amongst others:

- Inventory habitat types and attributes in the lower Columbia River and estuary and prioritize those that need protection and conservation; identify habitats and environmentally sensitive lands that should not be altered.
- Protect, conserve, and enhance priority habitats, particularly wetlands, on the mainstem of the lower Columbia River and in the estuary.
- Monitor status and trends of ecosystem conditions (Estuary Partnership 2011).

In 2009, the Estuary Partnership updated the 1999 CCMP numeric target of protecting and/or restoring acres of habitat to 19,000 acres by 2014 and 25,000 acres by 2025; these were subsequently incorporated into the USEPA's 2009-2014 Strategic Plan.

[2] USEPA definition of biological integrity: capability of supporting and maintaining a balanced, integrated, adaptive community of organisms having a species composition, diversity, and functional organization that is comparable to representative natural habitat in the region (Frey 1977; Karr and Dudley 1981).

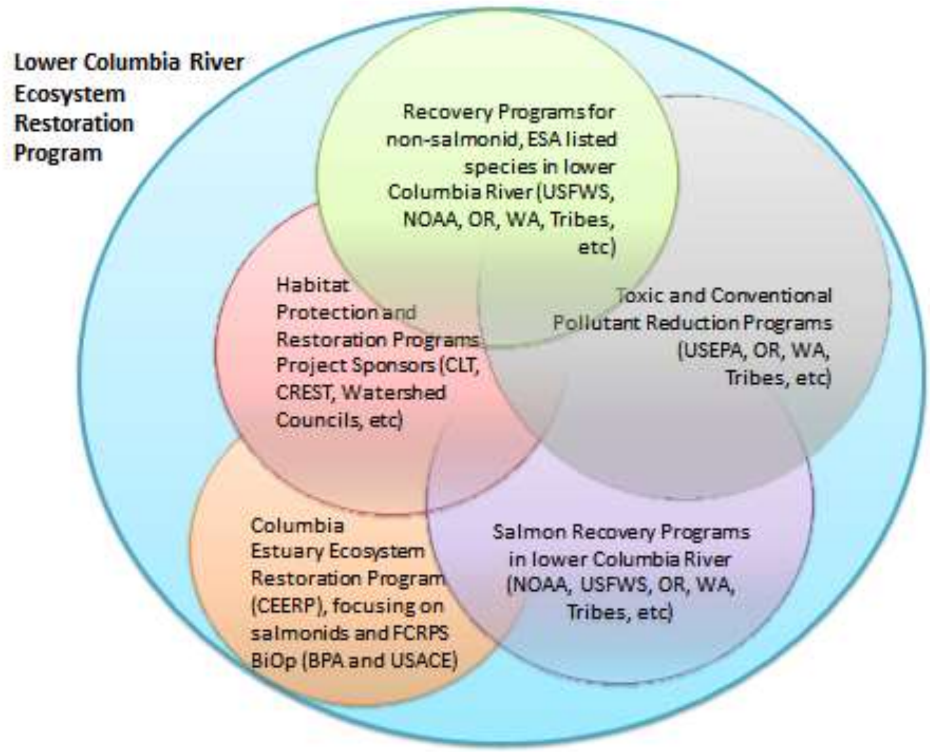


Figure 2. Illustration of the major programs and partners in the Lower Columbia River Ecosystem Restoration Program. There are many active restoration, toxic contaminant reduction and ESA listed species recovery programs in the lower river and their goals overlap significantly. This allows both funders and restoration practitioners to leverage dollars and address recovery objectives for multiple species. Coordination and communication amongst these programs and partners can ensure the vision/goals and objectives of the Lower Columbia River Ecosystem Restoration Program are fully addressed.

Sections 2 through 6 of this report address the first action above, that is, identifying the types and locations of those habitats that are priority for protection and restoration in order to protect the lower river's biological integrity and restore the ecosystem structure and function. It is important to note that this Program uses an ecosystem-based approach that is broader than salmon recovery, although salmon recovery is a major focus and the majority of funding for on the ground actions is currently supported through local, state and federal agency salmon recovery programs. The Program overlaps largely with these programs but also encompasses programs for protecting waterfowl, nesting and migratory bird habitat, recovery of other ESA listed species and reduction of toxic contaminants. Figure 2 provides context of how this program fits within other restoration and ESA listed species programs.

Past Accomplishments in Implementing an Ecosystem-Based Restoration Approach of the lower Columbia River

In 2003, the region developed a series of science-based steps to use in an ecosystem-based approach to restoration for the lower Columbia River (Johnson et al.), and the approach was reviewed by the NPCC's Independent Scientific Review Panel (ISRP). The document was largely focused on salmon recovery, and to rectify this for our needs we expanded step 2 below to include additional focal species. The modified approach calls for the following steps (*text in italics denote modifications added by authors of this document*):

1. Describe the fundamentals of restoration science and assess disturbance across landscape and at individual site scales. The approach draws from the disciplines of restoration ecology, landscape ecology, and conservation biology. Restoration fundamentals include five basic restoration techniques: conservation, creation, enhancement, restoration, and protection. The usefulness of a given restoration technique depends on the level of disturbance at the landscape and local scales. Restoration success is dependent on recovering and sustaining ecosystem functions and processes.
2. Determine usage of CRE habitats by salmonid life history type, i.e., determine which habitats are most important and why. It is essential for strategic restoration planning to know how fish of various life history types use CRE habitats in space and time in order to identify the habitat attributes juvenile salmon need (capacity) and to establish what habitats are important to what types of fish (life history type). Ensure adequate habitat needs are met to ensure diversity in life history strategies. *Apply similar prioritization approaches to Columbia White-tailed deer, overwintering/migratory waterfowl and other focal species.*
3. Determine what CRE habitats have been lost relative to historical conditions (pre-development in 1900s). *Prioritize the remaining stands of habitats where large losses have occurred, for future protection.*
4. Identify and prioritize restoration actions…and establish a reasonable future condition, given constraints on the system (e.g., flow regulation). Optimal habitat conditions for a site under present-day conditions may differ from optimal historical conditions.
5. Determine what specific habitats can be restored and where, i.e., develop an inventory of possible actions. Develop an inventory of priority actions at site, landscape scales and ensure project sponsors and funding agencies support and use in funding priorities.
6. Implement locally supported and scientifically based restoration projects. *Support capacity of restoration partners to develop scientifically based and collaborative projects that are supported by landowners, local community, funders and relevant agencies.*
7. Monitor actions using standardized protocols and apply the results to adaptively manage future restoration actions. Restoration projects should be treated as "experiments" with reference sites included in the monitoring design. The results of each experiment should be evaluated and future or ongoing restoration actions revised as necessary. A process to coordinate, monitor performance, collect and disseminate data, and adaptively manage multiple projects should be used. (Johnson et al. 2003).

The Estuary Partnership and partners have been working towards implementation of the steps outlined in this approach in the Lower Columbia River Ecosystem Restoration Program (Table 2). As this document describes, the region is now close to full implementation with most or all aspects of steps 1, 3-7 identified in Johnson et al. (2003). Task 1 was accomplished through the creation of Tier 1 of the Estuary Partnership's Restoration Prioritization Framework in 2006 (Evans et al. 2006; Thom et al. 2011) in collaboration with the Pacific Northwest National Laboratory (PNNL). Significant progress on step 2 has been made through the Estuary Partnership's Ecosystem Monitoring Program (see Section 7), the PNNL "Juvenile Salmon

Ecology and Restoration of Tidal Freshwater Habitats" project funded by BPA and the NMFS project through USACE "Estuarine Habitat and Juvenile Salmon: Current and Historical Linkages in the Lower Columbia River and Estuary, Final Report 2002-2008". The contribution of the Ecosystem Monitoring Program to this knowledge gap is ongoing but importantly the USACE Anadromous Fish Evaluation Program (AFEP) project "Contribution of Tidal Fluvial Habitats in the Lower Columbia River Estuary to the Recovery of Diverse Salmon Stocks and the Implications for Strategic Estuary Restoration" by NMFS is expected to provide a lot of key information specifically answering this question in several more years. Step 3 is addressed in Restoration Prioritization Strategy, Line of Evidence 1 described below in Section 2. Section 7 describes our approach to steps 4-7.

Table 2. Progress on Implementing the Approach to Ecosystem-Based Restoration of the lower Columbia River (Johnson et al. 2003)

Step	Description	Ongoing Efforts
1	Describe the fundamentals of restoration science (as they apply to LCRE ecosystem restoration)	Restoration Prioritization Framework Tier 1(see Evans et al. 2006)
2	Determine usage of LCRE habitats by salmonid life-history type, i.e., determine which habitats are most important and why; *expand to other focal species (CWTD, Pacific flyway)*	Ongoing research and monitoring; Restoration Prioritization Strategy, Line of Evidence 2, *expand with other lines of evidence for focal species*
3	Determine which LCRE habitats have been lost relative to historical conditions (pre-development in 1900s)	Restoration Prioritization Strategy, Line of Evidence 1
4	Identify and prioritize restoration strategies for the lower river and establish a reasonable future condition, given constraints on the system (e.g., flow regulation)	This document, including GIS files and upcoming datasets as they become available
5	Determine which specific habitats can be restored and where, i.e., develop an inventory of possible actions	Restoration Inventory geodatabase, Section 7
6	Implement locally supported and scientifically based restoration projects	Described in Section 7
7	Monitor actions using standardized protocols and apply the results to adaptively manage future restoration actions	Described in Section 7

Additionally, in 2004, the NPCC developed a subbasin plan for the lower river that identifies a list of focal species (e.g., Pacific salmonids, lamprey, sturgeon, Columbia White-tailed deer (CWTD), bald eagles, osprey, Dusky Canada goose, Sandhill cranes) and recommended actions to address limiting factors and restore or protect their associated habitats. The Lower Columbia River Ecosystem Restoration Program integrates some key actions in the subbasin plan (NPCC 2004), and actions identified in other regional plans, including the WA and OR salmonid recovery plans, the 1994 PCJV implementation plan for migratory and overwintering birds and aspects of the USEPA Action Plan for toxic contaminants. These are described in the relevant sections below.

Overview of the Restoration Prioritization Strategy –prioritization of habitats across the lower river

With funding provided by the USEPA, the Estuary Partnership worked with PNNL, the Yakama Nation, USFWS, ODFW, LCFRB, NMFS, PCJV and the USEPA Toxics Reduction Working Group to develop a Restoration Prioritization Strategy, allowing users to comprehensively analyze the entire lower river and prioritize some areas over others for habitat protection and restoration based on the potential for greatest ecological uplift. This is opposed to a "bottom up" prioritization approach that emphasizes local or watershed prioritizations but may not include the larger landscape or ecosystem scale considerations. This Strategy addresses steps 3 – 4 and aspects of step 2 in the ecosystem-based approach of Johnson et al. 2003, as modified above, and is the major focus of this document.

The Restoration Prioritization Strategy uses a "multiple-lines-of-evidence" approach (also known as "multi-criteria decision analysis" from Malczewski 1999 in the Geographic Information Systems [GIS] field) to identify priority areas for habitat protection and restoration. This approach allows the user to make a decision using one or multiple selection factors, each with a set of criteria and predefined thresholds. For example, a person wishes to purchase a home. The selection factors a person might use in making the decision include one or all of the following considerations: the price of the home, the safety of the surrounding neighborhood, the quality of the local schools and walkability to nearby stores and restaurants. The person then has to define their preferences or criteria for evaluating these selection factors, such as a home price that is affordable for them. To continue this example, a high priced house might be >$500,000, while a low cost home might be <$200,000. If the person considered this selection factor alone, s/he might choose a home within the $200,000 to $500,000 range. However, s/he would most likely want to consider neighborhood safety and quality of nearby schools and define thresholds for criteria indicating suitable conditions (e.g.,< 20 violent crimes/year/1,000 people).

The Restoration Prioritization Strategy uses this same approach to identify areas in the lower river that will provide the greatest ecological uplift through restoration or protection actions using multiple selection factors. The selection factors include 1) natural habitat diversity, 2) suitable migratory and rearing habitat for juvenile "ocean-type" Chinook salmon, 3) important rearing habitats for lower Columbia River (LCR) "ocean-type" ESUs, 4) potential Columbia White-tailed deer habitat, 5) potential overwintering and migratory bird habitat, 6) toxic contaminant cleanup sites or other hot spots and 7) low production agricultural lands. To define the criteria and thresholds for these selection factors that we wish to target in our restoration program, we used the results from the following analyses, respectively: 1) a habitat change analysis using historic T sheets in comparison to current (2010) land cover data; 2) a Habitat Suitability Model for juvenile "ocean-type" salmon using results from an Oregon Health and Science University (OHSU) model to determine times and locations that meet water temperature, depth, and velocity conditions favorable to juvenile salmon, based on Bottom et al. (2005) criteria and 3) tidally influenced areas within those tributaries listed within Oregon and Washington salmon and steelhead recovery plans as priority for LCR fall and late fall Chinook and chum populations as well as areas along the mainstem <25 km of a tributary with "Tule" Chinook populations (see NOAA "Tule" Harvest BiOp method in Cooney and Holzer 2011). Selection factors 4 -7 are incomplete at the time of this version but are expected to be added to the report in fall 2012. Additionally, selection factors are herein termed individual "lines of evidence".

Overlaying the results of these seven analyses will allow managers to identify on a map of the lower river, those critical areas for restoration and protection. Each line of evidence included in the Restoration Prioritization Strategy can be used in combination with the others or be the sole selection factor, depending on the focus and goals of the user. For example, recovery planners in Oregon and Washington may be mainly focused on priority tributaries and mainstem areas for the lower Columbia River salmonid populations (Line of Evidence 3) in combination with historic habitat changes (Line of Evidence 1), while BPA and the USACE may be interested in historic habitat changes and the availability of juvenile Chinook rearing and migratory habitat (Line of Evidence 2). Furthermore, USFWS managers may wish to identify specific types of riparian habitats that have been lost since the 1870s (Line of Evidence 1) to use in prioritizing overwintering and migratory bird habitats (Line of Evidence 5).

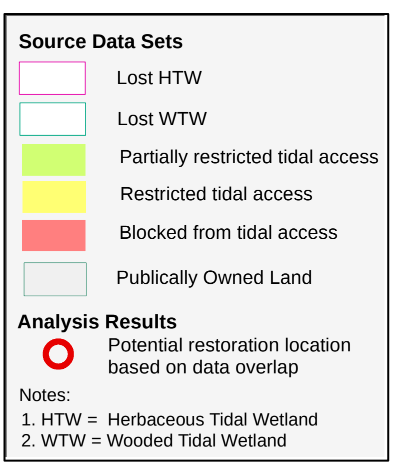
Applying the Results of the Restoration Prioritization Strategy

The figures below illustrate how this Strategy will be employed when prioritizing areas for restoration and protection, targeted at increasing available habitat for juvenile salmonids. The Levels of Evidence which have been incorporated in these figures include:

1. Line of Evidence 1 - Historical habitat change in the lower Columbia River 1870-2010
2. Line of Evidence 2 - Salmonid Habitat Suitability Index Model
3. Line of Evidence 3 – Lower Columbia River Salmonid Recovery Plan Priorities

as well as landscape assessment tools such as the “tidally impaired” and parcel ownership datasets.

Figure 3 illustrates the loss of critical habitat from historical times. For juvenile salmonids, critical habitat is comprised of tidally influenced wetlands. By overlaying this data on top of data showing tidal and tidally restricted lands, the user can see where tidal wetlands could potentially be restored based on the current Columbia River hydrograph. Favorable restoration areas can be seen on the map, where the lost wetlands coincide with areas of 'restricted' or 'blocked' tidal access. Red circles on the map indicate where these favorable areas intersect with publically owned lands. Public lands typically offer the quickest and easiest opportunities for habitat restoration.



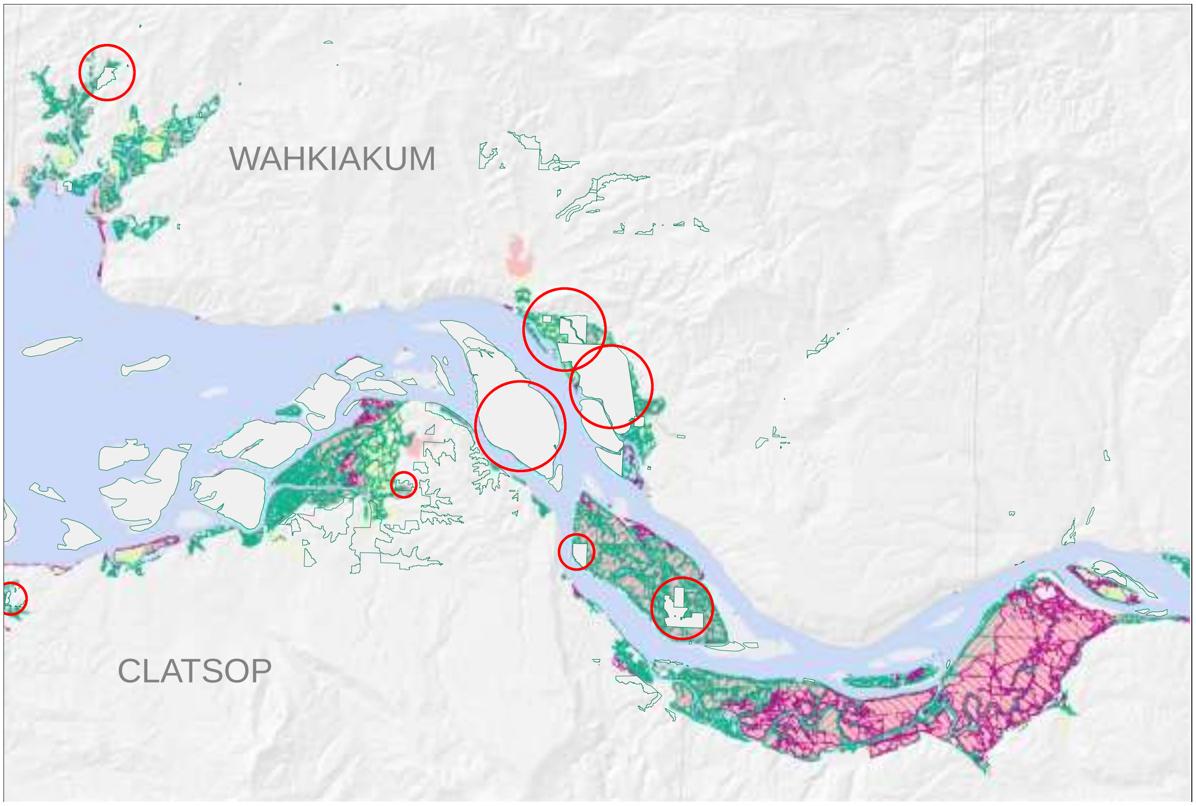
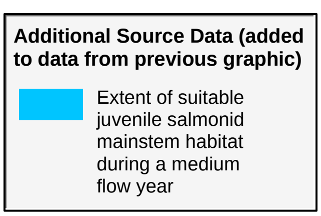


Figure 3. Results of Line of Evidence 1- Historical Habitat Change in the lower Columbia River, 1870-2010. The results are shown overlain on top of areas that are within the historical floodplain and currently "tidally impaired".

A salmon recovery manager may wish to not only look at the loss of tidal wetlands within the floodplain, but also consider the context of that loss, that is in combination with in-water conditions that are favorable for rearing juvenile salmonids. Figure 4 incorporates predicted in-water suitability based on a combination of water temperature, velocity and depth. Suitable habitats include areas where threshold criteria for these three parameters are met for a specified frequency of time. Modeled data is included for a medium flow year, based on the current hydrograph. The map helps to illustrate where recoverable tidal wetlands are in close proximity to favorable areas of the mainstem lower Columbia for juvenile salmonid rearing.



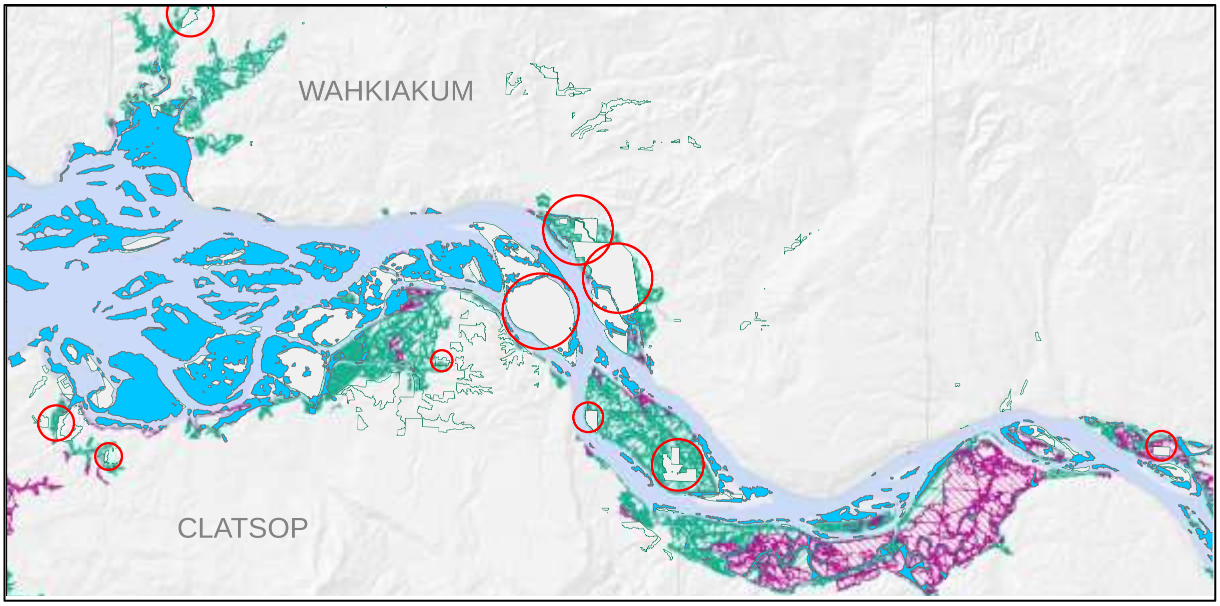
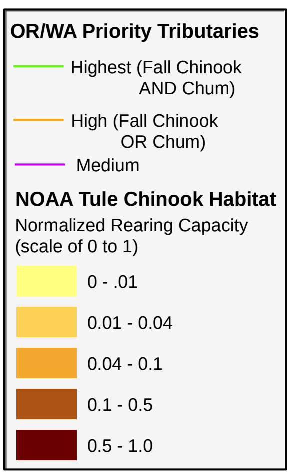


Figure 4. Figure 3 above with the addition of the results of Line of Evidence 2 – Habitat Suitability Index Model.

Finally, salmon recovery managers can also consider the importance of tributaries which support important lower Columbia River salmon stocks. The states of OR and WA have prioritized the lower Columbia tributaries for salmonid recovery. In addition, NOAA has developed a model to identify important rearing habitat restoration opportunities for "Tule" Chinook salmon which are spawned in these tributaries, and rear in the lower Columbia River. These data are included in Figure 5, which shows the proximity of these areas to the favorable areas identified in the previous figures.



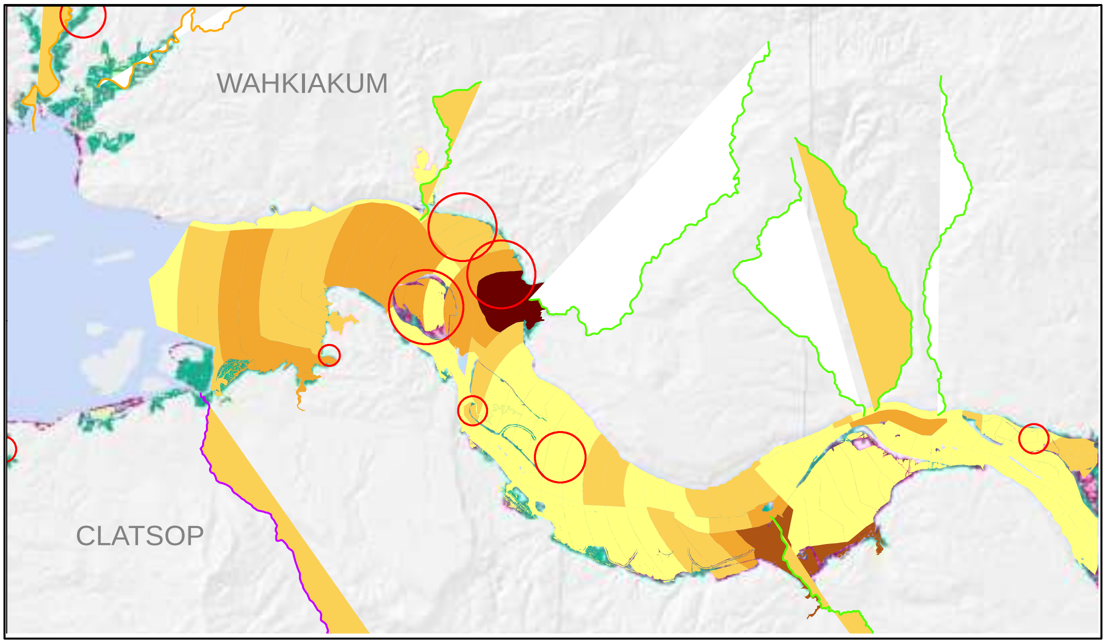


Figure 5. Figure 4 above with the addition of the results of Line of Evidence 3 – Lower Columbia River Salmonid Recovery Plan Priorities.

Once a user identifies areas that are important to protect or restore for ecological uplift, the user then can use a series of landscape assessment tools to determine what is most feasible for these sites. The result of the Restoration Prioritization Strategy is a GIS map(s) or inventory of identified critical areas that can be combined with the results of landscape assessment tools such as the landscape disturbance analyses, "tidally impaired" dataset and parcel ownership data to identify appropriate techniques and levels of effort needed to restore individual sites or to combine multiple projects to restore larger areas. A brief description of several key landscape assessment tools follows below.

Additionally, the Restoration Inventory, a geodatabase of identified restoration and protection actions (shown as the stars in the next figure) can be overlain on the priority areas to highlight gaps in restoration actions in priority areas.

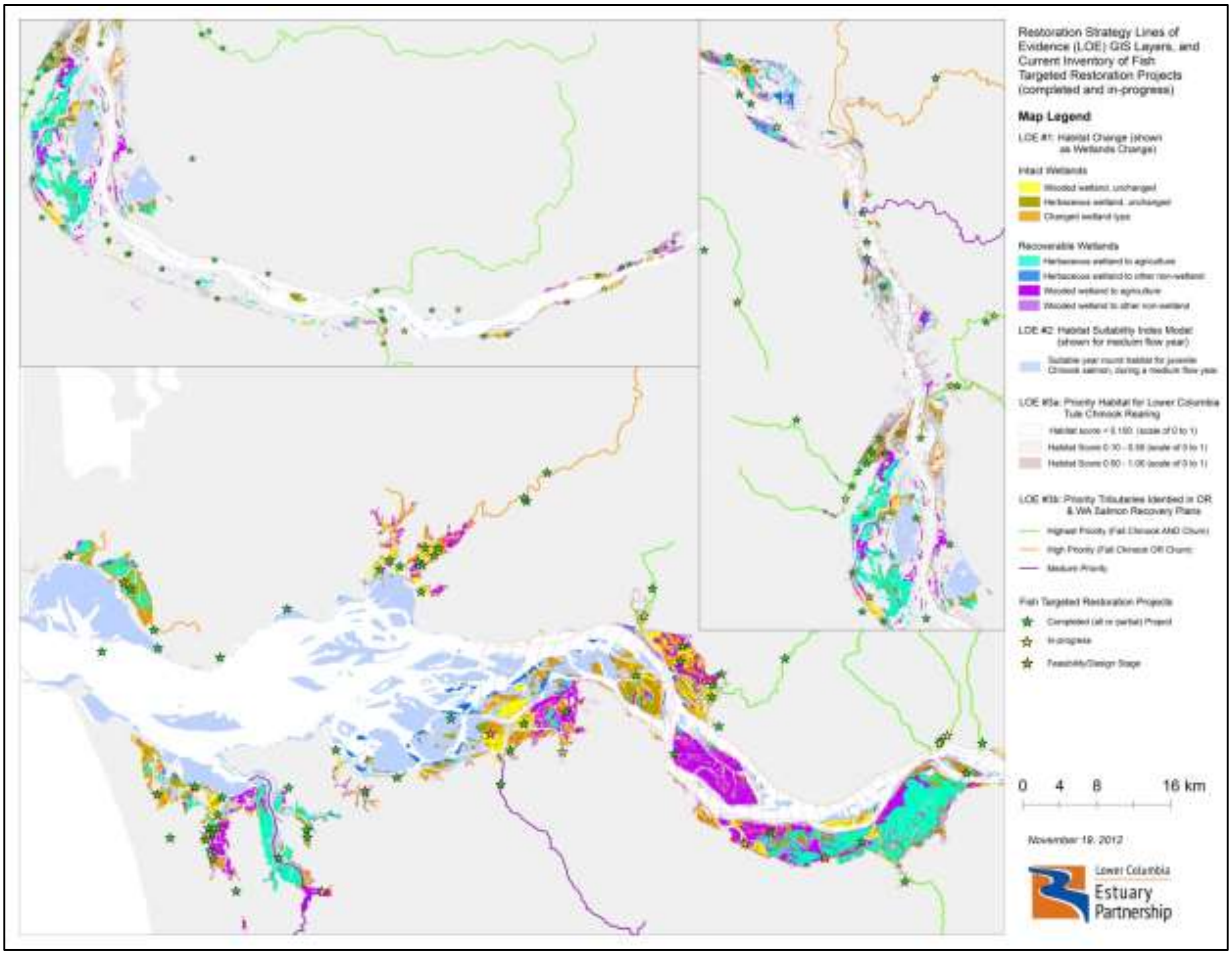


Figure 6. Results of Lines of Evidence 1-3 combined with projects tracked in the Restoration Inventory. Stars show projects focused on salmon recovery that are planned, underway or completed as of November 2012. This combination can help identify priority areas for restoration where projects do not yet exist.

Finally, the Restoration Prioritization Strategy is a GIS-based model that is not static; it was constructed to be easily updated or combined with additional datasets as they become available. The application of the Restoration Prioritization Strategy is described in Section 6.

Landscape Assessment Tools

The Estuary Partnership has created or compiled a suite of GIS and other datasets that can be useful in identifying, assessing the feasibility of, designing or evaluating restoration projects. All of these are available, as is the Restoration Prioritization Strategy, over the Estuary Partnership's website: www.estuarypartnership.org. A brief description of some of these tools and an example of how they can be used in combination follows:

A. *Restoration Prioritization Framework Tier 1 – Disturbance Model*

In 2006 with funding from BPA, the Estuary Partnership with the Pacific Northwest National Laboratory (PNNL) developed the Restoration Prioritization Framework to address step 1 of the ecosystem-based approach in Johnson et al. 2003 (Evans et al. 2006; Thom et al. 2011). The Prioritization Framework was broken into two components: a disturbance model (Tier 1) and a project evaluation tool (Tier 2).Tier 1 used existing data for a series of stressors such as diking, toxic contaminants, roads, population, flow restrictions, etc. to model disturbances on individual site and landscape scales (Figure 7). Management areas (HUC 6 watersheds) and individual sites (on average 130 acre parcels) are assigned rankings of "low", "moderate", or "high" disturbance based on results of this model. Site and management area boundaries for the lower river Reaches are shown in Figure 7. The units are color coded according by their scores output by the model. For any particular location, the relationship between site score and management area score can indicate the types of restoration (i.e., preservation, conservation, enhancement, restoration or creation) that would achieve the highest likelihood of success for that location. Figure 8 (adopted from Shreffler and Thom 1993), illustrates these relationships. Figure 9 shows actual site and management area disturbance scores plotted on this same type of scale. For example, where site and management area disturbance scores are low, portraying sites with low disturbance surrounded by a relatively intact landscape (Box G, in Figure 8 and Figure 9), acquisition or simple enhancement techniques are most appropriate. In comparison, where site and management area disturbance scores are both high, portraying highly disturbed sites surrounded by a highly disturbed landscape (Box C in Figure 8 and Figure 9), habitat creation or more intensive enhancement techniques are probably most appropriate. The likelihood of long term success in restoring natural processes is hindered in these sites.

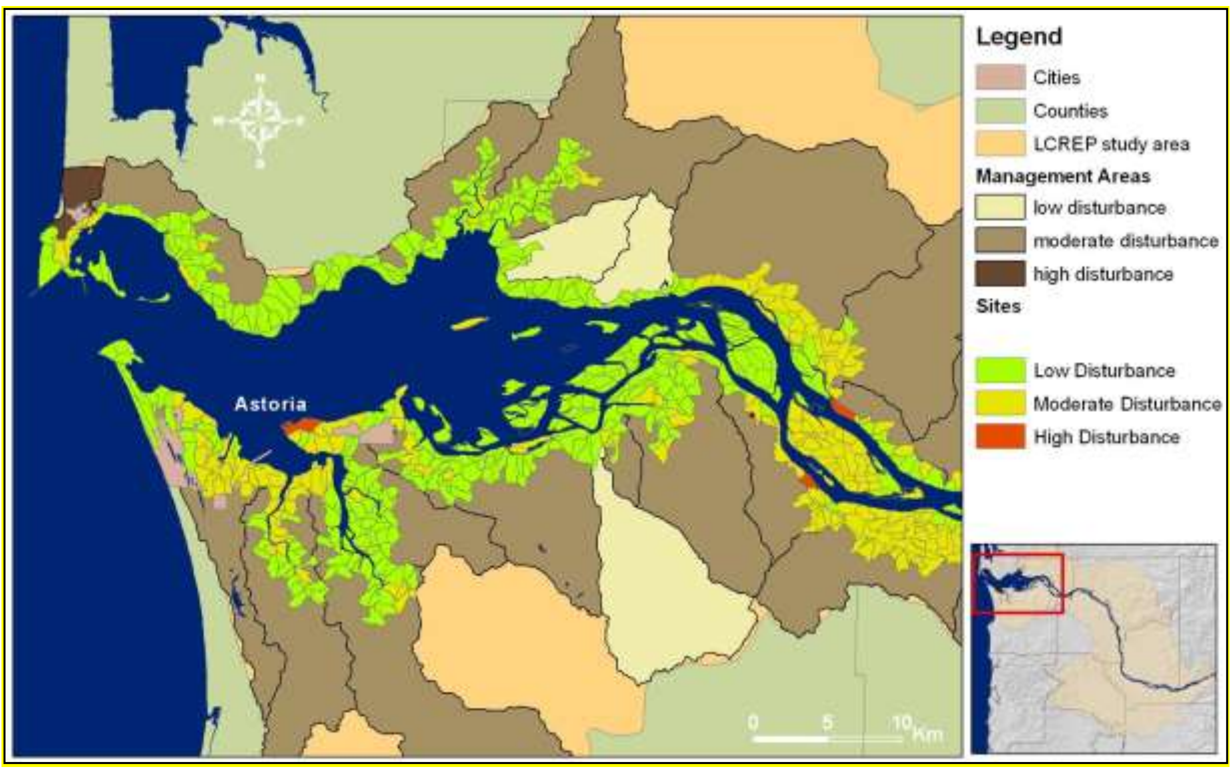


Figure 7. Tier 1 Site and Management Area for Reaches A and B

High Site Disturbance	**A** Restore Enhance Create	**B** Enhance Create Restore	**C** Enhance Create
Moderate Site Disturbance	**D** Enhance Restore Preserve	**E** Conserve Enhance Create Restore	**F** Enhance Create Restore
Low Site Disturbance	**G** Conserve Preserve	**H** Conserve Enhance Restore	**I** Enhance
	Low Management Area Disturbance	**Moderate Management Area Disturbance**	**High Management Area Disturbance**

Figure 8. Restoration strategies applied to sites based on level of disturbance. Adopted from Schreffler and Thom, 1993.

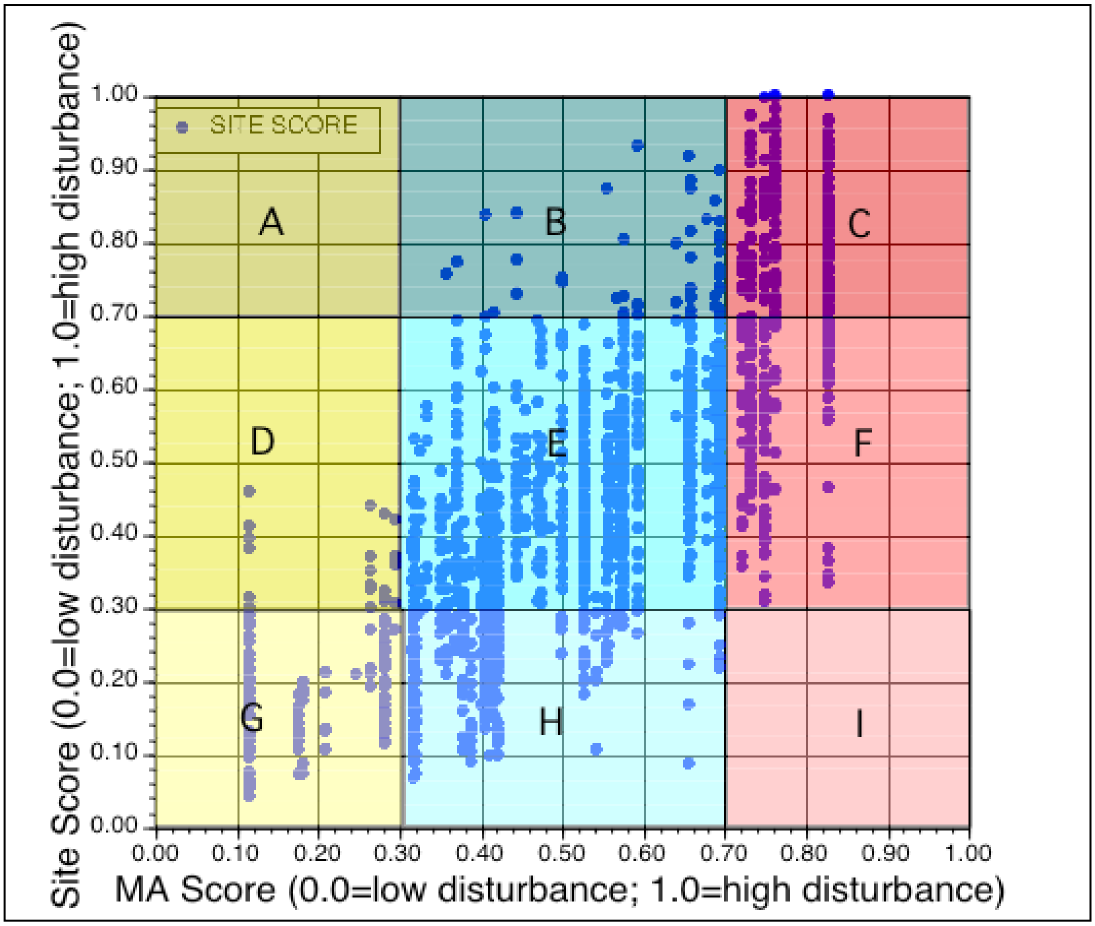


Figure 9. Tier 1 Plot of Site and Management Area scores, divided into 9 segments. Higher numbers in axes denote higher levels of disturbance. Sites that fall in Box G have low Site and Management Area disturbance scores, so protection or low intensive techniques are appropriate. Sites in Box C have high Site and Management Area disturbance scores so more intensive restoration or habitat creation techniques will be needed. Likelihood of restoring natural processes is greatly hindered for these sites.

B. *Lower Columbia River Terrain Model* - This ArcGIS 'terrain' dataset is a seamless elevation model which includes the most current topographic and bathymetric data that have been collected for the Lower Columbia mainstem and floodplain. It is the most comprehensive elevation model that has been developed for the region. All topographic data and the majority of the bathymetric data were collected subsequent to 2008. Historical bathymetric data was included in gap areas, in order to provide as complete coverage as possible. The datasets were compiled and merged into the seamless model by the United States Army Corps of Engineers, in 2010. Much of the recent shallow water bathymetric data was collected under contract by the Estuary Partnership. The model has seen a variety of applications, including hydrodynamic and sediment modeling, as well as simple flood inundation predictions in GIS. The dataset is freely available upon request from both the Corps of Engineers Portland District, and the Estuary Partnership.

C. *Columbia River Estuarine Ecosystem Classification (CREEC)* - Developed through collaboration between the Estuary Partnership, University of Washington, and USGS, the CREEC is a hierarchical classification which characterizes the unique ecosystem of the

Lower Columbia River and Estuary. The framework was developed for applications in large river systems such as the lower Columbia, which are characterized by very long reaches of tidal freshwater, and hence are not well described by previously existing classification frameworks. The various hierarchical levels define the hydrologic regimes, as well as the geophysical processes which have formed the unique landscape over geologic time. Four of the six overall levels are directly applicable to estuarine research, restoration, monitoring, and management. The dataset is freely available from both the USGS and the Estuary Partnership websites (anticipated online access in August 2012). A USGS Open File report describing the concept and application of this framework as applied to the Lower Columbia is accessible at http://pubs.usgs.gov/of/2011/1228/.

D. *Tidally impaired dataset* – this GIS dataset maps historic floodplain habitat that is no longer fully hydrologically connected as a result of levees, dikes, culverts, tidegates or other structures. It represents potential juvenile salmon rearing and refugia habitat that could be made more accessible through restoration actions. The Estuary Partnership developed this dataset as an aspect of the 2010 land cover dataset (Level 6 of the CREEC) by using high resolution LiDAR elevation models to compare site elevations to an approximate high water benchmark, to generate a tidal/non-tidal estimate.

E. *Fish passage barrier inventory* – this GIS dataset was created in 2012 and maps all hydrologic barriers to historic floodplain habitat including levees, dikes, tidegates and culverts.

F. *Parcel ownership* - The Estuary Partnership maintains the latest GIS parcel (taxlot) information from surrounding counties. The data is useful for scoping potential projects, contacting land owners and determining overall availability of lands under various types of ownership.

G. *Reference Sites data (RSS)*- The Estuary Partnership has been collecting habitat data at approximately 40 undisturbed locations within the lower Columbia since 2007. These sites represent how the ecosystem ideally functions in the absence of some of the major anthropogenic impacts (i.e., levees, tidegates, dredge material fill, invasive species) which are currently impacting much of the floodplain habitat. In many cases, they can be considered benchmarks for measuring the success of restoration practices, or the restoration trajectory, at neighboring sites. The Estuary Partnership maintains a geodatabase of reference site locations, as well as a suite of data for various habitat quality metrics that have been collected at these sites, including water surface elevations, temperature, sediment accretion, vegetation composition, channel cross sections, among other parameters.

H. *Lower Columbia River Shoreline Condition Inventory and Video*- In 2006, the Estuary Partnership collected georeferenced video footage of 630 miles of the lower Columbia River mainstem, side channels and sloughs. The Estuary Partnership created a shoreline features GIS dataset, based on information derived from the digital video, which can be used to assess the shoreline condition at any location. The Shoreline Condition Inventory is composed of a geodatabase of each river reach (A – H), containing vector data representing the shoreline character. The primary shoreline characterization attribute distinguishes modified versus unmodified shoreline. Additional attributes provide further detail, such as modification type (e.g., levee, dredge material, residential, road/rail fill) or natural habitat type (i.e., riparian, tidal marsh, tidal swamp). Point features indicate locations of in water and over water structures (pile structures, outflows, culverts, tidegates, navigation structures, etc.).

The figures below demonstrate how a restoration practitioner can use these landscape assessment tools to identify potential restoration actions on a landscape. **Error! Reference source not found.** shows known hydrologic barriers to an area of the historic lower Columbia floodplain as well as the impact these barriers have on the habitat. For example, the figure on right shows where there is total and partial blockage of hydrologic flows to historic floodplain habitat as well as where uplands are located.

Figure 10. Example of applying landscape assessment tools to a sample parcel, with a levee restricting flow and fish access. Fish passage barrier inventory dataset overlain on aerial image of several parcels, with the tidally impaired dataset shown.

If the restoration practitioner was interested in restoring hydrologic flows and/or fish access to a site, these datasets allow him to assess where the restoration action would be useful. The areas in red and green are partially or totally blocked hydrologically, and flows or fish access could be improved through improvements to or removal of the structures. This is contrary to the areas in blue which are already accessible or tidally connected and areas in pink that represent uplands that would not be inundated under the current river flow management.

Figure 11. Example of combining Restoration Prioritization Strategy results with landscape assessment tools to a sample parcel, with a levee restricting flow and fish access. Same area of landscape with results of Line of Evidence 1 shown and parcel ownership.

Figure 11 on left then demonstrates those areas where historical wooded or herbaceous wetlands have been lost (shown in purple and pink respectively) and where habitat remains intact (shown in green). This information is useful in determining the historic condition of the site, which a restoration practitioner could use in establishing a target future condition for the site. Finally, Figure 11 on right informs the practitioner that the areas shown in turquoise are already under conservation status and the areas in green are federally owned. Publically owned and conserved land is often more readily available for restoration actions than those that are privately owned (the areas shown in red). The parcel ownership dataset identifies land ownership so the restoration practitioner can use it to further delve into identifying landowners, with the ultimate goal of contacting them to determine their interest in restoring hydrologic flows and fish access to these parcels.

Similar types of analysis can be completed to identify restoration actions focusing on Columbia white-tailed deer, Pacific waterfowl and toxic contaminant reduction using the results of the relevant Lines of Evidence (4-6 respectively) and assessment tools.

2. Line of Evidence 1 – Historical Habitat Change in the Lower Columbia River, 1870 - 2010

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 datasets 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.

Background

As part of the USEPA's National Estuary Program (NEP), the Estuary Partnership is tasked with creating and implementing a Comprehensive Conservation and Management Plan (Management

Plan) for the lower Columbia River and estuary (LCRE). Through actions outlined in this plan, the Estuary Partnership seeks to preserve and 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 has developed a comprehensive, GIS based 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 Line of Evidence 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 datasets 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 12. 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 et al. 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 datasets currently exist: the University of Washington School of Aquatic and 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).

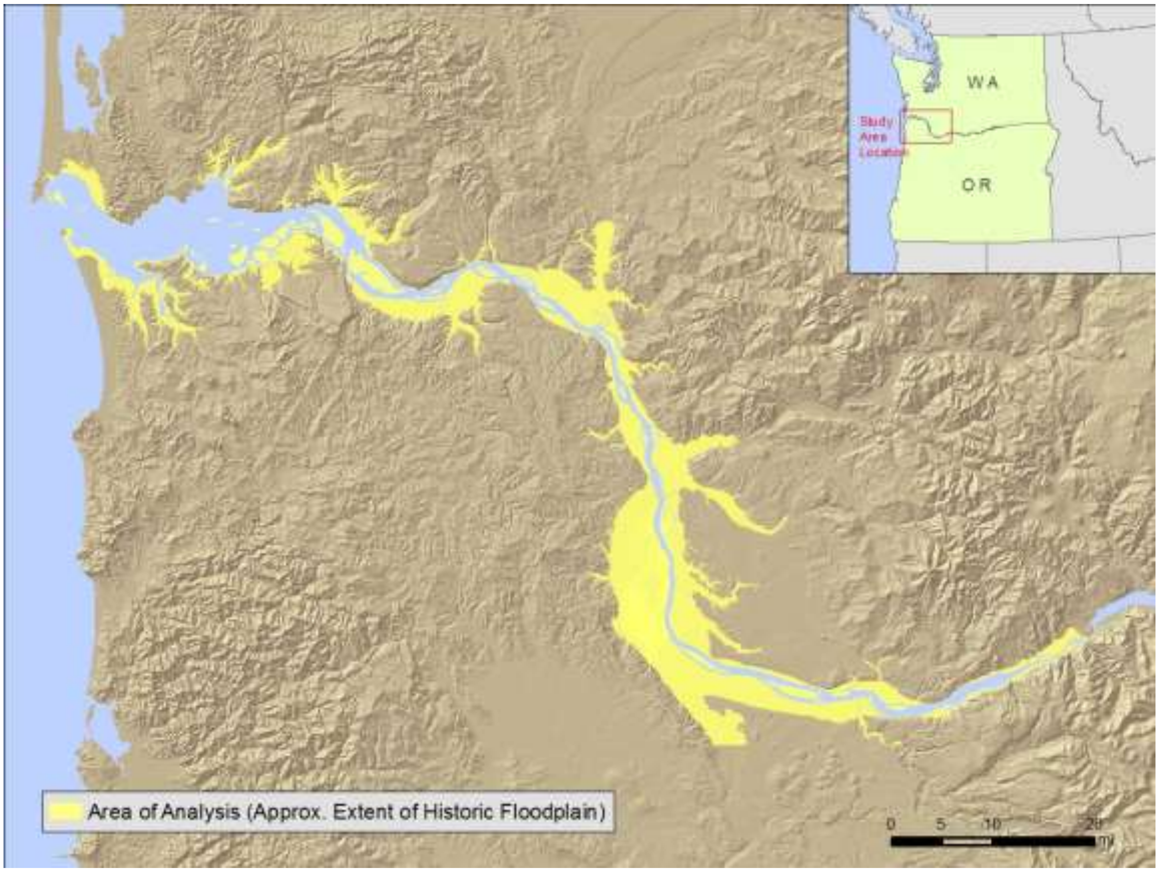


Figure 12. Geographical location of the lower Columbia River, and the approximate extent of its historical floodplain, which comprised the study area.

To represent current conditions, the Estuary Partnership used its recently completed 2010 land cover classification (Estuary Partnership 2011). This dataset 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 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 datasets. 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 dataset, as described above, was considered acceptable for this analysis.

Numerous land cover change analyses have been performed for the LCRE in recent years (Thomas 1983; Allen 1999; Garano 2003), 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 datasets 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 datasets, however it was not practical for illustrating spatial patterns of change. The analysis was limited to the lower 46 miles of river floodplain. Graves et al. (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 datasets 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 (2003a), as well as the NOAA-CAP program, 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 (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 datasets 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 baseline datasets. Often, the analyst is faced with trying to compare datasets 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 datasets may be required prior to the analysis. Our baseline historical dataset 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' dataset. 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' DataSet

The dataset 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 dataset (Lower Columbia Estuary Partnership, Sanborn Map Company 2010) can be currently obtained from the Estuary Partnership, and is 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 dataset differed from the pixel (raster) based approach that is commonly applied to remotely sensed satellite data in land cover analysis. The process 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 applied to classify the segments. The final result was a vector based land cover dataset, with more uniform boundaries between adjacent cover types compared to a raster dataset. In addition, habitat patches generated by the segmentation method tend to be more contiguous compared to raster based analyses, which often result in highly pixelated data. Figure 13 provides a comparison of the final datasets 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 datasets 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.

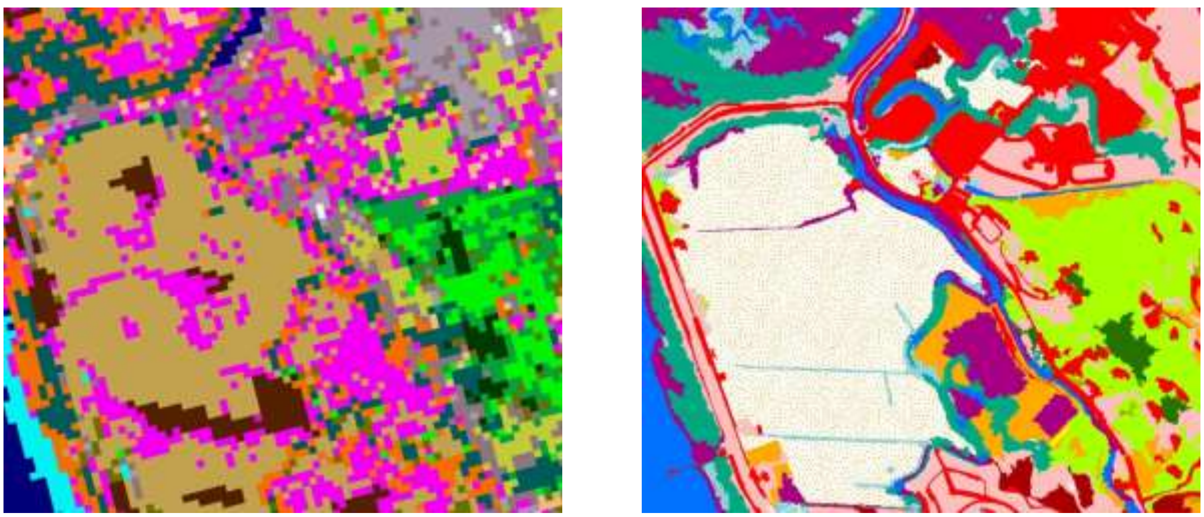


Figure 13. Comparison of traditional pixel based land cover data classification (shown on left. Source is NOAA C-CAP 2006, 30 meter resolution), and high resolution, segment based land cover classification (shown on right. Source is 2010 Estuary Partnership dataset, 1 meter resolution) shown for the 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 3 lists the land cover classes, and their associated areal extents calculated for the LCRE, that were used in the 2010 LCEP land cover dataset.

A standard accuracy assessment was performed on the dataset. 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 3. Land cover classes used in the 2010 Lower Columbia Estuary Partnership land cover dataset, 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 Dataset

The Estuary Partnership utilized the following four existing sources to generate the baseline historical dataset: 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 dataset); 4) Thomas/Graves et al. 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. dataset. 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 14 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. dataset, and the land cover classes were more compatible with the classes contained in the baseline 'current' dataset, relative to both the Graves and Christy datasets.

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 15 illustrates the overlap issue that we encountered.

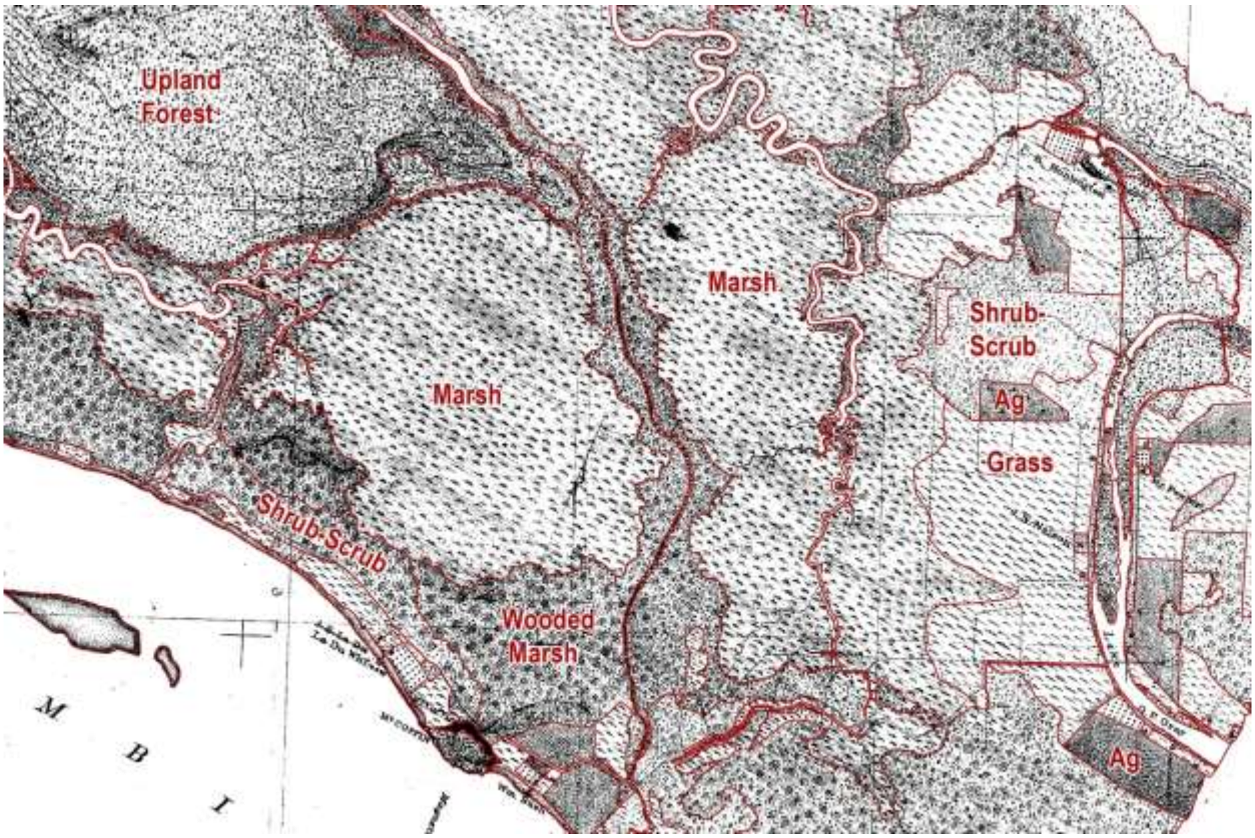
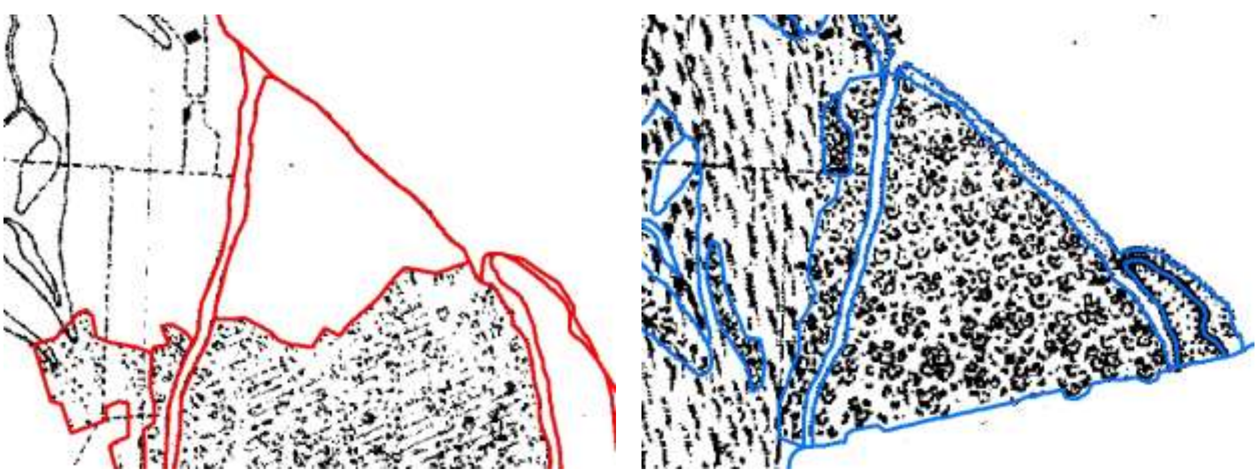


Figure 14. Example of baseline historical data used for the land cover change analysis. Georeferenced version of a late 1800s Office of Coast Survey T-sheet, with outlines of polygons delineated by the WET lab (based on the T-sheet vegetation symbols). Labels indicate the cover classes assigned to the polygons by WET lab staff.



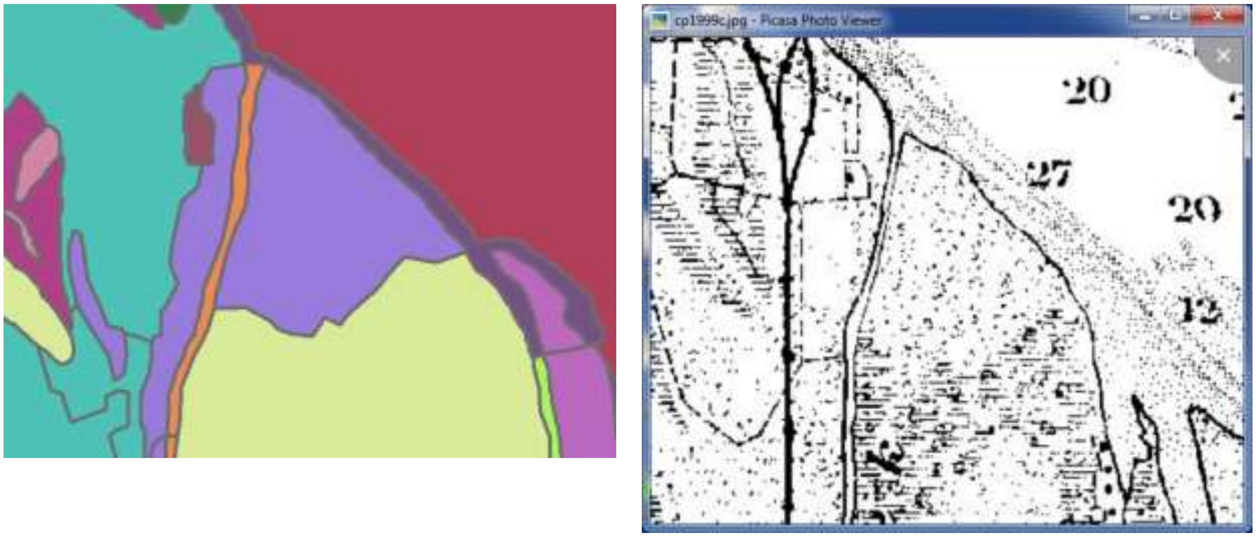


Figure 15. Example of edge matching process for WET labs polygons of 1880s T-sheet maps. Upper left: T-sheet 1455b with corresponding WET labs polygons overlain. Upper right: T-sheet 1495 with corresponding WET labs polygons overlain. Note differences in symbols between T-sheets 1455b and 1495, for the same spatial area. Lower left: Resulting Estuary Partnership edge matched polygon boundaries generated for the baseline historical dataset for change analysis. Lower Right: 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 datasets, and the methods used to create it are well documented. Figure 16 shows an example of a GLO survey map for the Columbia River and the resulting GIS polygons generated by Christy et al., delineating the various vegetation types.

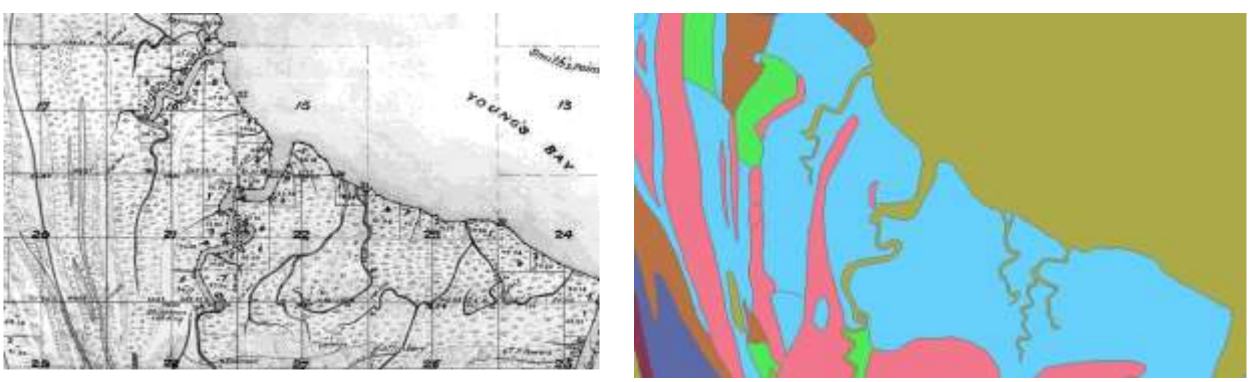


Figure 16. Example of baseline historical data source used for the land cover change analysis. Image on left shows a digital version of a late 1800s GLO survey map. Map symbols depicting various land use/land cover types is evident. Image on right shows GIS polygons delineated by Christy, based on the 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 dataset. This data was supplemented with the Christy et al. GLO interpretation for areas not covered by the Wet labs data. For regions where neither of these datasets provided coverage, portions of the Graves et al. T-sheet interpretation were utilized. These were limited to very small areas in the lower estuary. Figure 17 shows the coverage extents utilized for each of the datasets. 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' dataset provided complete floodplain coverage, the historical dataset was the limiting factor spatially.

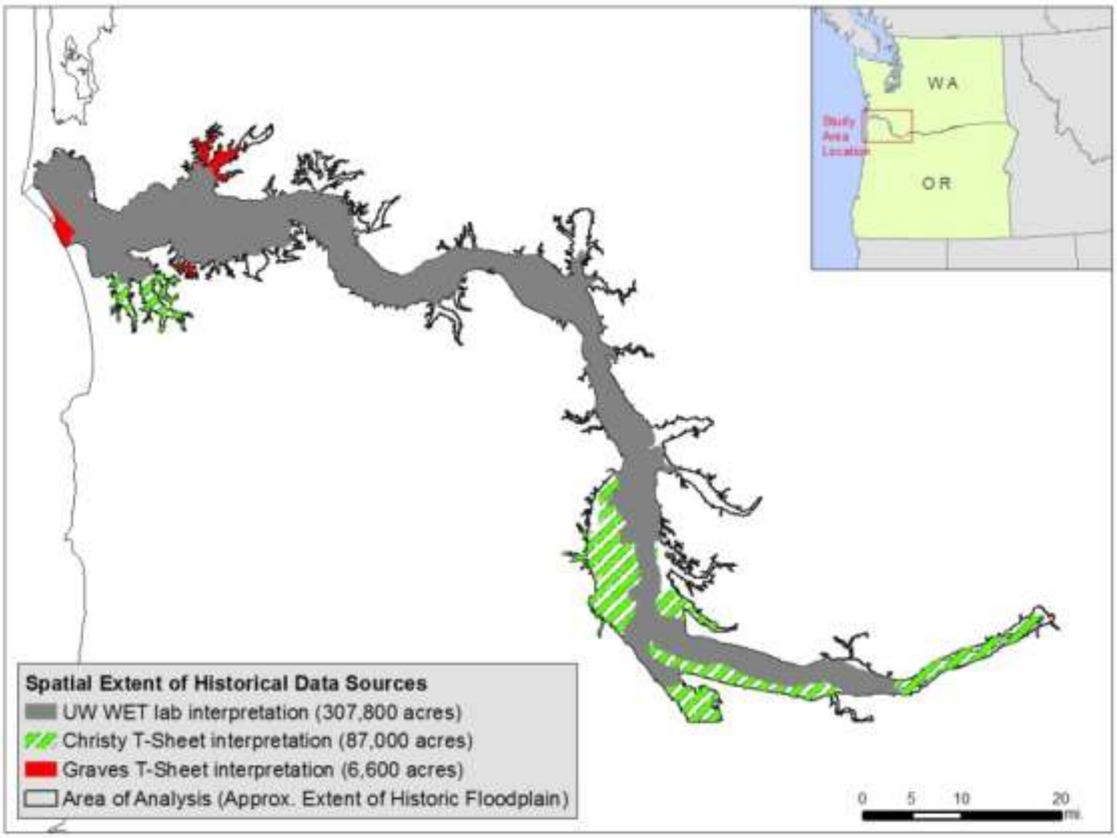


Figure 17. Map showing spatial extent of coverage from each of the historical data sources that was used in the final baseline dataset for land cover change analysis. WET labs data constituted 77% of the total area analyzed, Christy GLO data 24%, and Graves/CREST data the remaining 1%. Note areas within 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' dataset. 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 4 lists the different cover classes from each of the historical sources. Table 5 lists the normalized classes, and the classes from each source dataset that were aggregated into each normalized class.

Table 4. Land cover classes used in the data sources chosen for the baseline historical dataset. 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 dataset 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 Grass: upland, floodplain		Emergent Wetland	Marsh or wet meadow, composition unknown Tidal marsh, salinity undifferentiated Wetland, composition unknown Marsh, composition unknown Wapato Marsh
Orchard: upland, floodplain Cultivated: upland, floodplain		Prairie	Prairie, wet and dry undifferentiated Seasonally or perennially wet prairie Upland and xeric prairie
		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
		Water and Wetlands	Water Bodies > 1 chain across Seasonally flooded lake or pond > 1 chain

Dwellings: upland, floodplain Road: upland, floodplain Levee: upland, floodplain Overwater Structure: floodplain Unclassified		Woodland	Doug Fir - White Oak Doug Fir

Table 5. 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’ Dataset**
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	S	Shrubs: upland,		Doug Fir (Savannah)	Upland Shrub/Scrub

non-wetland		floodplain		Rose or briar thickets Brush fields or thickets on slopes and ridges Brush, composition unknown Brush fields or thickets on bottoms or wet terraces	
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 datasets was converted to these classes, an overlay analysis was performed in ArcGIS, using the 'Union' geoprocessing task. The resulting output was a GIS dataset representing habitat change, with attribute fields representing the original historic class, the current class, and the type of change.

Results

Table 6 shows total acreages of all normalized land cover classes (columns 2 and 3), for both the historical and current datasets. 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 7 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 6. Areas (in acres) of normalized land cover classes for the historic and current datasets (columns 2 and 3). Relative percent coverages for each class with respect to total area analyzed (columns 4 and 5), and relative to total land (non-water) area (columns 6 and 7).

Normalized Land Cover Class	Historic Dataset (acres)	Current Dataset (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 7. Identical results as presented in Table 6 but with the 'forested' and' shrub scrub' wetland classes combined into 'wooded' wetlands classes.

Normalized Land Cover Class	**Historic Dataset (acres)**	**Current Dataset (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	39,439	12,289	-27,150	9.8	3.1	17.2	4.9

tidal wetlands)							

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 8. 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 25,355 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 acres of this class existing presently.

Table 8. 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 5. 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 (Table 7, 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 18). 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 19) are included to help visualize the differences between reaches.

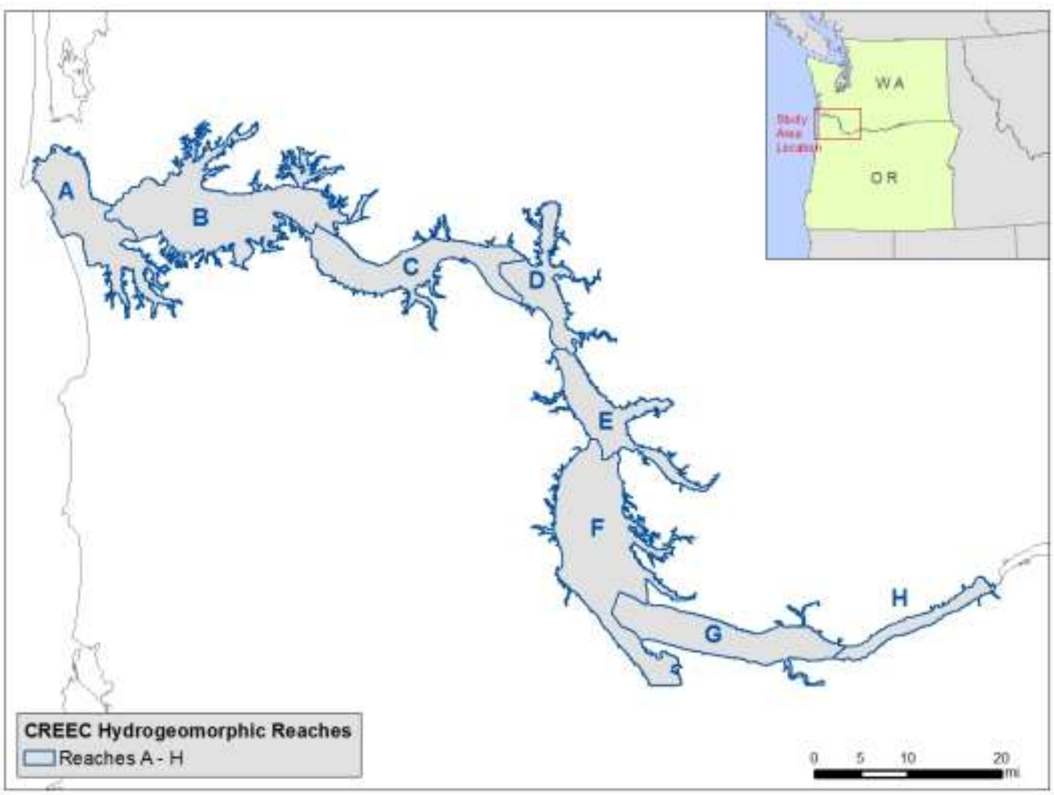


Figure 18. Columbia River Estuarine Ecosystem Classification (CREEC) Level 3 hydrogeomorphic reaches. The reach boundaries comprise the approximate historic floodplain of the LCRE.

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.

FROM: / TO:	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%	

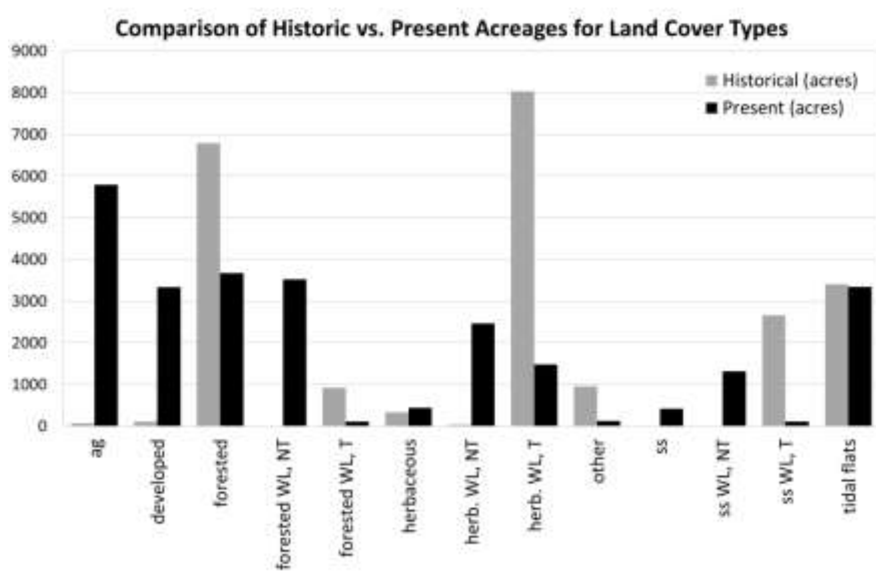


Figure 19a. Comparison of historic versus current acreages for normalized land cover types for hydrogeomorphic Reach A of the LCRE. Note: the combined 'wooded' wetland categories are not shown.

Table 8b: 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%	

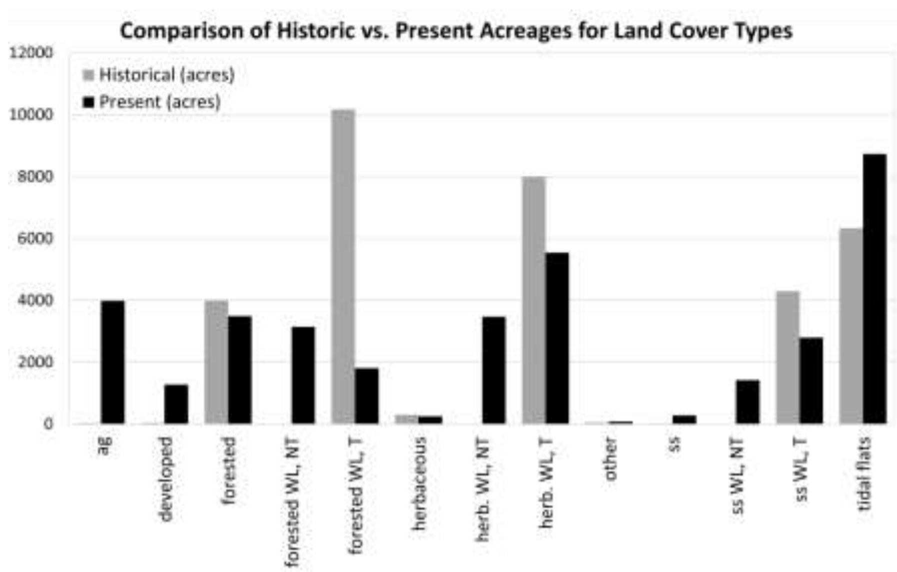


Figure 14b: Comparison of historic versus current acreages for normalized land cover types for hydrogeomorphic **Reach B** of the LCRE. Note: the combined 'wooded' wetland categories are not shown.

Table 8c: 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%	

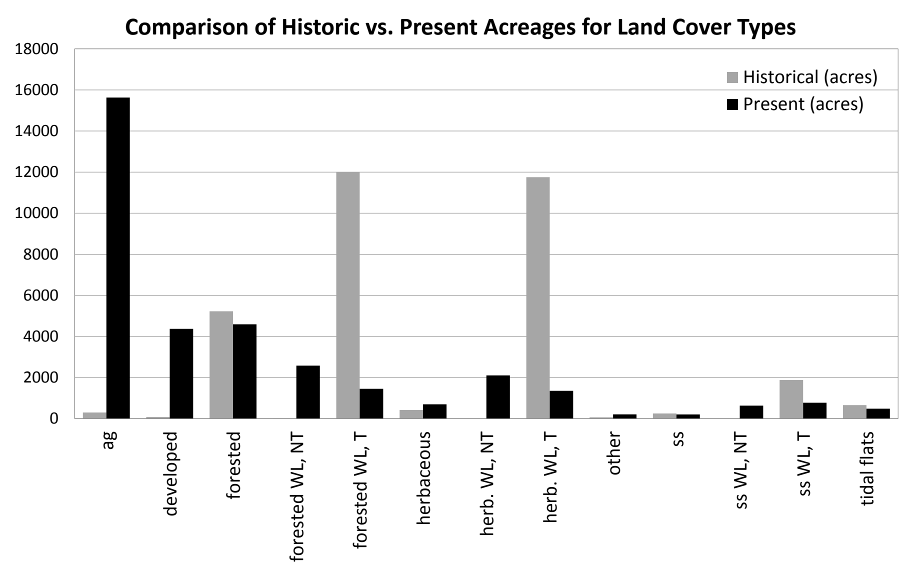


Figure 14c: Comparison of historic versus current acreages for normalized land cover types for hydrogeomorphic **Reach C** of the LCRE. Note: the combined 'wooded' wetland categories are not shown.

Table 8d: 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%	

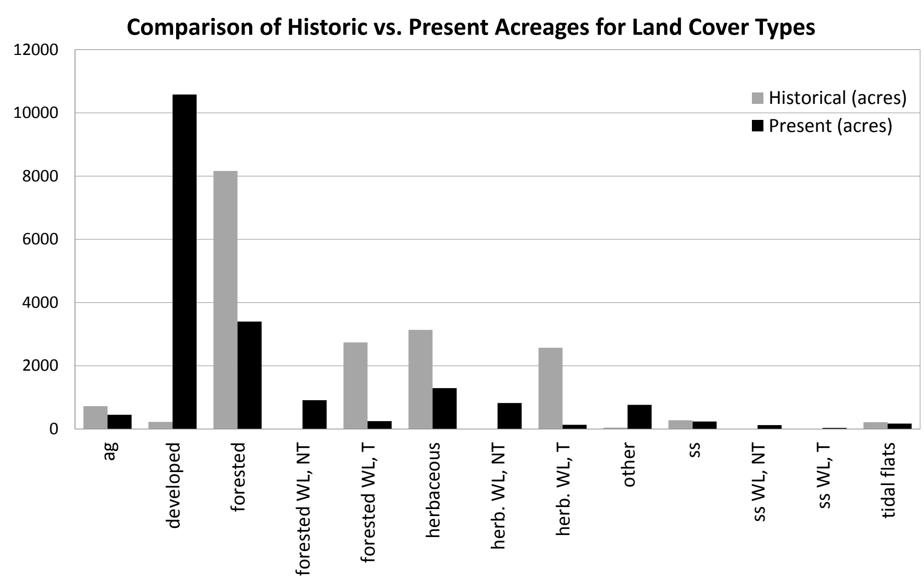


Figure 14d: Comparison of historic versus current acreages for normalized land cover types for hydrogeomorphic **Reach D** of the LCRE. Note: the combined 'wooded' wetland categories are not shown.

Table 8e: 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%	

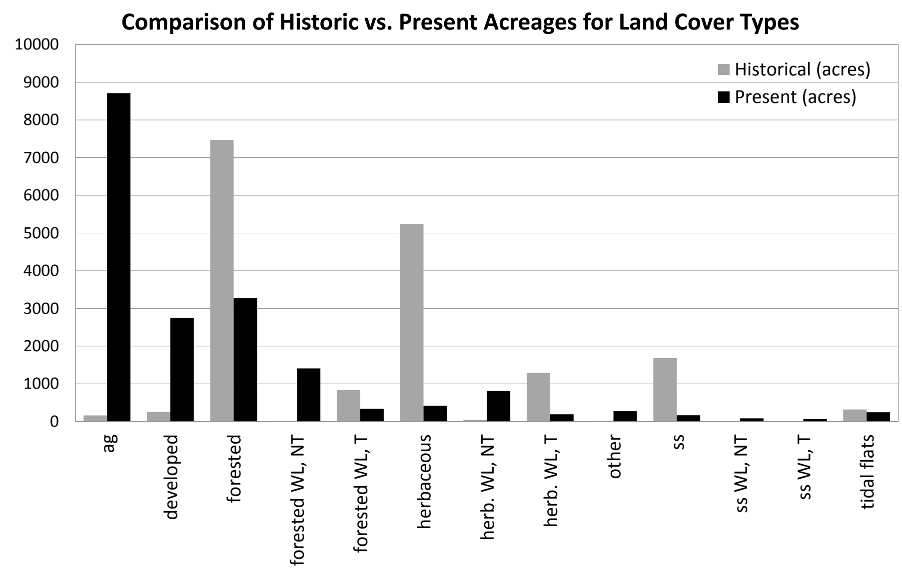


Figure 14e: Comparison of historic versus current acreages for normalized land cover types for hydrogeomorphic **Reach E** of the LCRE. Note: the combined 'wooded' wetland categories are not shown.

Table 8f: 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%	

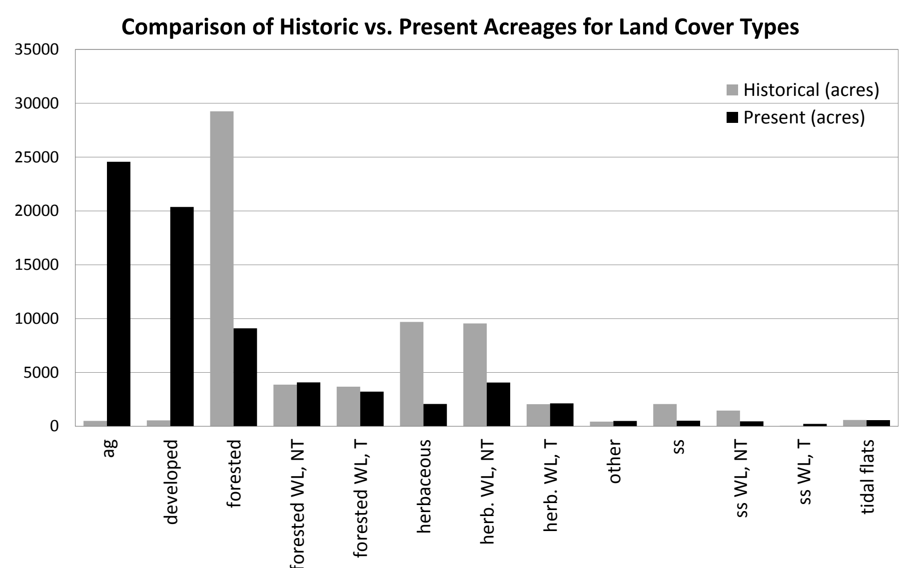


Figure 14f: Comparison of historic versus current acreages for normalized land cover types for hydrogeomorphic **Reach F** of the LCRE. Note: the combined 'wooded' wetland categories are not shown.

Table 8g: 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%	

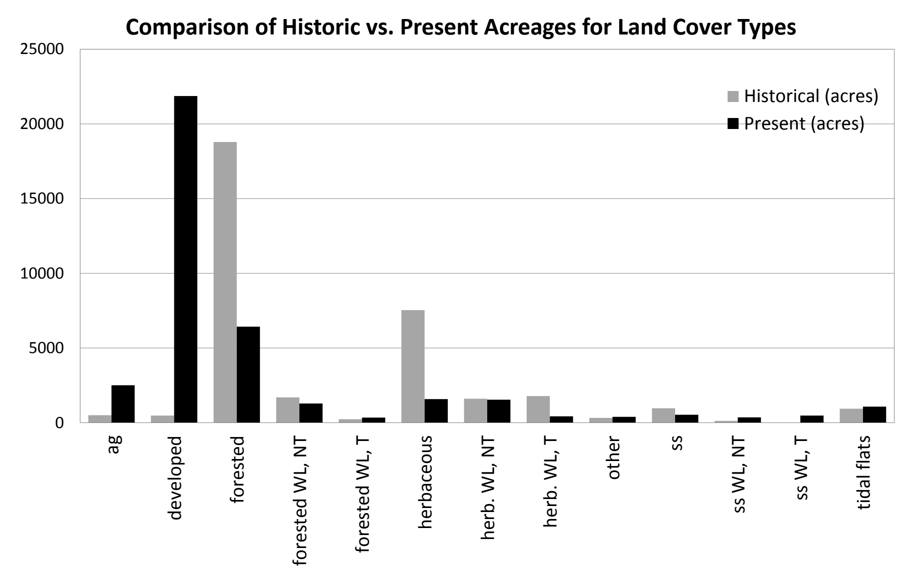


Figure 14g: Comparison of historic versus current acreages for normalized land cover types for hydrogeomorphic **Reach G** of the LCRE. Note: the combined ‘wooded’ wetland categories are not shown.

Table 8h: Matrix showing change (In acres) between normalized land cover classes from 'Historical' to 'Current' time period for hydrogeomorphic **Reach H** 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	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%	

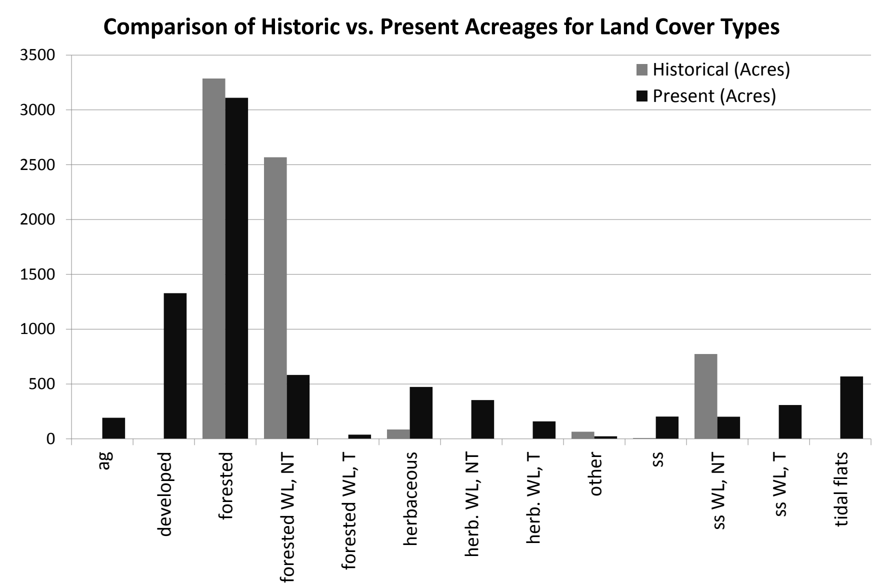


Figure 14h: Comparison of historic versus current acreages for normalized land cover types for hydrogeomorphic **Reach H** of the LCRE. Note: the combined 'wooded' wetland categories are not shown.

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. 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. 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. 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 and Christy et al.) 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 dataset and only represented a small relative source of error, we used the data as is.

Despite the shortcomings we have identified, the historical dataset 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 dataset, 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 dataset 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 dataset (the 'current' dataset 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.

3. Line of Evidence 2 – Habitat Suitability Index Model

Summary

NOAA recommends protecting and restoring shallow water, low velocity and low salinity environments in salmon recovery programs. This analysis maps times and locations where these conditions are met within the mainstem lower Columbia and examines their distribution throughout the lower river. Specifically, we employ a 3-D hydrodynamic model and spatial analyses to predict and map spatial and temporal changes in the availability of suitable migratory and rearing habitat for juvenile "ocean-type" Chinook salmon in the mainstem lower Columbia River. To define conditions suitable for juvenile Chinook, we used criteria from Bottom et al. (2005), updated in Burla (2007), for water temperature, velocity, depth and salinity. We then developed a spatial index of the first three criteria and mapped locations where these thresholds were met for a given frequency of time during low, medium and high river discharge years. Results show spatial and temporal trends in habitat patches. Under all flow conditions, the quantity of suitable habitat patches and size of patches increased moving downstream from Bonneville Dam to the mouth. The opposite trend was seen in the variability of suitable habitat patch size and location as one went upstream between months April – September. There was also an increase in variability in patch size and location between flow conditions. We found river reaches A, B and C having rather stable suitable habitat patches that remained under different flows and months, while upriver, in reaches F, G and H, the opposite was true. The upriver river reaches are characterized by a high variability in suitable habitat patch location and size. Gaps in habitat generally occurred near armored areas, such as around Swan Island, the city of Portland and near Kelso. These results imply that different restoration techniques are needed in order to restore or protect suitable juvenile salmon habitat for upstream versus downstream areas.

Introduction

One of the core tenets of building sustainable restoration programs is the use of adaptive management to test uncertainties through a scientific framework and adapt current methods and practices to reflect the most up to date practices (Thom et al. 2011). Since 2000, there has been growing interest in the relationship between small and individual habitats and the larger ecosystem. These concepts include that spatial location and variance are key to both understand a system and to improve it. Fausch et al. echoed these sentiments in 2002, asking, "*How can we hope to address pressing issues in stream fish management if we abstract patterns and processes from the context that gives them meaning in the first place*". Locally, Simenstad first highlighted the need for the view of the Columbia River Estuary as a corridor for fish (2001), a need similarly echoed by Fresh et al. (2005), Bottom et al. (2005), and the Estuary Recovery Plan Module (NMFS 2011). While these research considerations have been expressed, identifying those key areas across the riverscape for juvenile salmonids had not occurred, and thus has not been incorporated into restoration decision making.

Specifically, NOAA recommends that the following should be considered in designing Columbia River estuary restoration programs:

- Shallow water, low velocity, and low salinity surface environments with associated wetland vegetation are features that define juvenile salmonid habitat,
- Diverse distribution of habitat a surrogate for diversity and spatial structure of salmon population, and
- Preservation and restoration of shallow water, low velocity, and low salinity environments an important strategy for recovery of salmon and to mitigate for anthropogenic modifications (Casillas 2009).

It follows that restoring natural habitat diversity is key to restoring diversity of salmonid life history strategies, especially when focusing on shallow water, low velocity and low salinity areas. The objective of this study was to characterize the lower Columbia River to identify areas for restoration and protection in the lower Columbia River that would enhance habitat for "ocean-type" juvenile salmonid foraging and refuge.

Bottom et al. (2005) described characteristics of this habitat in terms of *habitat opportunity* and *habitat capacity* (Figure 20). Habitat opportunity is the ability to access areas where as capacity is the quality of habitat provided. Looking at the larger system, equally important is where these habitat areas are located in relation to one another and in relation to fish use (Fresh et al. 2005; Bottom et al. 2005). Several recent reports have identified needs, management actions and recommendations for restoration (Johnson et al. 2003; Bottom et al. 2005; Fresh et al. 2005; NMFS 2011). For this study, we focus on identifying *where* restoration implementation may be most effective.

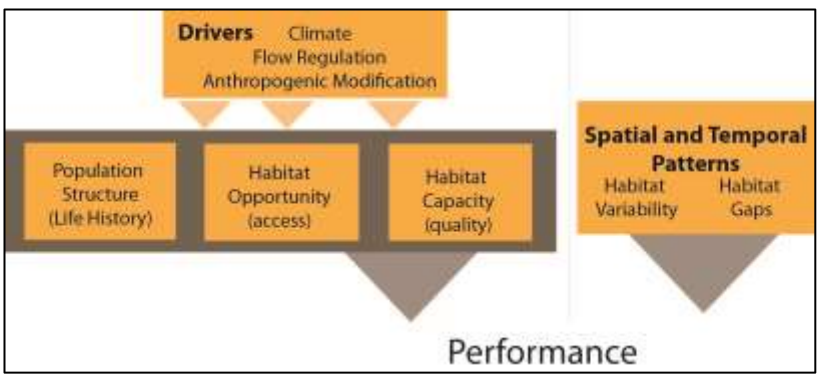


Figure 20. Conceptual Model of Juvenile Salmonid Performance. Left side of diagram adapted from Bottom et al. 2005. Spatial and temporal considerations of variability in habitat under different conditions and gaps between habitats impact performance as well.

All anadromous salmon and steelhead populations within the Columbia River Basin utilize the estuary as a migration corridor. However, Chinook salmon, especially subyearlings, and other salmon such as chum and coho to a lesser degree, can rear extensively in shallow water and vegetated habitats within the estuary, including tidal channels, tributary confluence and nearshore areas (e.g., Bottom et al. 2005; Fresh et al. 2005). These exhibit a range of residence periods depending on the species, from days to weeks (chum) to several months (Chinook) (Thorpe 1994).

Restoration approaches can be directly linked to affecting components in the Conceptual Model in Figure 20. From historical conditions, as related directly to salmonid performance, there are two significant, overriding human drivers on the system: 1- Flow regulation decreases spring flows, and therefore, decreases spring flooding in the floodplains. Under flooded conditions, fish can access and feed in these seasonally wet areas, but in dry conditions, there is no habitat accessible to fish. 2- Artificial diking decreases floodplain areas further, limiting access, use and transport of materials such as marsh macrodetritus and insects from these areas. Studies suggest a near 60% loss in available floodplain habitat during the spring freshet (Kukulka and Jay 2003). Restoration needs include both (1) *Protection of current shallow water habitats and riparian zones* as well as, (2) *Improving total amount of access in terms of area and time available* (Bottom et al. 2005; NMFS 2011).

However, areas within the estuary are dynamic and variable, and a migrating juvenile salmonid experiences not the average amount of habitat opportunity, nor the average capacity over the estuary, but local conditions from freshwater to the estuarine as it travels and uses the area. Thus, ideally, a variety of foraging and refuge opportunities should be available along the migration corridor (Simenstad 2001). Site characteristics such as how big (patch size/edge) and how far (connectivity/distance) may play an important role in maintaining these populations and their diversity (Fresh et al. 2005). We will term this third need as: (3) *Protection and enhancement of areas along the continuum of the estuary to minimize habitat gaps and maximize habitat available.*

Associated with this third need is the need to provide refuge and feeding opportunities at different flow levels and discharge rates. Logistically, with flow regulations at the dam, water levels in the upper reaches may quickly change over time, and thus, the areas available for fish access also change. Bottom et al. (2008) describes this in terms of providing a continuum of different habitat types to support life history diversity, summarizing that depending on migration and use of the estuary, fish use different areas based on what is available to them and needed for them at the time of their passage. Therefore, a fourth need is to: (4) P*rovide habitat under differing flow regimes to increase resilience and support life history diversity* (Fresh et al. 2005). These needs are similar to those identified by the ESA Recovery Plan recommended Management Actions (NMFS 2011).

Spatial habitat suitability models are uniquely appropriate for assessing differences in habitat suitability over a landscape (e.g., Hirzel et al. 2006) and are widely used in management including restoration decision making. The basic tenet is that there are certain areas on a landscape or riverscape, where conditions are more suitable for preservation or restoration than another. Mapping these areas helps both document current conditions and potential areas for resource allocation.

In *Salmon at River's End* (Bottom et al. 2005), a type of habitat suitability model is used to assess differences between present day and historical conditions. Bottom et al. use a series of linked hydrodynamic models (ELCIRC and SELFE) to characterize habitat opportunity in regions across the estuary for present versus historical conditions. In the 2005 assessment, criteria for habitat opportunity were defined by several indices based on species limitations, including thresholds for depth (0.1-2m) and velocity (<0.3m /s) (see Bottom et al. 2005 for review of thresholds). For each node within the model's domain, the number of hours that the point met the conditions was recorded. Time periods evaluated included the annual average as well as the months of May and December to capture high and low flow extremes. In 2007, Burla expanded this original work, examining temperature (<19°C), and salinity (<5 psu) as part of the assessment as well.

Since these original two studies, there have been adaptations and enhancements to the SELFE model. In 2005, one of the primary concerns of the researchers was the utility of the water depth projections with the limited bathymetric data available (Bottom et al. 2005). Recent bathymetric data has been recently used to update the model. In addition, the spatial domain of the model has been extended to the Bonneville Dam. In the past five years, there have been additional field studies that provide more information to threshold selection and additional monitoring data has been collected in shallow water areas that can be used to improve the skill of the model. In addition, while this original work is the result of a hydrodynamic model, there is the potential to transform results into a GIS format, enabling enhanced landscape assessment of changes over time and enabling use with other datasets.

To address our objective, in this study we complete a habitat suitability assessment to inform restoration decision making, specifically to provide baseline information on juvenile salmonid habitat opportunity, identify spatial and temporal gaps in habitats, and identify key limiting factors. The approach leverages methods of Bottom et al. (2005) and Burla's (2007) enhancements, though our objective is to focus on restoration potential rather than historical changes. Thus we adapt criteria and approach to highlight restoration needs. We use the most recent hydrodynamic model, adjust time to capture peak differences among conditions, and update thresholds based on additional research. Finally, results are translated into a GIS format to enable assessment of landscape trends and opportunities with regards to the four restoration goals.

Methods

To identify landscape trends and opportunities associated with the four restoration goals, we followed a three step process:

1) Develop spatially explicit Habitat Suitability Index
2) Map Habitat Suitability Patches under different scenarios, and
3) Calculate landscape and distance metrics under different scenarios.

Each step is described in more detail below.

Develop Habitat Suitability Index

In the lower Columbia River, we needed to consider two aspects of habitat suitability: site suitability and limiting factors at the local scale and connectivity as related to fish access under differing conditions across the riverscape. Our primary concern in developing the habitat suitability index was to use criteria that would be suitable to use across space and sensitive to capture temporal differences.

Hydrodynamic Model

We used the OHSU CORIE SELFE model as the base data for the assessment. This model was also employed for Bottom et al. (2005) and was recently updated with the new Estuary Partnership bathymetry and USACE Terrain model. The model contains over 60,000 nodes, or points that anchor its mesh. For each node within the model domain, the SELFE model predicts water level, temperature, velocity, and salinity every few minutes for all of the vertical layers within the model over multiple years.

To develop the habitat suitability index we:

- Define criteria that thresholds for suitable habitat.
- Identify when and where criteria are met using the CORIE hydrodynamic model
- Develop index to characterize suitability for each node and each scenario

Define criteria and thresholds for suitable habitat

We identified critical time periods, biophysical parameters, and potential sources of variation due to discharge. The criteria used in this assessment are found in Table 10, and are based off of the original work from Bottom et al. (2005). A survey of regional fisheries biologists was conducted in 2011 with these thresholds reviewed. As a result, the threshold for velocity was slightly adapted (*S. Simenstad, N. Sather, D. Bottom, pers comm)*. Seasonal time frames were selected to capture both the extremes in limiting conditions (temperature stations), as well as the periods when the abundance of juvenile Chinook is greatest according to early work by Rich (1920) and McCabe et al. (1986) as well as current finding from on-going research collections (*N. Sather, unpublished)*.

For this assessment, the modeled values for temperature, velocity and salinity within the upper 2m of the water column are averaged. The frequency that this average is exceeded or met within the time frame was recorded for each node by month, and then averaged over the time frame of interest (Table 10).

Table 10. Habitat Suitability Assessment Criteria

Parameter	Criteria	Time frame
Temperature	Frequency below 19°C	8/1 to 8/31 5/1 to 5/31
Water Depth	Frequency between 0.1m and 2.0m	4/1 to 9/30 November
Velocity	Frequency below 0.25 m/s	4/1 to 9/30 November
Salinity	Frequency below 5psu	4/1 to 9/30
Combined Velocity and Temperature	Frequency Temperature below 19°C and Velocity below 0.25 m/s	4/1 to 9/30 November

Discharge and Difference in Habitat

Differences in flow discharge impacts opportunity, capacity and thereby the performance of salmonids (see Figure 20). Amount of discharge from Bonneville Dam can vary tremendously from year to year. Thus, to capture spatial differences in opportunity and capacity, it was important that our model be able to spatially identify where and how habitat is different both locally as well as along the riverscape.

We examined recorded discharge at the dam (Figure 21) and selected three consecutive years: 1999, 2000, and 2001 to represent different flow conditions: high flow (1999), average flow (2000), and low flow. (2001).

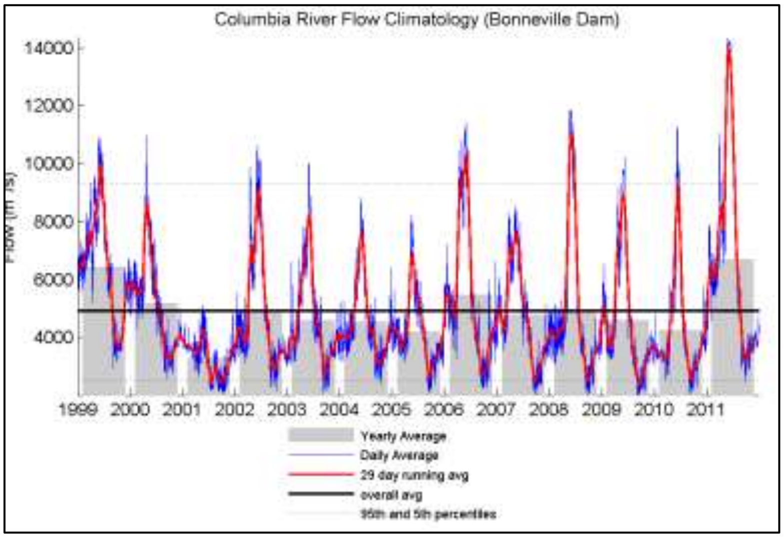


Figure 21. Columbia River Flow at Bonneville (Source: Center for Coastal Margin Observation and Prediction (CMOP), http://www.stccmop.org/).

Identify when and where are criteria are met using the CORIE hydrodynamic model

For each node within the model domain, over each time period, we recorded the frequency that criteria in table 1 were met for each assessment parameter. Nodes were used to create a Triangulated Irregular Network (TIN) and converted to raster datasets with a resolution of 30m.

Develop index to characterize suitability for each node and each scenario

The parameter for combined velocity and temperature as well as the water level metric were binned or reclassified into 6 ordinal classes based on frequency of meeting their respective criteria:

- 0 = <0.01%
- 1 = 1-20%
- 2 = 20-40%
- 3 = 40-60%
- 4 = 60-80%
- 5 = Over 80%

An estuary-wide habitat suitability index was created for the April-Sept season for each flow condition where:

Habitat Suitability Index (HSI) = (RWL *RVT)/25

RWL = Reclassified Water Level Data Value (from 6 classes above)
RVT = Reclassified Velocity/Temperature Data Value (from 6 classes above)

For the purpose of this assessment, scores of 0.08 – 0.16 are considered moderate, 0.16 to 0.4 as high, and above 0.4 as very high. Table 11 provides some examples of HSI values linked to water level, velocity and temperature criteria.

Table 11. Example of Habitat Suitability Index Values. Scores greater than 0.16 are considered as high suitability and greater than 0.4 as very high suitability. Total number of hours in this time period is 4,392.

% Time Water Level Meets Criteria	In Hours	Score	% Time Velocity and Temperature Meets Criteria	In Hours	Score	HSI	Suitability
1-20%	44 - 879	1	1-20%	44 - 879	1	0.04	Low
20-40%	880-1757	2	20-40%	880-1757	2	0.16	Mod
40-60%	1758-2619	3	60-80%	1758-2619	4	0.48	Very High
20-40%	880-1757	2	40-60%	1758-2619	3	0.24	High

Map Habitat Suitability patches under different scenarios

High habitat suitability patches, defined as areas with a HSI > 0.16 and a contiguous area > 1ha were mapped for each of the three flow scenarios in the estuary. The resulting raster datasets were reclassified into binary values of either 1-meeting criteria or 0- not meeting HSI and area criteria. Areas with very high suitability (HSI> 0.4) were identified as well for each flow condition. Within the model, there were some anomalies with water “pooling” within some of the diked areas. After review, these areas were eliminated from the habitat suitability model patch results.

Calculate landscape and distance metrics under different scenarios

Stable patch area and change per year were identified and gaps between habitat patches for the same flow year were mapped. Details of these assessments and their relationship to the four restoration goals can be found in Table 12.

Table 12. Assessment of Restoration and Conservation Areas

Restoration Goal	Restoration Metric	Assessment Methods
Protect currently functioning areas	Identify areas from HSI that consistently provided refuge access under three different flows. Results are mapped and integrated over hydrogeomorphic units	The three raster datasets representing habitat patches from above were queried on a pixel by pixel creating a third binary dataset, where: Stable Habitat = Habitat in 2001(low flow) & Habitat in 2000 (moderate flow) & Habitat in 1999 (high flow). Only areas where the same pixels were identified as meeting the HSI and area criteria in all three years were mapped.
Increase the total amount of access in terms of area and time available	Identify areas with low or variable frequencies of meeting limiting factors in terms of water temperature during year and single	Annual and inter-annual variability for water level was examined for each node, difference between minimum and maximum frequencies per year and per month were identified.

	months	Finally, for each limiting criteria, zones where the average frequency between flows differed by greater than 10% were identified.
Identify gaps	Identify areas where there is a long distance (as the fish swims between refuge opportunities)	*Path distance* is a term used to refer to the distance along a route or path. This differs from Euclidean distance which is the shortest distance between two points. In the case of salmonids, Euclidean distance does not capture the distance that the fish must swim. Rather, they must swim around barriers such as islands, and the routes they must take must be aquatic. Thus, path distance between the stable habitat patches was calculated, using land forms as boundaries. Areas with a greater than 1000 m distance between patches were identified.
Identify Matrix of Habitats	Identify areas of high variability, where under different flow conditions, an adjoining area provides opportunity	Habitat patches from the three years were compared using raster math, developing one dataset that showed all of the areas (by pixel) that met the habitat criteria under any of the different flows, and one dataset that represented areas that always met the criteria Refer to Figure 22 (Stable Habitat from protection goal). Zones with areas marked as "always" surrounded by areas as "at any time" were identified.

Results

Habitat suitability was mapped for all three flow conditions (Figure 22). Habitat suitability scores were generally higher nearer the mouth of the Columbia River than near the dam and low flow conditions showed lower habitat suitability in all areas.

Habitat patches shows a continuum of responses and variability from Bonneville Dam to the mouth of the Columbia River (Figure 23 a, b). In all flow conditions, the percent of reach with habitat patches increased going from the dam to the mouth, as did the habitat patch size. Salinity had been eliminated from the analysis, which could be a complicating factor in the sites nearer the mouth. Spatial and temporal variability increased in the opposite direction, from the mouth to the dam, there was an increase in variability of patch size and location between months (April – September) for all flow conditions. There was also an increase in variability in patch size and location between flow conditions. For ease of reference to these difference conditions, we defined three zones of response: Zone 1 with reaches A, B and C. Zone 2 with reaches D & E and Zone 3 with reaches F, G, and H. Zone 1 was characterized by a low variability in patch size and location under differing flows and between months. Zone 3 was characterized by a high variability in location and size.

Gaps in habitat generally occurred near armored areas, for example, up and downstream of Swan Island, Portland on the Willamette River, near Kelso, and up and downstream of the Lewis and Clark Bridge on the Columbia River. Other areas, such as up and downstream of Hewlett Point near the confluence of the Columbia and Willamette were also identified as gaps in habitat.

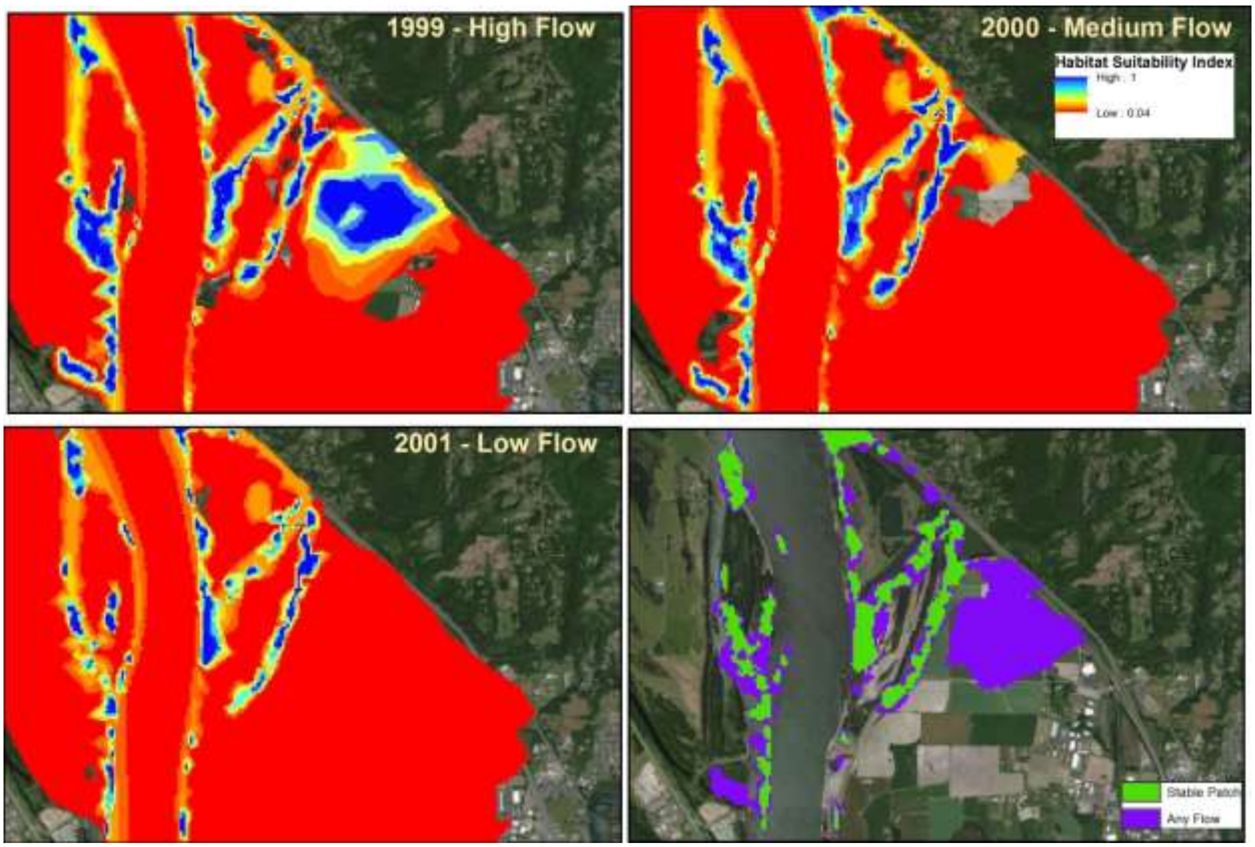
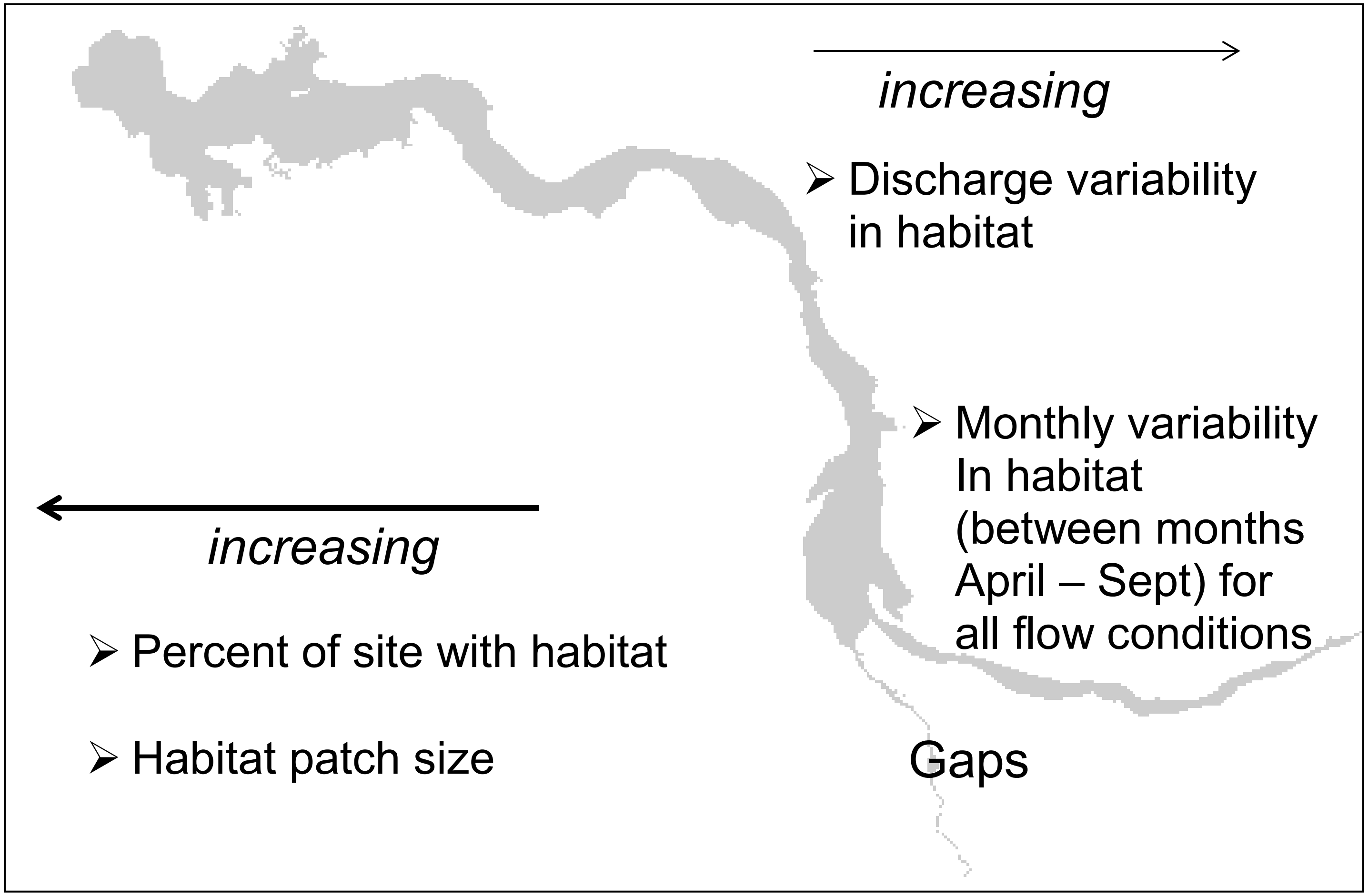


Figure 22. Sample of results for Habitat Suitability Index for three flows (upper and lower left). Example of areas that would be identified as “Stable Refuge” (green) and “Any Refuge” (purple) in lower right.


increasing
Discharge variability in habitat
Monthly variability In habitat (between months April – Sept) for all flow conditions
increasing
Percent of site with habitat
Habitat patch size
Gaps

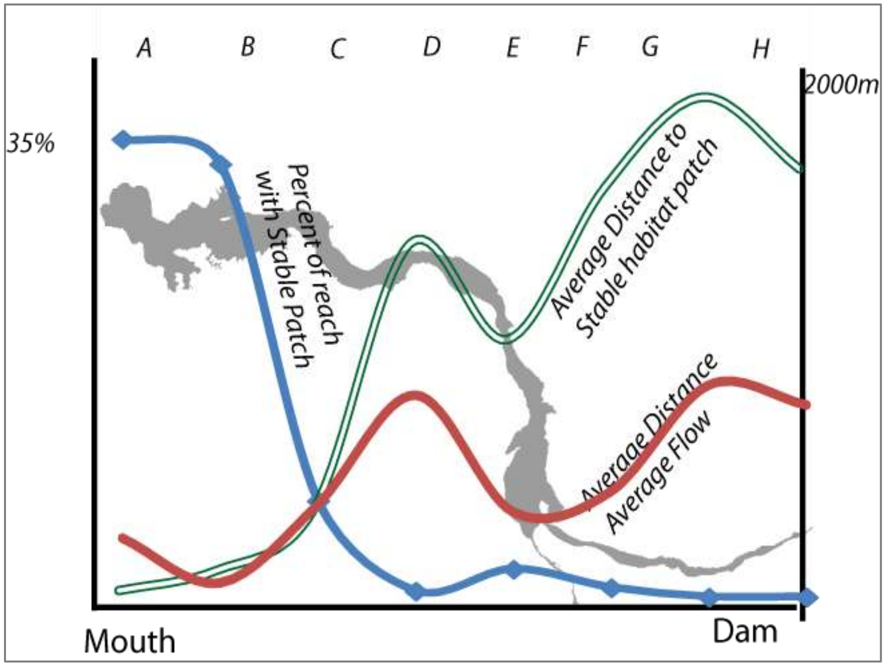


Figure 23a, b. Riverscape trends in habitat suitability. Figure a (top). Spatial and temporal variability in habitat extent and quality increases from the mouth to Bonneville Dam. Percent of site with habitat and patch size increase in the reverse direction. Figure b (bottom). Responses are not linear. The amount of reach with stable patches decreases on an asymptote after reach B, and distance between stable patches likewise increases going from the mouth to the same. Under average flow conditions, these differences are not as pronounced. Reach D, however, stands out as an anomaly in the trends. It contains less habitat with greater distances between habitat patches.

Individual Parameter

Individual biophysical parameter results are summarized in Table 13.

Table 13. Trends in model factors across the estuary

Parameter	Criteria	Results
Temperature	Frequency below 19°C	**Estuary:** Temperature threshold is exceeded in most areas in August, though there are forecasted cooler areas. **Spatial trends of significance:** In 2001, the representative low discharge year, there are fewer refuge areas in higher reaches (closer to the dam) than in areas closer to the mouth. As the fish travels, Cathlamet Bay is the first large refuge area between Bonneville Dam and the mouth in low flow conditions. There are smaller pockets between the dam and mouth.
Water Depth	Frequency between 0.1m and 2.0m	**Estuary:** Across the Lower Columbia, areas nearer the mouth are more consistent in access throughout different flows, with the same point nearer the dam may provide access under one flow, but not another. **Spatial trends of significance:** Refuge and access opportunities up stream are more flow dependent than sites towards the mouth.
Velocity	Frequency below 0.25 m/s	During all flow scenarios, the estuary and off channel areas provide low velocity refuges. Channelized areas under all flow scenarios have few areas that meet the velocity thresholds **Spatial trends:** There is low spatial difference between flow conditions.
Salinity	Frequency below 5psu	In low flow years, the average salinity is higher farther upstream. After discussing with Science Workgroup, this factor was eliminated from analysis.

Discussion - Application of Results to Restoration

The results from this analysis can be used in a *top down* approach to strategically locate potential conservation or restoration sites throughout the estuary to address limiting factors or increase resilience. Similarly, local and regional trends can be used in a *bottom up* approach to identify potential limiting factors and restoration trajectories for potentially new restoration sites.

While we developed one habitat suitability index across the estuary, there is a fundamental difference across the estuary driven by discharge. Points nearer the dam were always more variable in suitability due to water level within a year and between years. Often adjoining areas to a good habitat patch in one year, that would be at a slightly different elevation, would receive a higher suitability score in the following year with a different flow. Because of this variability in water level, areas near the dam had very few identified “stable habitat patches”. This is critical for restoration planning. Developing a matrix of protected or restored habitats, that is one habitat adjoining another with differing elevations will be necessary for the higher reaches.

This fundamental variability in habitat suitability could have an impact on assessing restoration projects. Valuing restoration potential by forecasted inundation time alone per unit area will always result in sites with similar characteristics located nearer the mouth being ranked higher than those near the dam. For the recommendations below, we acknowledge this difference and separate out the concept of protecting habitat patches from protecting matrices of patches.

Table 14 applies assessment results to potential restoration priorities by reach and zone; these are summarized visually in Figure 24.

Table 14. Restoration Approaches by Zone

	Zone 1	**Zone 2**	**Zone 3**
Protect Currently Functioning Areas	High Priority. These areas provide consistent access to large areas of benthic habitat, though fluxes in salinity may be a stressing condition in reach A. During Low Flow conditions, Cathlamet Bay provides some of the largest zones of refuge both in area and time inundated and Grays Bay to the north providing consistent but smaller areas. Considering time inundated, the value of unique restoration approaches to enhance tidal and mud flat areas should be further studied.	Protecting functioning areas is a priority in zones 2 & 3, but in this context, it should be considered with conserving adjoining habitats. This is necessary to provide multiple refuge opportunities for different life history strategies and under different discharge conditions.	
Increase Access	Increasing access, particularly to diked areas will likely yield consistent opportunities. However, multiple access opportunities on the main channel exist. Tributaries were not examined in this study.	Priority.	High Priority. Areas in reaches F and G both have diked areas and limited access in hours.
Gap Reduction		High Priority. Areas, particularly developed areas in zones D-G have long distances between habitats.	
Protect or Restore Matrix of Habitats		Developing a matrix of adjoining habitats or areas that would provide refuge at different times of the year and under different flow conditions is needed. In reaches D, F, and G, there appears to be specific opportunities where stable habitat adjoins flow dependent habitats. These areas should be looked at in conjunction with the habitat change analysis to prioritize areas for restoration.	

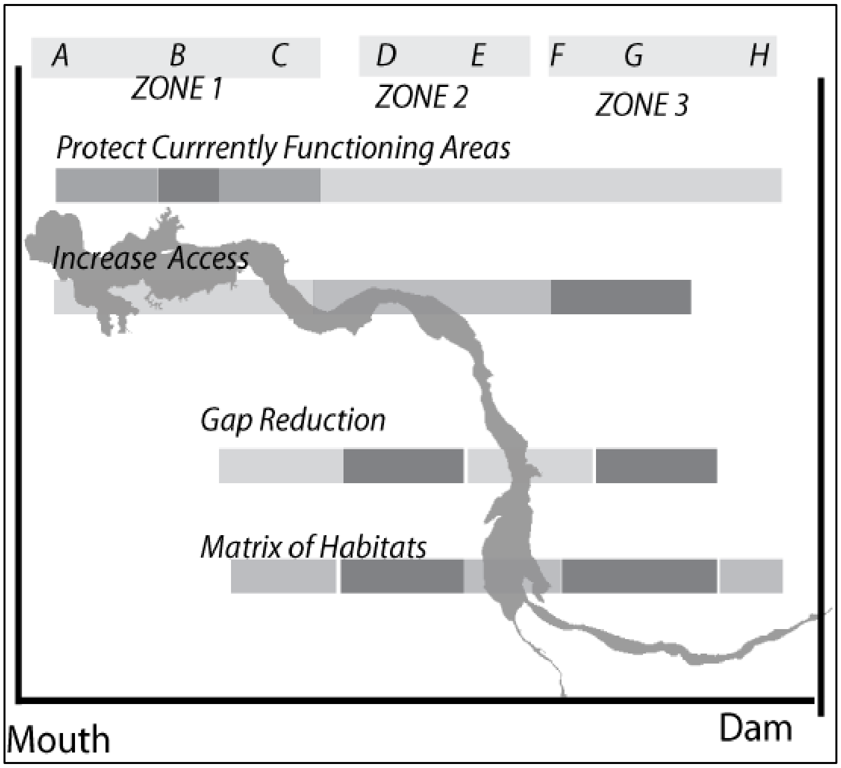


Figure 24. Restoration approaches by reach and zones. The darker the shading, the higher the restoration priority across area.

Reach D appears to be an anomaly in the general trend of distance between habitats and habitat patches, with greater gaps and smaller patches. Before enhancement of attributes (temperature, velocity, etc.), direct site restoration should be considered to provide additional refuge opportunities.

The habitat suitability index can be used with the aforementioned priorities in restoration to identify specific areas within reaches to apply approaches.

- Areas with very high habitat suitability scores (> 0.4) in higher reaches should be considered for protection and restoration of adjoining habitats.
- Areas with high habitat suitability scores (>0.16) in all flow conditions and large (>1ha) adjoining areas that depending on flow have high suitability should be considered for acquisition or restoration.
- Areas with moderate suitability scores (0.08 - 0.16) should be examined to see if limiting factors can be improved.
- Areas with very high suitability scores (> 0.4) in the lower reaches should also be examined for protection and enhancement opportunities
- Areas identified as having gaps in habitat should be examined for microhabitat

The model results could help define the probability of success of proposed projects, connectivity associated with various reaches in the system, and habitat quality, the latter of which is partly defined by temperature and habitat complexity.

The recommended application of the model results for identifying priority areas for protection and restoration are explained in Section 6 below. This method was vetted by the Science Work Group in fall and winter 2011.

4. Line of Evidence 3 – Lower Columbia River Salmonid Recovery Plan Priorities

Summary

This Line of Evidence supports the Oregon and Washington salmon recovery plans for Lower Columbia River ESUs. It focuses on habitats within tidally influenced areas of tributaries and along the mainstem that are used extensively for juvenile salmonid rearing and are as a result, essential for salmonid recovery. Specifically, this analysis emphasizes Lower Columbia River fall Chinook and chum populations, which demonstrate "ocean-type" life history strategies. The tidally influences areas within tributaries designated within the plans for primary populations for *both* ESUs were identified here as very high priority for protection and restoration actions. Those tidally influenced areas within tributaries designated within the plans for a primary population for one of the ESUs were identified as high priority. Along the mainstem lower Columbia River, we used a simple weighting system to prioritize areas immediately downstream and within 25 kilometers of tributary confluences for primary fall Chinook populations, following NMFS recommendations in the 2010 "Tule" Harvest Biological Opinion.

Introduction

This Line of Evidence specifically focuses on supporting the recovery of Lower Columbia River Chinook salmon (*Oncorhynchus tshawytscha*), Columbia River chum salmon (*O. keta*) and where habitat requirements overlap in the mainstem and tidal tributaries, Lower Columbia River steelhead (*O. mykiss)* and Lower Columbia River coho salmon (*O. kisutch*). All of these salmonids spawn and rear in the lower Columbia River or its tributaries in Oregon and Washington and were listed as threatened under the Endangered Species Act (ESA) between 1998 and 2005 (NMFS 2012). Each is considered an evolutionarily significant unit (ESU) or, for steelhead, a distinct population segment (DPS) (NMFS 2012), hereafter termed "species" or "ESU".

The focus of this analysis on these two species, Chinook and chum, results from their "ocean-type" life history, meaning that juveniles begin migrating downstream at 1 to 4 months old and make extensive use of the habitats along the mainstem Columbia River and/or tidal tributaries before entering the ocean (NMFS 2012). Steelhead and coho have more "stream-type" life histories, meaning they rear more in freshwater areas and pass through the mainstem lower Columbia and tidal tributaries relatively rapidly. While it is important to support the entire life cycle of all four ESUs (i.e., the entire migratory route in the mainstem and tidal tributaries), we chose to prioritize those habitats within our study area that are used extensively by juveniles for rearing and refugia. It should be noted that researchers find coho and to some extent steelhead in many of these habitats. As a result, while we are explicitly focusing on supporting Chinook and chum populations under this analysis, we will also be providing benefits to coho and steelhead in many cases.

For the geographic areas of the tidally influenced portions of tributaries in Washington and Oregon, this Line of Evidence draws heavily from two documents:

- *The Oregon Lower Columbia Conservation and Recovery for Salmon and Steelhead* (ODFW 2010) - encompasses the Lower Columbia River salmonid populations within Oregon, including the tidal Willamette River.
- *Washington Lower Columbia Salmon Recovery and Fish & Wildlife Subbasin Plan* (LCFRB 2010) - encompasses the Lower Columbia River salmonid populations in southwest Washington below Bonneville Dam.

ODFW and LCFRB developed these plans, respectively, with NMFS and stakeholder committees that included representatives from government agencies, tribes, industry and environmental organizations, as well as the public. These plans will be updated periodically, necessitating an update to this Line of Evidence.

For the mainstem lower Columbia River, this Line of Evidence incorporates the work by NMFS described in Cooney and Holzer (2011) (updated for this effort) used in the 2010 Lower Columbia "Tule" Harvest Biological Opinion. The authors of this work anticipate incorporating additional analyses in the near future; this aspect of this Line of Evidence should also concomitantly be updated when relevant.

Methods

Tidal Tributaries in Washington and Oregon

The Oregon and Washington recovery plans describe target statuses for each ESU. The plans describe which populations to target for the different levels of viability and how they reached these determinations (quoted from NMFS 2012):

1. "Evaluated the baseline status of their respective populations using techniques based on those recommended by the Willamette-Lower Columbia Technical Recovery Team (WLC TRT).

2. Identified limiting factors for each Lower Columbia River salmon and steelhead population.

3. For each population, quantified the estimated baseline impacts of six categories of threats—tributary habitat loss and degradation, estuary habitat loss and degradation, hydropower, harvest, hatcheries, and ecological interactions.

4. Established a target status for each population, taking into consideration (1) each population's potential for improvement, in view of available habitat and historical production, (2) the degree of improvement needed in each stratum to meet WLC TRT guidelines for a viable ESU, and (3) for some ESUs, the desire to accommodate objectives such as maintaining opportunities to harvest hatchery-origin fish.

5. Calculated the improvements in abundance and productivity and, in some cases, spatial structure and diversity, that each population would need to achieve its target status (i.e., to close the "conservation gap," which is the difference between the baseline and target status for each population).

6. Identified a “threat reduction scenario” for each population, meaning a specific combination of reductions in threats that would lead to the population achieving its target status.

7. Identified and scaled recovery strategies and actions to reduce threats by the targeted amount in each category. Management unit planners identified recovery strategies and actions through workshops and meetings with stakeholders, including representatives of implementing and affected entities.

8. Considered the probable effects of actions, established benchmarks for implementation, and identified critical uncertainties and research, monitoring, and evaluation needs for each species.

9. Developed implementation frameworks that address organizational structures for implementation of the actions, prioritization methods, tracking systems, coordination needs and approaches, and stakeholder involvement.”

ESU populations within Oregon and Washington are targeted for one of three statuses:

- “Primary” - populations targeted for viability, meaning high persistence probability

- “Stabilizing” - populations expected to remain near their current status (usually low) because the feasibility of recovery is low and a high level of uncertainty of success

- “Contributing” - populations fall in the middle and are targeted for some improvement in status (NMFS 2012).

Primary populations are those targeted for restoration to a high persistence probability. Many of these populations now have a medium persistence probability, and some are even low. However, they are targeted for high persistence probability in order to achieve a high probability of stratum and ESU persistence. Contributing populations are those for which some restoration will be needed to achieve an average persistence probability across the stratum. Stabilizing populations are those that are targeted for maintenance at their baseline persistence probabilities, likely to be low. A population is designated as stabilizing if the feasibility of restoration of the population is low and there is a significant amount of uncertainty associated with restoration. Considerations for these designations include the feasibility of reducing predation, harvest, habitat, hatchery and hydropower impacts and their associated mortality rates.

Mainstem Columbia River

The focus in the geographic region is on protecting and restoring habitats along the mainstem important for ocean-type salmonids, specifically Lower Columbia fall Chinook salmon. These salmonids are associated with relatively short tributary rivers entering the lower Columbia mainstem. Research of ocean-type Chinook salmon in British Columbia, Puget Sound and the Oregon coast demonstrate that significant portions of juveniles may migrate downstream shortly after emergence (e.g., cited in Cooney and Holzer 2011: Lister and Genoe 1970; Reimers 1973;

Healy1980; Carl & Healy 1984; Levings et al. 1986; Bottom et al. 2005), and each of these studies highlights the importance of lower tributary and mainstem intertidal habitats as rearing areas for migrating juvenile Chinook (Cooney and Holzer 2011).

Cooney and Holzer 2011 developed a simple method for estimating the relative capacity for extended rearing in reaches downstream of each Lower Columbia fall Chinook population designated as primary in the Lower Columbia Salmon and Steelhead Recovery Plan (NMFS 2012). In their analysis, estimates of the amount of currently available intertidal rearing habitat in 1 km reaches extending downstream from the natal spawning/rearing areas used by each primary population were accumulated and summarized. The analyses applied a weighting factor based on a spatially explicit relationship derived from empirical sampling for juvenile densities across the Skagit delta (see Beamer et al. 2005). In the Skagit delta study, the relative density of rearing pre smolts dropped off as a linear function of the inverse of the distance downstream from entry into the estuary and with the number of channel branching upstream of a given piece of habitat. Cooney and Holzer 2011 assumed that the same basic relationship applies to pre smolts originating from each of the primary Lower Columbia populations.

Specifically, Cooney and Holzer 2011 used a relationship documented in Beamer et al. 2005 that habitat use by juvenile fall Chinook, as measured by relative juvenile densities, dropped off as a function of distance and channel complexity (number of alternative pathways) in the Skagit delta at a relationship of 1/distance, ultimately leveling off at a distance of approximately 24 km. Cooney and Holzer 2011 adapted this relationship and used the results to generate weighted estimates of the amount of downstream rearing habitat potentially available to each of the primary lower Columbia fall Chinook populations. Essentially, they chopped the mainstem lower Columbia downstream from the centerline of those tributaries designated “primary” for fall Chinook into 1 km segments and then assigned relative weights (0 to 1 as a function of 1/distance) to each segment. Based on the Skagit data, they assumed that habitats more than 25 km downstream were unlikely to support juvenile rearing, and these areas received a 0.

Results

Tidal Tributaries in Washington and Oregon

Table 15 lists the target statuses for all ESUs in each tributary in Washington and Oregon. Those tributaries that are targeted primary populations for fall Chinook or chum are highlighted in light green. Those that are targeted primary populations for both fall Chinook and chum are highlighted in darker green. We chose to weigh those tributaries target as primary populations for both fall Chinook and chum higher than those targeted for one of the ESUs. These were then weighted higher than those tributaries not targeted as primary for either ESU. The exception to this is Grays River in Washington, which LCFRB considers of very high priority because of its stronghold, legacy chum population.

Table 16 then lists the results of this simple prioritization scheme. The tidally influenced portions of these tributaries are priority for restoration and protection actions over the tidally influenced portions of the remaining tributaries in Oregon and Washington below Bonneville Dam (Figure 25).

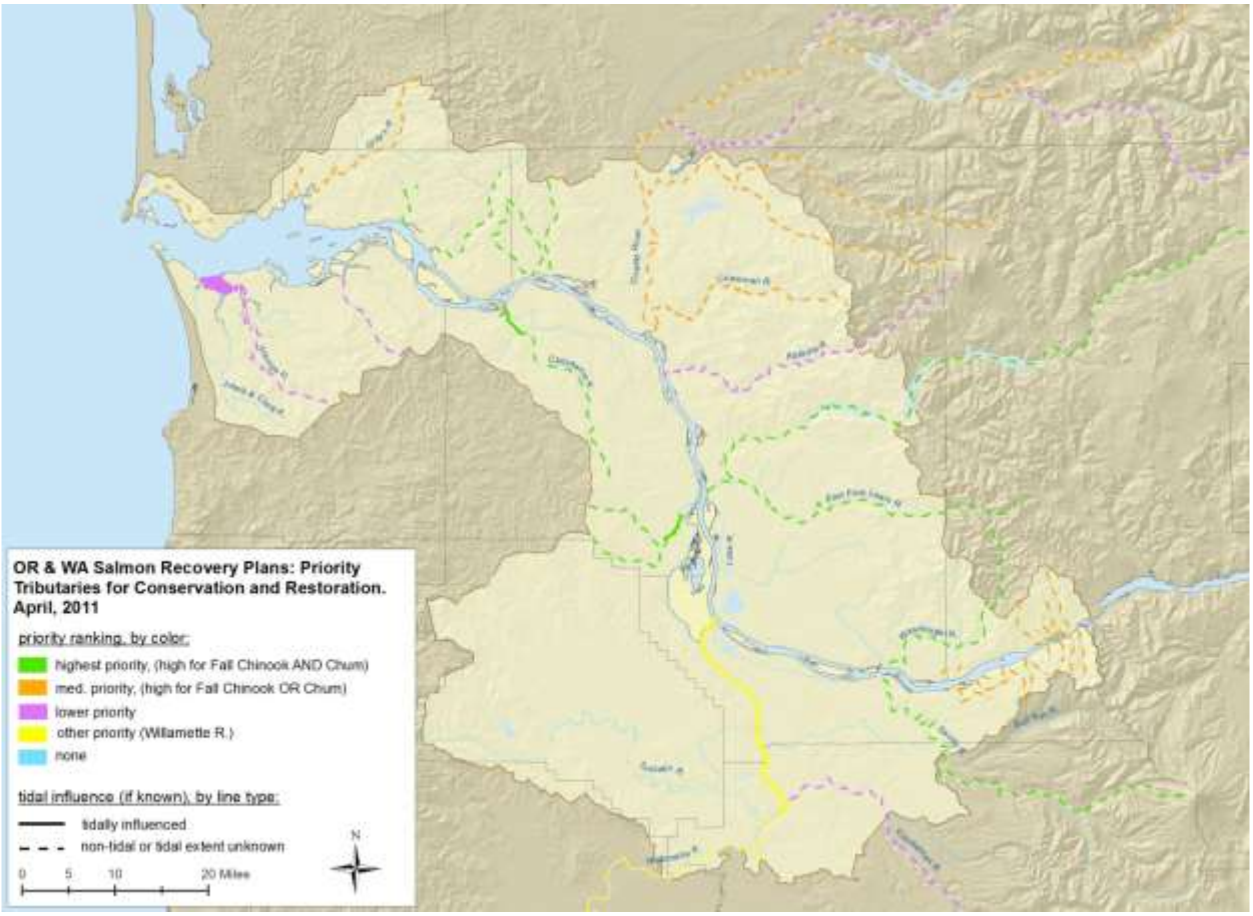


Figure 25. Results of Prioritization of Tributaries in Oregon and Washington Recovery Plans

Mainstem Columbia River

The results of Cooney and Holzer (2011) are presented in a map of the lower Columbia River (Figure 26) and in Table 17. Essentially, all mainstem areas immediately downstream and within 25 km of a tributary targeted as primary for fall Chinook are designated higher priority for restoration and protection actions than those areas that fall outside the 25 km buffer. Within the 25 km buffer, the priority, which is weighted from 0 to 1, 1 being highest, also decreases for each kilometer as one travels farther downstream from the confluence of the tributary.

Table 15. Target Status for all Lower Columbia Salmon and Steelhead populations (from ODFW 2010 and LCFRB 2010). Tributaries targeted for primary populations for fall Chinook **or** chum are highlighted in light green. Those that are targeted primary populations for **both** fall Chinook and chum are highlighted in darker green.

	Lower Columbia River Chinook Salmon			**Lower Columbia River Coho salmon**	**Columbia River Chum salmon**		**Lower Columbia River Steelhead**	
Tributary	spring	fall	late fall		summer	fall	winter	summer
Youngs Bay		stabilizing		stabilizing		stabilizing		
Big Creek		contributing		stabilizing		stabilizing		
Chinook, Deep, Wallacut Rivers		contributing		primary		**primary**	primary	
Grays River		contributing		primary		**primary**	primary	
Skamakowa Creek		**primary**		primary		**primary**	contributing	
Elochoman River		**primary**		primary		**primary**	contributing	
Mill Creek		**primary**		contributing		**primary**	primary	
Abernathy Creek		**primary**		contributing		**primary**	primary	
Germany Creek		**primary**		contributing		**primary**	primary	
Clatskanie River		**primary**		primary		**primary**		
Scappoose River		**primary**		primary		**primary**		
Cowlitz River		contributing		primary	contributing	contributing	contributing	
Toutle SF	contributing	**primary**		primary			primary	
Toutle NF	contributing	**primary**		primary			primary	
Upper Cowlitz	primary	stabilizing		primary			primary	

Cispus	primary	stabilizing		primary			primary	
Tilton	stabilizing	stabilizing		stabilizing			contributing	
Coweeman River		**primary**		primary		contributing	primary	
Kalama River	contributing	contributing		contributing		contributing	primary	primary
Lewis River (North Fork)	primary	**primary**	**primary**	contributing		**primary**	contributing	stabilizing
Lewis River (East Fork)		**primary**		primary		**primary**	primary	primary
Salmon Creek		stabilizing		stabilizing		stabilizing	stabilizing	
Willamette River	primary	contributing		primary		contributing	primary	
Clackamas River	primary	contributing		primary		contributing	primary	
Washougal River		**primary**		contributing		**primary**	contributing	primary
Sandy River	**primary**	contributing	**primary**	primary		**primary**	primary	
Lower Gorge Tributaries		contributing		primary		**primary**	primary	

Table 16. Results of prioritization scheme using Oregon and Washington recovery plan priorities. Tidally influenced areas in these tributaries are designated priority over tidally influenced areas of remaining Oregon and Washington tributaries.

Prioritization	Tributary
Very high priority	Grays River
	Skamakowa Creek
	Elochoman River
	Mill Creek
	Abernathy Creek
	Germany Creek
	Clatskanie River
	Scappoose River
	Lewis River (North and East Forks)
	Washougal River
	Sandy River
High priority	Chinook, Deep, Wallacut Rivers
	Cowlitz River
	Toutle South and North Forks
	Upper Cowlitz
	Cispus
	Tilton
	Coweeman River
	Lower Gorge Tributaries

Table 17. Tributaries in Oregon and Washington targeted as primary populations for Lower Columbia fall Chinook.

Tributary
Skamakowa Creek
Elochoman River
Mill Creek
Abernathy Creek
Germany Creek
Clatskanie River
Scappoose River
Cowlitz River
Toutle South and North Forks

Coweeman River
Lewis River (North and East Forks)
Washougal River
Sandy River

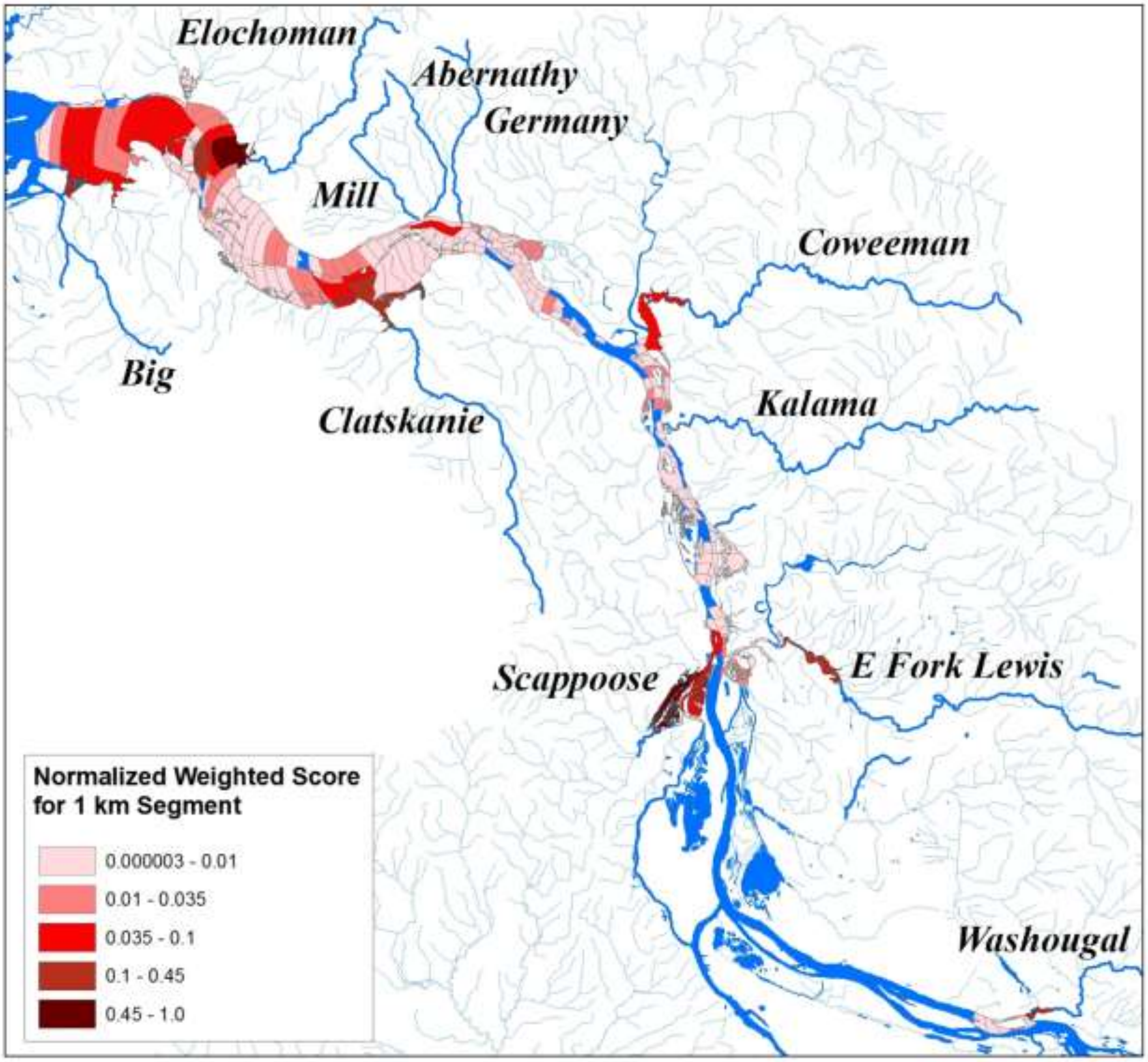


Figure 26. Results for prioritization of mainstem lower Columbia. Areas immediately downstream and within 25 km of a tributary targeted as primary for fall Chinook are designated higher priority than those areas that fall outside the 25 km buffer.

5. Other Lines of Evidence (underway)

Summary

This section is a placeholder for several currently ongoing analyses that will be incorporated into future versions of this document. This includes a Columbian White-tailed deer habitat map; a map identifying priority areas for overwintering, migratory and nesting birds; a map of identified toxic contaminant clean-up sites and other "hot spots" and finally, a map identifying areas important for filling gaps in landscape connectivity. All of these analyses should be completed in summer 2012, undergo a peer review process and then incorporated into the Program and plan by fall/winter 2012.

Line of Evidence 4 - Columbian White-tailed Deer Habitat

The Columbian White-tailed deer (CWTD) is an endangered subspecies of white-tailed deer. Once ranging over much of western Washington and Oregon, it now exists in two remnant populations: one near Roseburg, OR, and one near Cathlamet, WA. While the Roseburg population has been delisted, the Lower Columbia population has not yet recovered. Habitat in this area is highly fragmented, and barriers to population expansion prevent useable habitats from being pioneered. In addition, the current locations of "large" CWTD populations, such as the Julia Butler Hanson National Wildlife Refuge (with Tenasilahe and Crims Islands) are subject to periodic flooding, making them less than optimal for the long term recovery and viability of the subspecies. Other suitable habitats often have conflicting land use objectives, so translocation to these areas may prove undesirable for biological, social or political reasons.

Much of the recovery strategy for the lower Columbia River population has been the translocation of deer past habitat barriers to suitable environments. While many areas of potential habitat exist, areas outside the immediate core range have never been quantified or analyzed for conflicting issues. This project will characterize habitat with respect to its potential for supporting CWTD populations, and will prioritize suitable habitats based on additional factors including land ownership, habitat patch size and habitat connectivity.

The USFWS is developing this product in a multi-phased project:

- **Phase 1: Habitat suitability modeling of Lower Columbia River corridor**
  Figure 27 shows the historical range of CWTD broken up into six smaller sections. The ultimate goal is to map the entire range for potential CWTD habitat, but this will occur in three distinct efforts.

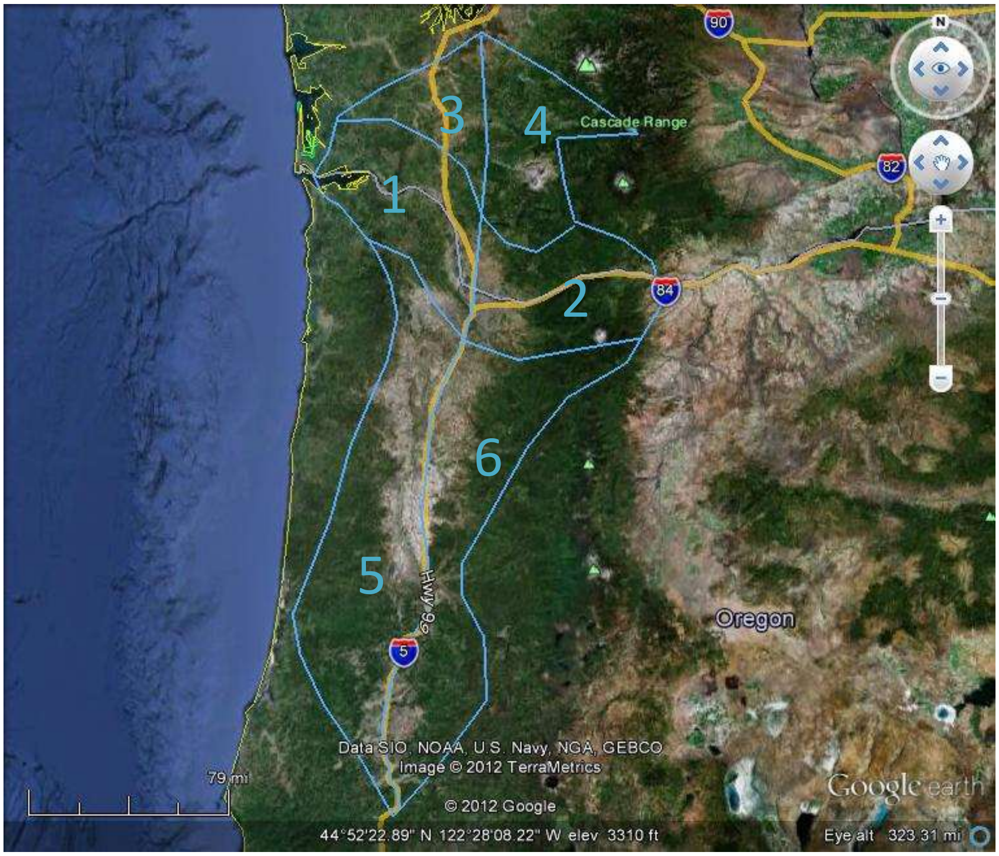


Figure 27. Columbia White-tailed Deer Project Study Area

The first area to be mapped will include Sections 1-2. Section 1 encompasses the current range of the Cathlamet - based CWTD population and together these sections represent the most desirable areas to focus translocation efforts, based on proximity to this existing population. In addition, extensive data exists for much of this area, including high quality elevation and land cover data which has been developed for other Lower Columbia River research efforts. Sections 1-2 will constitute the pilot mapping area, where the model and methods will be developed and refined for further application in other sections.

Modeling will include as inputs existing data of different types. These data will include, but will not be limited to, land cover (such as National Land Cover Dataset, NOAA Coastal Change Analysis Program, Estuary Partnership 2010, Oregon and Washington GAP Analysis Program), digital elevation models (from which elevation, slope, and aspect can be derived and utilized), forest inventory (such as US Forest Service LANDFIRE dataset), and land use (distance to developed area, percent of impervious surface, etc.). The determination of CWTD habitat criteria will be based on existing scientific literature, and the professional knowledge of staff from USFWS Julia Butler Hansen National Wildlife Refuge for the Columbian White tailed deer. Known locations of existing populations will be used to generate statistical, decision tree models (such as CART), for predicting the probability of occurrence throughout Sections 1-2. Areas of interest might include habitats which consist of deciduous, mixed deciduous, mixed shrub, savannah, and parkland (mixed meadow and forest), at yet to be determined elevation, slope, aspect, and percent coverage, and which are outside of a certain distance to a populated area. Habitats will be classified on a 4 tiered basis, including unsuitable, poorly suited, good suitability and ideal suitability.

Once the USFWS identifies suitable habitats (fair/good and excellent/ideal suitability), the USFWS will apply additional modeling to prioritize these areas based on additional metrics. These will likely include some combination of the following: habitat patch size, land ownership, fragmentation metrics, as well as least cost distance estimates between habitat patches to identify the best corridors connecting habitats that can be utilized by the subspecies.

- **Phase 2: Habitat suitability modeling of Washington Historical Range**
  The second phase of this project will apply the modeling methods that were developed and refined in Phase 1 mapping of Sections 1-2 to extend the modeling to Sections 3-4 of the project study area. Sections 3-4 comprise the northernmost extent of the upper Columbia and Washington CWTD range. The USFWS will prioritize suitable habitats based on additional metrics as described in Phase 1.

- **Phase 3: Habitat Suitability modeling of lower Willamette Valley and I-5 Corridor in Oregon**
  The third phase of this project will apply the same modeling methods that have been developed and refined in Phases 1-2 to extend the modeling to Sections 5-6. These sections, comprising the Willamette Valley and I-5 corridor in Oregon, are a transition zone between the existing lower Columbia population and the Roseburg population. These sections likely contain the greatest extent of potential CWTD habitat. Again, initial model results will be verified, and calibration/refinement will be performed if necessary.

- **Phase 4: Landowner Outreach**
  The Estuary Partnership and USFWS will then partner with regional entities (e.g., Columbia Land Trust, Scappoose Bay and Lower Columbia River Watershed Councils) to conduct outreach to landowners with potential CWTD habitat. This outreach would consist of polling the residents for interest in accepting CWTD or selling conservation easements for the purpose of supporting CWTD. The USFWS will provide important guidance and input in this phase.

Line of Evidence 5 - Pacific Flyway Habitats

The Lower Columbia River Implementation Plan (Pacific Joint Venture 1994) describes the approximately 26,000 hectares (64,200 acres) of habitat within the lower Columbia River study area set aside for protection as of 1994:

- The USFWS manages the Lewis and Clark (15,400 hectares - 38,000 acres), Julia Butler Hansen (1,930 hectares - 4,775 acres), Ridgefield (2,000 hectares - 5,150 acres), Franz Lake (215 hectares - 535 acres), Steigerwald Lake (255 hectares - 627 acres) and Pierce (135 hectares - 330 acres) National Wildlife Refuges;

- WADFW owns several small parcels along the lower Columbia and approximately 610 hectares (1,500 acres) of former floodplain in the Vancouver Lowlands;

- ODFW's Sauvie Island Wildlife Area encompasses about 4,860 hectares (12,000 acres);

- BPA's Burlington Bottoms (JR Palensky), adjacent to Sauvie Island and approximately 170 hectares (430 acres), was acquired for wildlife mitigation purposes;

- The Nature Conservancy's preserves at Blind Slough, which includes 270 hectares (670 acres) of tidal spruce swamp, and Pierce Island in the Columbia Gorge;

- Approximately half of the Columbia River Gorge National Scenic Area, where the US Forest Service owns about 24,300 hectares (60,000 acres) is located below Bonneville Dam and within the study area;

- Oregon State parks include extensive wetlands at Fort Stevens State Park near Astoria and in several parks in the Columbia Gorge; and

- Other public ownerships that provide protection for wetland habitats include parks owned by Clark County (more than 240 hectares [600 acres] in the Vancouver Lowlands), Metro (Smith and Bybee lakes near the confluence of the Willamette and Columbia), and the City of Portland's 60-hectare [160-acre] Oaks Bottom Wildlife Refuge on the Willamette).

The 1994 Plan lists the following *additional* habitat objectives for protecting overwintering, migratory and nesting bird habitats in the lower Columbia:

1. Ensure that at least 4,600 hectares (11,500 acres) of low-lying pastureland in private ownership will remain in agricultural production with farm management practices that are compatible with providing needed waterfowl feeding areas.

2. Permanently protect, through easements or fee title acquisition, an additional 1,600 hectares (4,000 acres) of tidal wetlands, 1,280 hectares (3,200 acres) of freshwater wetlands, and approximately 500 hectares (1,200 acres) of uplands that are important to maintaining the habitat values of the wetlands that they are associated with.

3. Restore or create at least 500 hectares (1,250 acres) of tidal wetlands, and 100 hectares (250 acres) of freshwater wetlands.

4. Enhance wildlife habitat values on 270 hectares (680 acres) of tidal wetlands, 1,450 hectares (3,600 acres) of freshwater wetlands, and 700 hectares (1,750 acres of uplands.

These habitat objectives were meant to address waterfowl population goals, which is to maintain populations equal to the greatest population since 1970:

- Maintain habitat capable of supporting a peak population of 6,500 tundra swans

- Maintain habitat capable of supporting a peak population of 2,000 snow geese
- Maintain habitat capable of supporting a peak population of 50,000 Canada geese
- Maintain habitat capable of supporting a peak population of 90,000 ducks
- Maintain habitat capable of supporting a peak population of 150,000 shorebirds
- Maintain nesting populations of colonial birds at or above their present numbers (Pacific Joint Venture 1994).

The plan lists habitat management and waterfowl population objectives for specific areas of the lower river.

This plan has not been updated, and the quantity and locations of protected habitats and bird abundances have significantly changed since 1994. The objective of this line of evidence is to undertake a GIS analysis by overlaying current landowner data and 2010 land cover data to determine if gaps remain within the habitat objectives 1-4 above. Once this is complete, the objectives can be updated by the Pacific Joint Venture with regional partners.

Line of Evidence 6 - Toxic Contaminant "Hot Spots"

For this line of evidence, the Estuary Partnership is collaborating with the USEPA Toxics Reduction Working Group. In 2011, the Estuary Partnership compiled flow and chemical contaminant data for tributaries between Bonneville Dam and the plume into a centralized, geospatial database. This effort built upon and expanded USEPA's "*Columbia River Basin: State of the River Report for Toxics*" (2009) that was limited to flame retardants, mercury, dichlorodiphenyltrichloroethane (DDT) and polychlorinated biphenyls (PCBs) in fish. The tasks for this effort were completed by GSI Water Solutions and included the compilation of recent datasets (primarily post-2000 with the inclusion of the 1996 bi-state study) into a relational database and exploratory data analyses and syntheses. One objective was to identify "hot spots" for contaminants and data gaps in the lower Columbia. The deliverables from this project can be used in combination with other datasets to identify problem areas for clean up as part of ecosystem restoration and monitoring needs to identify and track sources and concentrations.

Methods

Data was compiled from the USACE, Oregon Department of Environmental Quality (ODEQ), Washington Department of Ecology (WDOE), USEPA, Portland Harbor Lower Willamette Group (LWG), National Oceanic and Atmospheric Administration (NOAA), and US Geological Survey (USGS). The media and parameters that were compiled in the database from within the area of interest are summarized in Table 18. The media included sediment, biota, and water (conventional grab and semi-permeable membrane device, or SPMD) samples. The parameters included polycyclic aromatic hydrocarbons (PAHs), flame retardants, PCBs, pesticides, metals (including mercury), water temperature and dissolved oxygen. The data included in the database are primarily from post-2000 samples; however, data from the bi-state study from the mid-1990's were also included for time series comparisons.

Table 18. Parameters and Media Compiled for Contaminant Database of lower Columbia River.

Media	Parameters
Biota	Pesticides Flame Retardants PAHs Metals PCBs
Sediment	Pesticides Flame Retardants PAHs Metals PCBs
SPMD	Pesticides Flame Retardants PAHs Metals PCBs
Water	Pesticides Flame Retardants PAHs Metals PCBs Temperature Dissolved oxygen

A quality assurance/quality control step provided standardization of the database including reviewing the database for duplicates, for samples with multiple results for a single analyte, zero or negative values and minimum detection limits.

Results

As there are an infinite number of chemical contaminants, the USEPA Toxic Reduction Working Group identified key classes in which to group contaminants: trace elements, PAHs, hydrophillic pesticides, hydrophobic pesticides, estrogenic compounds, bioaccumulative compounds, lead and mercury. For this effort the Estuary Partnership in collaboration with the USEPA Toxic Reduction Working Group reviewed the dataset to identify which analytes have been sampled in the past and in relatively sufficient quantities to evaluate. We then further identified “indicator” contaminants (e.g., copper and mercury for metals) to represent a subset of the key classes of chemical contaminants (current use versus legacy pesticides).

GSI Water Solutions ran simple descriptive analyses for these key indicator contaminants. Appendix C contains tables that summarize by indicator analyte, the number of samples analyzed, the number of detections, minimum concentration and maximum concentration for each media. The sample counts included in these tables do not include the Portland Harbor LWG data as those data would skew the results, based on the large number of samples in that reach of the Willamette River. Appendix C also includes two types of figures that were prepared for the analytes in water (grab, SPMD), sediment and biological samples including:

> **1. Contaminant distribution maps**. These maps present sample locations, contaminant concentration ranges above risk based screening level values, and the location of potential monitoring sites proposed in 1999. Portland Harbor data from the LWG database is included in these figures.
>
> **2. Concentration versus river mile plots.** These plots present data for two time periods. Data collected pre-2000 are presented in the upper portion of the figure and data collected post-2000 are presented in the lower portion of the figure. For several analytes, duplicate plots are presented with different concentration scales. In addition, plots fore selected analytes are presented for the Willamette River.

Copper (indicator of metals)

- Copper was detected in about
  - 99% of sediment samples
  - 96% of surface water grab samples
  - 94% of biological samples
- Limited surface water data for copper in the lower Columbia River are available
- Most available data are from the Portland Harbor Superfund Site located on Willamette River
- Most copper data above risk based screening level values

Chloropyrifos (indicator of current use pesticides)

- Chloropyrifos was detected in about 70% of surface water grab samples
- Limited data were identified in the Willamette River
- No surface water data for chloropyrifos were identified in the lower Columbia River

Mercury (indicator of metals)

- Mercury was detected in about
  - 84% of sediment samples
  - 78% of surface water grab samples
  - 94% of biological samples
- Concentrations generally low compared with other areas in basin
- Pre-2000 data had more outliers; apparent concentration decrease since pre-2000
- Post-2000 concentrations slightly higher concentrations upriver than downstream
- No big spikes; no obvious sources
- Higher concentrations in Willamette River than Columbia River
- Concentrations exceed risk based screening levels values in both rivers
- Biological sample data for mercury in the lower Columbia River is widely available and sample locations are distributed in each reach of the river
- Biological sample data are densest in the Portland Harbor Superfund Site located on Willamette River

- Mercury concentrations in biological samples sediment were generally less than 0.2 milligrams per kilogram (mg/kg) in the Columbia River samples collected pre-2000 and approximately seven sample concentrations exceeded 0.5 mg/kg. Post-2000 samples are generally less than 0.15 mg/kg, with only 1 sample concentration exceeding 0.5 mg/kg.
- Mercury concentrations in tissue are also fairly uniform, primarily ranging from 0.01 to 0.6 mg/kg in the Columbia River and from ND to 0.9 in the Willamette River

Total PAHs

- Total PAHs were detected in about
  - 58% of sediment samples
  - 72% of surface water grab samples
  - 61% of biological samples
  - 38% of the SPMD samples
- Limited sediment data for Total PAHs in the lower Columbia River are available and most concentrations are in the lowest mapped concentration range (0 – 465 ug/kg). A few higher concentration samples are present in the Kelso/Longview area.
- Majority of concentrations below laboratory detection limits (i.e., non-detects)
- Sediment sample data are densest in Portland Harbor Superfund Site located on Willamette River and most concentrations are in the highest mapped concentration ranges (>22,800 ug/kg).
- No apparent concentration trends in pre-2000 to post-2000 data
- Both pre and post-2000 data shower higher concentrations at mouth of the Columbia, and near Longview and Portland
- Potential PAH source area near Longview
- Highest concentrations in the lower Willamette River and most concentrations are above risk based screening concentrations.

Total PCBs

- Total PCBs were detected in about
  - 47% of sediment PCB Aroclor samples
  - 42% of surface water PCB Aroclor samples
  - 60% of biological PCB Aroclor samples and 90 percent in PCB congener samples
  - 100% of the SPMD PCB Aroclor and congener samples
- Limited post-2000 biological sample data for Total PCBs in the lower Columbia River are available and most concentrations are in the lowest mapped concentration ranges (0 – 265,000 ng/kg).
- Very limited pre-2000 biological data are available for the Columbia River and no data are available for the Willamette River
- Concentrations in Columbia River above risk based screening levels, but less than concentrations in the lower Willamette River.
- Post-2000 Columbia River data indicates potential concentration spikes which could may be related to sources
- Biological sample data are densest in Portland Harbor Superfund Site located on Willamette River and most concentrations are in the highest mapped concentration ranges (>880,000 ng/kg).

- Highest concentrations noted in the lower Willamette River and most concentrations are above risk based screening concentrations

Total DDx (legacy pesticides)

- Total DDx (i.e., DDT/DDD/DDE, o, p' and p,p' iomers) were detected in about
  - 53% of sediment samples
  - 88% of surface water grab samples
  - 96% of biological samples
  - 100% of the SPMD samples
- Sediment Samples
  - Sediment data for Total DDx in the lower Columbia River are widely available and sample locations are distributed in each reach of the river and most concentrations are in the three lower concentration ranges (< 46.1 ug/kg).
  - Higher sediment concentrations noted in Columbia River at river miles 10, 35, and 100
  - Concentrations in Columbia River above risk based screening levels, but generally less than concentrations in the lower Willamette River
  - Sediment sample data are densest in Portland Harbor Superfund Site located on Willamette River and most concentrations are in the two higher mapped concentration ranges (>46.1 ug/kg)
  - Highest concentrations in the lower Willamette River and most concentrations are above risk based screening concentrations
  - Widespread pre-2000 and post-2000 sediment data are available for Total DDx in the Columbia River. During both time periods, Total DDx concentrations are generally not detected and detected concentrations are mostly less than 5 ug/kg
  - Limited pre-2000 sediment data are available for the Willamette River. Total DDx sediment sample data are densest in Portland Harbor Superfund Site located on Willamette River and concentrations are in the highest at river miles 6 and 7
- Biological Samples
  - Biological data for Total DDx in the lower Columbia River are widely available and sample locations are distributed in each reach of the river and concentrations are highly variable
  - Concentrations in Columbia River above risk based screening levels, but generally less than concentrations in the lower Willamette River
  - Biological sample data are densest in Portland Harbor Superfund Site located on Willamette River and concentrations are highly variable.
  - Widespread pre-2000 and post-2000 biological data are available for Total DDx in the Columbia River. Total DDx concentrations were mostly less than 400 ug/kg I pre-2000 data and lest than about 100 ug/kg in post-2000 data
  - Pre-2000 biological data are very limited for the Willamette River. Post-2000 Total DDx biological sample data are densest in Portland Harbor Superfund Site located on Willamette River and concentrations are in the highest at river miles 6 and 7
  - Pre-2000 biological sample data had higher concentrations than post-2000 sample data

  - Post-2000 biological sample data shows higher concentrations at mouth of Columbia River and near river miles 75, 80, and 140
- SPMD Samples
  - SPDM sample data have not been collected and analyzed for DDx within the Columbia or the Willamette Rivers. Available data are from the Columbia Slough

PBDEs (indicator of human activity)

- Total PBDEs were detected in about
  - 89% of biological samples
  - 88% of the SPMD samples
- SPDM sample data have not been collected and analyzed for PBDEs within the Columbia River. Only one sample was collected within the Willamette River
- Biological sample PDBE data are available within each reach of the study area and concentrations are variable
- Pre-2000 biological sample PBDE data are not available for the Columbia and Willamette Rivers
- Post-2000 biological sample PBDE data are available for the Columbia River and most densely collected between river miles 100 and 130
- Biological sample data concentrations in Columbia River are above risk based screening levels and similar to concentrations in the lower Willamette River
- Post-2000 biological sample PBDE data are limited in the Willamette River

Discussion

The results of this effort documented yet again that there is an alarming lack of information in the lower Columbia regarding the extent of the problem that chemical contaminants pose to the ecosystem, aquatic organisms and human health. We found that of the indicator contaminants – those contaminants for which we could find the most information – still had very little information for historic (pre-2000) and/or recent (post-2000) concentrations with the exception of mercury, DDx and within the lower Willamette River, PAHs. Of those contaminants that we found sufficient information (chloropyrifos excluded due to insufficient data), all showed concentrations above risk based screening thresholds in at least some areas of the lower Columbia and Willamette Rivers.

We did document several "hot spots" for chemical contaminants through this effort. These included:

- For PAHs - both historic and recent data shower higher concentrations at mouth of the Columbia, and near Longview and Portland. Highest concentrations were found in the lower Willamette River but there may be a potential PAH source area near Longview also.
- PCBs also show an urban signature, meaning concentrations are highest around the Portland to Longview area.
- For DDx – elevated levels in biological samples scattered throughout study area, while sediment concentrations are highest in the estuary and within the lower Willamette River. Sediment samples at river miles 10, 35, and 100 in Columbia River and river miles 6 and 7 in Willamette show highest concentrations. DDx concentrations have decreased since pre-2000 but still pose significant risk.

The group used the results of this effort to identify a list of sites to locate further research on chemical contaminant concentrations and source tracking. These locations are listed in Table 19 along with whether the site was selected for status and trends monitoring of chemical concentrations or for diagnostic research to identify potential contaminant sources. Many sites are listed for both, as managers can use the results of the status and trends to identify locations for diagnostic source tracking research upstream of those sites where researchers find elevated concentrations of chemical contaminants.

Table 19. Sites Selected for Further Chemical Contaminant Research in the lower Columbia River.

Original Location (recommended in LCREP 1999)	**River Mile**	**Updated Recommended Locations** (as of 4/13/11)	**Type of Monitoring (status and trends or source tracking)**
Columbia River, Warrendale	141	Columbia River, Warrendale @ RM 141	Status and trends
Columbia River upstream of Camas and Sandy River	122	DROPPED this station	
Columbia River downstream of Camas and Sandy River	~115	Columbia River downstream of Camas and Sandy River @~RM 115	Status and trends
		ADDED: Columbia River between RM 102 and 115	Source tracking
Columbia River upstream of the Willamette River	102	Columbia River upstream of the Willamette River @ RM 102	Status and trends
		ADDED: Columbia Slough near confluence with Willamette River	Source tracking
Willamette River upstream of mouth – St. Johns Bridge		Willamette River upstream of mouth – Morrison Street Bridge	Status and trends
Willamette River upstream of mouth – At upstream end of Multnomah Channel		Willamette River upstream of mouth – At upstream end of Multnomah Channel	Status and trends
Willamette River @ the Falls		Willamette River @ the Falls	Status and trends
Columbia River upstream of Multnomah Channel	~93/94	RM 93/94 (upstream of Multnomah Channel, downstream of Willamette)	Status and trends
Lake River – downstream of Vancouver Lake	~90?	Lake River – downstream of Vancouver Lake	Status and trends; Source tracking
Multnomah Channel downstream end near Scappoose Bay	~89?	Multnomah Channel downstream end near Scappoose Bay	Status and trends

Mouth of the Lewis River	~87	Mouth of the Lewis River	Status and trends; Source tracking
	~88	ADDED: mouth of Scappoose Bay	Source tracking
Columbia River upstream of Columbia City	85	DROPPED this station	
Columbia River @ Columbia City	83	Columbia River @ Columbia City	
Kalama River at Mouth	73	Columbia River downstream of Kalama River @~RM 73	Status and trends
Cowlitz Mouth – 2 locations upstream and downstream of mouth	68	Columbia River at confluence with Cowlitz River (1 station; see below for 2nd station)	Status and trends; Source tracking
	~65	Columbia River below confluence with Cowlitz River and downstream of Longview	Status and trends; Source tracking
Columbia River @ Beaver Army Terminal	53	Columbia River @ Beaver Army Terminal	Status and trends, ECY will continue to monitor with SPMDs
Cathlamet Channel	~49	Between RM 40 and Beaver Army Terminal	Status and trends
Columbia River Estuary – numerous locations	<40	More detailed research needed; stratified random, probabilistic design recommended	Status and trends

The next step for this line of evidence is twofold: 1) collect more chemical contaminant data in the selected locations to better understand the extent of the problem and how it may be impacting the efficacy of our ecosystem restoration program and 2) prioritize the "hot spots" listed above and previously identified cleanup sites. The states of Oregon and Washington as well as USEPA maintain lists of hazardous waste sites (e.g., Brownfield, Superfund) in the lower river. These lists were compiled and mapped (Figure 28), but we have not evaluated the sites for whether the contaminants are of concern to aquatic organisms or have offsite impacts. This step would be important for identifying which sites should be included in the ecosystem restoration program. The Estuary Partnership is working with the Yakama Nation, which has completed such a prioritization for the lower Columbia River contaminant sites, on this step and hopes to include their methods and results in the next version of this Guide.

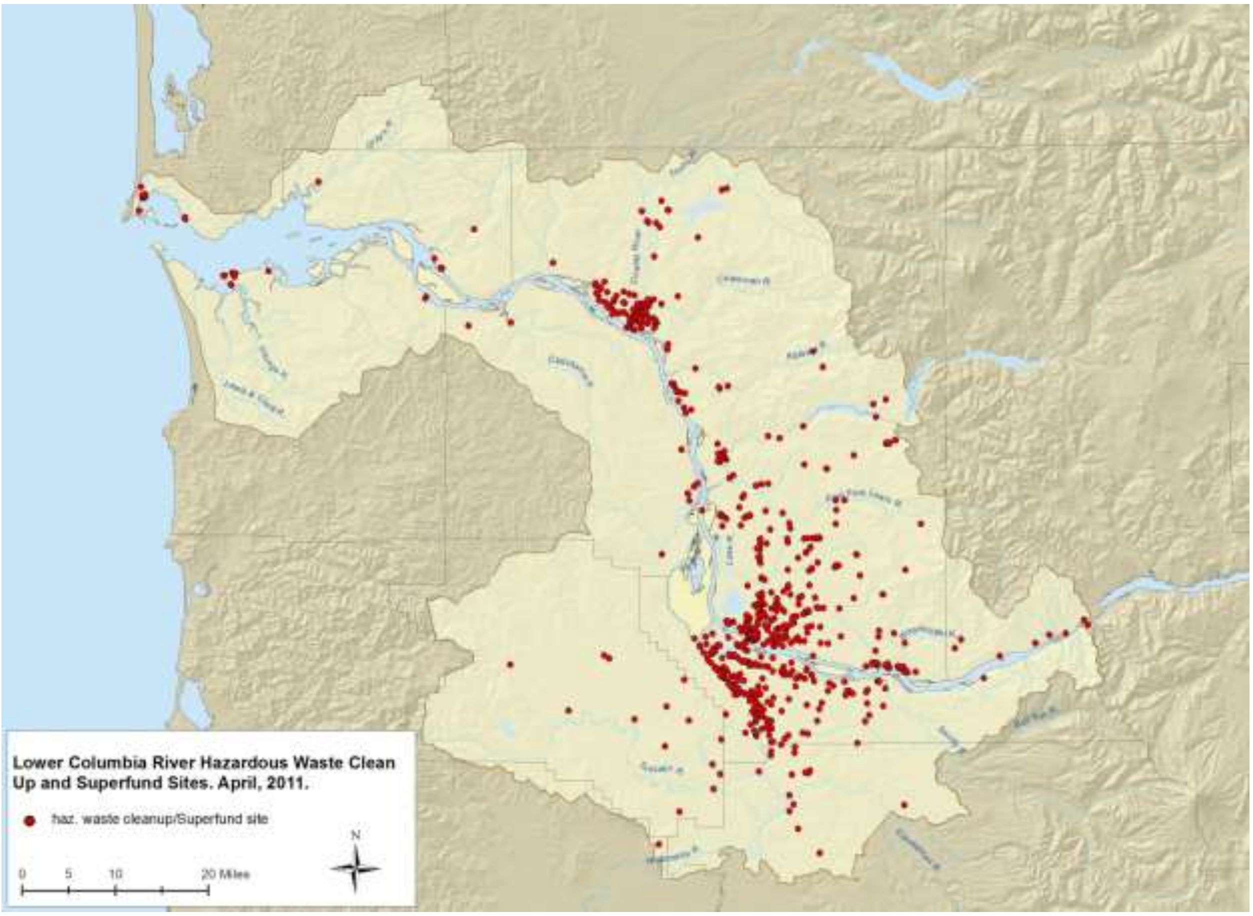


Figure 28. Map of hazardous waste cleanup sites from ODEQ and WADOE databases. This map does not identify which sites pose hazards for aquatic organisms or prioritize by chemical contaminants found at the individual sites. These analyses should be the next step for this line of evidence.

Line of Evidence 7 - Marginal Agricultural Areas

One issue limiting the effectiveness of the Lower Columbia River Ecosystem Restoration Program is gaining the support from the local agricultural community and other large landowners. To help gain this support the Estuary Partnership is hoping to work with US Department of Agriculture Natural Resources Conservation Service (NRCS) to map marginal agricultural areas within the study area. In collaboration with this agency, the Estuary Partnership will conceptually identify areas that are of high value for agricultural production and those that are less so. We anticipate using NRCS soils maps and economic data for the majority of this effort. The ultimate objective is to use the results to initiate discussions into potentially maintaining the higher quality agricultural areas in production where feasible and discuss options for lower production areas, such as the potential for incorporating these areas in ESA listed species restoration actions. If feasible, the deliverables shall be available in winter 2012.

6. Application of the Lines of Evidence

Summary

Results from the multiple lines of evidence (Sections 2-5) were applied to identify priority areas for protection or restoration that will provide the greatest ecological uplift. These results can then be used alone or in combination, depending on the user's goals.

Results of Line of Evidence 1 - Historical Habitat Change 1870 – 2010, demonstrated large losses of tidal herbaceous wetlands, tidal wooded wetlands, forested, herbaceous and other classes since historic conditions. To recover historic habitat diversity, the following habitats were prioritized for protection by river reach:

River Reach	Priority Habitats
A	1. Tidal herbaceous wetland, 2. Tidal wooded wetland
B	1. Tidal wooded wetland, 2. Tidal herbaceous wetland
C	1. Tidal wooded wetland, 2. Tidal herbaceous wetland
D	1. Tidal herbaceous wetland, 2. Tidal wooded wetland, 3. Forested, 4. Herbaceous
E	1. Herbaceous, 2. Forested, 3. Shrub scrub, 4. Tidal herbaceous wetland
F	1. Forested, 2. Herbaceous, 3. Non-tidal herbaceous wetland, 4. Shrub scrub
G	1. Forested, 2. Herbaceous, 3. Tidal herbaceous wetland
H	Non-tidal wooded wetland

Numeric targets by region will be created in summer 2012 and added to future versions of this document.

Results of Line of Evidence 2 – Habitat Suitability Index Model, demonstrated spatial and temporal trends in areas or "patches" suitable for juvenile "ocean-type" Chinook salmon. Under all flow conditions, the quantity of suitable habitat patches and size of patches increased moving downstream from Bonneville Dam to the mouth. The opposite trend was seen in the variability of suitable habitat patch size and location as one went upstream. We found river reaches A, B and C as having rather stable suitable habitat patches that remained under different flows and months, while upriver, in reaches F, G and H, the opposite was true. The upriver river reaches are characterized by a high variability in suitable habitat patch location and size. Gaps in habitat generally occurred near armored areas, such as around Swan Island, the city of Portland and near Kelso. These results imply that different restoration techniques are needed in order to restore or protect suitable juvenile salmon habitat for upstream versus downstream areas.

One result of this analysis is that inundation of habitats, while valuable in assessing habitat opportunity for juvenile salmon, if used alone in assessing the value of habitats will result in higher prioritization for habitats within the lower river reaches. This is because these areas are more stable and less influenced by dam discharge than upstream areas. On the one hand, flow and river stage conditions within the upper reaches will yield less time for access of habitats by juvenile salmon, but on the other, the amount of habitats in this area is greatly minimized and therefore highly valuable. Because of these considerations, we separate out the concept of protecting habitat patches from protecting matrices of patches.

Results of Line of Evidence 3 – Lower Columbia River Salmonid Recovery Plan Priorities identified the tidal portions of the tributaries Skamakowa Creek; Elochoman River; Mill, Abernathy and Germany Creeks; Lewis (both North and East Forks) and Washougal Rivers in Washington and Clatskanie, Scappoose and Sandy Rivers in Oregon as the highest priority for protection and restoration actions. The tidal tributaries of Chinook, Deep, Wallacut, Grays and Cowlitz Rivers in Washington and the lower gorge tributaries in both states are high priority for protection and restoration, whereas the remaining tributaries are considered medium priority. Immediately at the confluence and up to 25km downstream of the tributaries along the mainstem lower Columbia River are also priority areas for protection and restoration activities.

Finally, the other lines of evidence, priority areas for Columbia white-tailed deer, Pacific Northwest flyway, toxic contaminant hot spots and agricultural areas will be added to this report in future versions as they become available.

Next steps for the Program are to integrate these priority areas into existing regulatory and resource management frameworks. This will include efforts by Estuary Partnership staff and others to engage state, tribal, federal and local government agencies to adopt the target priority areas within this guide as funding priorities and within land use planning and zoning practices. This will allow implementers security over the long term to use limited resources to pursue these sites, working with landowners and agencies to develop mutually beneficial activities. The tools within this guide will also resource management agencies to assess the habitat value of specific areas and coordinate recovery and management actions for multiple species simultaneously.

Application of Line of Evidence 1 - Historic Habitat Changes to Identify Priority Habitats for Protection

Native flora and fauna evolved under those environmental conditions and mixes of habitats which persisted for thousands of years previous to changes resulting from large-scale development (e.g., Brush 2009). The changes from natural conditions can favor some species over others, and cause significant declines in some species (Peterson et al. 2000). While the relationships between fauna and their habitats are not always well understood (Levin 2005), natural settings under which native species evolved represent a landscape that supports their populations (Cicchetti and Greening 2011). Protection and restoration to recover naturally occurring habitat mosaics can provide benefits to native fauna (Peterson and Turner 1994), as encapsulated by Simenstad et al. (2000) restoration actions should be "grounded on the historic landscape template that influenced evolution of…species and metapopulations in that system". As a result, resource managers in many areas have used natural habitat diversity or mosaic as an end point for restoration actions (e.g., Cicchetti and Greening 2011: Tampa Bay). Preserving what's left or recovering aspects of historic habitat diversity is the goal for this Line of Evidence.

Section 2 above presents the methodology and results of the Line of Evidence 1 – Historical Habitat Change in the lower Columbia River, 1870-2010. The objective of this line of evidence is to first identify the natural habitat diversity that existed in the lower Columbia prior to widespread human disturbance since the 1870s. Second, by identifying those habitats in which significant coverage has been lost or those that were rare to begin with, we can then prioritize protecting any remaining intact areas of these habitats or restoring them where practical to protect what's left of the historic habitat diversity. These areas of remaining habitats within the lower Columbia River become priority areas for protection and restoration.

Results of the historical habitat change analysis, including matrices (Table 9) and graphs (Figure 19) of historical habitat coverage versus 2010 habitat coverage for each cover class were provided to the Science Work Group (SWG) in August 2011. Results were summarized and provided to the SWG in the following formats:

- Matrices of historic habitat coverage, current habitat coverage, what the historic habitat changed to, % historic habitat coverage and % current habitat coverage by River Reach, including maps of these changes
- Maps of loss and remaining intact habitats by region (Reaches A, B; Reaches C, D; Reaches E, F; and Reaches G, H) by habitats (forested upland, herbaceous wetlands and tidal wooded wetlands)
- Bar graphs by River Reach of historic coverage (in acres) in comparison to current coverage by habitat type.

The SWG then identified which habitats should be considered a priority for protection into the future in order to recover or protect what's left of natural habitat diversity. The SWG considered the following concepts in their review of the change analysis results:

- Large patterns of loss/change by river reach, by region and by entire lower river
- Dramatic losses of individual habitats
- Proportion of historic habitat coverage (ratio of coverage in relation to other habitats) in comparison to current proportion
- Geographic distribution historically versus current (whether habitats have shifted upstream/downstream).

The SWG identified those habitats that represented >10% of the cover for an individual river reach. For those, the SWG prioritized habitats that suffered significant decreases in coverage (i.e., >25% loss in coverage), and further prioritized the habitats by severity of loss (i.e., the greater % loss, the higher the ranking). The SWG gave even greater weight to those habitats if there was a total loss or very little remaining habitat, as shown in the 2010 land cover dataset. Finally, the SWG reviewed "rare" habitats (i.e., those habitats that had <10% cover for an individual river reach), and prioritized those habitats that suffered significant relative decreases (e.g., shrub scrub).

Based on these considerations, the SWG identified the following habitats as priority by location (in order):

Table 20. Priority Habitats by River Reach (in order of priority)

Geomorphic River Reach	Priority Habitats
A	1. Tidal herbaceous wetland, 2. Tidal wooded wetland
B	1. Tidal wooded wetland, 2. Tidal herbaceous wetland

C	1. Tidal wooded wetland, 2. Tidal herbaceous wetland
D	1. Tidal herbaceous wetland, 2. Tidal wooded wetland, 3. Forested, 4. Herbaceous
E	1. Herbaceous, 2. Forested, 3. Shrub scrub, 4. Tidal herbaceous wetland
F	1. Forested, 2. Herbaceous, 3. Non-tidal herbaceous wetland, 4. Shrub scrub
G	1. Forested, 2. Herbaceous, 3. Tidal herbaceous wetland
H	Non-tidal wooded wetland

Priority Habitat	Relevant Reaches
Tidal herbaceous wetlands	A – E, G
Tidal wooded wetland	A - D
Forested	A, D - G
Herbaceous	D - G
Shrub scrub	E, F
Non-tidal herbaceous wetland	F
Non-tidal wooded wetland	H

The SWG identified tidal herbaceous wetland, forested, tidal wooded wetland and herbaceous classes as priority habitats for protection for the entire lower river.

The SWG identified two next steps for applying these results to identify places within the lower river for protection:

1. Determine if the habitat losses can be recovered by examining if the historic habitat changed to another valuable habitat, to low/moderately intensive agriculture or to development and industry. If the habitat changed to development, industry or intensive agriculture, the habitat might be not be recoverable and will need further evaluation.

2. Map remaining locations of priority habitats on current land cover and parcel ownership data to determine where priority habitats are under existing conservation. Parcels that have remaining priority habitats that are not under conservation will be listed as priority areas for future acquisition.

Figure 29 illustrates the results of Step 1 for reaches A- E for two priority habitats, tidal herbaceous wetland and tidal wooded wetlands. In reaches A - C, most of the priority habitats are intact or recoverable (e.g., in low intensive agriculture or “tidally impaired” areas); whereas as we move upriver in reach D, we begin to find significant coverage loss to development or industry. Table 21 lists the results of this step for the remaining reaches and priority habitats.

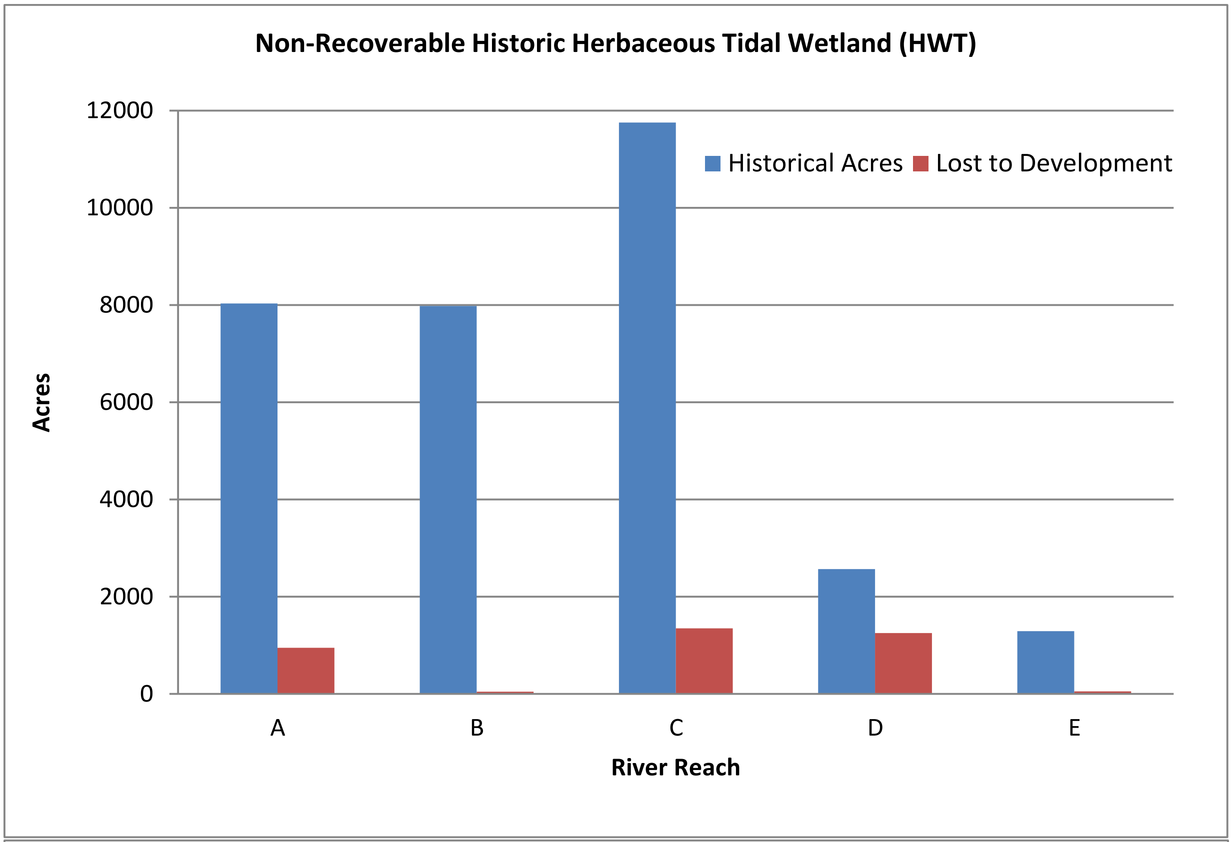
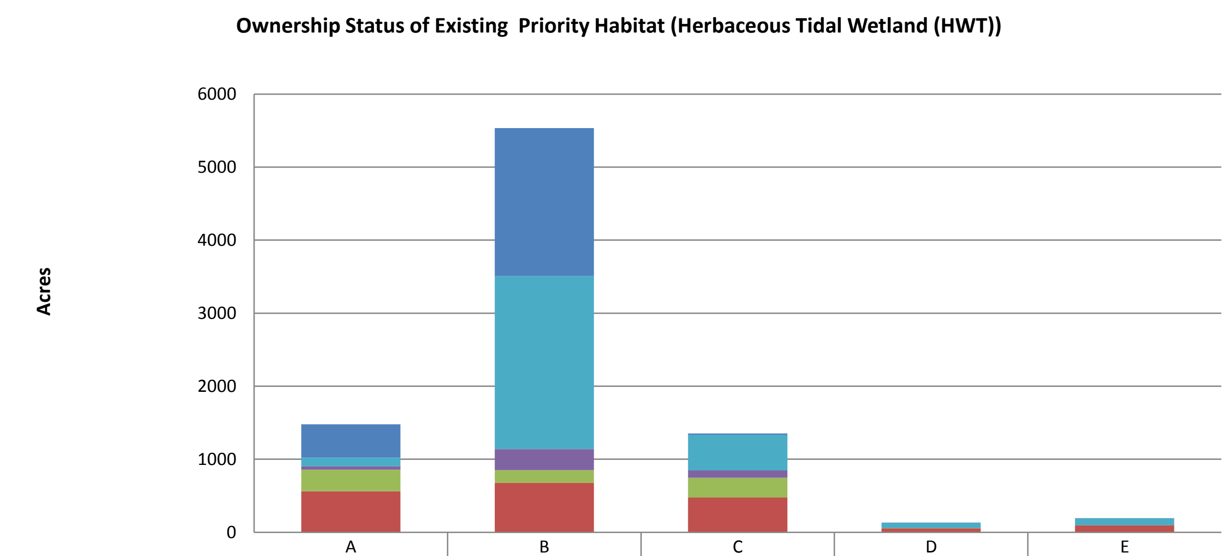
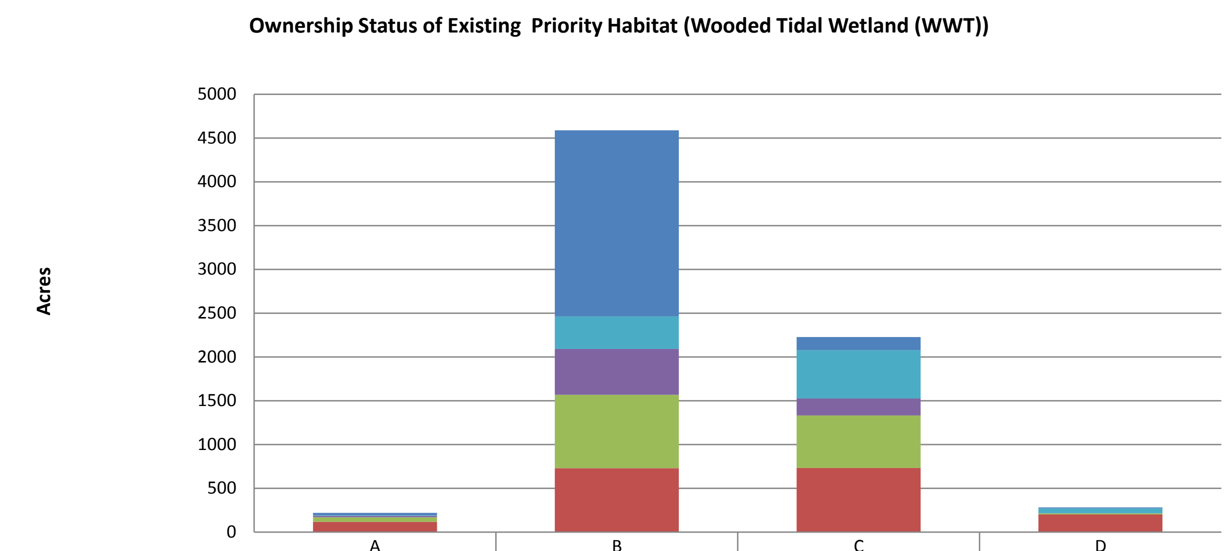


Figure 29. Non-recoverable Priority Habitats in reaches A – D.

Figure 30 illustrates the results of Step 2 for these same priority habitats and river reaches. This graph illustrates existing priority habitats, whereas the next two figures (Figure 31 and Figure 32) illustrates additional areas where these priority habitats may be recoverable through restoration actions. Table 21 also lists the results of this step for the remaining reaches and priority habitats.

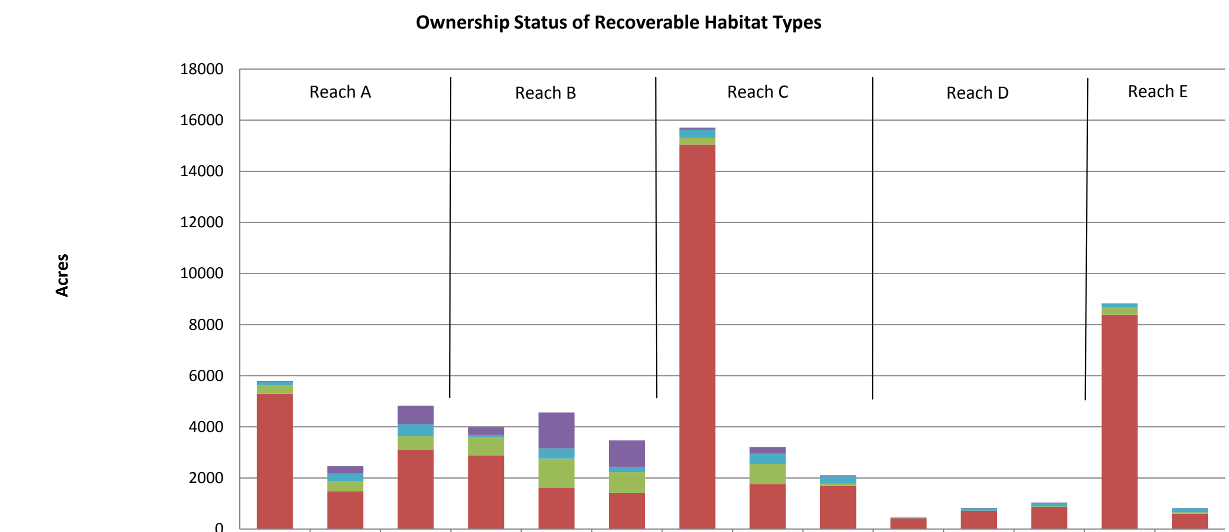


	A	B	C	D	E
Unsure: public agency	456	2025	18	1	2
Unsure	119	2369	488	74	93
Private Conservation	49	288	100	0	0
Public Agency/ Water	295	172	270	2	1
Private/ Non-Access Public	561	679	477	56	96



	A	B	C	D
Unsure: public agency	28	2126	148	11
Unsure	7	371	553	57
Private Conservation	15	525	194	0
Public Agency/ Water	53	837	599	13
Private/ Non-Access Public	116	730	732	201

Figure 30. Conservation status of existing priority habitats, tidal herbaceous wetland and tidal wooded wetlands. We were unclear whether some areas under public ownership are managed for conservation purposes and therefore marked these as "unsure".



	Reach A			Reach B			Reach C			Reach D			Reach E	
	Ag	HWNT	WWNT	Ag	WWNT	HWNT	Ag	WWNT	HWNT	Ag	HWNT	WWNT	Ag	HWNT
Unsure: Public Agency	25	299	732	291	1409	1034	82	252	36	17	9	37	1	2
Unsure	152	293	456	109	393	202	329	405	293	11	93	107	137	161
Public/ Private Conservation	312	397	543	704	1146	817	250	786	85	0	1	22	291	52
Private/ Non-Access Public	5298	1475	3101	2879	1612	1416	15046	1766	1689	423	720	871	8392	603

Figure 31. Conservation status of areas where priority habitats may be recoverable through restoration actions. (Ag = agriculture, HWNT = nontidal herbaceous wetland, WWNT = nontidal wooded wetland). We were unclear whether some areas under public ownership are managed for conservation purposes and therefore marked these as "unsure".

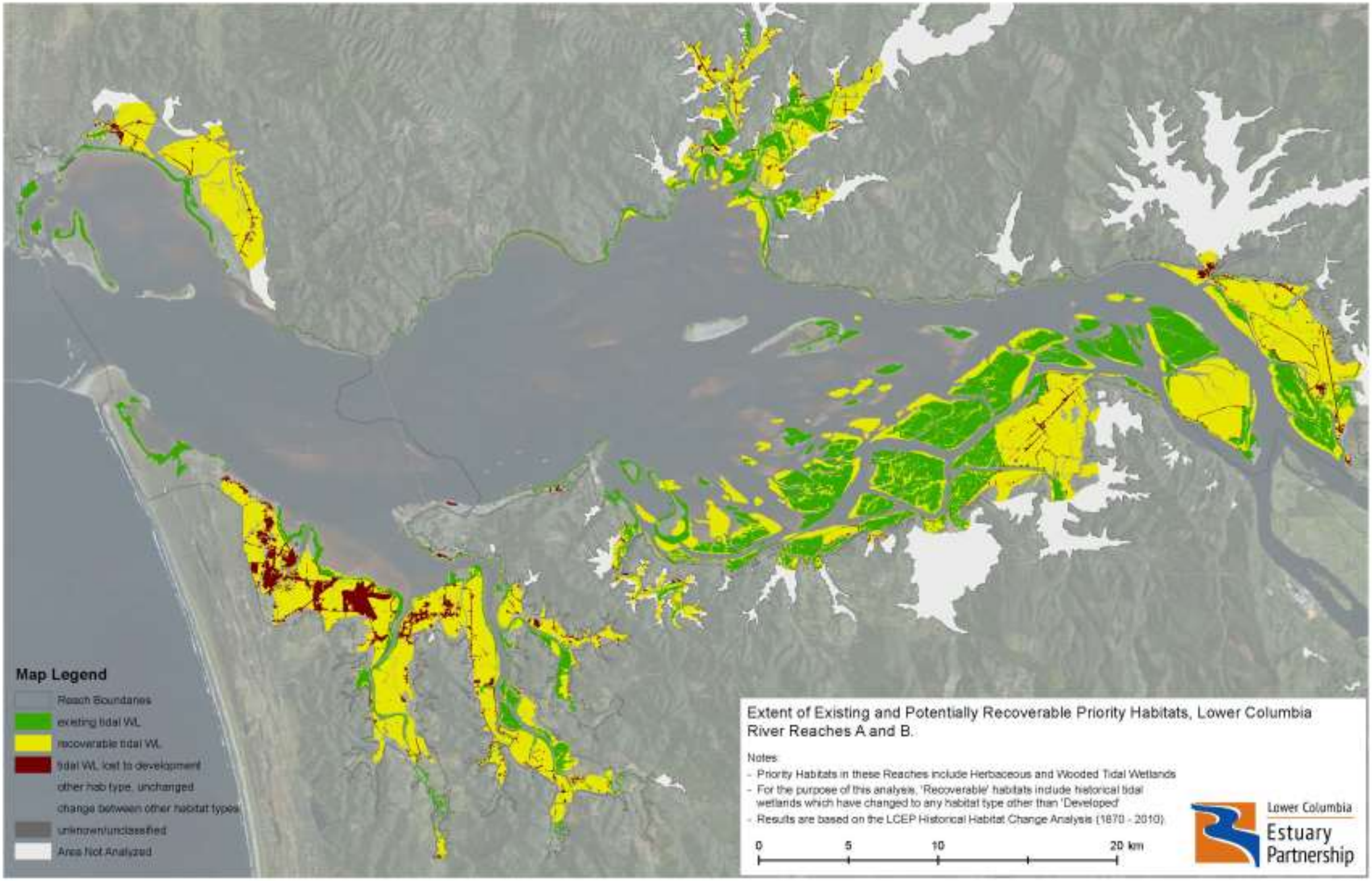
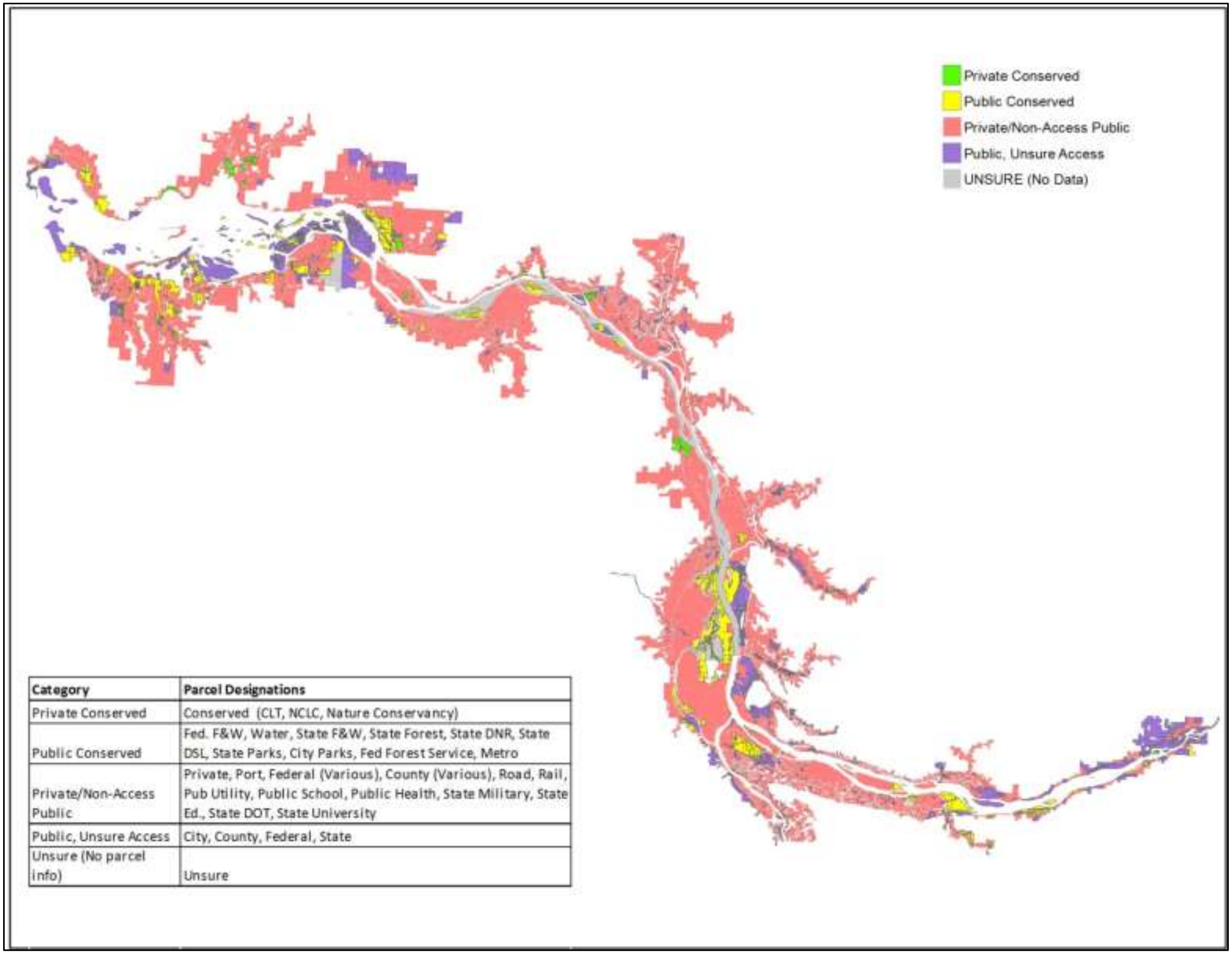


Figure 32. Priority Areas for Protection and Restoration in Reaches A and B based on historic habitat loss. Areas shown in green are priority habitats that are still intact; these are priority for protection actions. Areas shown in yellow are areas where priority habitats could be recovered through restoration actions, such as tidal reconnection and native plantings.



Category	Parcel Designations
Private Conserved	Conserved (CLT, NCLC, Nature Conservancy)
Public Conserved	Fed. F&W, Water, State F&W, State Forest, State DNR, State DSL, State Parks, City Parks, Fed Forest Service, Metro
Private/Non-Access Public	Private, Port, Federal (Various), County (Various), Road, Rail, Pub Utility, Public School, Public Health, State Military, State Ed., State DOT, State University
Public, Unsure Access	City, County, Federal, State
Unsure (No parcel info)	Unsure

Figure 33. Parcel Ownership within Floodplain based on taxlot information

Table 21. Comparison of historical coverage, recoverable areas and areas under conservation status for priority habitats by river reach.

Reach	Priority Habitat	Historical Extent (acres)	Lost, non-recoverable (converted to developed) (acres)	Recoverable habitat types (presently existing types which could be converted back to priority habitat)	Recoverable (presently existing Acres of Recoverable Habitat)						Created or Intact (Presently Existing Acres of Priority Habitat)						
					acres available (entire Reach)	acres available (within extents of taxlot data)	Private/ Non-Access Public	Public/ Private-Conserved	Unsure: public agency, access unknown	Unsure: no taxlot data	Acres Existing (entire reach)	Acres existing (within extents of taxlot data)	Private/ Non-Access Public	Public Agency/ Water	Private - Conserved	Unsure: public agency, access unknown	Unsure: no taxlot data
A	Herb Tidal WL (HWT)	8,031	950	Ag	5,787	5,718	5,298	312	25	152	1,480	1,375	561	295	49	456	119
				HWNT	2,464	2,314	1,475	397	299	293							
	Wooded Tidal WL (WWT)	3,578	406	Ag	5,787	5,718	5,298	312	25	152	219	215	116	53	15	28	7
				WWNT	4,832	4,474	3,101	543	732	456							
B	Wooded Tidal WL (WWT)	14,459	412	Ag	3,982	3,916	2,879	704	291	109	4,589	4,300	730	837	525	2,126	371
				WWNT	4,559	4,272	1,612	1,146	1,409	393							
	Herb Tidal WL (HWT)	7,983	45	Ag	3,982	3,916	2,879	704	291	109	5,533	3,345	679	172	288	2,025	2,369
				HWNT	3,469	3,319	1,416	817	1,034	202							
C	Wooded Tidal WL (WWT)	13,876	1,590	Ag	15,707	15,631	15,046	250	82	329	2,226	2,070	732	599	194	148	553
				WWNT	3,210	3,130	1,766	786	252	405							
	Herb Tidal WL (HWT)	11,753	1,345	Ag	15,707	15,631	15,046	250	82	329	1,353	1,203	477	270	100	18	488
				HWNT	2,103	2,051	1,689	85	36	293							
D	Herb Tidal WL (HWT)	2,570	1,251	Ag	451	444	423	0	17	11	133	65	56	2	0	1	74
				HWNT	822	772	720	1	9	93							
	Wooded Tidal WL (WWT)	2,740	1,901	Ag	451	444	423	0	17	11	283	238	201	13	0	11	57
				WWNT	1,037	951	871	22	37	107							
	Forested	8,164	3,742								3,399	3,006	2,698	20	0	168	513
	Herbaceous	3,135	2,264								1,293	1,216	1,037	2	0	132	122
E	Herbaceous	5,243	660								442	399	361	1	4	1	75
	Forested	7,473	1,446								3,462	3,256	2,864	25	131	46	396
	Shrub Scrub	1,680	229								181	166	149	0	0	0	32
	Herb Tidal WL (HWT)	1,290	51	Ag	8,822	8,755	8,112	571	1	137	192	156	96	1	0	2	93
				HWNT	818	752	603	52	2	161							
				WWNT	1,490	1,430	1,191	97	29	172							
F	Forested	29,253	12,405								9,165	7,943	5,909	775	3	1,029	1,450
F	Herbaceous	9,688	2,110								2,086	1,961	736	891	0	298	160
F	Herb Tidal WL (HWT)	11,604	574	Ag	24,737	24,472	19,735	2,632	1,968	403	2,132	1,792	573	684	0	188	687
F	Shrub Scrub	2,069	1,293	HWNT	4,092	3,872	1,223	1,152	1,438	278	520	462	340	55	0	54	72
G	Forested	18,790	11,070								6,430	5,540	4,102	701	4	704	919
G	Herbaceous	7,537	4,280	Ag	2,510	2,456	1,671	269	505	66	1,578	1,507	789	608	5	101	75
G	Herb Tidal WL (HWT)	1,786	1,091	HWNT	1,540	1,504	478	466	547	48	427	300	277	5	2	16	127
H	Wooded Tidal WL (WWT)	3,342	430	WWNT	785	617	48	235	333	168	347	139	4	28	5	102	208
H				HWNT	354												

Application of Line of Evidence 2 - Habitat Suitability Index Model to Identify Priority Habitats for Protection and Restoration

The objective for this Line of Evidence is to support the recovery of life history diversity in Pacific salmonids. It specifically focuses on "ocean-type" salmonid species, such as fall Chinook, as these species spend more extensive time in tidal areas rearing than "stream-type" salmonids. However, the criteria used in this analysis are thought to be protective of other ESUs, such as chum and coho, that can also occur in similar habitats under less restrictive conditions.

For salmon recovery NOAA recommends protecting and restoring shallow water, low velocity and low salinity environments as key juvenile salmon habitats (Casillas 2009, Bottom et al. 2005). This analysis mapped times and locations where these conditions are met within the mainstem lower Columbia. Specifically, we employed OHSU's CORIE SELFE 3-D hydrodynamic model to predict and map spatial and temporal changes in the availability of suitable migratory and rearing habitat for juvenile "ocean-type" Chinook salmon in the mainstem lower Columbia River. To define conditions suitable for juvenile Chinook, we used criteria from Bottom et al. (2005), updated in Burla (2007), for water temperature, velocity, depth and salinity. We then developed an index of the first three criteria and mapped locations where these thresholds were met for a given frequency of time during low, medium and high river discharge years.

Results demonstrated spatial and temporal trends in habitat areas or "patches". Under all flow conditions, the quantity of suitable habitat patches and size of patches increased moving downstream from Bonneville Dam to the mouth. The opposite trend was seen in the variability of suitable habitat patch size and location as one went upstream between months April – September. There was also an increase in variability in patch size and location between flow conditions. We found river reaches A, B and C having rather stable suitable habitat patches that remained under different flows and months, while upriver, in reaches F, G and H, the opposite was true. The upriver river reaches are characterized by a high variability in suitable habitat patch location and size. Gaps in habitat generally occurred near armored areas, such as around Swan Island, the city of Portland and near Kelso. These results imply that different restoration techniques are needed in order to restore or protect suitable juvenile salmon habitat for upstream versus downstream areas.

One result of this analysis is that inundation of habitats, while valuable in assessing habitat opportunity for juvenile salmon, if used alone in assessing the value of habitats will result in higher prioritization for habitats within the lower river reaches. This is because these areas are more stable and less influenced by dam discharge than upstream areas. On the one hand, flow and river stage conditions within the upper reaches will yield less time for access of habitats by juvenile salmon, but on the other, the amount of habitats in this area is greatly minimized and therefore highly valuable. Because of these considerations, we separate out the concept of protecting habitat patches from protecting matrices of patches.

Table 14 (from Section 3 repeated), translates results into potential restoration priorities by river reach and zone, which are summarized visually in Figure 24 (from Section 3 repeated).

Table 13. Restoration Approaches by Zone

	Zone 1: Reaches A, B and C	Zone 2: Reaches D and E	Zone 3: Reaches F, G and H
Protect Currently Functioning Areas	High Priority. These areas provide consistent access to large areas of benthic habitat, though fluxes in salinity may be a stressing condition in reach A. During Low Flow conditions, Cathlamet Bay provides some of the largest zones of refuge both in area and time inundated and Grays Bay to the north providing consistent but smaller areas. Considering time inundated, the value of unique restoration approaches to enhance tidal and mud flat areas should be further studied.	Protecting functioning areas is a priority in zones 2 & 3, but in this context, it should be considered with conserving adjoining habitats. This is necessary to provide multiple refuge opportunities for different life history strategies and under different discharge conditions.	
Increase Access	Increasing access, particularly to diked areas will likely yield consistent opportunities. However, multiple access opportunities on the main channel exist. Tributaries were not examined in this study.	Priority.	High Priority. Areas in reaches F and G both have diked areas and limited access in hours.
Gap Reduction		High Priority. Areas, particularly developed areas in zones D-G have long distances between habitats.	
Protect or Restore Matrix of Habitats		Developing a matrix of adjoining habitats or areas that would provide refuge at different times of the year and under different flow conditions is needed. In reaches D, F, and G, there appears to be specific opportunities where stable habitat adjoins flow dependent habitats. These areas should be looked at in conjunction with the habitat change analysis to prioritize areas for restoration.	

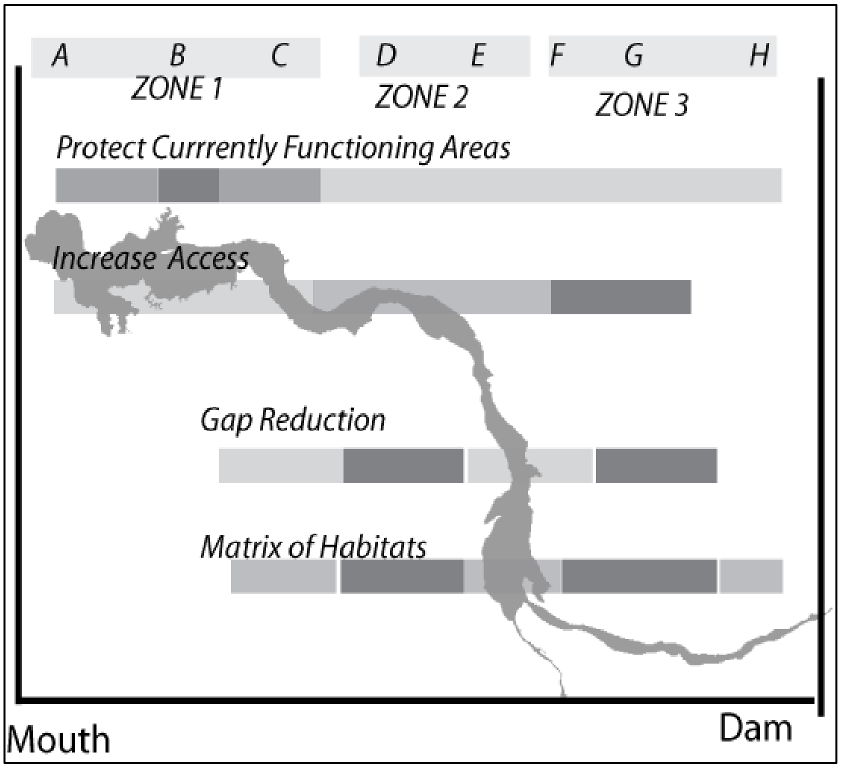


Figure 19. Restoration approaches by reach and zones. The darker the shading, the higher the restoration priority across area.

The habitat suitability index can be used with these aforementioned restoration priorities to identify specific areas within reaches to apply techniques:

- Areas with very high habitat suitability scores (> 0.4) in all reaches should be considered for protection and restoration of adjoining habitats.
- Areas with high habitat suitability scores (>.16) in all flow conditions and large (>1ha) adjoining areas that depending on flow have high suitability should be considered for acquisition or restoration.
- Areas with moderate suitability scores (0.08 - 0.16) should be examined to see if limiting factors can be improved.
- Areas identified as having gaps in habitat should be examined for microhabitat

Model results could also help define the probability of success of proposed projects, connectivity associated with various reaches in the system, and habitat quality, the latter of which is partly defined by temperature and habitat complexity.

Application of Line of Evidence 3 – Lower Columbia River Salmonid Recovery Plan Priorities to Identifying Priority Habitats for Protection and Restoration

Similar to Line of Evidence 2, the objective of this Line of Evidence is to support the recovery of life history diversity in Pacific salmonids. Whereas Line of Evidence 2 focuses on all "ocean-type" ESUs, including upriver stocks, this Line of Evidence is focused on Lower Columbia River stocks specifically.

As described in Section 3 above, the results of this analysis identify the tidal portions of the tributaries Skamakowa Creek; Elochoman River; Mill, Abernathy and Germany Creeks; Lewis (both North and East Forks) and Washougal Rivers in Washington and Clatskanie, Scappoose and Sandy Rivers in Oregon as the highest priority for protection and restoration actions (Table 16 [repeated from Section 4 above]). The tidal tributaries of Chinook, Deep, Wallacut, Grays and Cowlitz Rivers in Washington and the lower gorge tributaries in both states are high priority for protection and restoration, whereas the remaining tributaries are considered medium priority. Immediately at the confluence and up to 25km downstream of the tributaries along the mainstem lower Columbia River are also priority areas for protection and restoration activities using a weighted system (see Figure 26 [repeated from Section 4]).

Table 15. Results of prioritization scheme using Oregon and Washington recovery plan priorities. Tidally influenced areas in these tributaries are designated priority over tidally influenced areas of remaining Oregon and Washington tributaries.

Prioritization	Tributary
Very high priority	Grays River
	Skamakowa Creek
	Elochoman River
	Mill Creek
	Abernathy Creek
	Germany Creek
	Clatskanie River
	Scappoose River
	Lewis River (North and East Forks)
	Washougal River
	Sandy River
High priority	Chinook, Deep, Wallacut Rivers
	Cowlitz River
	Toutle South and North Forks
	Upper Cowlitz
	Cispus
	Tilton
	Coweeman River
	Lower Gorge Tributaries

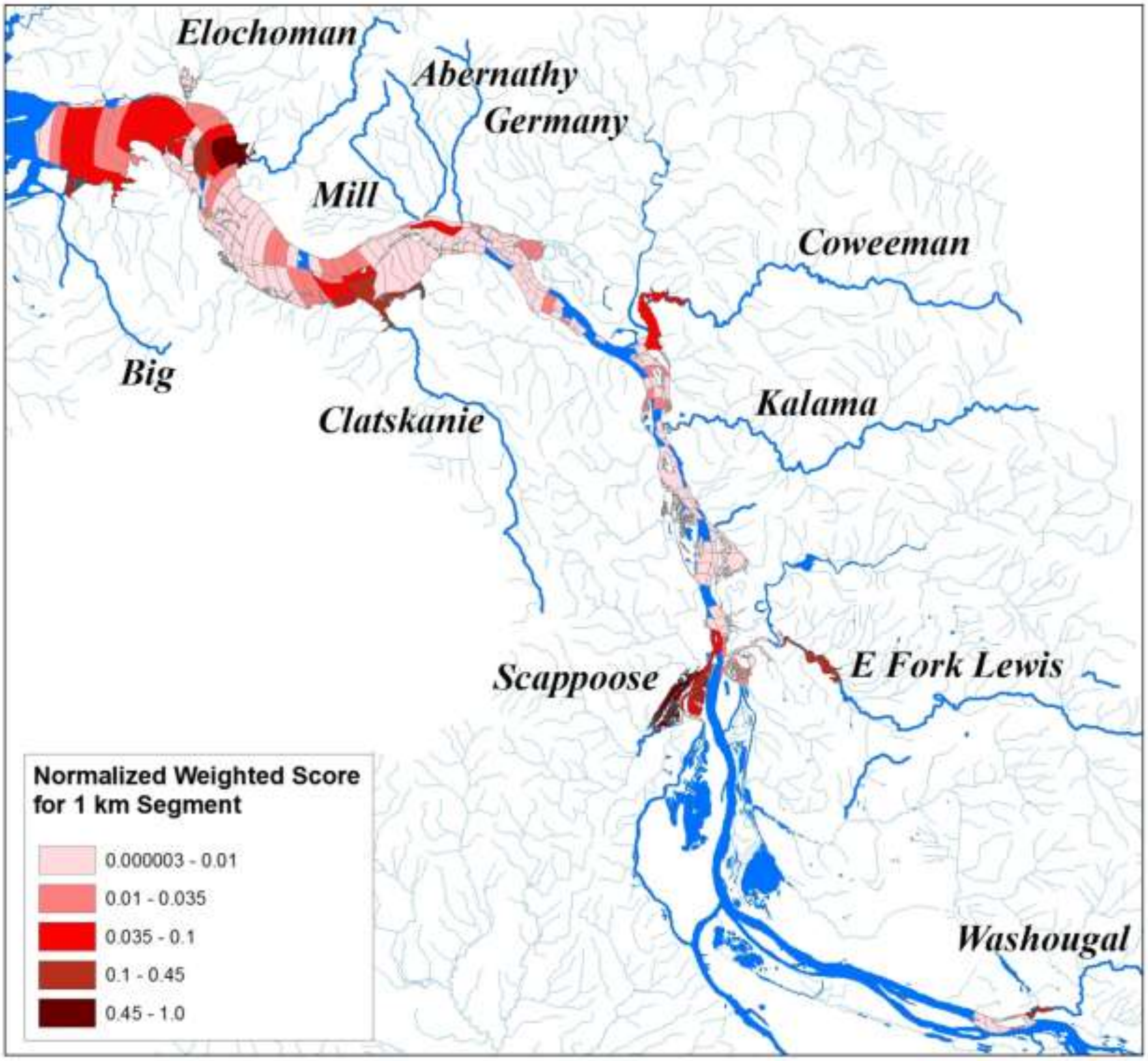


Figure 21. Results for prioritization of mainstem lower Columbia. Areas immediately downstream and within 25 km of a tributary targeted as primary for fall Chinook are designated higher priority than those areas that fall outside the 25 km buffer.

Finally, other lines of evidence, such as priority areas for Columbia white-tailed deer, Pacific Northwest flyway, toxic contaminant hot spots and agricultural areas will be added to this report in future versions as they become available.

Use of the Lines of Evidence

The Restoration Prioritization Strategy uses a "multiple-lines-of-evidence" approach to identify priority areas for habitat protection and restoration. This approach allows the user to make a decision using one or multiple selection factors, each with a set of criteria and predefined thresholds. Using the example from Section 1 where a person wishes to purchase a home, the selection factors a person might consider in making the decision include the price of the home, the safety of the surrounding neighborhood, the quality of the local schools and walkability to nearby stores and restaurants. The person then has to define their preferences or criteria for evaluating the selection factors, such as a home price that is affordable for them. To continue this example, a high priced house might be >$500,000, while a low cost home might be <$200,000. If the person considered this selection factor alone, s/he might choose a home within the $200,000 to $500,000 range. However, s/he would most likely want to consider neighborhood safety and quality of nearby schools and define thresholds for criteria indicating suitable conditions (e.g., > 20 violent crimes/year/1,000 people).

The Restoration Prioritization Strategy uses this same approach to identify areas in the lower river that will provide the greatest ecological uplift through restoration or protection actions using multiple selection factors, each as a stand-alone "line of evidence":

1) natural habitat diversity

2) suitable migratory and rearing habitat for juvenile "ocean-type" Chinook salmon

3) important rearing habitats for lower Columbia River (LCR) "ocean-type" ESUs

4) potential Columbia White-tailed deer habitat

5) potential overwintering and migratory bird habitat

6) toxic contaminant cleanup sites or other hot spots and

7) low production agricultural lands.

The Estuary Partnership, including the Science Work Group, then defined the criteria and thresholds that we wish to target in our restoration program, using the results from the analyses undertaken for each line of evidence, respectively:

1) a habitat change analysis using historic T sheets in comparison to current (2010) land cover data

2) a Habitat Suitability Model for juvenile "ocean-type" salmon using results from an Oregon Health and Science University (OHSU) model to determine times and locations that meet water temperature, depth, and velocity conditions favorable to juvenile salmon, based on Bottom et al. (2005) criteria and

3) tidally influenced areas within those tributaries listed within Oregon and Washington salmon and steelhead recovery plans as priority for LCR fall and late fall Chinook and chum populations as well as areas along the mainstem <25 km of a tributary with tule Chinook populations (see NMFS "Tule" Harvest BiOp method in Cooney, 2011).

Selection factors 4 -7 are incomplete at the time of this version but are expected to be added to the report in winter 2013.

Similar to the person purchasing a home, the user of the Restoration Prioritization Strategy can use the results of one or multiple line of evidence in their decision in choosing priority habitats, depending on their goals and objectives. As an example, salmon recovery programs in Oregon and Washington may be mainly focused on priority tributaries and mainstem areas for the lower

Columbia River salmonid populations (Line of Evidence 3) in combination with historic habitat changes (Line of Evidence 1) and the availability of juvenile Chinook rearing and migratory habitat (Line of Evidence 2). However, USFWS managers may wish to identify specific types of riparian habitats that have been lost since the 1870s (Line of Evidence 1) to use in prioritizing overwintering and migratory bird habitats (Line of Evidence 5). The results of each line of evidence is a GIS-based file that can be overlain on top of the other lines of evidence to be used in whatever combination the user chooses.

Identifying Spatial Gaps in Implementation

Section 7 below describes the Restoration Inventory Geodatabase. This GIS-based database houses information on identified restoration and protection actions within the study area, including the status of implementing these actions. This database will be maintained by the Estuary Partnership and continually updated as project sponsors continue to work with landowners to identify and develop additional actions. It allows users to map all projects within the lower river that have been identified, are underway or are completed.

Users can combine the priority areas identified for the individual lines of evidence with the information in the Restoration Inventory to highlight gaps in implementation in the identified priority areas – or those priority areas where no actions have been identified or completed. This analysis can be completed for each line of evidence as a stand-alone product or used in combination, depending on the goal of the user (e.g., USFWS, BPA, USEPA, LCFRB). The results should produce key information to understanding past progress and potential new areas of focus for restoration actions going forward.

Additionally, the priority areas identified for each line of evidence can be overlain with the landscape assessment tools, such as the Restoration Prioritization Framework Tier 1 disturbance model (see Section 1) and land ownership datasets to identify appropriate techniques and levels of effort needed to restore individual sites or to combine multiple projects to restore larger areas. These tools help project practitioners assess the likelihood of success in restoring natural processes or landscape scale structure and function for their proposed actions.

Finally, through an expansion of this database described in Section 7 below, the information housed in the database will be collected for all projects in a comparative manner. The goal for this expansion is to allow the information for all projects throughout the lower river to be rolled up and analyzed to assess the cumulative benefits the Program has provided for the lower Columbia ecosystem. This analysis could also highlight gaps in implementation that remain hidden when evaluating projects on an individual basis. A conceptual diagram of how all the Strategy, the Restoration Inventory and landscape assessment tools fit together is shown in Figure 34.

Next Steps

Next steps for the Lower Columbia River Ecosystem Program are to integrate the priority areas identified by the individual lines of evidence into the relevant regulatory and resource management frameworks. This will include efforts by Estuary Partnership staff and others to engage state, tribal, federal and local government agencies to adopt the target priority areas within this guide as funding priorities and within land use planning and zoning practices. This will allow project sponsors with long range goals to acquire parcels the security over the long term to use their limited resources to pursue these sites and work with landowners and agencies to develop mutually beneficial activities. The tools within this guide will also resource management agencies to assess the habitat value of specific areas and coordinate recovery and management actions for multiple species simultaneously.

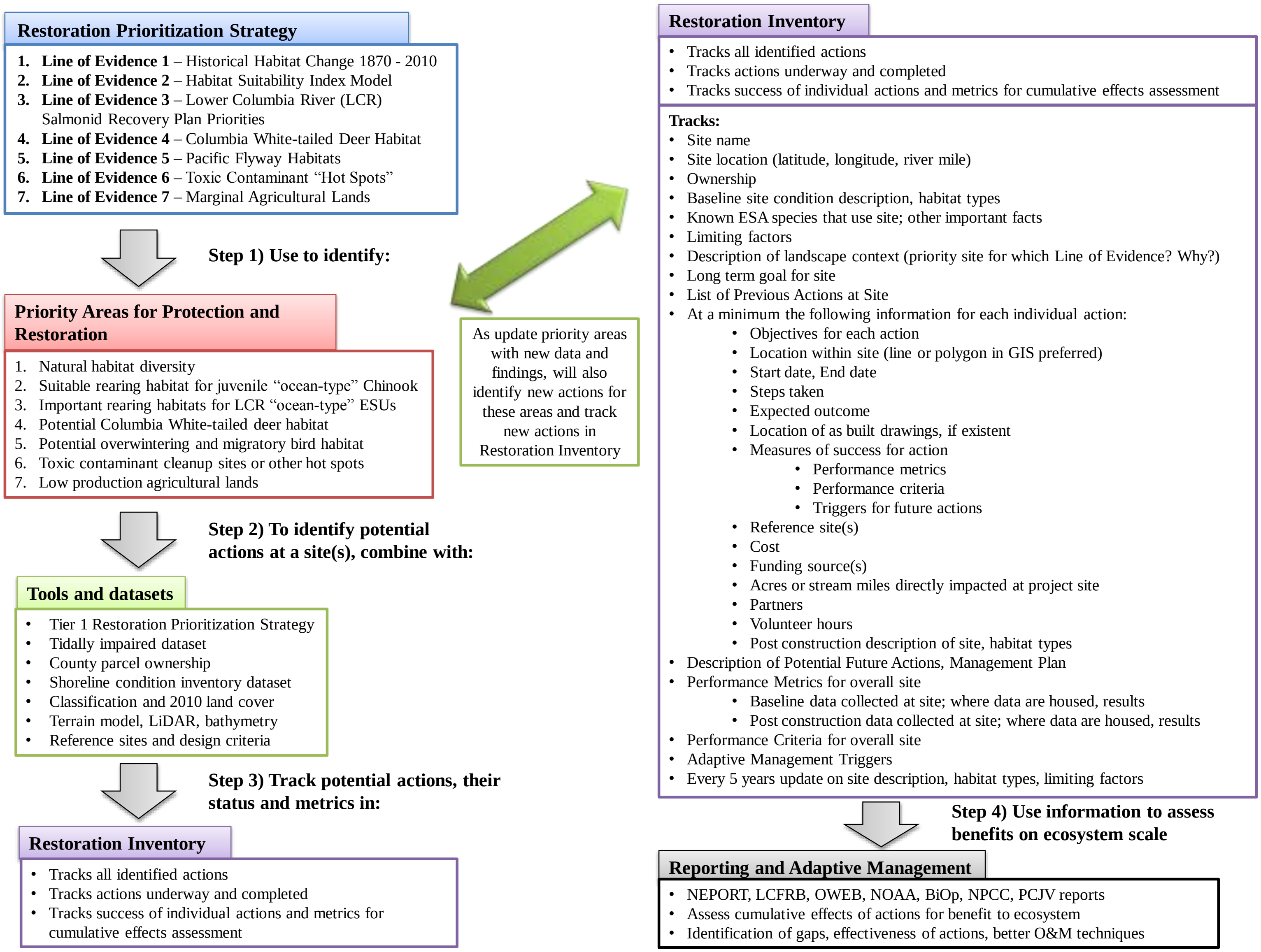


Figure 34. Conceptual diagram describing use of Restoration Prioritization Strategy, tools, datasets and Restoration Inventory to identify, develop and track restoration and protection actions in the lower Columbia.

7. Implementation Strategy

Summary

Integral to the Lower Columbia River Ecosystem Restoration Program is on-the-ground restoration and protection activities. A "typical" restoration project includes multiple phases: 1) landowner outreach to identify potential projects (parcel acquisition can be an additional step [fee or less than fee simple]); 2) baseline data collection (usually assessing topography, hydraulics and hydrology, water temperature and other site characteristics); 3) feasibility and alternatives analysis; 4) design; 5) permitting, often requiring additional data collection (e.g., listed species presence/absence, wetland delineation); 6) contracting and construction; 7) post construction action effectiveness monitoring; 8) reporting and 9) long term operation and maintenance. Predictive modeling to determine project alternatives and feasibility (phase 3), inform engineering designs and permits (phases 4 and 5) and evaluate project success (phase 7), requires additional data (water stage, tributary discharge, topography, bathymetry) and resources such as the specific technical expertise to develop, run and interpret model results. Each of these phases requires staffing, time, and technical and financial resources from the project sponsor. Additionally, to incorporate best available science and fill gaps in restoration actions, project sponsors require opportunities to learn from lessons gained by other restoration practitioners, incorporate latest findings from scientific studies contributing to the understanding of the lower river, and collaborate on individual projects. At the same time, funding entities like NPCC/BPA, NOAA, USFWS and LCFRB want to ensure they are funding technically sound and strategically placed projects.

The Lower Columbia River Ecosystem Restoration Program includes six major components that were designed to address the needs of natural resource protection managers, project funders and restoration practitioners:

1) a Restoration Prioritization Strategy that identifies priority areas for protection and restoration (see Sections 2-6 above);
2) a technical assistance program that provides capacity and support for restoration partners' efforts in working with landowners to identify, develop, manage and monitor landscape scale or complex projects
3) a scientific review and competitive bid process to evaluate, prioritize and fund individual restoration projects;
4) a Restoration Inventory geodatabase that tracks identified actions in a GIS-based system;
5) outreach and coordination efforts designed to ensure communication and coordination amongst partners, best available science is being used throughout the lower river and identification of issues and gaps; and
6) an adaptive management framework that includes
    a) an ecosystem monitoring program to track trends in the overall condition of the lower river, provide a suite of reference sites for use as end points in our restoration actions and place results of our findings into the context with the larger ecosystem;

b) an action effectiveness monitoring program that tracks whether restoration actions are meeting partners' goals or whether future actions are necessary, identifies which actions are working best and informs how we can improve efficacy of our actions;
c) critical uncertainties research designed to address specific questions (e.g., contribution of salmon use of estuarine habitats to adult returns) and
d) implementation monitoring.

Funding assistance for Phase 1, landowner outreach, and parts of Phase 7, extensive action effectiveness monitoring, is not addressed specifically through this Program, although these phases are inherently key for Program implementation. At this time, funding issues are partly addressed for intertidal reconnection or passage improvement actions benefiting juvenile salmon, through direct contracts with BPA and a subset of project sponsors (e.g., the Estuary Partnership, CREST, CLT, Cowlitz Indian Tribe and WADFW). At the time of writing this report, the authors did not have a more holistic resolution to resource capacity issues of sponsors (or funding agencies!) outside this focused area.

Finally, the Estuary Partnership strongly believes that for ecosystem restoration and species recovery actions to be successful, it is imperative that the region address toxic contaminants, by knowing and reducing sources of historic, current and emerging chemicals, understanding their pathways and encouraging safer alternatives (i.e., green chemistry) *within our restoration and RME activities*. This section provides an overview of the life cycle of a "typical" restoration project, how these components help address the resource needs of restoration practitioners in the lower Columbia River and how we hope to continually improve the program through adaptive management.

Life Cycle of a "Typical" Restoration Project

First and foremost, we acknowledge that there is no such thing as a "typical" restoration project. Additionally, readers will lump and split project development, implementation and monitoring steps in different ways. However, for planning purposes it is useful to describe the general phases of projects as we have done below.

A "typical" restoration project includes multiple steps (Figure 35):

1) Landowner outreach to identify potential projects –Making connections and creating relationships and trust with landowners is a significant effort which is often overlooked by funding entities. This can entail project sponsors participating in community events, attending meetings, going door to door, written correspondence, etc. Once a line of communication is created, the project sponsor then needs to determine if mutually beneficial goals can be met on a very basic level. The sponsor has to determine how best to forward the project concepts to the landowner and any possible funders.

   Parcel acquisition for fee or less than fee can often be considered a separate step or can be built into a project. While not always the case, projects located on public lands are often less difficult to implement than those on private lands.

2) Baseline data collection and analysis (typically site hydrology and hydraulics, temperature regime, topography, geomorphology, fish use, photo points and vegetation surveys) - Use existing and collected data to identify limiting factors and other constraints, e.g., surrounding infrastructure.

3) Feasibility and alternatives analysis – Develop a conceptual framework to understand the fundamental links between landscape/physical processes, site dynamics, disturbances, limiting factors, and hypothesized solutions. Numerical models or other predictions (empirical) can aid in quantifying feasibility of actions. The goal is to identify restoration/enhancement alternatives that address the site's limiting factors and that are compatible with stakeholder goals and applicable constraints. Work with project stakeholders to assess the feasibility of each alternative (e.g., cost, constructability, whether it effectively addresses the site's limiting factors, maintenance requirements, longevity, etc.) and select a preferred alternative(s) for the site.

4) Design - Develop initial (conceptual through 30%) designs and use them to vet project details with landowners, regulatory agencies, funders and other stakeholders. With 30% design, sponsors typically initiate the permitting process, engaging regulatory agencies to identify their concerns and determine a path forward for complying with applicable regulations. Material specifications and quantities, CADD drawings, construction sequencing, and initial cost estimates also are developed. With 60-100% design, sponsors refine designs based on feedback they received at conceptual to 30% designs. These designs may require additional data collection to allow more specificity and improvements.

5) Permitting – Meet with regulatory agencies between 10% and 30% level of design to identify issues, determine regulatory requirements, and identify the most appropriate means of compliance. For restoration projects, conversations often center around how to tailor design and construction such that the project will comply with available programmatic permits. Collect any additional data needed for permits (e.g., listed species presence/absence, wetland delineation, removal/fill volumes). Complete and submit permit applications between 60% and 100% design. Feedback from regulatory staff is often sought throughout the design process and incorporated into project designs as needed to avoid permitting complications later in the process.

6) Contracting and construction - Develop bid package and complete bid procurement process to hire construction contractors. Project sponsors typically are intimately involved in construction oversight to ensure the project is constructed as designed; confirm quantities, elevations, and materials deliveries; interface with the public and regulatory agencies; address unanticipated issues; help ensure worker safety; and other project management functions. The typical construction "window" is short (usually one to two months per year), primarily due to concern regarding impacts to ESA-listed species. Surveys to complete "As-Built" designs are done in this phase to determine whether a project was built per project specifications.

7) Post construction action effectiveness monitoring – Sponsor collects post construction data to determine if actions met project objectives, and if not, the reasons behind any shortcomings. This monitoring can take years or decades to see meaningful change. See AEMR section below for details.

8) Reporting – Project results are documented in writing and sent to funding partners, regulatory agencies, and other stakeholders.

9) Long term operation and maintenance – Long term operation and maintenance is frequently required for actions to ensure successful outcomes, especially tidegates or other water control structures that require routine cleaning and operation. Young plantings often suffer predation or are overgrown by invasive species and need further treatment to help ensure success.

Predictive modeling to determine project feasibility (phase 3), inform engineering designs and permits (phases 3 through 5) and evaluate project success (phase 7), requires additional data (water stage, tributary discharge, topography, bathymetry) and resources such as the specific technical expertise to develop, run and interpret model results. Each of these phases requires a significant amount of staffing, time, technical and financial resources from the project sponsor. As a result, included within each of these nine phases project sponsors are required to identify funding sources that are appropriate for the project. Important considerations for funding partners include the project location within the basin and species affected by the project. Funders are usually reluctant to fund initial phases (1-3).

Other important considerations for both project sponsors and funders are the partnerships and community support for the project. Projects typically encompass multiple stakeholders so meeting the goals for all can sometimes take a significant effort in negotiations. This includes working with the landowner and local residents that may be affected, and addressing real or perceived concerns. Landholdings straddle various socio-cultural and economic interests, so our ability to foster collaborative approaches is critical for the success of the comprehensive restoration program.

Additionally, to incorporate best available science and fill gaps in restoration actions, project sponsors require opportunities to learn from lessons gained by other restoration practitioners, incorporate latest findings from scientific studies contributing to the understanding of the lower river, and collaborate on individual projects. This is applicable to funding agencies well where managers wish to ensure projects they fund use the best available science and are strategically located in priority areas and to fill gaps.

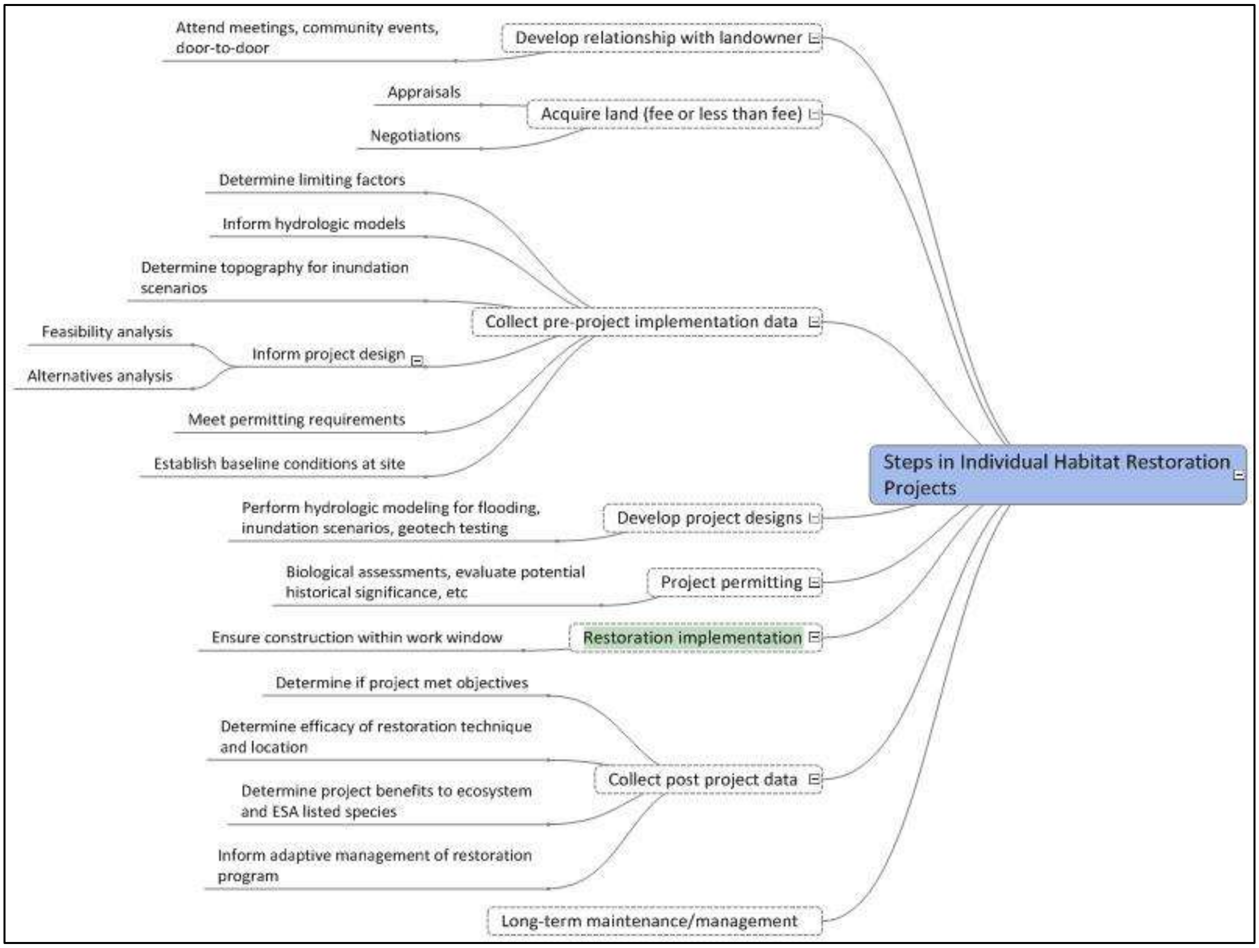


Figure 35. Life Cycle of a "Typical" Restoration Project

Restoration Prioritization Strategy

The Ecosystem Restoration Program is described thoroughly in Sections 2-6 above. This tool is used by the region to identify priority areas for protection and restoration to ensure we are implementing a holistic, ecosystem-based approach to restoring the lower river. Identified priority areas are compared to projects tracked within the Restoration Inventory geodatabase to track progress in restoring the priority areas and identify where future efforts are needed. For more information on the Restoration Prioritization Strategy, see the relevant section(s) above. The Restoration Inventory geodatabase is described below.

Technical Assistance Program

The Estuary Partnership's Technical Assistance Program is designed to support the capacity of restoration partners with all phases of restoration projects, but largely focusing on feasibility, design, monitoring and reporting phases. The Program includes several components: a) "on-call" technical assistance from engineering and modeling firms, b) assistance and expertise provided by Estuary Partnership staff, c) equipment lending library and d) assistance with professional growth and training opportunities. The Program was started in 2009 and has largely been focused on the first component, while components b and c were started in 2011. We hope to largely expand components b and c and begin offering the last component (d) in 2013.

"On-call" Technical Assistance

Since 2009, the Technical Assistance Program has focused primarily on the first component, or providing "on-call" technical assistance from engineering firms to project sponsors. The Estuary Partnership maintains "on-call" technical assistance contracts with multiple engineering firms to provide assistance as needed to project sponsors. Project sponsors can request technical services such as engineering, baseline data collection, geotechnical investigations, and hydrological modeling. The focus of the "on-call" technical assistance is to allow project sponsors to reach up to the 30% design phase (subsequent phases are funded through the competitive bid process described in Section 7.2 above).

The Estuary Partnership maintains "on-call" contracts with the following consulting firms, selected through a competitive Request for Qualifications process: InterFluve, Inc., Henderson Land Services, David Evans and Associates, Tetra Tech, Environmental Science Associates, Lower Columbia Engineering and Cardno ENTRIX. Project sponsors may also work with other firms with which they have already established relationships. Once project sponsors identify a need for technical assistance, they submit a short application to the Estuary Partnership, available through the Estuary Partnership's website. The Estuary Partnership staff reviews the application on a rolling basis, and if the Estuary Partnership determines the proposed use of technical assistance funding is consistent with the program's goals, authorizes the use of the funds and provides a summary of the request to the BPA. (When the Estuary Partnership requests technical assistance funding from BPA, the Estuary Partnership submits an application to BPA, who makes the funding decision.) The Estuary Partnership developed abbreviated evaluation criteria to evaluate project applications, which BPA reviewed and approved. The criteria include the project's consistency with the 2008 FCRPS BiOp actions, the potential increase in habitat structure and function, the potential increase in accessibility to the site for salmonids, the potential increase in the quality of salmonid habitat, and the project's size. Specifically, the project must be located in a tidally-influenced area and include improved fish access to historic floodplain habitat.

Because project sponsors use technical assistance funding for initiating project development and largely for identifying possible project actions and their feasibility, and not for larger project elements, funding requests are usually limited to approximately $70,000. The Estuary Partnership and the BPA generally make funding decisions within four weeks of receiving a request for technical assistance. The brevity of the application and review process allows project sponsors to expedite project development activities.

Staffing Expertise and Assistance

The Estuary Partnership and regional partners previously identified gaps in restoration activities upriver of Portland; consequently, the Estuary Partnership has been developing and implementing projects in this reach since 2010. This project implementation role includes a partnership with the U.S. Forest Service (USFS) whereby the Estuary Partnership helped the USFS develop a Watershed Restoration Action Plan (WRAP) for all Columbia River tributaries within the lower portion of the Columbia River Gorge. The WRAP process is used by the USFS to prioritize restoration within 6th-field watersheds in which they have a significant ownership. Estuary Partnership staff are leading implementation of the Lower Columbia River Gorge Tributaries WRAP, which includes twenty-four high priority projects.

The Estuary Partnership expanded this role in project implementation in 2011 by hiring additional staff, including individuals with expertise in native plant restoration, wetland delineation, hydrodynamic modeling and fluvial geomorphology. The Estuary Partnership also has two GIS and data management experts. These staff are available to partners to help provide additional capacity for baseline data collection; modeling to assess project alternatives and feasibility; action effectiveness monitoring for a subset of indicators (e.g., plantings, topography, bathymetry, water conditions, water stage, discharge, channel morphology) and GIS and database products.

One of the roles of the Estuary Partnership is to ensure regional partners have access and use best available science in restoration, species recovery and RME activities. The Estuary Partnership has invested in staffing technical expertise because making these resources available to partners will not only help increase the capabilities of project partners, but also will allow the region to assess and design more holistic restoration projects; predict impacts to aquatic resources and species of concern and evaluate changes in critical habitat and simulate basin scale processes including climate change within the lower river.

Currently, there is a large amount of high quality publically available data that could be used to drive future modeling efforts. With the backing of action agencies, and our partners, Estuary Partnership staff will provide expertise and guidance to coordinate and facilitate the development of a modeling platform that can be available to entities within the lower river. As part of this platform the Estuary Partnership will provide:

1) Modeling expertise that can be utilized by project partners and action agencies involved with restoration projects and habitat evaluation within the lower river.
2) Greater access to the best available modeling technology.
3) A framework for modeling collaboration and information sharing aimed at facilitating the scientific and technical development of ongoing restoration efforts.
4) Technical guidance related to the use and application of models and modeling standards
5) Significant cost savings to local sponsors and our project partners

Equipment Lending Library

The Estuary Partnership has developed and hopes to expand a technology lending library which can serve entities within the lower river involved in habitat restoration. The main focus of the lending library will be to provide equipment, technology and training to facilitate increasing local capacities. As part of the effort, the Estuary Partnership maintains a collection of equipment used for data collection, including survey grade and mapping GPS units; water surface elevation and water temperature monitoring equipment and other equipment needed to collect information prior to project implementation. The equipment will be available to entities who are working within the lower river, including non-profits; public and private entities; academic institutions and NGO’s. The equipment is requested through an online reservation system and must be used pursuant to the mission of the Lower Columbia River Ecosystem Restoration Program.

Professional Training Assistance

To build and maintain knowledge and expertise of restoration practitioners in the lower river and keep them abreast of the latest techniques and science regarding river and wetland restoration, species recovery and multi species management, we hope to provide assistance in professional growth and training opportunities. This will entail scholarships for partners to send staff to trainings, conferences and workshops on related subjects. We envision that project partners will submit a short application to the Estuary Partnership, available through the Estuary Partnership's website, on a rolling basis. The Estuary Partnership staff reviews the application, and if the Estuary Partnership determines the proposed scholarship request is consistent with the Program's goals, authorizes the use of the funds.

Landscape Assessment Tools

In addition to the Restoration Prioritization Strategy datasets described above, the Estuary Partnership creates, compiles and maintains a number of additional publicly available datasets that are useful for the identification, design and evaluation of restoration actions. All of these are available, as is the Restoration Prioritization Strategy, over the Estuary Partnership's website: www.estuarypartnership.org. A brief description of some of these tools follows. An example of how they can be used in combination with each other and the Restoration Prioritization Strategy is included in Section 1 above.

Restoration Prioritization Framework Tier 1 – Disturbance Model

In 2006 with funding from BPA, the Estuary Partnership with the Pacific Northwest National Laboratory (PNNL) developed the Restoration Prioritization Framework to address step 1 of the ecosystem-based approach in Johnson et al. 2003 (Evans et al. 2006; Thom et al. 2011). The Prioritization Framework was broken into two components: a disturbance model (Tier 1) and a project evaluation tool (Tier 2).Tier 1 used existing data for a series of stressors such as diking, toxic contaminants, roads, population, flow restrictions, etc. to model disturbances on individual site and landscape scales (Figure 7). Management areas (HUC 6 watersheds) and individual sites (on average 130 acre parcels) are assigned rankings of "low", "moderate", or "high" disturbance based on results of this model. Site and management area boundaries for the lower river reaches are shown in Figure 7. The units are color coded according by their scores output by the model. For any particular location, the relationship between site score and management area score can indicate the types of restoration (i.e., preservation, conservation, enhancement, restoration or creation) that would achieve the highest likelihood of success for that location. Figure 8 (adopted from Shreffler and Thom 1993), illustrates these relationships. Figure 9 shows actual site and management area disturbance scores plotted on this same type of scale. For example, where site and management area disturbance scores are low, portraying sites with low disturbance surrounded by a relatively intact landscape (Box G, in Figure 8 and Figure 9), acquisition or simple enhancement techniques are most appropriate. In comparison, where site and management area disturbance scores are both high, portraying highly disturbed sites surrounded by a highly disturbed landscape (Box C in Figure 8 and Figure 9), habitat creation or more intensive enhancement techniques are probably most appropriate. The likelihood of long term success in restoring natural processes is hindered in these sites. The site and management area scores are used in the Tier 2, project review and evaluation step described below.

Lower Columbia River Terrain Model - This ArcGIS 'terrain' dataset is a seamless elevation model which includes the most current topographic and bathymetric data that have been collected for the Lower Columbia mainstem and floodplain. It is the most comprehensive elevation model that has been developed for the region. All topographic data and the majority of the bathymetric data were collected subsequent to 2008. Historical bathymetric data was included in gap areas, in order to provide as complete coverage as possible. The datasets were compiled and merged into the seamless model by the United States Army Corps of Engineers, in 2010. Much of the recent shallow water bathymetric data was collected under contract by the Estuary Partnership. The model has seen a variety of applications, including hydrodynamic and sediment modeling, as well as simple flood inundation predictions in GIS. The dataset is freely available upon request from both the Corps of Engineers Portland District, and the Estuary Partnership.

Columbia River Estuarine Ecosystem Classification (CREEC) - Developed through collaboration between the Estuary Partnership, University of Washington, and USGS, the CREEC is a hierarchical classification which characterizes the unique ecosystem of the Lower Columbia River and Estuary. The framework was developed for applications in large river systems such as the Lower Columbia, which are characterized by very long reaches of tidal freshwater (nearly 200 km, in the case of the Lower Columbia), and hence are not well described by previously existing classification frameworks. The various hierarchical levels define the hydrologic regimes, as well as the geophysical processes which have formed the unique landscape over geologic time. Four of the six overall levels are directly applicable to estuarine research, restoration, monitoring, and management. The dataset is freely available from both the USGS and the Estuary Partnership websites (anticipated online access in August 2012). A USGS Open File report describing the concept and application of this framework as applied to the Lower Columbia is accessible at http://pubs.usgs.gov/of/2011/1228/.

Parcel ownership - The Estuary Partnership maintains the latest GIS parcel (taxlot) information from surrounding counties. The data is useful for scoping potential projects, contacting land owners, and determining overall availability of lands under various types of ownership.

Reference Sites data (RSS)- The Estuary Partnership has been collecting habitat data at approximately 40 undisturbed locations within the Lower Columbia since 2007. These sites represent how the ecosystem ideally functions in the absence of some of the major anthropogenic impacts (i.e., levees, tidegates, dredge material fill, invasive species) which are currently impacting much of the floodplain habitat. In many cases, they can be considered benchmarks for measuring the success of restoration practices, or the restoration trajectory, at neighboring sites. The Estuary Partnership maintains a geodatabase of reference site locations, as well as a suite of data for various habitat quality metrics that have been collected at these sites, including water surface elevations, temperature, sediment accretion, vegetation composition, channel cross sections, among other parameters.

Tidally impaired dataset – this GIS dataset maps historic floodplain habitat that is no longer fully hydrologically connected as a result of levees, dikes, culverts, tidegates or other structures. It represents potential juvenile salmon rearing and refugia habitat that could be made more accessible through restoration actions. The Estuary Partnership developed this dataset as an aspect of the 2010 land cover dataset (Level 6 of the CREEC) by using high resolution LiDAR elevation models to compare site elevations to an approximate high water benchmark, to generate a tidal/non-tidal estimate. High water benchmarks were mapped regionally by:

- River Mile (RM) 0 to 46

  This area is primarily tidally dominated. Used MHHW to NAVD88 conversion generated by NOAA Vdatum tool. This dataset was further calibrated using Ecosystem Monitoring Program and Reference Sites water surface elevation data at monitoring sites.
- RM 46 - 140

  This area transitions to increasing effects of Bonneville Dam discharge. This region was further calibrated using NOAA verified tidal elevations at Longview, St. Helen and Vancouver, in addition to Ecosystem Monitoring Program and Reference Sites water surface elevation data at monitoring sites.

Lower Columbia River Shoreline Condition Inventory and Video- In 2006, the Estuary Partnership collected georeferenced (GPS stamped) video footage of 630 miles of the Lower Columbia River mainstem, side channels, and sloughs. The video can be viewed in a geospatial context, using a proprietary ArcGIS plug in, in order to examine the shoreline at any desired location. In addition, the Estuary Partnership created a shoreline features GIS dataset, based on information derived from the digital video, which can also be used to assess the shoreline condition at any location, without the need for viewing the video. The Shoreline Condition Inventory is composed of three parts:

1) a number of spatially-referenced video files, containing footage of the shoreline recorded from a boat traveling along the shoreline;
2) a geodatabase of each river reach (A – H), containing vector data representing the shoreline character, as derived from the video footage and
3) additional reference data sources used to enhance shoreline characterization detail in the geodatabases.

The Inventory includes over 605 miles of shoreline (a gap exists surrounding the Portland airport as a result of radio interference). All video footage was recorded by the Partnership, over a period extending from June 2005 – October 2006. The primary shoreline characterization attribute distinguishes modified versus unmodified shoreline. Additional attributes provide further detail, such as modification type (e.g., levee, dredge material, residential, road/rail fill) or natural habitat type (i.e., riparian, tidal marsh, tidal swamp). Point features indicate locations of in water and over water structures (pile structures, outflows, culverts, tidegates, navigation structures, etc.).

Scientific Review and Selection of Proposed Restoration Actions

Since 2003, the Estuary Partnership, working with its partners, has developed and continuously refined a scientific review process to competitively select the most technically sound projects, involving multiple phases: 1) advertisement and proposal receipt; 2) site visits; 3) evaluation using Tier 2 of the Restoration Prioritization Framework (Evans et al., 2006; Thom et al., 2011); 4) peer review of designs, cost and constructability issues; and 5) Science Work Group, Project Review Committee scientific review and scoring, using the Estuary Partnership's project evaluation criteria. These steps are described in more detail below. Upon final funding approval by the funding agency (e.g., BPA), the Estuary Partnership then manages contracts, tracks projects using its restoration inventory, and provides updates and results to funders and partners.

Since 2003, a primary entity supporting habitat restoration for salmon recovery in the lower river has been the NPCC/BPA, amounting to a current regional annual budget of approximately $15 million. The support from BPA has allowed the Estuary Partnership and regional partners to leverage additional restoration funding, including two years of funding through the USEPA's Targeted Watersheds Program and six years of funding through the NOAA's Community-based Restoration program. Additionally, the Estuary Partnership and regional partners have obtained project specific funding from Oregon Watershed Enhancement Board, Lower Columbia Fish Recovery Board (Salmon Recovery Funding Board), East Multnomah Soil and Water Conservation District (EMSWCD), National Fish and Wildlife Foundation (NFWF) and North American Wetlands Conservation Act (NAWCA). The combination of these funds has allowed the program to expand and support a large number of restoration or protection projects.

While the Lower Columbia River Ecosystem Restoration Program focuses on the lower river in its entirety, and its importance for all species of fish and wildlife, a primary objective of the primary funding entity contributing to this Program is restoring habitat for the 13 ESA- listed salmonids and implementing actions listed in the 2008 Federal Columbia River Power System Biological Opinion (FCRPS BiOp). BPA funding specifically targets the identification, development, and implementation of restoration projects designed to protect and restore habitat important for juvenile salmonids. Hence, at this time and until other funding entities provide additional resources, projects implemented through the process outlined below must meet these objectives.

Estuary Partnership Project Scientific Review Process

1) Advertisement and Proposal Receipt - an announcement of the next review cycle is released to initiate the scientific review process during three cycles of each calendar year. Project proposals received by the due date are recorded and distributed to the Estuary Partnership Science Work Group, Project Review Committee members. Committee members also receive the project evaluation criteria, a scoring sheet and a copy of the funding announcement.

2) Site Visits – the Estuary Partnership works with project sponsors to schedule site visits to each project site. Members of the Project Review Committee visit each project site, where project sponsors lead tours and answer reviewer questions re: restoration actions. The site visits allow reviewers to review the project site, ask questions of project sponsors and allow project sponsors to provide an overview and additional information to Committee members.

3) Review using the Prioritization Framework (optional) – the Estuary Partnership can evaluate project proposals using Tier 2 of the Restoration Prioritization Framework developed by the Estuary Partnership and PNNL in 2006 (Evans et al., 2006; Thom et al., 2011). Tier 2 allows evaluators to assess each proposal relative to site and surrounding landscape disturbances and provide a scientific method for comparing specific projects across each other using the project's expected change in ecosystem function and its likelihood of success.

Tier 2 of the Prioritization Framework provides a scientific framework for evaluating projects across each other using predicted changes in ecosystem function, likelihood of success, size of project and cost. Evaluators complete a spreadsheet for each project (Table 22), assessing predicted changes in multiple ecosystem functions (e.g., organic matter flux, primary production, habitat opportunity, capacity) and metrics indicating potential success of project (e.g., long term maintenance, resilience). The Tier 1- disturbance model (see landscape assessment tools described above) site and management unit scores are integrated into this assessment. The project scores are ranked according to their raw scores, and the resulting information is provided to the Project Review Committee as additional information to consider in their project evaluation in step 5 below.

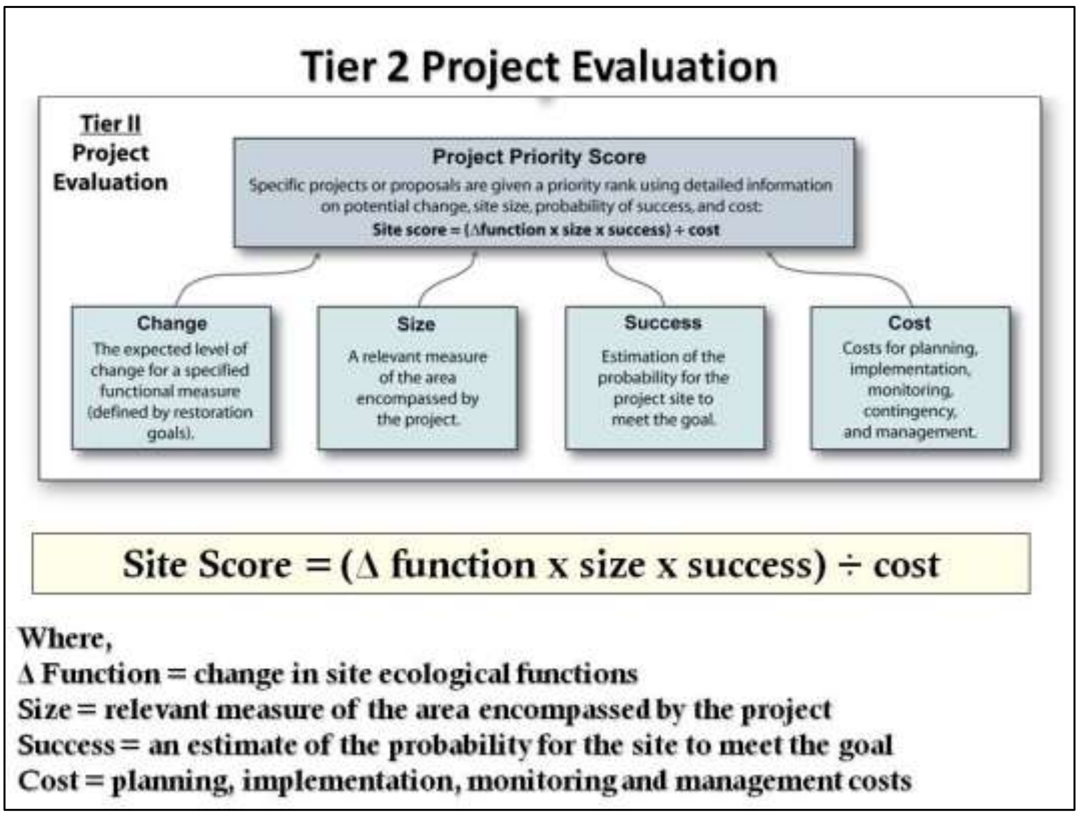


Figure 36. Restoration Prioritization Framework Tier 2 provides a scientific basis for evaluating projects across each other using predicted changes in ecosystem function, likelihood of success, size of project and cost.

4) Design Review (as needed) - the Estuary Partnership contracts with outside firms or engineers to provide another level of review of proposed projects. Engineers, modelers and landscape architects well familiar with designing, permitting and implementing restoration and mitigation projects review project proposals, attend site visits and the Project Review Committee meeting. These experts evaluate the projects from an implementation, engineering and cost over-run perspective. They then provide an assessment of each project to Project Review Committee members at their meetings (see #5 below).

5) Technical Review and Scoring - The Project Review Committee convenes to formally review and score the proposals. The Project Review Committee focuses largely on providing scientific review of potential ecosystem benefit from project actions and concerns they have with designs, long term success of actions, community support, cost or constructability. The Committee provides clear guidance on whether a project should be funded as proposed, and if not, provides recommendations on potential improvements to ensure a scientifically – based, successful project. They can, and often have, requested to see the project again at a further phase to ensure project sponsors are addressing their recommendations.

The Committee also scores projects, using the Estuary Partnership's evaluation criteria (available from the Estuary Partnership website: http://www.lcrep.org/sites/default/files/restoration/docs/Estuary%20Partnership%20Project%20Review%20Criteria.pdf). These criteria were developed in a regional workshop with over 100 participants and have been reviewed by the Northwest Power Conservation Council's Independent Scientific Review Panel (NPCC's ISRP). These criteria were updated to include the results from the Lines of Evidence 1-4 described above. Estuary Partnership staff tally project scores and rank them by median scores. Estuary Partnership staff then provide results from the scientific review and funding recommendations to the funding agency (e.g., BPA; see 2013 CEERP Strategy Report for how BPA then makes funding decisions).

Project Review Committee members include federal and state representatives from fish and wildlife management agencies and include a wide range and depth of expertise such as fisheries biologists, restoration program managers and salmon recovery planners; representative agencies include US Fish and Wildlife Service, US Environmental Protection Agency, NOAA National Marine Fisheries Service, US Army Corps of Engineers, Lower Columbia Fish Recovery Board, Oregon Department of Fish and Wildlife, and Washington Department of Fish and Wildlife.

Table 22. Example of a completed Tier 2 evaluation for an individual project.

Project Score = (function change x size x probability of success)					
offsite effect = >1	high=.67 to 1	mod=.34 to.66	low=0 to .33		
Project Analysis Results			**Prioritization Framework Data**		
Proj. Name	**Otter Point**		***Sites***	1890	
Proj. Score	**0.78**		***MA***	1840	
Cost/Proj. score	**321,428.57**		***Site score***	0.397	
Cost/Functional Acre	**7,462.69**		***MA score***	0.482	
			Avg. Adj sites score	0.285	
A. Analysis of change in function, process, value					
Functions	Preserved	Increase	Decrease	No change	Unsure
Primary production		1			
OM Flux		1			
Sediment Trapping		1			
Nutrient Processing		1			
Flood Attenuation		1			
Food Web Support		1			
Opportunity		1			
Capacity		1			
Natural Complexity		1			
Natural Biodiversity		1			
Sum Score	0	10	0	0	0
Analysis score	1.00				
B. Analysis of change in size of functional area					
Total Area of project	33.5	acres			
Area of function restored or preserved	33.5	acres			
Prop. of Tot. Area	1.00				
C. Analysis of predicted success of project					
Factor	High	Moderate	Low	Unsure	Notes
Case studies	1				
Restoration strategy	1				appropriate techniques for site score/ management area score relationship
Habitat forming processes	1				
Landscape features		1			moderate disturbance (from Tier 1)
Site condition		1			moderate disturbance (from Tier 1)
Adjacent habitat condition	1				low disturbance (from Tier 1)
Self-maintenance		1			
Resilience		1			
Time frame	1				
Sum Score	5	4	0	0	
Analysis score	0.78				

Project Management

Upon receipt of final funding approvals from the funding entity (e.g., BPA), the Estuary Partnership negotiates contracts with the project sponsors using the project proposal as the template. The Estuary Partnership then provide the funder with oversight over project implementation, quarterly progress reports and an annual report that describes status and progress made of all projects funded under that fiscal year contract. Additionally, the projects are uploaded into the Estuary Partnership's Restoration Inventory geodatabase for tracking. Information is made available on the Estuary Partnership's mapping website and maps are produced for partners upon request.

Restoration Inventory Geodatabase

Since 2003, the Estuary Partnership working with its partners has tracked restoration projects throughout the region in its Restoration Inventory, a GIS based database. In this database, the Estuary Partnership records all identified, planned and completed protection and restoration projects for the lower Columbia River and estuary, amounting to over 200 projects, representing 16,614 acres restored and/or protected. Information presently tracked in the database include the project sponsor; project actions; site descriptions; limiting factors and threats addressed; acres and stream miles protected or restored; project costs; and known species using the project site. The Estuary Partnership queries the database and produces summary reports and maps upon request meeting the various needs of funding agencies (BPA and USEPA) or other regional partners. We report annual progress to USEPA and partners through an annual brochure document. This database also provides the information provided over the Estuary Partnership's online mapping website.

As explained in Section 6, identified projects included in the Restoration Inventory can be routinely overlaid with the results of the Restoration Prioritization Strategy to determine overlap (where projects and priorities come together) or gaps (where priorities exist but projects have not yet been identified). In the former case, the results are provided to the Project Review Committee for consideration in evaluating and scoring individual projects (Section 7.2), whereas in the latter case, the information is supplied to restoration practitioners in hopes of ultimately addressing the identified priority gap.

In 2012, the Estuary Partnership is expanding the role of the Restoration Inventory to provide better documentation of project progress and long term success of implemented actions. The objective of the expansion is twofold: 1) provide a central location for project implementers to document individual actions, track their progress at a site and identify when future restoration actions are needed if actions are not meeting original goals, and 2) provide the data for regional entities such as the Estuary Partnership, LCFRB, ODFW, BPA, USACE, and NOAA to track restoration actions on a cumulative basis and quantify the benefits. Based on a combination of the "site evaluation card" metrics in the Cumulative Effects of Restoration project (USACE 2010) and discussion with restoration practitioners at a project development coordination meeting in 2011, the following metrics would be tracked in the expanded Restoration Inventory:

- Site name
- Site location (latitude, longitude, river mile)
- Ownership
- Baseline site condition description, habitat types
- Known ESA species that use site; other important facts
- Limiting factors
- Description of Landscape Context (is this a priority location in Restoration Prioritization Strategy?)
- Long term goal for site (e.g., scrub shrub habitat, manage for western pond turtles)

- List of Previous Actions/Interventions at Site (e.g., dike breach, tide gate retrofit, LWD, plantings)
- At a minimum the following information for each individual action, intervention:
    - Objectives for each action (e.g., develop salmonid access to a former wetland and restore natural tidal wetland functions)
    - Location within site (line or polygon in GIS preferred)
    - Start date, End date
    - Steps taken
    - Expected outcome
    - Location of as built drawings, if existent
    - Measures of success for action, intervention
        - Performance metrics
        - Performance criteria
        - Triggers for future actions, interventions
    - Reference site(s)
    - Cost
    - Funding source(s)
    - Acres or stream miles directly impacted at project site
    - Acres or stream miles affected (for increased fish access projects)
    - Partners
    - Volunteer hours
    - Post construction description of site, habitat types
- Description of Potential Future Actions (if known), Management Plan (by reference if plan exists)
- Performance Metrics for overall site (if different than action/intervention) – (e.g., wetted area; presence of salmonids; wetland vegetation cover and community structure; accretion rate; survival benefit units).
    - Baseline data collected at site; where data are housed, results (e.g., photo points, topography, water level, sediment accretion)
    - Post construction data collected at site; where data are housed, results
- Performance Criteria for overall site (if different than action/intervention)– Wetted area at mean higher high water extends over 80% of the project site within 12 months of levee breach. The following are examples:
    - Juvenile salmonids occur in densities within the range found in reference sites over a three-year period following breaching
    - Wetland species composition and percent cover trend toward being similar to that in appropriate reference sites
    - Sediment and organic matter are actively accreting at the site over a five-year period following breaching
- Adaptive Management Triggers – Poor performance of any of the criteria after 1-2 years may require intervention to correct
- Every 5 years update site description, habitat types, limiting factors

If the information that is collected is comparable across projects and is collected for all projects, the information can be used in a “meta-analysis” called for in the *Cumulative Effects of Restoration* project (USACE 2010).

The Estuary Partnership wishes to move toward compiling this information, rather than final reports from project sponsors in winter 2013. Project sponsors would complete a form from the database, available from the Estuary Partnership website, providing this information. The sponsor's information within the database will be made electronically available to the project sponsor and linked to other similar databases such as LCFRB's SalmonPORT and BPA's Taurus.

Outreach, Coordination and Identification of Gaps

One of the Estuary Partnership's primary responsibilities as a National Estuary Program is to provide increased communication and coordination of research, monitoring and restoration efforts in the lower Columbia River and estuary. A large part of this is accomplished through the monthly Estuary Partnership Science Work Group meetings, annual estuary Research Monitoring and Evaluation (RME) Coordination meetings, quarterly restoration project development coordination meetings, annual Estuary Partnership Science to Policy Summits and biennial Columbia River Estuary Conferences. All these forums provide regular opportunities amongst partners for the technical exchange of the emerging results of scientific studies and updates on restoration and RME activities. These forums provide opportunities for regional partners to learn from each other so we all can incorporate the latest findings into our work, brainstorming for new ideas and new ways to collaborate on projects and identifying emerging issues, critical uncertainties and gaps in RME or restoration activities as well as ways of resolving these issues and gaps.

- **Science Work Group** – members meet monthly and work to ensure a consistent and cooperative approach to solving regional scientific issues. In 2011, the Science Work Group focused on refining the methods and applying the results of this Restoration Prioritization Strategy, developing an estuarine indicator system for the lower Columbia River, and reviewing results of the comprehensive status and trends analysis of the Ecosystem Monitoring Program. This group is coordinated by the Estuary Partnership and is open to anyone with technical knowledge and working towards implementing the actions of the Estuary Partnership's Comprehensive Conservation and Management Plan (CCMP).
- **Estuary RME Coordination** – members meet annually to provide updates on their RME activities and their plans for the upcoming sampling season. This meeting is coordinated by the Estuary Partnership with USACE, BPA, LCFRB and ODFW input and support. Membership includes principal investigators of RME projects funded through the USACE's AFEP, BPA's Fish and Wildlife Program and states' salmon recovery programs. The meetings have been held since 2009 and have not yet included investigators of water quality, toxic contaminants or other species but could do so upon request.
- **Quarterly Project Development Coordination** – members meet quarterly at rotating locations to provide an update on projects they have recently identified, begun developing and/or are underway. Members also discuss larger issues holding up or of concern to restoration activities, identify knowledge gaps or critical uncertainties and help to identify ways to resolve these issues. These meetings have been held since 2010 and are coordinated by the Estuary Partnership. Membership is open to government agencies and not-for-profit entities working on habitat restoration in the lower river.

- **Science to Policy Summit –** these are annual workshops to bring those involved with emerging science together with policy makers and people working on the ground. Community leaders from tribal government, academia and applied science, agriculture, transportation, fisheries, recreation, elected officials, and local, regional, state and federal government agencies participate in each summit. Scientists with expertise in habitat restoration, ecosystem function, toxics contaminants, climate change and many other disciplines contribute regularly as speakers and participants.
- **Columbia River Estuary Conference** – these are biennial conferences that allow technical exchange on a large scale amongst researchers, scientists, resource managers and planners. These conferences have been held in Astoria since 1999 and are open to any who wish to attend. Topics of the conferences include the following:
    - 1999 - Biological Integrity
    - 2001 - Habitat Conservation and Restoration
    - 2003 - Research Needs
    - 2006 - Estuarine and Ocean Ecology of Juvenile Salmonids
    - 2008 - Ecosystem Restoration
    - 2010 - Adaptive Management
    - 2012 - New Scientific Findings and their Management Implications

In addition to these regular occurring coordination activities, the Estuary Partnership convenes topical workshops and conferences, such as the two-day April 2012 Estuarine Indicators Workshop. Previous workshops have focused on issues facing habitat restoration, water quality and toxic contaminants, bathymetry data gaps and updating land cover dataset. Finally, the Estuary Partnership participates in regional efforts such as the USEPA Toxics Reduction Working Group, Northwest Association of Networked Ocean Observation Systems (NANOOS), Pacific Joint Venture, and Pacific Estuarine Research Federation to provide regional representation and input as well as bring back information gleaned from these groups to share with regional partners.

Adaptive Management Framework

The Lower Columbia River Ecosystem Restoration Program includes an adaptive management framework that includes a) an ecosystem monitoring program to track trends in the overall condition of the lower river, provide a suite of reference sites for use as end points in our restoration actions and place results of our findings into the context with the larger ecosystem; b) an action effectiveness monitoring program that assesses whether restoration actions are meeting partners' goals or whether future actions are necessary, identifies which actions are working best and informs how we can improve efficacy of our actions; c) critical uncertainties research designed to address specific questions (e.g., contribution of salmon use of estuarine habitats to adult returns) d) implementation monitoring and e) a governance structure to ensure information is shared and acted upon. This last component includes regular coordination opportunities to learn from results of the latest scientific findings, brainstorm new ideas and lessons learned, collaborate on projects, identify gaps (see above) will then allow not only restoration practitioners to integrate information into their restoration actions but also resource managers and funders to incorporate the findings into funding priorities.

A key component of adaptive management of the Lower Columbia River Ecosystem Restoration Program is research, monitoring and evaluation (RME). With properly designed and implemented RME, regional partners can ensure efforts and funding are being applied properly, learn from on-going efforts to improve future activities and assess beneficial (or negative) impacts of efforts on site, landscape and ecosystem-wide scales as well as for overall species recovery. Several key questions that estuary RME should address include the following status and trends type monitoring questions (for more information, see Estuary Partnership, 2012):

1. What is the biological integrity[3] of the LCRE and is it improving or declining? (Estuary Partnership, 1999a, b; NPCC, 2010, "Are Columbia River Basin fish and wildlife abundant, diverse, productive, spatially distributed, and sustainable?" and "Are Columbia River Basin ecosystems healthy?")
2. What is juvenile salmon performance (i.e., life history strategy diversity, spatial structure, growth, foraging success) in the lower river, and is it improving or declining? What are the limiting factors and threats that affect the status of an ESU within the estuary and are they improving or declining? (NMFS, 2011a, b)
3. What are the pollutants of concern, and are their concentrations increasing or decreasing? (from Estuary Partnership 1999a, b; "Are pollutant levels increasing or decreasing? Are concentrations of toxics in sediment and biota impairing native species?")
4. What are the ecosystem (biological, chemical and physical) processes and are those processes improving or degrading? (NMFS, 2011b)
5. What are the effects of climate change on estuary ecosystem condition and are they increasing or decreasing? How are the components adapting to stressors of climate change and how resilient are the components? (Estuary Partnership, 1999a, b; NPCC, 2010: "Is climate change affecting fish and wildlife in the Columbia River Basin?")

Other key questions we need to consider include a focus on action effectiveness or implementation monitoring and research:

1. Are the actions identified in the various management plans (e.g., CCMP, NOAA's Estuary Recovery Plan Module, NPCC's Subbasin plans, OR and WA salmon recovery plans) being implemented correctly, in sufficient scope, and according to schedule?
2. What are the effects of estuary management actions on ESA- listed species and their habitat?
3. Are additional actions needed?
4. Are there additional or new threats and limiting factors within the estuary beyond those considered in the various management plans?

A brief description of on-going estuary RME efforts, data management and how the results will be used in the Lower Columbia River Ecosystem Restoration Program is described below. First, however, is a brief description of the different types of RME:

- **Status and Trends Monitoring** - Effective ecosystem management requires knowledge of changes (particularly detrimental changes) that occur in the ecosystem, and of the factors that lead to those changes. The ultimate goal of status and trends monitoring is to track the status of a resource (e.g., river stage at a given point, salmon escapement in a

[3] USEPA definition of biological integrity: capability of supporting and maintaining a balanced, integrated, adaptive community of organisms having a species composition, diversity, and functional organization that is comparable to representative natural habitat in the region (Karr and Dudley, 1981; Frey, 1977).

specific tributary, plankton composition and biomass in a lake or slough) over time but also to allow researchers and managers the ability to distinguish between variability associated with natural conditions, from any changes or variability that may result from human intervention. The creation and maintenance of long term datasets have irreplaceable value for documenting the history of change (long term trends) within important resource populations, for evaluating the potential significance of human activities on natural resources and for visualizing and formulating testable hypotheses about the interactions among species, between species and their environment and the mechanisms for these interactions and how the ecosystem functions.

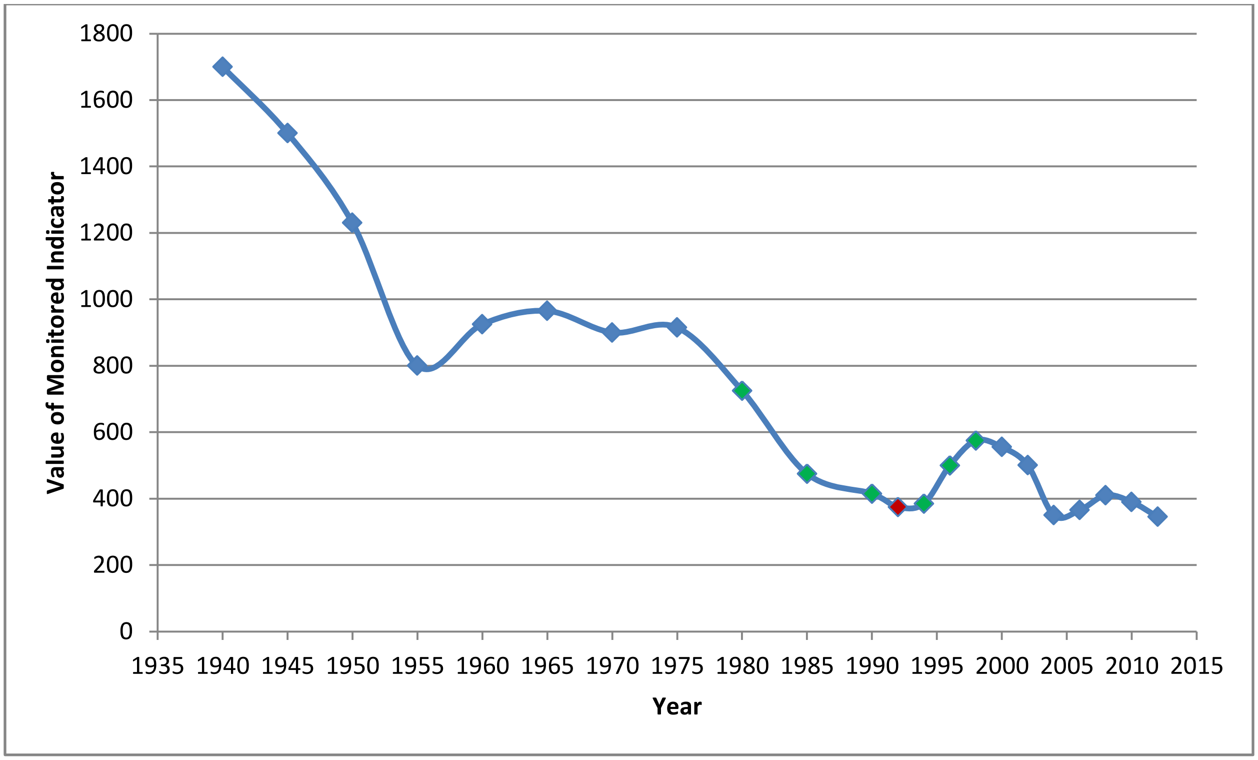


Figure 37. Conceptual diagram illustrating importance of long term datasets from status and trends monitoring. Blue points represent results from a conceptual long term dataset, while green represents a conceptual shorter term data collection effort. Red point represents time period of intervention aimed at restoring or recovering a natural resource. Obvious from this diagram is the long term trend of the resource, in which the intervention falls. If longer term data had not been collected, this long term trend would not have been captured and the intervention may be deemed successful.

- **Action Effectiveness Monitoring and Research** (AEMR) - The overall objective of action effectiveness monitoring and research is to provide information on the efficacy of management actions. Project sponsors desire to know whether the actions taken meet their intended goal, while funders and resource managers are interested in learning the effectiveness of a specific technique and the limits to that effectiveness. Focusing on the latter aspect, researchers usually test a set of representative management actions, such as specific types of habitat restoration, by monitoring a suite of variables pre and post implementation of the action, to evaluate the effects on surrounding habitats and provide feedback on potential methods for improving techniques, locations or other aspects of the action. Action effectiveness research usually involves project-scale monitoring of site-specific conditions to determine whether implemented actions were effective in creating the desired change and whether program-specific performance goals were met. This type of monitoring also can include long-term post-project implementation monitoring to see whether the actions continue to function as they were designed or intended. In some cases the information needed for action effectiveness monitoring may be provided by status and trends monitoring, but action effectiveness research generally requires focused evaluations of more specific parameters directly associated with actions.

- **Critical Uncertainties Research** - The overall objective of critical uncertainties research is to improve our basic understanding of relationships between ecological attributes and mechanisms. Uncertainties can include cause and effect relationships among organisms, limiting factors, threats, and activities meant to protect or restore ecosystem structure and function or recovery listed species.

- **Implementation and Compliance Monitoring –** This type of monitoring is to ensure that implemented management actions were constructed, operated and maintained as proposed over sufficient time and quantities, and according to schedule. This monitoring is important for evaluating whether recovery and restoration programs are meeting objectives and performance measures, such as the number of estuary habitat acres conserved or restored annually. Objectives and performance measures for implementation and compliance monitoring are specific to the programs they evaluate.

Ecosystem Monitoring Program

The Ecosystem Monitoring Program is an integrated status and trends program. The overall objectives of this Program is to track trends in the overall condition of the lower river, provide a suite of reference sites for use as end points in our restoration actions, and place results of findings into the context with the larger ecosystem. This Program is funded by the NPCC/BPA, and a primary goal of this program is to collect key information on ecological conditions for a range of habitats in the lower river characteristic of those used by out migrating juvenile salmon and provide information towards implementation of the 2008 FCRPS BiOp. Information collected describes synoptic conditions and changes over time in vegetated floodplain habitats and the opportunity, capacity and realized function (Simenstad and Cordell 2000) for juvenile salmonids. These habitats are the targets of regional restoration efforts, and this program provides integral information for understanding the success of the regional habitat restoration program. The results of this program provide information on ambient environmental conditions and insight into the cumulative effects of existing and new management actions and anthropogenic impacts as they occur.

The Program specifically collects status and trends data on the following:

- salmonid occurrence, diet, condition and residency at shallow water and vegetated sites in the mainstem and tributary confluences;
- habitat structure, including physical, biological and chemical properties of these habitats;
- food web characteristics, including primary and secondary productivity at these habitats and in the mainstem lower river and

- provides information allowing other researchers to assess the biogeochemistry of tidal freshwater region of the lower river to the biogeochemistry of the estuary, which is key in tracking ocean acidification and climate change impacts on estuary habitat capacity.

Applications of Results to Management - The Program has provided key information on a suite of 51 reference sites across the lower river. These sites will be used as end points for restoration projects and used in combination with the AEMR Program data described below. Data collected through this Program on vegetation, elevation and hydrologic patterns from these sites have been used to create regionally specific restoration design considerations for use by restoration practitioners in designing more successful restoration actions. Patterns include 5 vegetation zones and 3-4 hydrologic zones and elevation tolerance of the invasive species, reed canarygrass. Data collected through this Program have also documented preferential use of regions of the lower river by different salmonid ESUs.

Past Results - From 2004 through 2010, with funding from NPCC/BPA, the Ecosystem Monitoring Program accomplished the following major tasks: 1) developed a statistically valid, ecosystem-based monitoring plan for the estuary (focusing on juvenile salmon habitats); 2) developed and published a hierarchical estuarine ecosystem classification system (CREEC) in which to base sampling designs and habitat restoration strategies; 3) mapped over 19,000 acres of high and medium priority shallow water bathymetry gaps; 4) mapped land cover of the lower river floodplain in 2000 and 2010; 5) collected water chemistry data and juvenile salmonids to support the creation of 3 models related to salmonid uptake, transport, and ecological risk of toxic contaminants; 6) collected habitat structure data at 23 sites and comprehensively monitored 11 sites throughout the lower river for habitat structure; salmon occurrence, diet, condition, stock, and growth; prey availability and preference, providing in some areas the only contemporary juvenile salmon use data available; 7) initiated the characterization of the salmon food web at 4 sites representing the estuarine-tidal freshwater gradient; 8) collected abiotic environmental/water column condition data at 1-4 sites annually and 9) provided technical assistance to the USACE in creation of a terrain model of the lower river, resulting in a seamless bathymetry/topography map which will be invaluable in mapping salmon habitat opportunity in combination with river flow data.

In addition, NPCC/BPA funding provides leverage that allowed the Estuary Partnership to accomplish these additional estuary RME-related activities: 1) convened 5 technical workshops for researchers and managers on topics of interest such as land cover, bathymetry, toxic contaminants, and restoration; 2) provided monitoring coordination for entities involved in monitoring the lower river, exemplified by the estuary RME coordination meeting in spring 2010, 2011 and 2012 involving NMFS, PNNL, CREST, USACE, BPA, LCRFB and others; 3) compiled information and presented overviews of on-going monitoring activities at various events, including the Estuary and Ocean Subgroup, USEPA Toxics Reduction Working Group; and regional and national conferences; 4) played a key role in efforts supporting regional monitoring coordination, including Pacific Northwest Aquatic Monitoring Partnership's Integrated Status and Trends Monitoring group, an inventory of on-going effectiveness monitoring at restoration sites, and refinements to standardized protocols for restoration effectiveness monitoring; 5) acted as a central clearinghouse for GIS data while developing mapping website to house monitoring data collected in estuary; 6) supported on-going regional toxic contaminants reduction efforts, such as preparing the State of the River Report, presenting monitoring information at the workshops, developing a basin-wide contaminant monitoring strategy with USEPA's Toxics Reduction Workgroup, and supporting the institution of an Oregon Drug Take Back Program; 7) presented monitoring efforts at several regional and national conferences, including the Coastal and Estuarine Research Federation and National Conference on Ecosystem Restoration; 8) chaired an all day session on monitoring and restoration efforts in Pacific Northwest estuaries at the 2009 Coastal and Estuarine Research Federation conference with co-chairs, PNNL and South Slough National Estuarine Research Reserve and 9) participated in regional forums, such as Pacific Estuarine Research Federation (PERS), NANOOS, American Fisheries Society, and Pacific Joint Venture, to share information and coordinate RME and restoration efforts. Information exchanged and gained and networking with other researchers doing related work during these events provide invaluable insight and guidance for future RME and restoration efforts in the lower river.

Current Work - The Estuary Partnership is currently developing an estuarine condition index to provide a framework for illustrating and reporting ecosystem conditions, how they are changing over time, other information gleaned from the Program and management implications to the public, scientists and managers. This indicator system will use the US Environmental Protection Agency's Biological Condition Gradient (BCG) framework (Davies and Jackson 2006), which provides the following benefits to users:

1) Determine the environmental conditions that exist now relative to historic conditions. Through the BCG process stakeholders defined baseline conditions of the lower river "as naturally occurs". Current ecological conditions can then be compared and communicated relative to that baseline across different indicators.
2) Decide what environmental conditions are desired (target-setting). Through the BCG process stakeholders then set environmental goals for key ecological attributes (e.g., natural habitat mosaic, diversity of life history strategies for Pacific salmonids, natural processes).
3) Plan for how to achieve these conditions (management). The BCG provides a scientific basis for planning, restoration, protection and monitoring by providing a common language and shared quantitative goals.
4) Communicate with stakeholders—When biological and stress information is presented in the BCG framework, it is easy for the public to understand the status of the aquatic resources relative to what high-quality places exist and what might have been lost.

As this indicator system and numeric management targets are developed, they will be integrated into the Lower Columbia River Ecosystem Restoration Program (Sections 6 and 7, specifically), including the monitoring design of the Ecosystem Monitoring Program.

Also, the USACE is developing a centralized database that would house data collected under this program, the Action Effectiveness Monitoring and Research Program and Critical Uncertainties research projects funded through AFEP. This is expected to be a three year project completed in 2014.

Action Effectiveness Monitoring and Research Program

The Action Effectiveness Monitoring and Research (AEMR) Program is focused on providing information on all restoration actions in the lower river and tidal tributaries. The Program objectives are to provide information on whether restoration actions are meeting partners' goals or whether future actions are necessary; allows us to assess on ecosystem scale the impacts and ecological uplift partners are providing; identifies which actions are working best and informs us how we can improve the efficacy of our actions. Primarily funded by the NPCC/BPA and the USACE, the current focus is on actions aimed at restoring historic juvenile salmon habitats.

The goals for this Program have multiple levels. On an individual site scale, project sponsors such as CREST, CLT, the Cowlitz Indian Tribe, watershed councils and USACE for instance, desire to track the following information:

1. Were the actions taken at the site successful in meeting their objectives?
2. Is the site trajectory on a path to meet the long term management goals for the site?
3. Are future interventions/actions needed to meet the long term management goals for the site? What are the relevant triggers or information needed to make this decision?
4. Which actions were most successful, cost effective and timely? Which could use improvement? How can they be improved for future restoration work?

Funding entities such as NPCC/BPA, NOAA and USFWS desire to understand the following questions with AEMR:

1. Were the actions implemented as proposed and/or contracted? If not, why not and what are lessons learned?
2. Were the actions taken at the site successful in meeting their objectives? (#1 above)
3. Which actions were most successful, cost effective and timely? Which could use improvement? How can they be improved for future restoration work? (#4 above)

On a landscape or ecosystem scale, all entities are interested in tracking the following:

1. What kind of impact are the actions we implement on a site scale having on a cumulative basis? How can we better collect and manage AEMR data so that this can be assessed?
2. Do the results from actions on individual sites show an improvement in ecosystem conditions, measured in part through the Ecosystem Monitoring Program (described above)?
3. What are the gaps in actions, in locations, types and techniques?
4. How much is sufficient? Are we able to offset on-going anthropogenic impacts as well as recover from past degradation?

<u>Past Results</u>

From 2008 to 2011, the Estuary Partnership conducted AEMR at four project sites (Mirror Lake, Sandy River Delta, Scappoose Bottomlands, and Fort Clatsop). These AEMR sites represented different restoration activities (culvert enhancement to improve fish passage, large wood installation, re-vegetation, cattle exclusion, and culvert removal for tidal reconnection), habitats (bottomland forest, riparian forest, emergent wetland, and brackish wetland), and geographic reaches of the river (Reaches H, G, F, and A, ranging from tidal freshwater in Reach H, or the Columbia River Gorge, to saltwater intrusion in Reach A, near Astoria, Oregon). Standard extensive indicators were monitored at these sites and included water quality, landscape features, vegetation community and composition, planting survival, and fish community. Also, intensive indicators were monitored at three of the four sites and included salmonid condition, salmonid genetic stock identification, salmonid lipid content, toxic contaminants, prey availability, channel morphology, and sediment accretion. All the AEMR sites had varying levels of pre-restoration monitoring, which allowed for before and after comparisons related to restoration actions at the site. Additionally, two of the four sites had before-after-control-impact (BACI) statistical designs which improved the ability to quantify changes at the site level. However, most restoration projects do not have an associated reference or control sites and it is necessary to have an alternative method to analyze the impact of restoration actions. The Reference Site (RS) study was initiated to address this issue (Borde et al 2012). To determine the relative similarity between restored and reference sites, Borde et al (2012) compared data from 51 reference sites to AEMR datasets to demonstrate structural data from reference sites throughout the estuary can be used to evaluate restoration action effectiveness. Also, the RS study provided information about what metrics are most useful when conducting evaluations between reference and restoration sites. Given the limited opportunity for associated reference or control plots for most restoration projects, the ability to associate a restoration project to a suite of reference sites provides an alternative method for tracking the trajectory of a restoration site through time.

The pilot Estuary Partnership's AEMR sites have demonstrated the necessity of a standard set of protocols for data collection to evaluate restoration projects at the site and estuary scale. *Protocols for Monitoring Habitat Restoration Projects in the Lower Columbia River and Estuary* developed by Roegner et al (2009) provided a standardized approach for data collection on extensive indicators related to juvenile salmonids and provided guidance for statistical design for monitoring to restoration projects. The Roegner et al (2009) protocols established standard extensive indicators to track controlling factors (e.g. tidal regimes), structural factors (e.g. vegetation growth), and functional factors (e.g. fish community structure) that could be implemented efficiently and economically by project sponsors. Furthermore, a standardized protocol for monitoring standard extensive indicators allows for the correlation, through ratio estimators, to intensive indicators (e.g. floodplain wetted area, plant biomass export, material flux, Johnson et al 2012). Additionally, Johnson et al (2008) and Roegner et al (2009) presented statistical sampling designs for BACI and after only sampling which allow inferences to be made about the trajectory of the restoration. The concept of standard protocols coupled with statistical considerations provided project sponsors an approach to quantifying changes related to restoration actions and a tool to help adaptively manage restoration projects.

<u>Future Actions</u>

Since most AEMR efforts in the LCRE have primarily focused on juvenile salmonids, there is a need to expand efforts to other species in the LCRE ecosystem. As salmonid AEMR has shown, establishing a connection between extensive and intensive indicators can be an efficient method to monitor restoration effects for multiple environmental indicators. The same intensive/extensive concept needs to be applied to other species possibly through the establishment of factors that limit distribution or the identification of critical habitat. Once critical habitat features are established, current metrics and protocols could be adapted to provide data to address a particular species. The ultimate goal for AEMR in the LCRE would be build a set of core habitat indicators that could provide information for a rapid assessment of the landscape for multiple species.

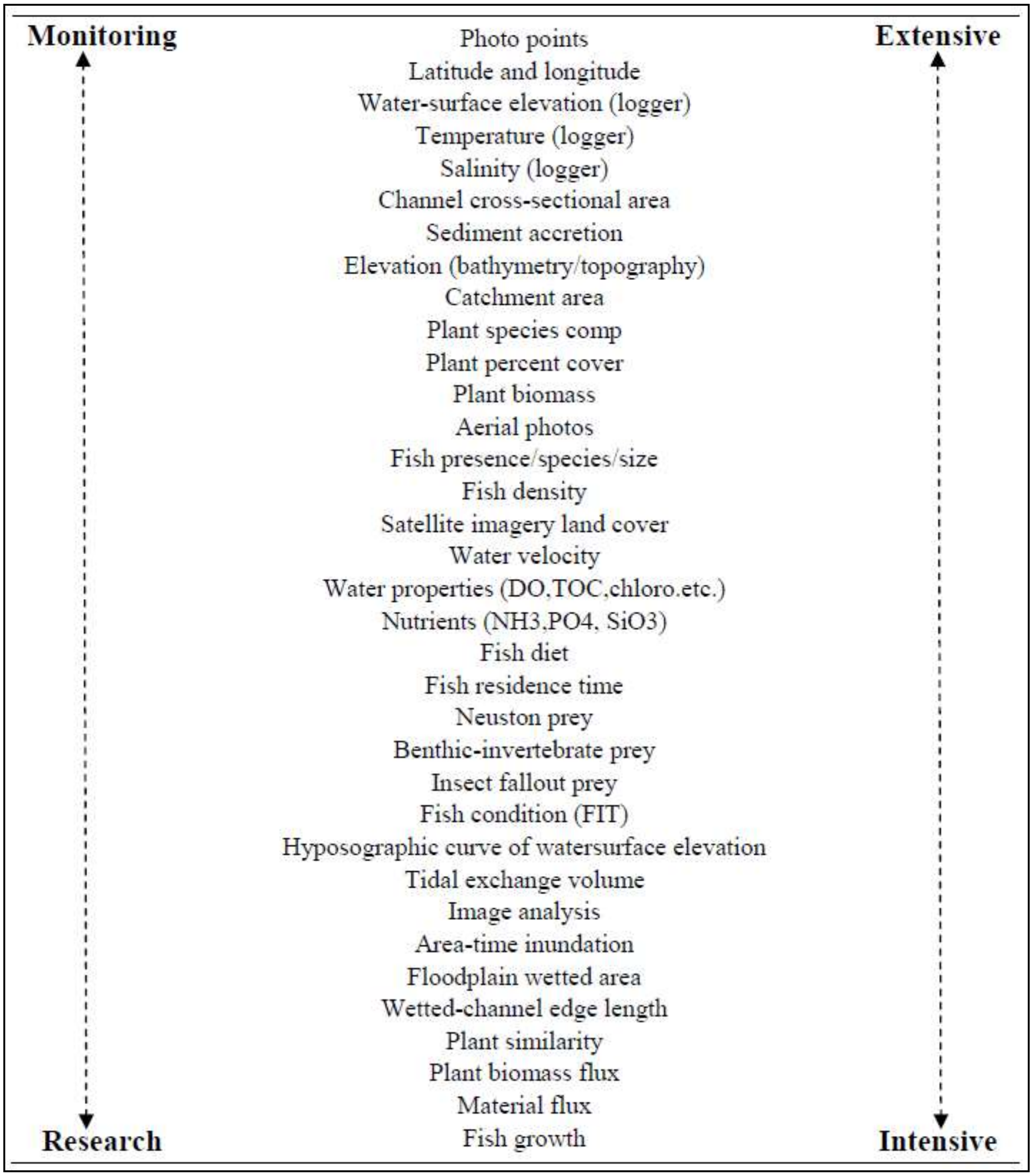


Figure 38. Indicators for Action Effectiveness Over the Monitoring/Research and Extensive/Intensive Spectrum (from Johnson et al. 2012). Extensive indicators (Level 3) are collected pre and post construction at every restoration site, while intensive indicators (Level 1) are collected at strategically identified sites. Level 2 indicators are a combination between the two and depend on funding.

AEMR allows project partners to track the progress of their restoration projects and allows funding entities a way to assess the cumulative effects of restoration investments. With regards to juvenile salmonids, it is now necessary to prioritize restoration actions for further AEMR, which includes examining restoration actions in other riparian habit types and reaches while periodically returning to previous AEMR sites to track long term changes. Periodically, revisiting previous restoration actions will inform the knowledge base of best restoration practices and help improve the understanding of the trajectory of restoration projects. Since there can be a spectrum of extensive and intensive data collected at a restoration site (Figure 38, Johnson et al. 2012) and the type of AEMR data can vary depending on project goals, Johnson et al. (2012) has suggested AEMR levels (Table 23). The use of AEMR levels provides a better understanding of design and type of AEMR occurring in the estuary and lower river and allows for improved communication and planning for continued research and monitoring. For other species in the LCRE, it is necessary to identify restoration goals and subsequently restoration actions of interest for AEMR. Efforts need to be made to determine common restoration goals and objectives for multiple species, which will provide opportunities to leverage resources to collect indicators that assess the broader ecosystem function and strengthen the overall knowledge of the ecology of the lower river.

Table 23. AEMR Levels (modified from Johnson et al. 2012)

Designation	Monitored Indicators	Statistical Design/ Reference Site	Term/Sampling Episodes
Level 1	Intensive suite of monitored indicators of ecosystem structures, processes, and functions	Mandatory	Long-term; 1-3, 6, and 10 y
Level 2	Extensive monitored indicators (core metrics of Roegner et al. 2009)	Depends on project and program objectives	Medium-term; 1, 3, and 5 y
Level 3	Standard extensive monitored indicators	Not necessary	Short-term; 1, 5 y

Finally, as AEMR data collection protocols become standardized, there will be a need to store datasets in a central location so they are accessible to project sponsors and funders for an estuary wide assessment andanalysis . The establishment of high level indicators can inform adaptive management for multiple species or help manage for a specific species. The development or adaptation an existing regional database will facilitate data sharing and increase the ability of project sponsors and funders to learn and build on previous AEMR work. A coordinated effort to implement and refine AEMR for multiple species and habitats will provide valuable information related to restoration actions at the site scale and the recovery of the lower river ecosystem as a whole.

Critical Uncertainties Research

This research is typically funded through the USACE AFEP and is designed to address critical uncertainties for salmon recovery and ecosystem restoration. The USACE is currently funding the research project "*Contribution of Tidal Fluvial Habitats in the Lower Columbia River Estuary to the Recovery of Diverse Salmon Stocks and the Implications for Strategic Estuary Restoration*" with the goal of determining the estuary's contribution to the spatial structure and life history diversity of Columbia River salmon stocks and the implications for the estuary. The research seeks to investigate four key questions:

1) How are salmonid genetic stock groups distributed through the estuary?
2) Do salmon life history, habitat use and performance vary by stock?
3) Which juvenile life histories contribute to adult returns and does estuarine habitat restoration benefit population resilience? And
4) How much restoration is needed to ensure stock persistence? (provided by Cindy Studebaker, USACE in April 2012)

A brief overview is provided below:

Objective 1 – Genetic Stock Distribution: Characterize temporal and spatial distribution of Chinook genetic stock groups in tidal fluvial reaches of the LCRE (Rkm 75 to Bonneville Dam) ('10 – '11).
Approach: Systematically investigate genetic stock groups, distributed spatially throughout the estuary, year-round.

Objective 2 - Stock-Specific Habitat Use: Investigate stock-specific habitat use, life histories, and performance of juvenile salmon in key habitats of reach F, C and B ('12 – '16).
Metrics: species presence and genetic stock id. (time and size at capture), residence time (PIT tagged fish), prey availability, consumption - stomach content and growth (measured from otoliths and scale increments), water depth and elevation, water properties (temperature, dissolved oxygen, etc.)

Objective 3 – Juvenile salmon rearing to adult return: Evaluate juvenile salmon life history strategies and their contributions to adult returns in selected tributaries (2014 – 2018).
Methods: Chemical analysis of adult Chinook otoliths from Grays, Coweeman, Lewis, Willamette, Sandy, Priest Rapids, Wenatchee, and Methow; Water chemistry of tidal tributary and main-stem sites to evaluate whether otolith barium can be used to reconstruct salmon entry into tidal-fresh environments; consider strontium marking – pending results from 2011 analysis.

Objective 4: Hydrologic and Life Cycle Modeling: Use hydrologic models and life-cycle models to evaluate estuary restoration needs and climate change effects on diverse salmon ESUs (2011 – 2015).
Approach: Study will apply a hydrologic model to simulate and characterize salmon habitat access/opportunity in tidal fresh water reaches under varying flow and bathymetric conditions.

- *Life cycle modeling:* Evaluate the potential response of selected salmon ESUs from improvements to estuary rearing opportunities and salmon performance. Focus – stock-specific performance
- *Hydrological modeling:* Model the dynamics of stock-specific habitat opportunities in the tidal-fluvial estuary in response to changing flow, temperature, depth, velocity, and climate conditions. Example, explore opportunities to integrate hydrodynamic model with other planning tools (e.g., Col River Ecosystem Habitat Classification System, Columbia River Treaty, etc.)

Objective 5 - Disseminate Information and results. Make research findings and analytical tools accessible to habitat restoration planners, engineers, biologists, and researchers.
Approach: prepare written documents (design technical memorandums, co-author 2013 Synthesis Memorandum, and prepare Annual Research Report) present findings to AFEP SRWG, EP Science Work Group, and restoration sponsors; support transfer of technology.

This research is anticipated to provide important information for strategic prioritization of habitats for "ocean-type" juvenile salmonids in the lower Columbia, and results will be integrated into this Program as appropriate.

Implementation Monitoring

The Estuary Partnership and funding entities complete implementation monitoring to ensure that funded restoration actions were constructed as proposed and according to budget and schedule. The Restoration Inventory geodatabase will be expanded to allow project sponsors to document individual restoration actions, issues that arose, whether the project was built to specifications and whether the project is successfully meeting objectives. This geodatabase will manage information such as "as-built" drawings, GIS files describing action locations and impacts, and project sponsors will provide this information (see Section 7.4) in lieu of text reports. This information will be important for evaluating actions on a cumulative basis, assessing benefits on an ecosystem scale and identifying gaps. Hence, it is important to ensure the Restoration Inventory tracks the information recommended in the USACE AFEP project "Evaluation of Life History Diversity, Habitat Connectivity, and Survival Benefits Associated with Habitat Restoration Actions in the Lower Columbia River and Estuary".

Data Management

In 2012 the USACE contracted with PNNL under AFEP funding to provide a regional database to store past and future RME data collected in the lower river and facilitate data sharing among research and restoration practitioners. The database will be developed to relate to other relevant regional data systems (e.g., PNAMP, cbfish) and will provide a publically accessible (web-based) "engine" for future comprehensive analysis. The project has four objectives:

- **Objective 1** – **Coordination:** Coordinate with CEERP funding agencies and regional stakeholders to finalize key management questions and database needs for RME and ecosystem restoration in the lower Columbia within CEERP's adaptive management framework.

- **Objective 2 - Database Development:** Develop and demonstrate a proof-of-concept geospatial database management and analysis system.

- **Objective 3** – **Analysis:** Analyze data to answer key management questions, and provide analytical support at program level.

- **Objective 4 - Disseminate Information and results.** Make research findings accessible to habitat restoration planners, engineers, biologists, and researchers.

The USACE will share progress and findings with the AFEP SRWG, Estuary Partnership SWG, and restoration sponsors. These venues and others will help the USACE coordinate development and application of the database. Ultimately, the USACE hopes to transfer the database to the Estuary Partnership for continued maintenance. Final deliverables are expected in 2014.

9. Literature Cited

Allen, T.H. 1999. Areal Distribution, Change and Restoration Potential of Wetlands within the Lower Columbia River Riparian Zone, 1949 – 1991. Oregon State University. Corvallis, OR.

Beamer, E., A. McBride, C. Greene, R. Henderson, G. Hood, K. Wolf, K. Larsen, C. Rice and K. Fresh. 2005. Delta and nearshore restoration for the recovery of wild Skagit River Chinook salmon: linking estuary restoration to wild Chinook salmon populations. Supplement to the Skagit Chinook Recovery Plan. Final draft 10/24/05. 94 p.

Bottom, D. L., C. A. Simenstad, J. Burke, A. M. Baptista, D. A. Jay, K. K. Jones, E. Casillas, M. H. Schiewe. 2005. Salmon at river's end: The role of the estuary in the decline and recovery of Columbia River salmon. U.S. Dept. of Commerce, NOAA Tech. Memo., NMFS-NWFSC-68, 246 p.

Bottom, D. L., G. Anderson, A. Baptista, J. Burke, M. Burla, M. Bhuthimethee, L. Campbell, E. Casillas, S. Hinton, K. Jacobson, D. Jay, R. McNatt, P. Moran, G. C. Roegner, C. A. Simenstad, V. Stamatiou, D. Teel, and J. E. Zamon. 2008. Salmon Life Histories, Habitat, and Food Webs in the Columbia River Estuary: An Overview of Research Results, 2002-2006. Report of Research by Northwest Fisheries Science Center, National Marine Fisheries Service, Seattle, WA.

Bottom, D. L., K. K. Jones, C. A. Simenstad, and C. L. Smith. 2009. Reconnecting social and ecological resilience in salmon ecosystems. Ecology and Society. 14(1): 5. On-line: http://www.ecologyandsociety.org/vol14/iss1/art5/

Brush, G. 2009. Historical land use, nitrogen and coastal eutrophication: A paleoecological perspective. *Estuaries and Coasts* 32: 18-28.

Bryan, G. W., L. G. Hummerstone, and G. R. Burt. 1987. Copper, zinc, and organotin as long-term factors governing the distribution of organisms in the Fal Estuary in southwest England. Estuaries 10:208-219.

Burla, M., A.M. Baptista, Y. Zhang, E. Casillas, and D.L. Bottom. 2007. Salmon Habitat Opportunity in the Columbia River Estuary: Modeling the physical environment to inform management decisions. Proceedings: Coastal Zone 2007, Portland, OR. http://www.csc.noaa.gov/cz/CZ07_Proceedings/PDFs/Monday_Abstracts/3464.Burla.pdf

Carpenter, D. E, W. L. Crowell, C. H. Hershner, K. J. Havens and M. Roggero, 2011. “Incorporating System-based Management Processes within an East Coast Ecosystem”, Presentation to the Coastal and Estuarine Research Federation, Daytona Beach, FL., November 2011.

Casillas, Ed. 2009. Role of Tidal Saltwater Habitats for Juvenile Salmonids (Myths vs Reality in the Columbia River Estuary). Presentation to the Northwest Power Conservation Council, September 2009 in Astoria, OR.

Christy, J.A., E.R. Alverson, M.P. Dougherty, S.C. Kolar, C.W. Alton, S.M. Hawes, G. Hickman, J.A. Hiebler, and E.M Nielsen. 2012. Classification of Historical Vegetation in Oregon and Washington, As Recorded by General Land Office Surveyors. Oregon Biodiversity Information Center, Institute fo Natural Resources, Portland State University. Portland, OR.

Christy, J.A., and E.R. Alverson. 2009. Synopsis of Methods Used to Map Historical Vegetation in Oregon, Based on General Land Office Survey Notes. Oregon Natural Heritage Information Center, Oregon State University. Corvallis, OR.

Cicchetti, G., and H. Greening. 2011. Estuarine biotope mosaics and habitat management goals: An application in Tampa Bay, Florida, USA. *Estuaries and Coasts* (May):1–15. doi: 10.1007/s12237-011-9408-4.

Cooney, Thomas and Damon Holzer, 2011.Lower Columbia "Tule" Chinook Populations: Estimating Intertidal Rearing Capacities and Survival Rates, Technical Review Draft, NOAA Northwest Fisheries Science Center, March 4, 2011 UPDATED DRAFT.

Cone, J. 1995. A Common Fate: Endangered Salmon and the People of the Pacific Northwest. Henry Holt and Company, Inc. New York, New York.

Coull, B. C. 1985. The use of long-term biological data to generate testable hypotheses. Estuaries 8:84-92.

Davies, S. P. and S. K. Jackson. 2006. The Biological Condition Gradient: a descriptive model for interpreting change in aquatic ecosystems. Ecological Applications 16: 1251-1266.

Emmett, Robert, Roberto LLanso, Jan Newton, Ron Thom, Michelle Hornberger, Cheryl Morgan, Colin Levings, Andrea Copping, and Paul Fishman, 2000. "Geographic signatures of North America West Coast Estuaries", *Estuaries*. Vol. 23, No. 6, p.765-792.

Evans, N.R., R.M. Thom, G.D. Williams, J. Vavrinec, K.L. Sobocinski, L.M. Miller, A.B. Borde,V.I. Cullinan, J.A. Ward, C.W. May and C. Allen, 2006. Lower Columbia River Restoration Prioritization Framework, Prepared for the Lower Columbia River Estuary Partnership by the Battelle - Pacific Northwest National Laboratory, Marine Sciences Laboratory, January 2006.

Fresh, K. L., E. Casillas, L. L. Johnson, D. L. Bottom. 2005. Role of the estuary in the recovery of Columbia River Basin salmon and steelhead: An evaluation of the effects of selected factors on salmonid population viability. U.S. Dept. of Commerce, NOAA Tech. Memo., NMFS-NWFSC-69, 105 p.

Frey, D. 1977. Biological integrity of water: an historical approach (PDF). Pages 127-140 in R.K. Ballentine and L.J. Guarraia (editors). The Integrity of Water. Proceedings of a Symposium, March 10-12, 1975, U.S. Environmental Protection Agency, Washington, D.C.

Garono, R.J., B.D. Anderson and R. Robinson. 2003a. Change in Land Cover Along the Lower Columbia River Estuary As Determined From LandSAT TM Imagery. Lower Columbia River Estuary Partnership, Bonneville Power Administration, US Army Corps of Engineers. Portland, OR.

Garono, R. J., R. Robinson and C.A. Simenstad. 2003b. Estuarine Land Cover Along the Lower Columbia River Estuary Determined from LandSAT ETM+ Imagery. Lower Columbia River Estuary Partnership: 17, Portland, OR.

Graves, J. K., J.A. Christy, P.J. Clinton and P.L. Britz. 1995. Historic Habitats of the Lower Columbia River. Columbia River Estuary Study Task Force: 14. Astoria, OR.

Hirzel A.H., G. Le Lay, V. Helfer, C. Randin, A. Guisan. 2006. Evaluating the ability of habitat suitability models to predict species presences. Ecological Modelling. 199(2): 142-152.

Johnson G. E., B. D. Ebberts, R. M. Thom, N. M. Ricci, A. H. Whiting, J. A. Southard, G. B. Sutherland, J.D. Wilcox, T. Berquam. 2003. An Ecosystem-Based Approach to Habitat Restoration in the Columbia River Estuary, Final Report. November 2003. Prepared for the U.S. Department of Energy, Prepared by: Pacific Northwest National Laboratory, Columbia River Estuary Study Taskforce, Lower Columbia River Estuary Partnership, Bonneville Power Administration and U. S. Army Corps of Engineers, Portland District.

Johnson, G. E., H. L. Diefenderfer, B. D. Ebberts, C. Tortorici, T. Yerxa, J. Leary, and J. R. Skalski. 2008 Federal Columbia River Estuary Research, Monitoring, and Evaluation Program (ERME). Available from PNNL, Portland, OR.

Johnson, G., C. Corbett, J. Doumbia, J. Sager, M. Schwartz, R. Scranton, and C. Studebaker, 2012. DRAFT Restoration Action Effectiveness Monitoring and Research in the Lower Columbia River and Estuary: Programmatic Plan, Appendix to DRAFT Columbia Estuary Ecosystem Restoration Program 2013 Strategy Report, July 2012.

Karr, J. R. 1981. Assessment of biotic integrity using fish communities. Fisheries (Bethesda) 6: 21-27. (7 pp., 193K, About PDF)

Karr, J.R. and D.R. Dudley. 1981. Ecological perspectives on water quality goals. Environmental Management 5:55-68. (14 pp., 411K, About PDF)

Kukulka, T. and Jay, D.A. 2003. Impacts of Columbia River Discharge on Salmonid Habitat: 1. A Nonstationary Fluvial Tide Model. Department of Environmental Science and Technology, Oregon Health and Science University, Beaverton, OR.

Levin, S. A. 2005. Self-organization and the emergence of complexity in ecological systems, *Bioscience* 55: 1075-1079.

Likens, G. E. 1983. A priority for ecological research. Bull. Ecol. Soc. Am. 64:234-243.

Lower Columbia River Estuary Partnership (Estuary Partnership), 1999a. Comprehensive Conservation and Management Plan. Lower Columbia River Estuary Partnership, Portland, Oregon.

Lower Columbia River Estuary Partnership (Estuary Partnership), 1999b. Comprehensive Conservation and Management Plan, Volume 2 – Aquatic Ecosystem Monitoring Strategy and Information Management Strategy. Lower Columbia River Estuary Partnership, Portland, Oregon.

Lower Columbia River Estuary Partnership (Estuary Partnership), Sanborn Map Company, 2011. High Resolution Land Cover Mapping in the Lower Columbia River Estuary. 2011. Lower Columbia River Estuary Partnership Report. Portland, OR.

Malczewski, J. 1999. GIS and *Multicriteria Decision Analysis*, John Wiley and Sons, Apr 5, 1999, 392 p.

McCabe, G.T., R.L. Emmett, W.D. Muir and T.H. Blahm. 1986. Utilization of the Columbia River estuary by subyearling Chinook salmon. Northwest Science. 60:113-124.

Mearns, A.J. 1981. Ecological effects of ocean sewage outfalls: Observations and lessons. Oceanus 24:45-54.

National Marine Fisheries Service (NMFS), 2011a. Guidance for Monitoring Recovery of Pacific Northwest Salmon & Steelhead listed under the Federal Endangered Species Act. Guidance to salmon recovery partners concerning prioritizing monitoring efforts to assess the viability of salmon and steelhead populations protected under the Federal Endangered Species Act. Idaho, Oregon and Washington, by Bruce A. Crawford and Scott M. Rumsey, January 2011, National Marine Fisheries Service, NW Region.

National Marine Fisheries Service (NMFS), 2011b. Columbia River Estuary ESA Recovery Plan Module for Salmon and Steelhead, Prepared for NOAA Fisheries Service by the Lower Columbia River Estuary Partnership. Available from NMFS, Portland, OR.

National Marine Fisheries Service (NMFS), 2012. Proposed ESA Recovery Plan for Lower Columbia River Coho Salmon, Lower Columbia River Chinook Salmon, Columbia River Chum Salmon and Lower Columbia River Steelhead, Prepared by the National Marine Fisheries Service, Northwest Region, April 2012.

Netboy. Anthony, 1958. Salmon of the Pacific Northwest: Fish vs. Dams. Birnfords & Mort, Publishers, Portland Oregon.

Netboy, Anthony, 1980. The Columbia River salmon and steelhead trout, their fight for survival. University of Washington Press. 180 p.

Northwest Power and Conservation Council (NPCC), 2004. Mainstem Lower Columbia River and Columbia River Estuary Subbasin Plan, Prepared for Northwest Power and Conservation Council by the Lower Columbia Estuary Partnership and Lower Columbia Fish Recovery Board, May 2004.

Northwest Power and Conservation Council (NPCC), 2006. Columbia River Basin Research Plan. Northwest Power and Conservation Council, Portland, OR.

Northwest Power and Conservation Council (NPCC), 2010. High-Level Implementation Indicators to Measure Success of the Fish and Wildlife Program, November 2010. Table of indicators Updated. Portland Oregon: Northwest Power and Conservation Council, November 2010. Available: http://www.nwcouncil.org/fw/program/hli/Default.htm (January 2012).
Questions from MERR relevant to the estuary:

- Are Columbia River Basin fish and wildlife abundant, diverse, productive, spatially distributed, and sustainable?
- Are Columbia River Basin ecosystems healthy?
- Is climate change affecting fish and wildlife in the Columbia River Basin?

Pacific Coast Joint Venture (PCJV), 1994. Joint Venture Implementation Plans: Lower Columbia River, Prepared by Oregon Wetlands Joint Venture, West Linn OR.

Peterson, G. W. and R. E. Turner, 1994. The value of salt marsh edge vs interior as a habitat for fish and decapod crustaceans in a Louisiana tidal marsh, *Estuaries* 17: 235-262.

Peterson, M.S. B. H. Comyns, J. R. Hendon, P. J. Bond and G. A. Duff, 2000. Habitat use by early life-history stages of fishes and crustaceans along a changing estuarine landscape: Differences between natural and altered shoreline sites, *Wetland Ecology and Management* 8: 209-219.

Poff, N. LeRoy, J. David Allan, Mark B. Bain, James R. Karr, Karen L. Prestegaard, Brian D. Richter, Richard E. Sparks, and Julie C. Stromberg, 1997. The Natural Flow Regime - A paradigm for river conservation and restoration, BioScience, Vol. 47 No. 11.

Polgar, T. T., J. K. Summers, R. A. Cummins, K. A. Rose, and D. G. Heimbuch. 1985. Investigation of relationships among pollutant loadings and fish stock levels in northeastern estuaries. Estuaries 8:125-135.

Rich, H. 1920. Early history and seaward migration of Chinook salmon in the Columbia and Sacramento Rivers. Fish Bulletin. 37:1-74.

Roegner, G.C., A. Baptista, D.L. Bottom, J. Burke, L. Campbell, C. Elliot, S.Hinton, D. Jay, M. Lott, T. Lundrigan, R. McNatt, P. Moran, C.A. Simenstad, D. Teel, E. Volk, J. Zamon, E. Casillas. 2008. Estuarine Habitat and Juvenile Salmon: Current and Historical Linkages in the Lower Columbia River and Estuary, 2002-2004. Report of research to United States Army Corps of Engineers, Northwest Fisheries Science Center, National Marine Fisheries Service. Seattle, WA.

Sagar, J.P., K. E. Marcoe, A. B. Borde, L. L. Johnson, J. L. Morace, T. Peterson, K. H. Macneale, R.M Kaufmann, V.I. Cullinan, S. A. Zimmerman, R. M. Thom, C.L. Wright, P.M. Chittaro, O. P. Olson, S. Y. Sol, D. J. Teel, G. M. Ylitalo, D. Lomax, W.B. Temple, A. Silva, C. A. Simenstad, M. F. Ramirez, J. E. O'Connor, C. Cannon, and M. Schwartz. 2012. Lower Columbia River Ecosystem Monitoring Program Annual Report for Year 7 (September 1, 2010 to December 31, 2011). Prepared by the Lower Columbia Estuary Partnership for the Bonneville Power Administration.

Seaweb, 2012. http://www.seaweb.org/resources/ebm.php. June 26, 2012.

Shalowitz, A.L. 1964. Shore and Sea Boundaries. Volume 2: Interpretation and Use of Coast and Geodetic Survey Data. US Government Printing Office, Washington DC.

Simenstad, C.A. 2001. Ecoscape perspective of juvenile salmon in the Columbia River estuary. Presentation. On-line link: http://www.sei.org/columbia/downloads/ecoscape.PDF

Simenstad, C. A., W. G. Hood, R. M. Thom, D. A. Levy and D. L. Bottom, 2000. Landscape structure and scale constraints on restoring estuarine wetlands for Pacific Coast juvenile fishes. In Concepts and Controversies in Tidal Marsh Ecology, ed. M.P. Weinstein and D. A. Kreeger, 597-630. Dordrecht: Kluwer.

Simenstad, C. A., J. L.Burke, J.E. O'Connor, C. Cannon, D.W. Heatwole, M.F. Ramirez, I.R. Waite, T.D. Counihan, and K.L. Jones. 2011. Columbia River Estuary Ecosystem Classification - Concept and Application. U.S. Geological Survey Open-File Report 2011-1228, 54 p.

Summers, J. K., T. T. Polgar, J. A. Tarr, K. A. Rose, D. G. Heimbuch, J. McCurley, R. A. Cummins, G. F. Johnson, K. T. Yetman, and G. T. Dinardo. 1985. Reconstruction of long-term time series for commercial fisheries abundance and estuarine pollution loadings. Estuaries 8:114-124.

Summers, J. K. and K. A. Rose. 1987. The role of interactions among environmental conditions in controlling historical fisheries variability. Estuaries 10:255-266.

Thom, Ronald M., Evan Haas, Nathan R. Evans and Gregory D. Williams, 2011. Lower Columbia River and Estuary Habitat Restoration Prioritization Framework, March/June 2011 Ecological Restoration 29:1–2.

Thomas, D.W. 1983. Changes in Columbia River Estuary Habitat Types Over the Past Century. Columbia River Estuary Data Development Program. Astoria, OR.

Thorpe, J.E. 1994. Salmonid fishes and the estuarine environment. Estuaries. 17:76-93.

United Nations Environment Program. 2006. Ecosystem-based management: Markers for assessing progress. 58pp. unep/gpa, The Hague.

USACE, 2010. Evaluation of Cumulative Ecosystem Response to Restoration Projects in the Lower Columbia River and Estuary, 2010 FINAL REPORT, By Pacific Northwest National Laboratory for the US Army Corps of Engineers, Portland District.

USEPA, 1992. Monitoring Guidance for the National Estuary Program, U.S. Environmental Protection Agency, Office of Water, Oceans and Coastal Protection Division, Washington D. C.

USEPA, 2000. Evaluation Guidelines for Ecological Indicators, Edited by Laura E. Jackson, Janis C. Kurtz and William S. Fisher, U.S. Environmental Protection Agency, Office of Research and Development, Research Triangle Park, NC.

USEPA, 2006. The Biological Condition Gradient: A Descriptive Model for Interpreting Change in Aquatic Ecosystems, by Susan P. Davies and Susan K. Jackson, Ecological Applications, 16(4), 2006, pp. 1251–1266.

USEPA, 2006/2010. 2006-2011 EPA Strategic Plan: Chartering Our Course, U.S. Environmental Protection Agency, Washington DC. September 2006, updated in 2010 for 2011-2015.

USEPA, 2012. Biological Indicators of Watershed Health: http://www.epa.gov/bioiweb1/html/biointeg.html. February 21, 2012.

Appendices

Appendix A

Summary of Previous Land Cover Change Analyses for the lower Columbia River

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 1999	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

Appendix B

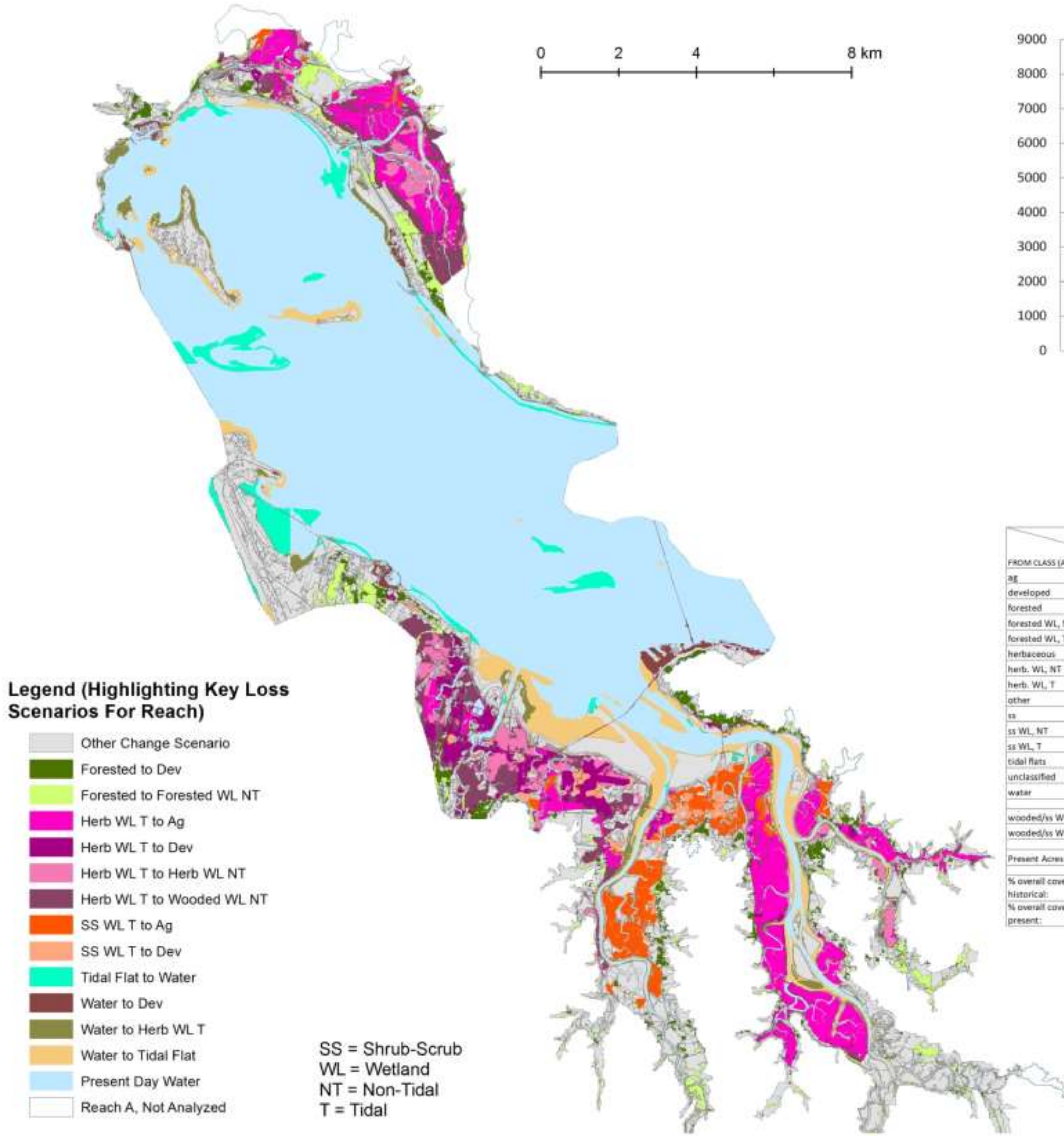
Detailed Habitat Change Maps

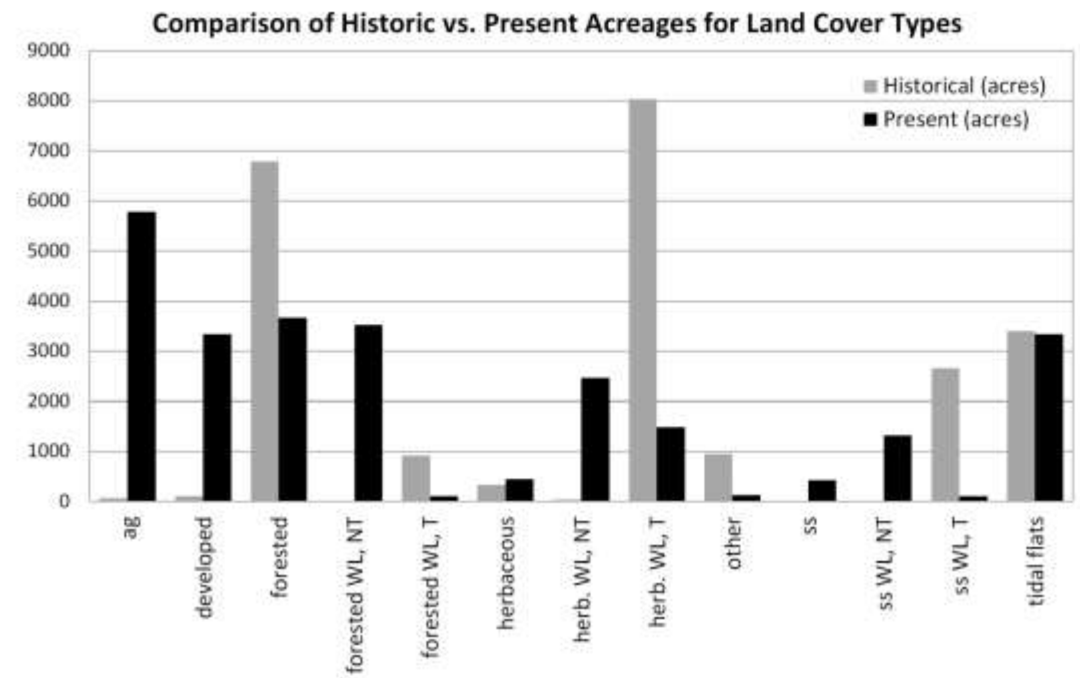
(Supplement to Section 2 - Restoration Prioritization Strategy, Line of Evidence 1)

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 (Figure 39 -Figure 46) - 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 (Figure 47 -Figure 58) – 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

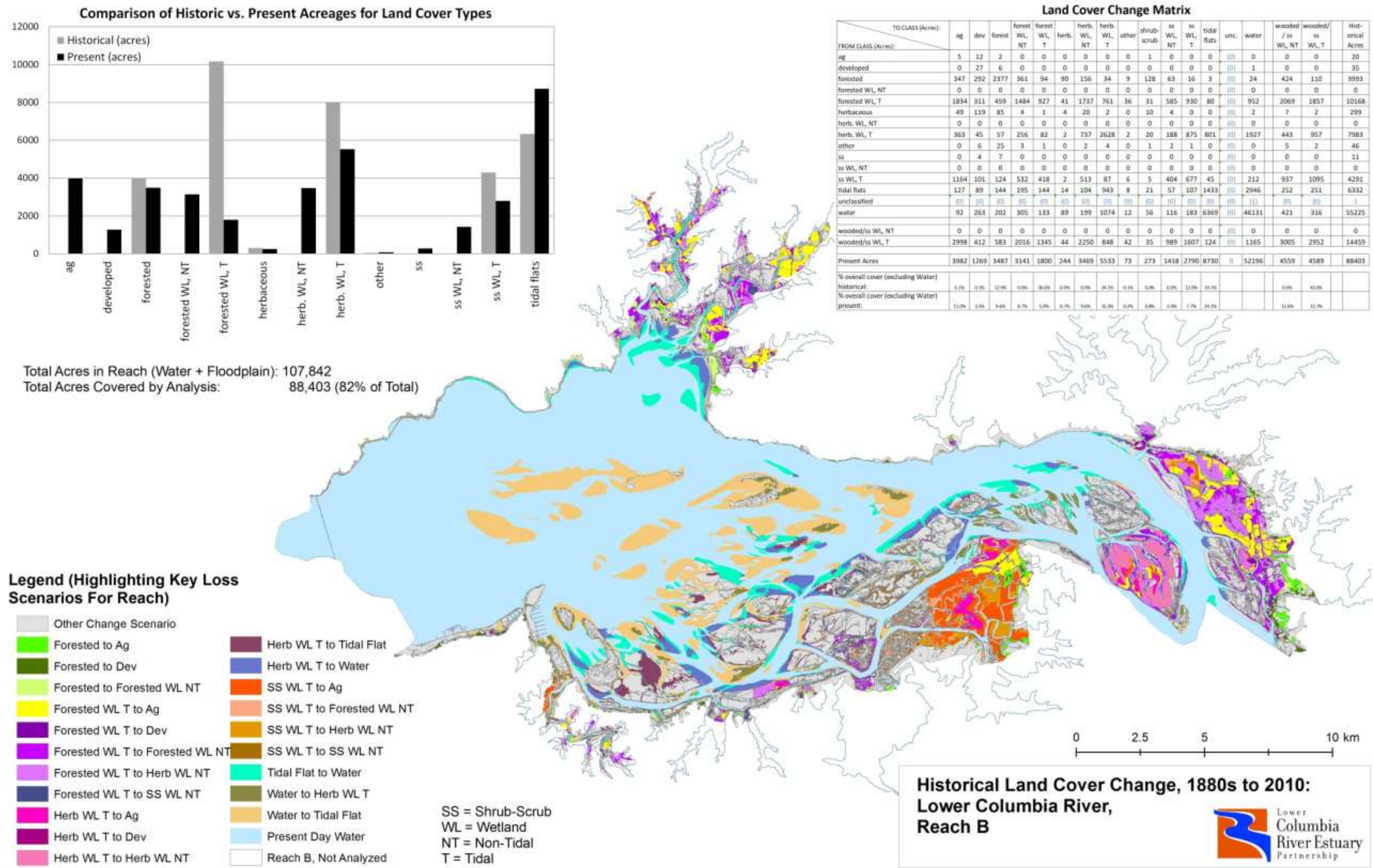
TO CLASS (Acres): / FROM CLASS (Acres):	ag	dev	forest	forest WL, NT	forest WL, T	herb.	herb. WL, NT	herb. WL, T	other	shrub-scrub	ss WL, NT	ss WL, T	tidal flats	unc.	water	wooded / ss WL, NT	wooded/ ss WL, T	Hist-orical Acres
ag	0	43	10	4	0	4	0	1	0	1	0	0	0	(0)	0	4	0	65
developed	0	88	11	1	0	0	1	0	0	0	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:	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]			[illegible]	[illegible]	
% overall cover (excluding Water) present:	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]			[illegible]	[illegible]	

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

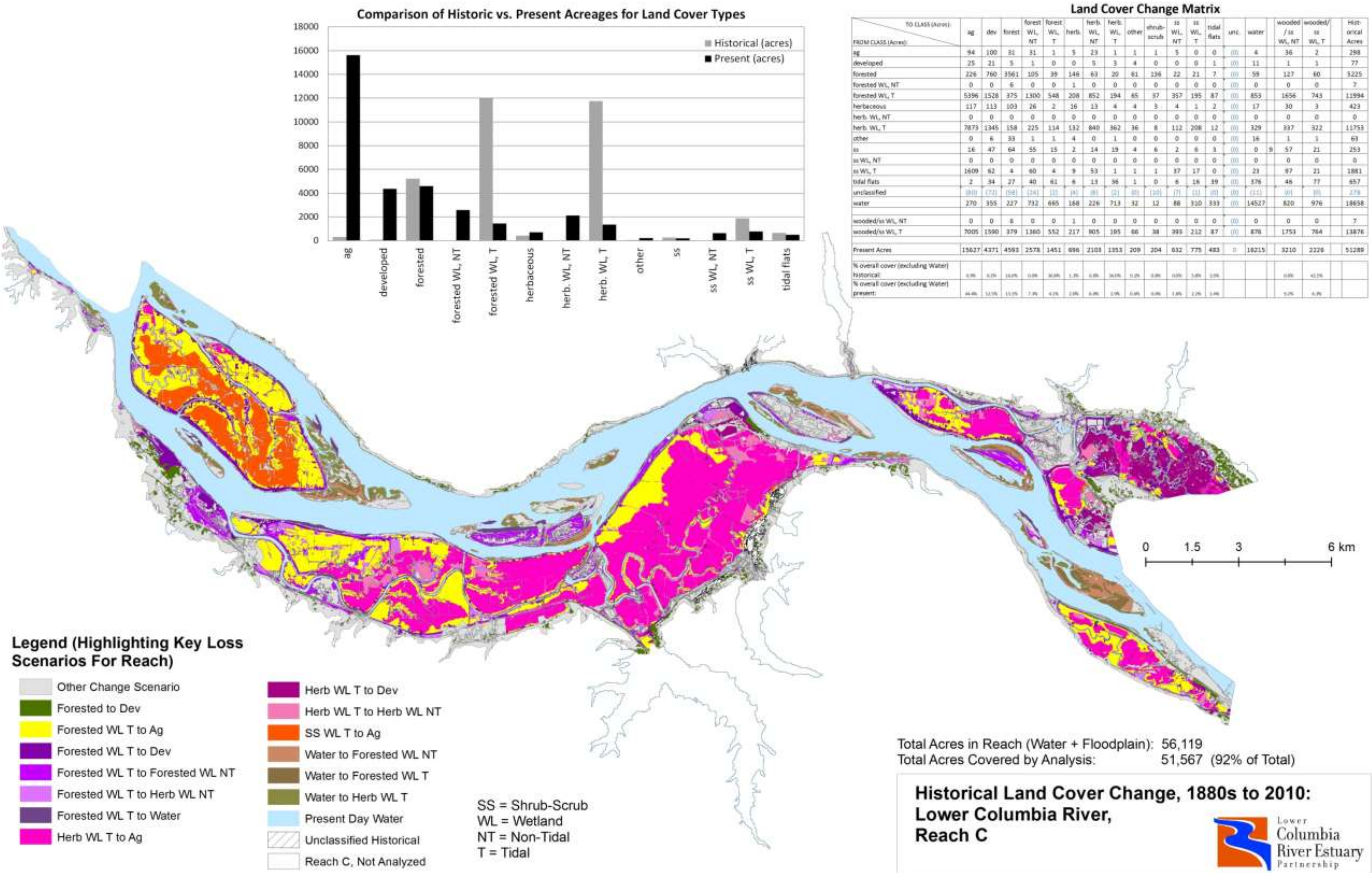
Figure 39. Reach Map, LCRE Reach A



Land Cover Change Matrix

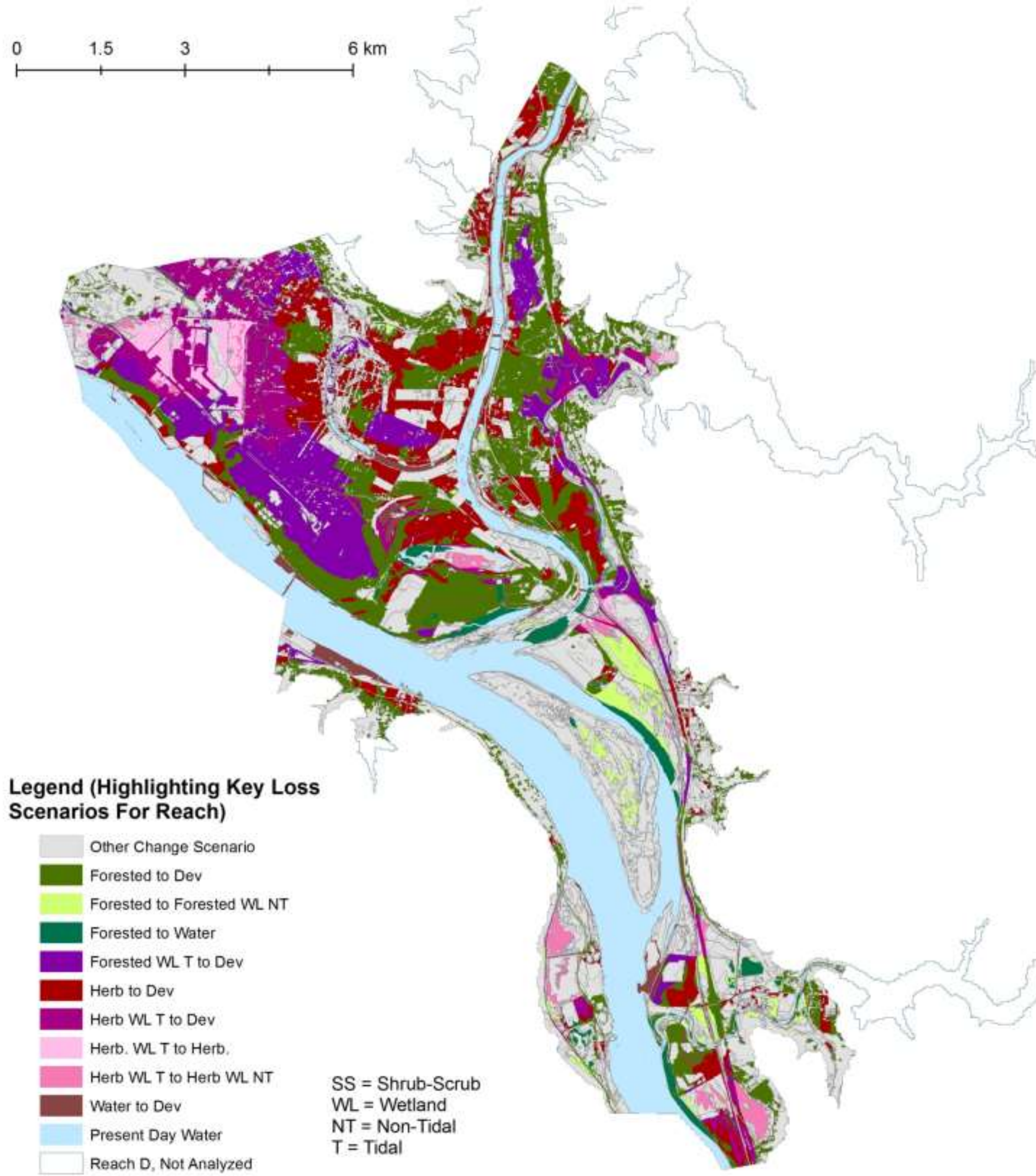
FROM CLASS (Acres): \ TO CLASS (Acres):	ag	dev	forest	forest WL, NT	forest WL, T	herb.	herb. WL, NT	herb. WL, T	other	shrub-scrub	ss WL, NT	ss WL, T	tidal flats	unc.	water	wooded / ss WL, NT	wooded/ ss WL, T	Hist-orical Acres
ag	5	12	2	0	0	0	0	0	0	1	0	0	0	(0)	0	0	0	20
developed	0	27	6	0	0	0	0	0	0	0	0	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:	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	12.9%	[illegible]			[illegible]	[illegible]	
% overall cover (excluding Water) present:	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]			[illegible]	[illegible]	

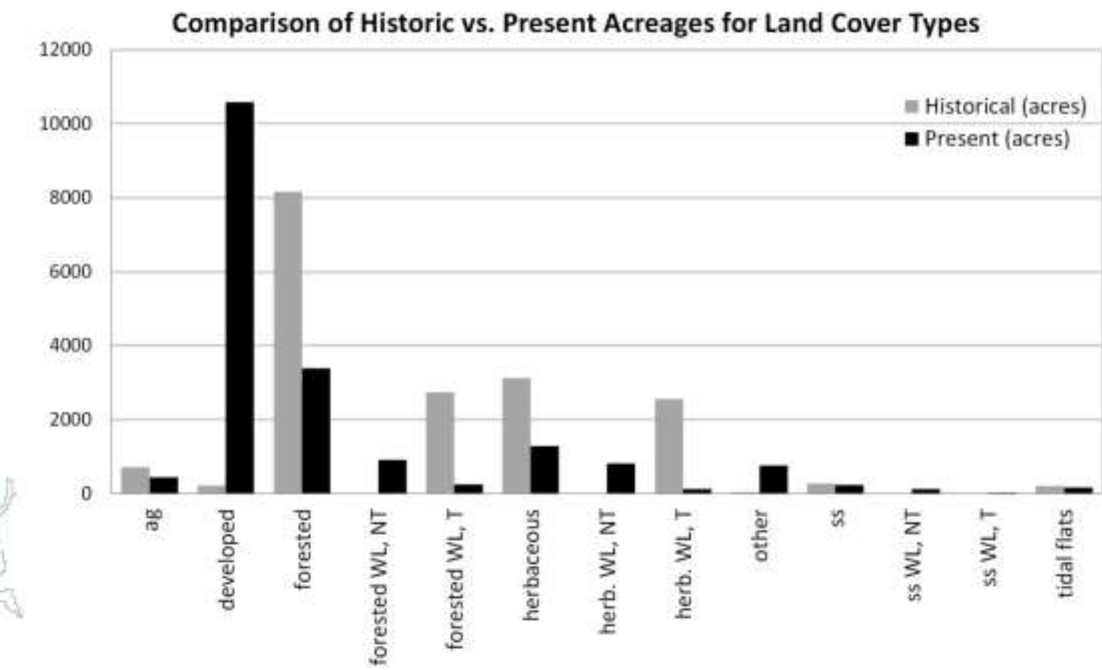
Figure 40. LCRE Reach B



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		Historical 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)		279
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:	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]				[illegible]	[illegible]		
% overall cover (excluding Water) present:	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]				[illegible]	[illegible]		

Figure 41. LCRE Reach C





Land Cover Change Matrix

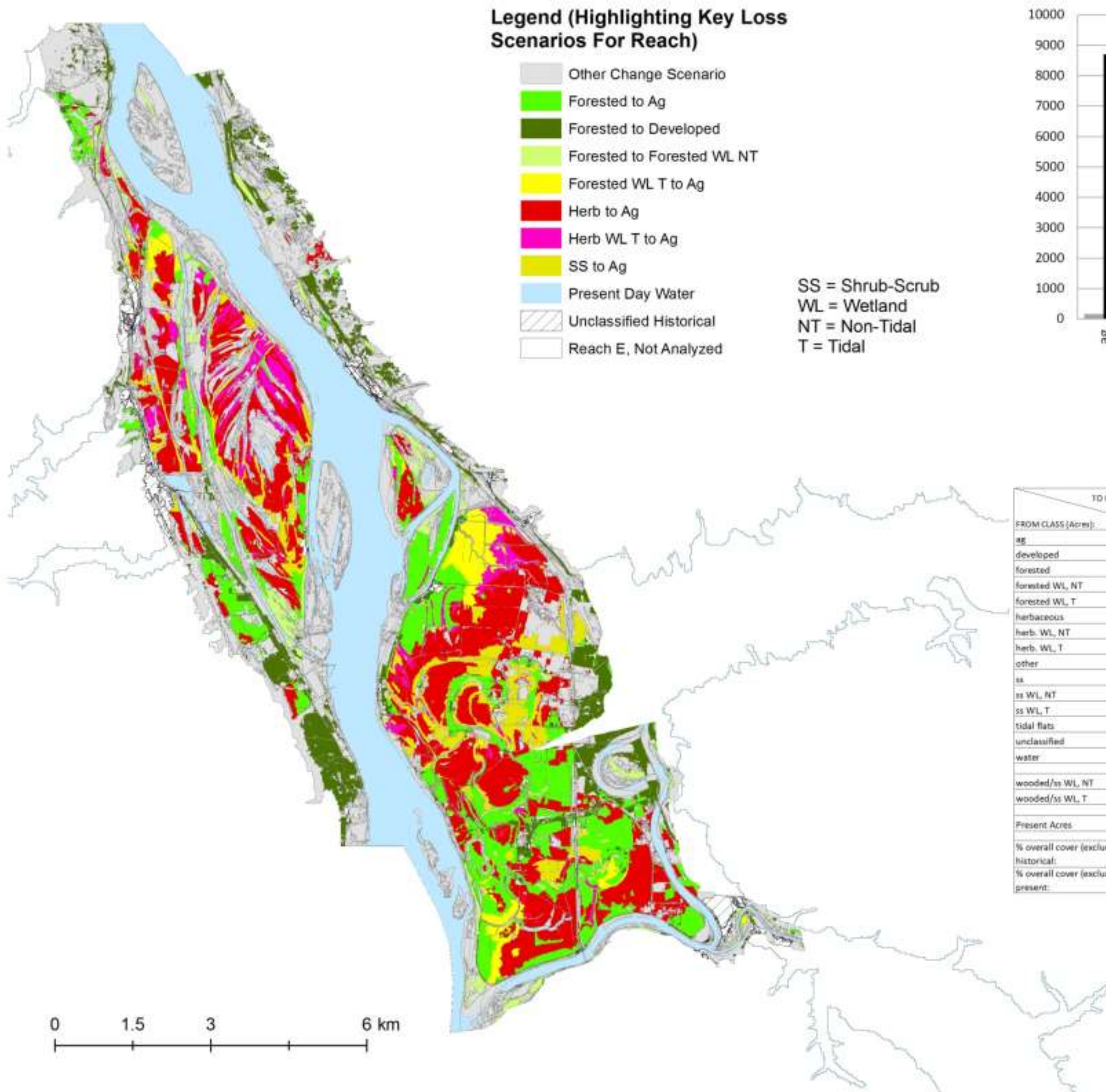
TO CLASS (Acres): / FROM CLASS (Acres):	ag	dev.	forest	forest WL, NT	forest WL, T	herb.	herb. WL, NT	herb. WL, T	other	shrub-scrub	ss WL, NT	ss WL, T	tidal flats	unc.	water	wooded / ss WL, NT	wooded/ ss WL, T	Hist-orical Acres
ag	13	574	78	4	1	6	7	0	28	2	2	0	0	(0)	7	6	1	722
developed	5	150	36	8	1	6	5	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%	45.3%	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%	

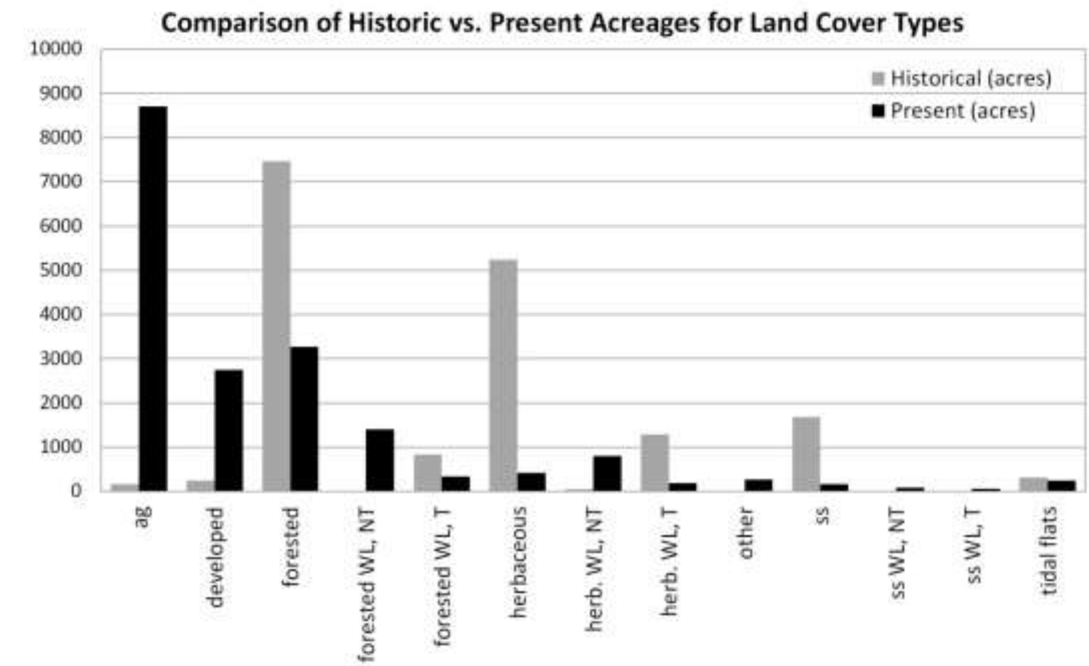
Total Acres in Reach (Water + Floodplain): 32,602
Total Acres Covered by Analysis: 24,220 (74% of Total)

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

Lower Columbia River Estuary Partnership

Figure 42. LCRE Reach D





Land Cover Change Matrix

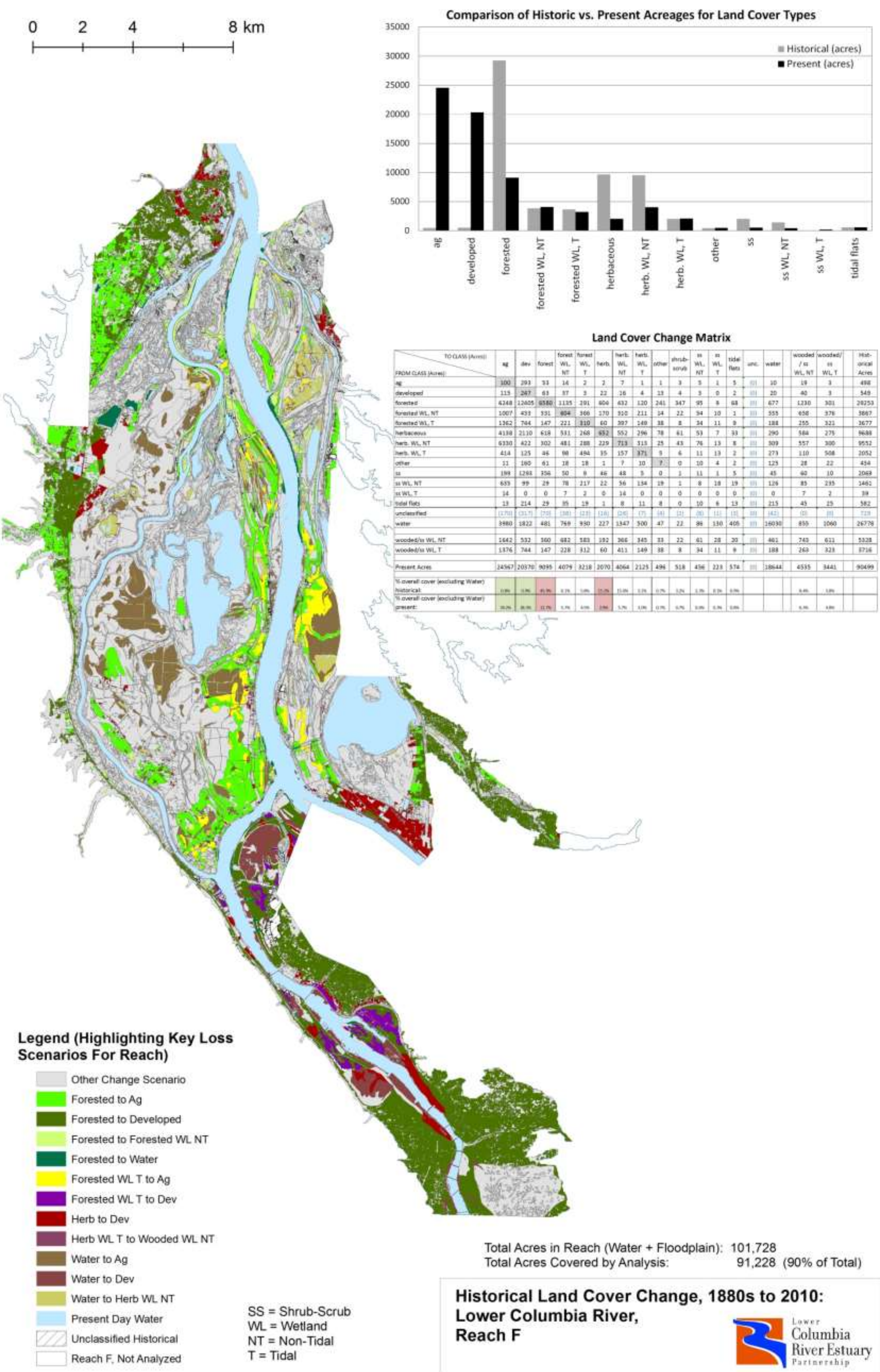
TO CLASS (Acres): / FROM CLASS (Acres):	ag	dev	forest	forest WL, NT	forest WL, T	herb.	herb. WL, NT	herb. WL, T	other	shrub-scrub	ss WL, NT	ss WL, T	tidal flats	unc.	water		wooded / ss WL, NT	wooded/ ss WL, T		Hist-orical Acres
ag	61	55	18	0	0	3	5	0	5	2	0	0	0	(0)	11		1	0		161
developed	59	110	53	4	0	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%	41.1%	0.1%	4.8%	30.2%	0.3%	7.4%	0.1%	[illegible]	0.0%	0.0%	1.8%				0.1%	4.8%		
% overall cover (excluding Water) present:	[illegible]	14.7%	17.3%	7.5%	1.8%	2.2%	4.3%	1.0%	1.5%	0.9%	[illegible]	[illegible]	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

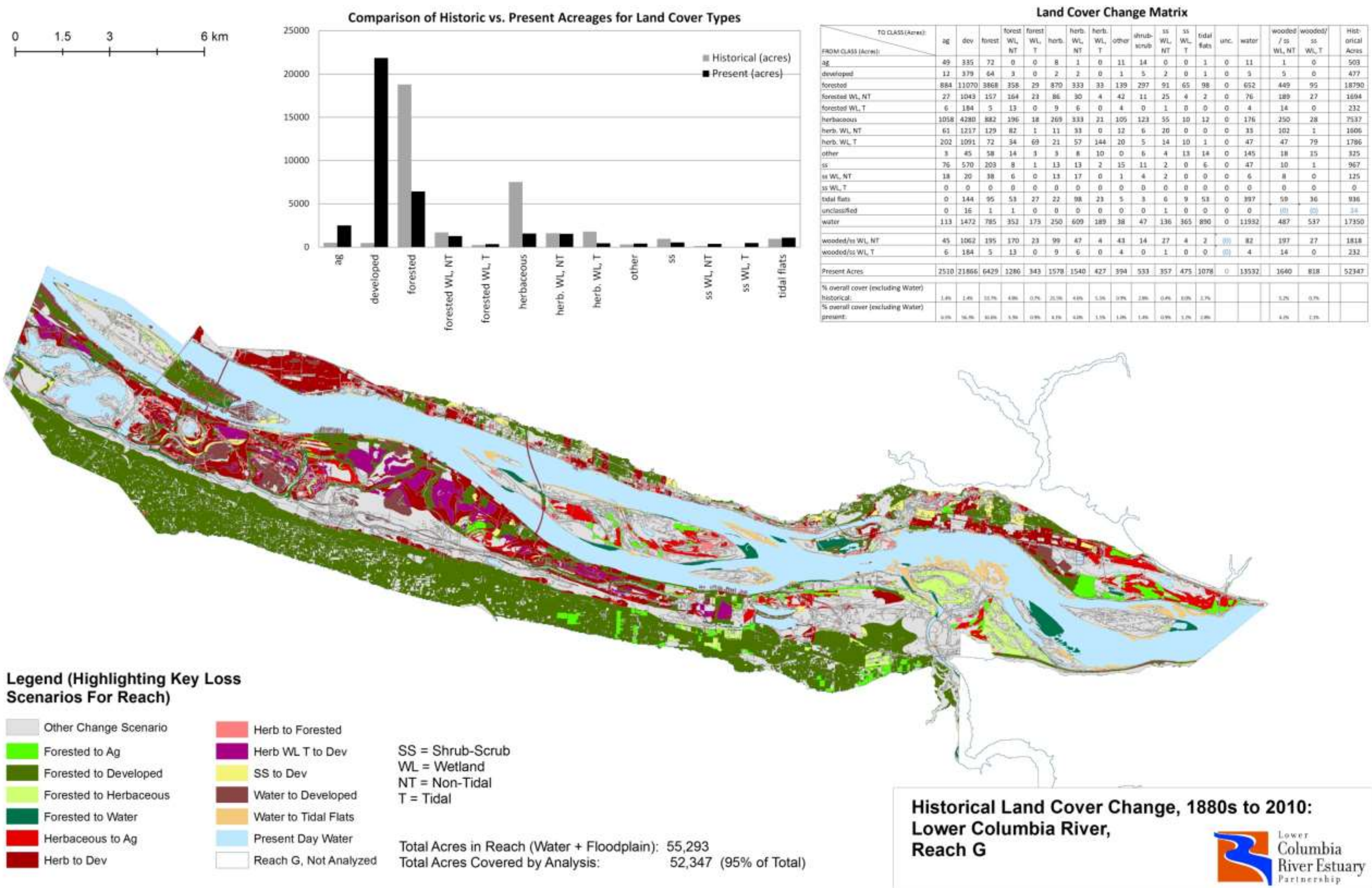
Figure 43. LCRE Reach E



Land Cover Change Matrix

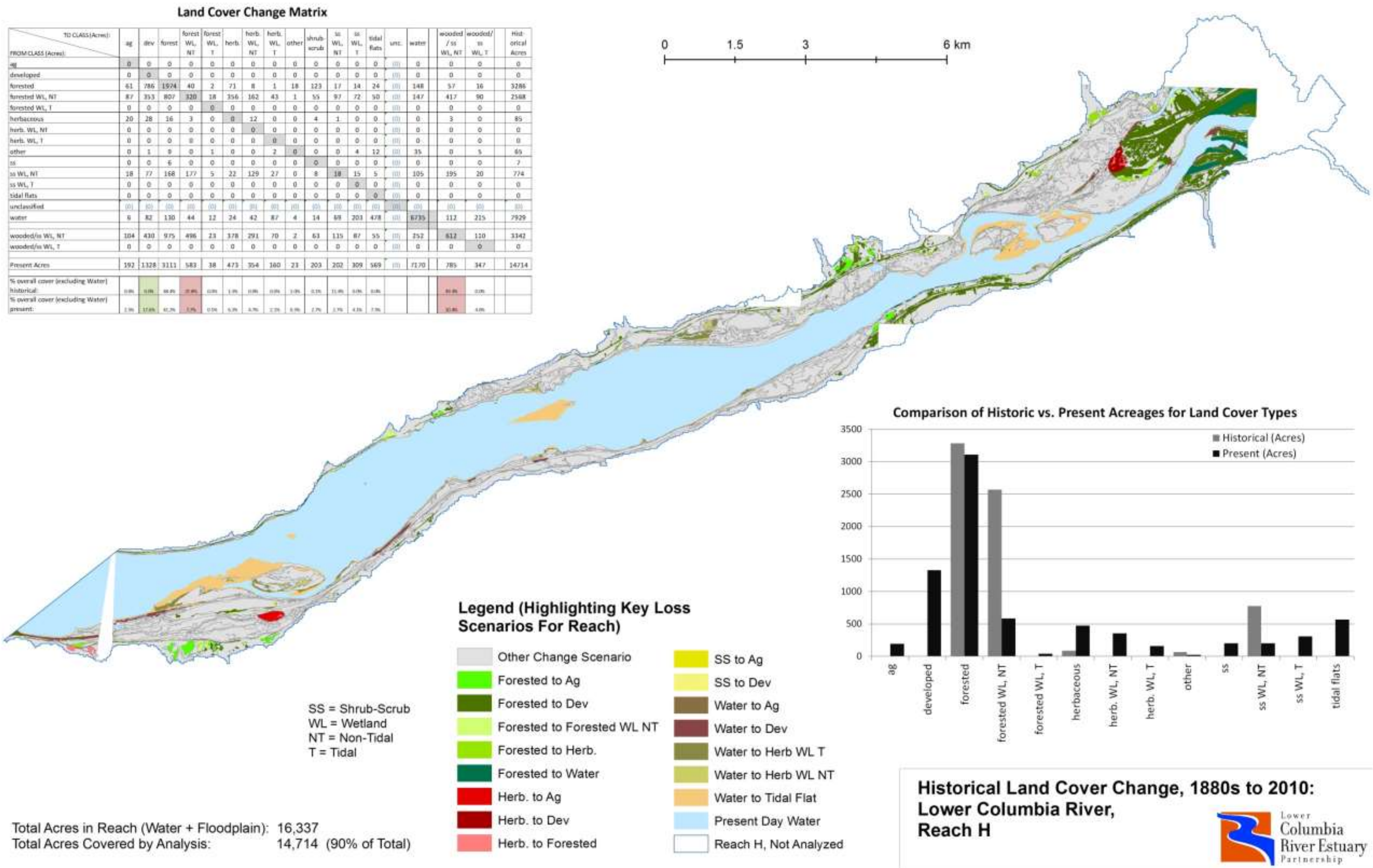
FROM CLASS (Acres) \ TO CLASS (Acres)	ag	dev	forest	forest WL, NT	forest WL, T	herb.	herb. WL, NT	herb. WL, T	other	shrub-scrub	ss WL, NT	ss WL, T	tidal flats	unc.	water	wooded / ss WL, NT	wooded/ ss WL, T	Historical Acres
ag	100	293	33	14	2	2	7	1	1	3	5	1	5	(0)	10	19	3	498
developed	115	247	63	37	3	22	16	4	13	4	3	0	2	(0)	20	40	3	549
forested	6248	12605	6580	1135	201	604	432	120	241	347	95	8	68	(0)	677	1230	301	28253
forested WL, NT	1007	433	331	604	366	170	310	211	14	22	34	10	1	(0)	355	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	315	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	8	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	38
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)	(26)	(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	24967	20370	9095	4079	3218	2070	4064	2125	496	518	456	223	574	(0)	18644	4535	3441	90499
% overall cover (excluding Water) historical:	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]			[illegible]	[illegible]	
% overall cover (excluding Water) present:	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]			[illegible]	[illegible]	

Figure 44. LCRE Reach F



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	Historical 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)	14
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:	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]			[illegible]	[illegible]	
% overall cover (excluding Water) present:	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]			[illegible]	[illegible]	

Figure 45. 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:	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]			[illegible]	[illegible]	
% overall cover (excluding Water) present:	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]			[illegible]	[illegible]	

Figure 46. LCRE Reach H

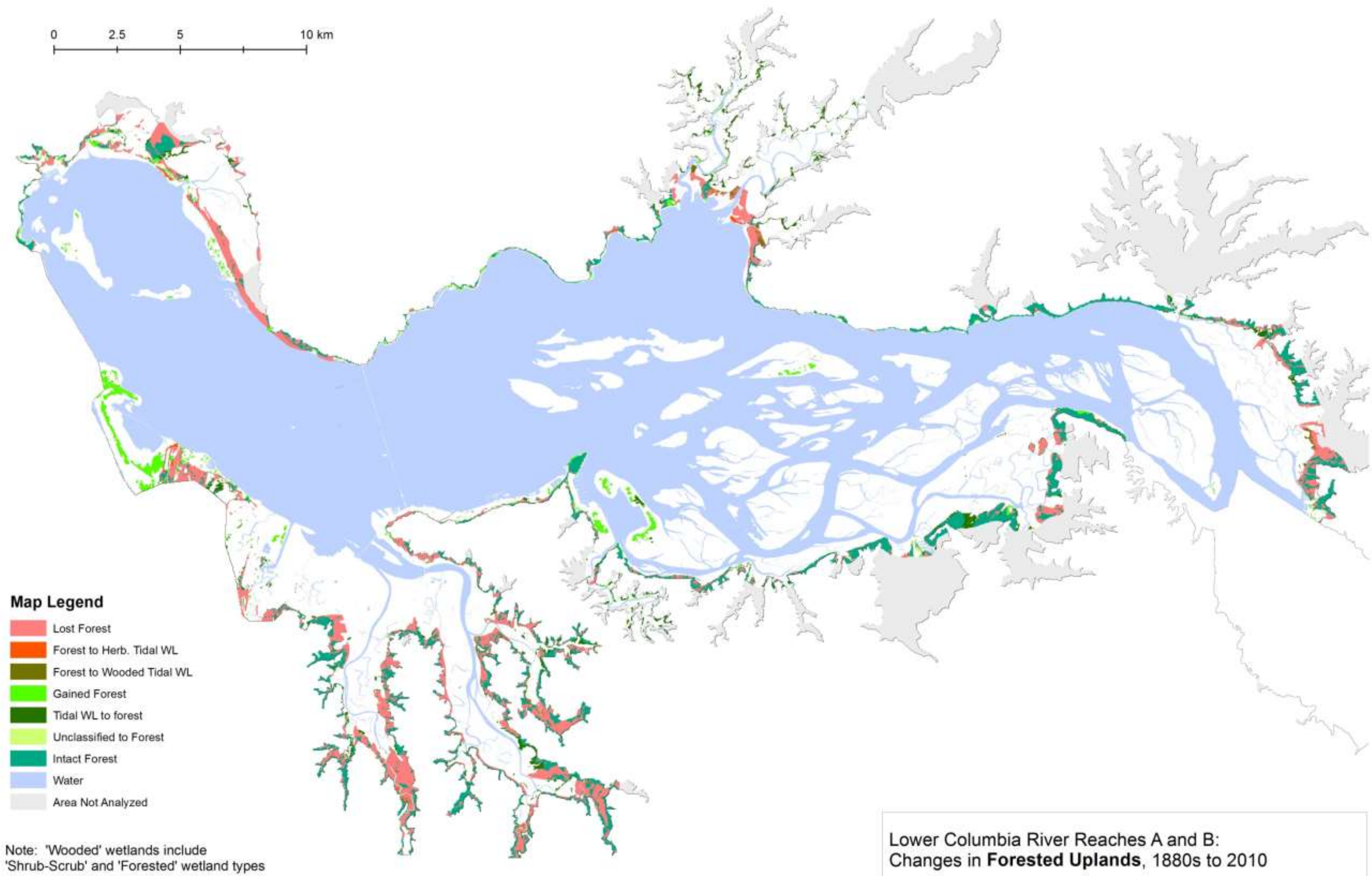


Figure 47. Regional Map – Changes in Forested Uplands, Lower Estuary

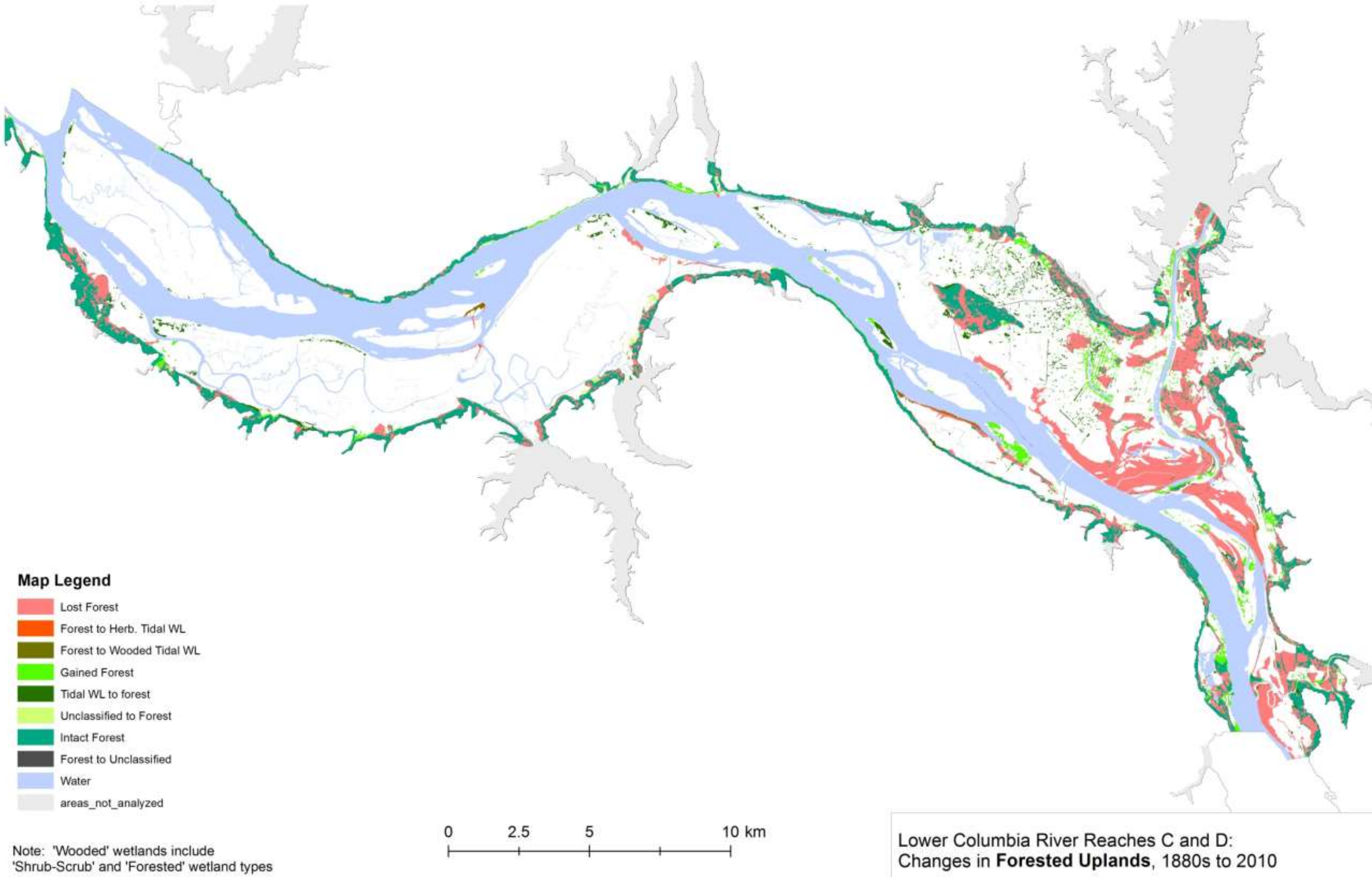


Figure 48. Regional Map – Changes in Forested Uplands, Mid-Lower Estuary

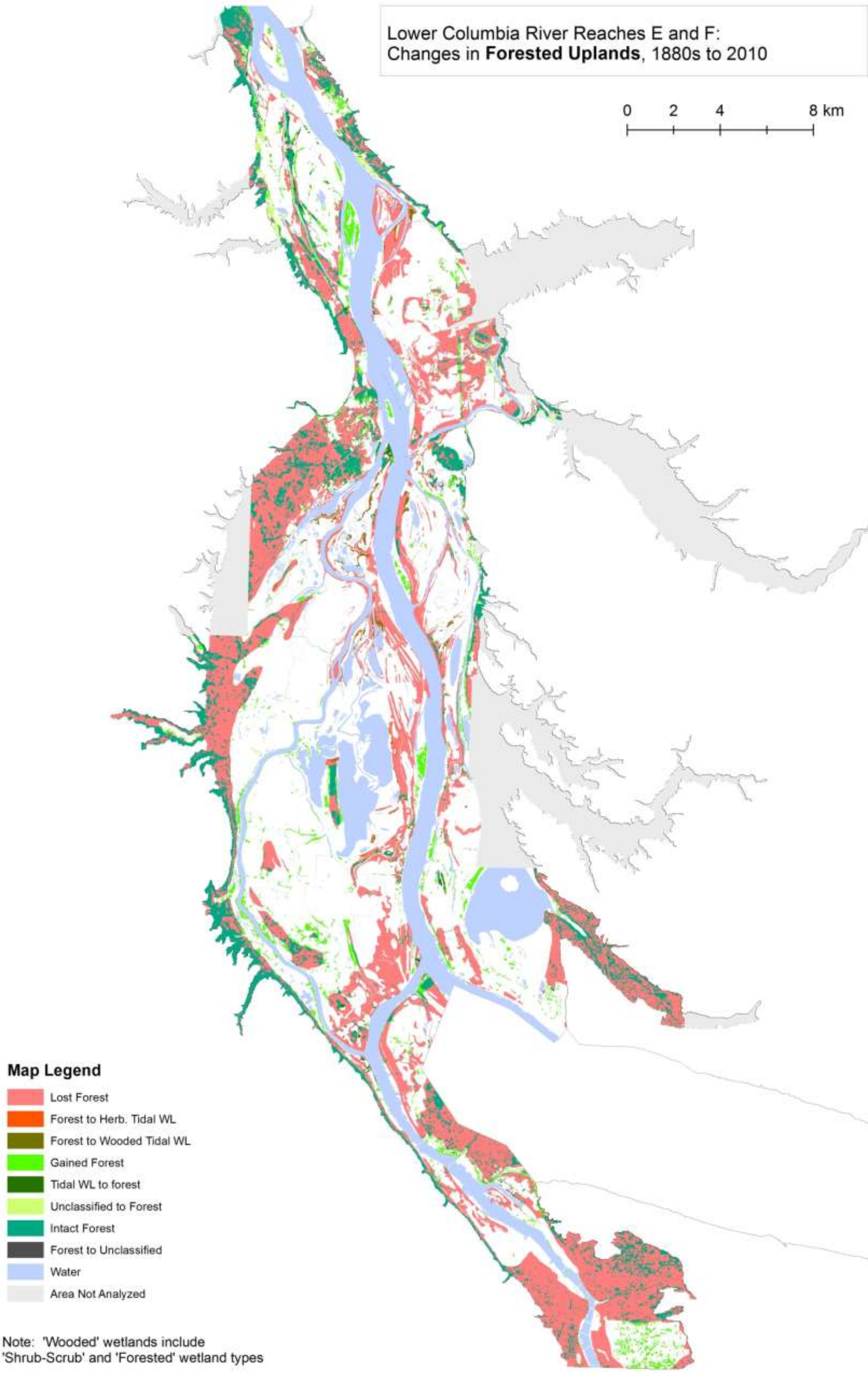


Figure 49. Regional Map – Changes in Forested Uplands, Mid-Upper Estuary

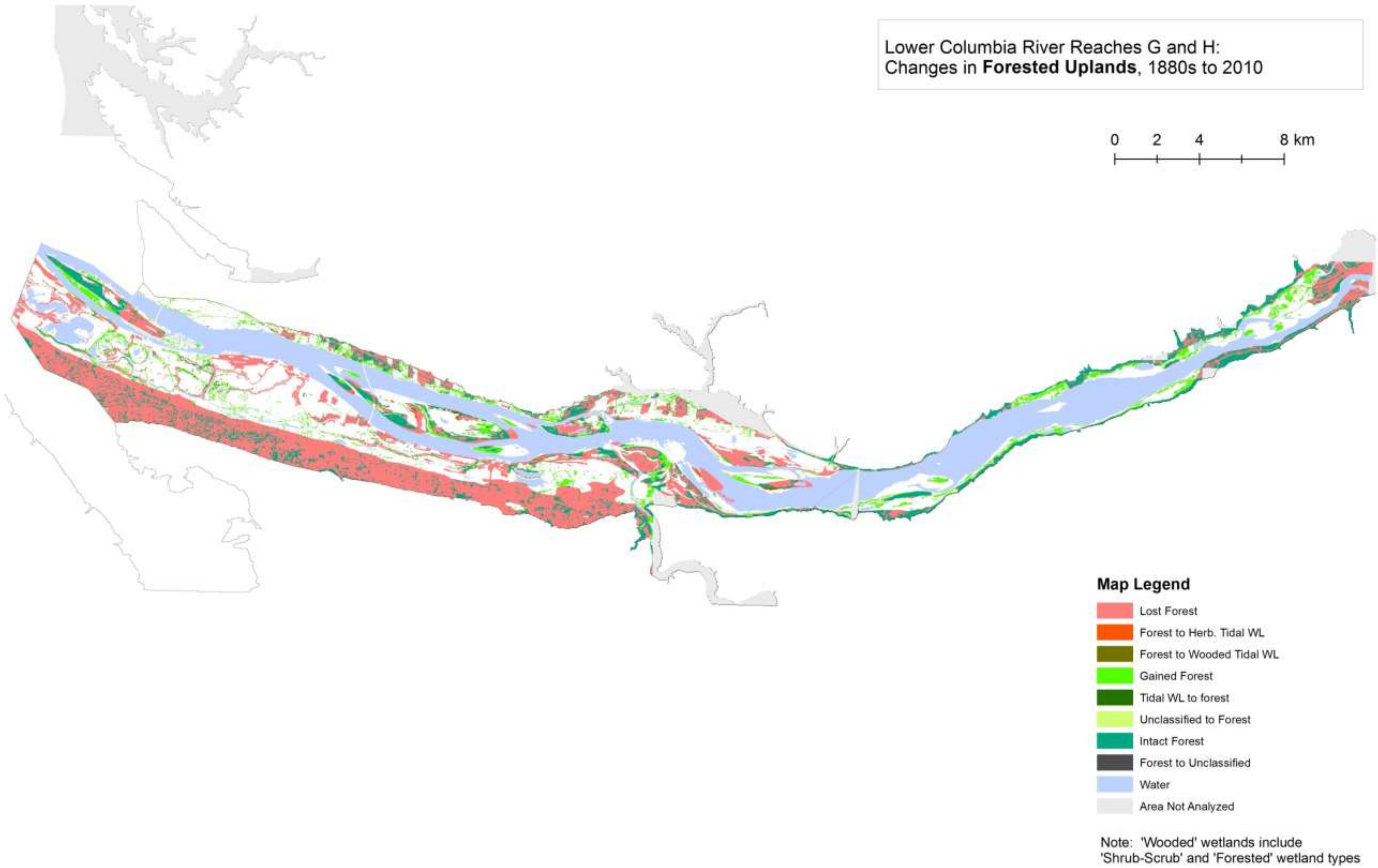


Figure 50. Regional Map – Changes in Forested Uplands, Upper Estuary

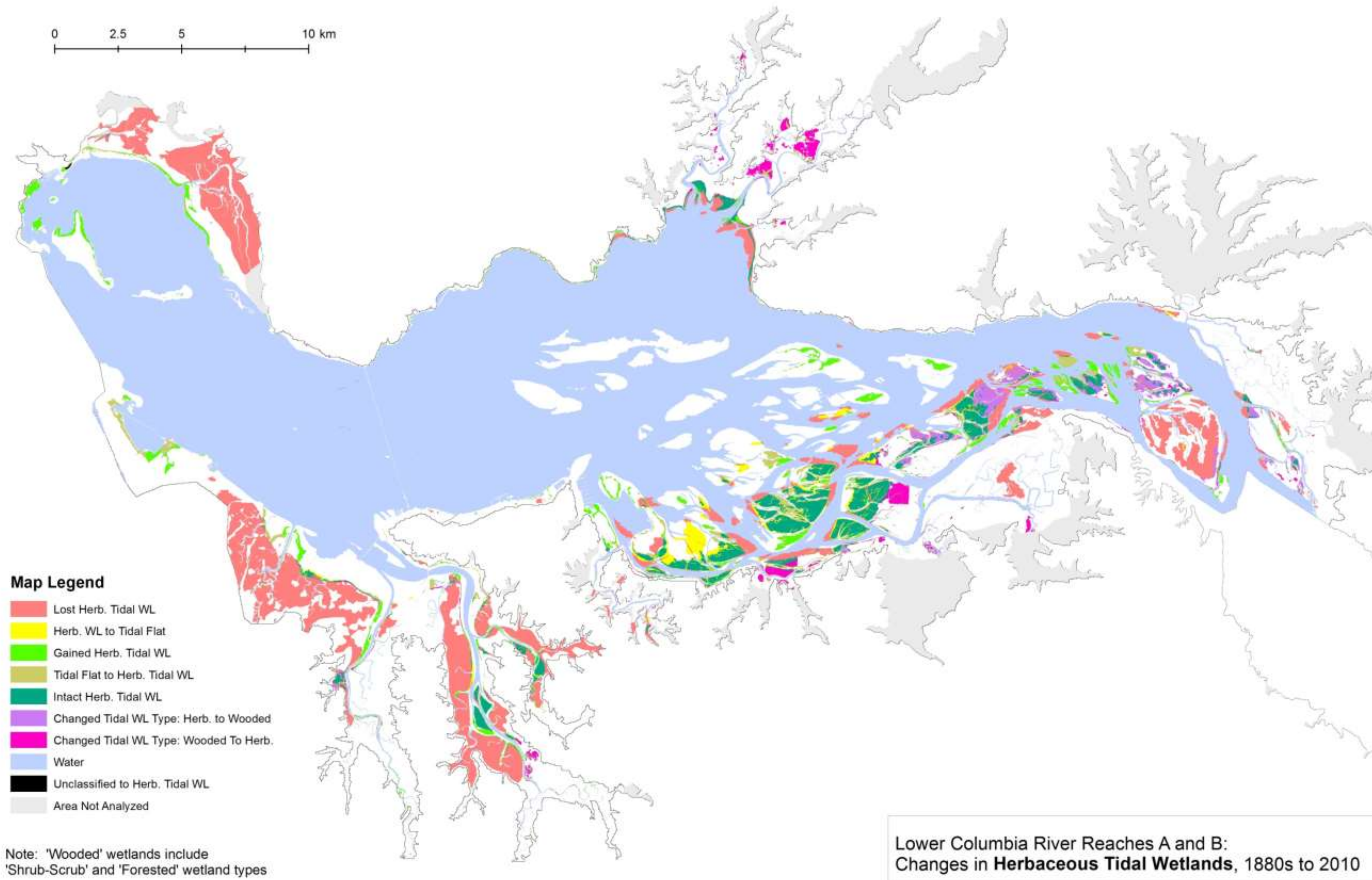


Figure 51. Regional Map – Changes in Herbaceous Tidal Wetlands, Lower Estuary

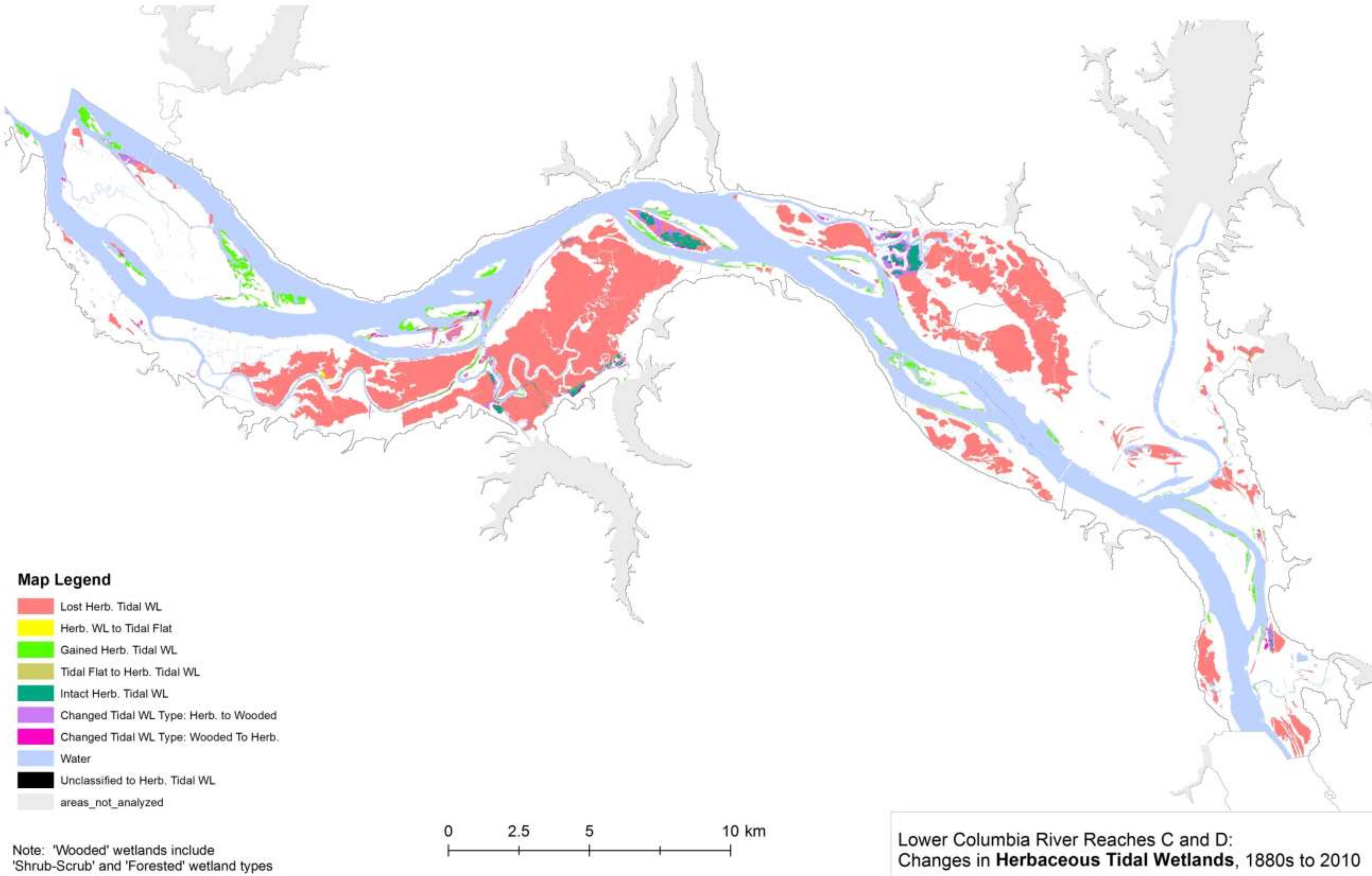


Figure 52. Regional Map – Changes in Herbaceous Tidal Wetlands, Mid-Lower Estuary

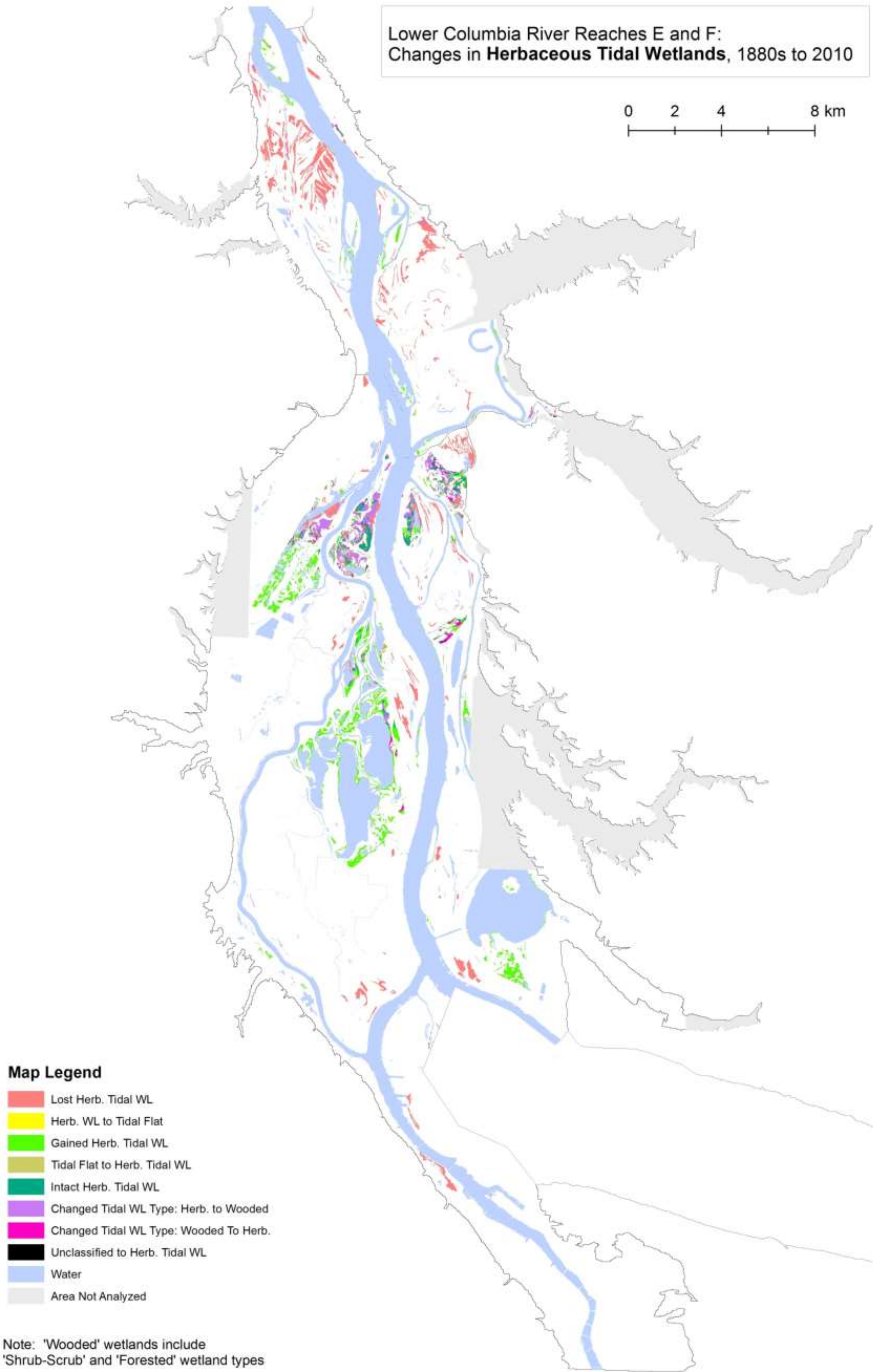


Figure 53. Regional Map – Changes in Herbaceous Tidal Wetlands, Mid-Upper Estuary

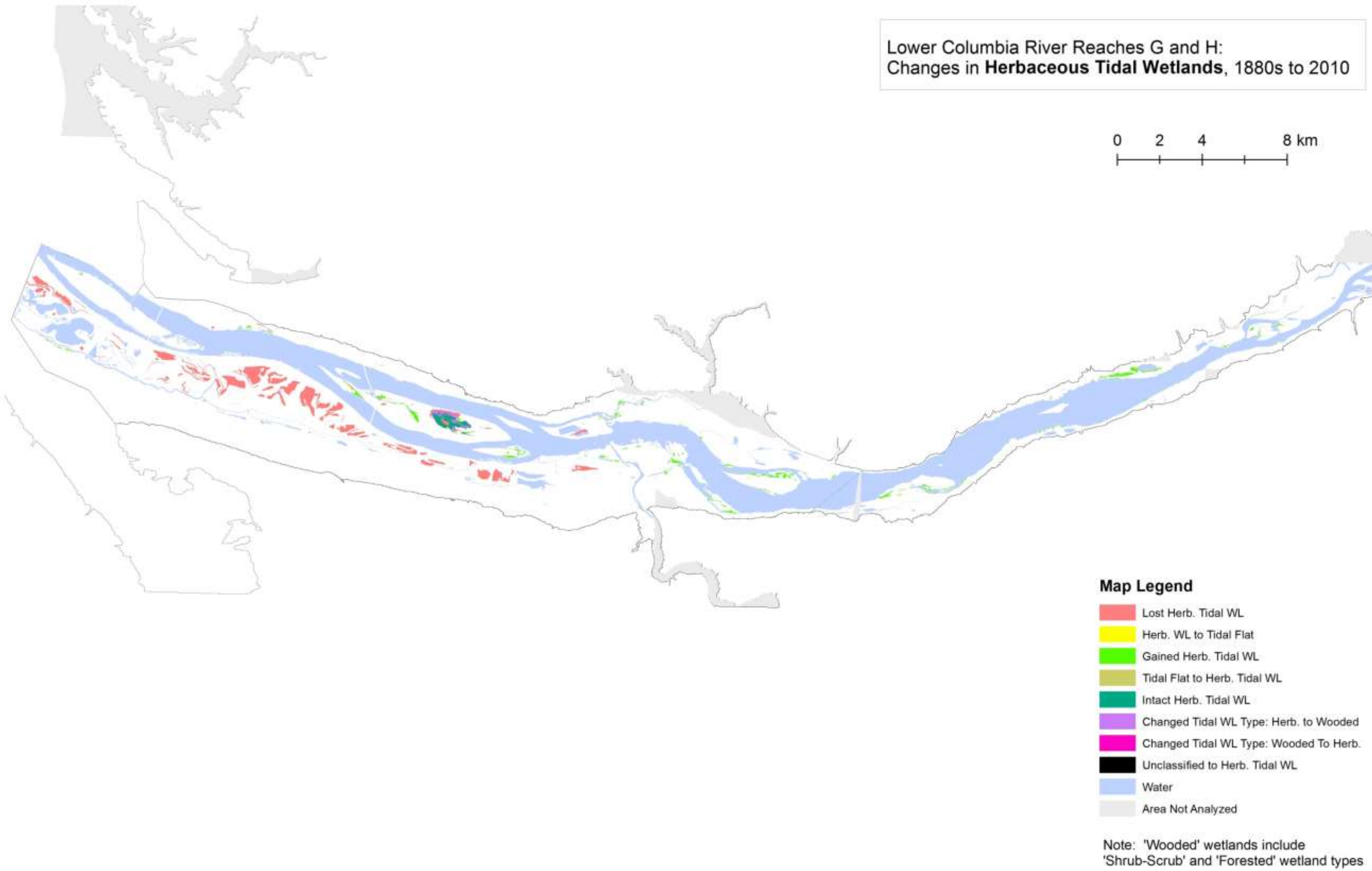


Figure 54. Regional Map – Changes in Herbaceous Tidal Wetlands, Upper Estuary

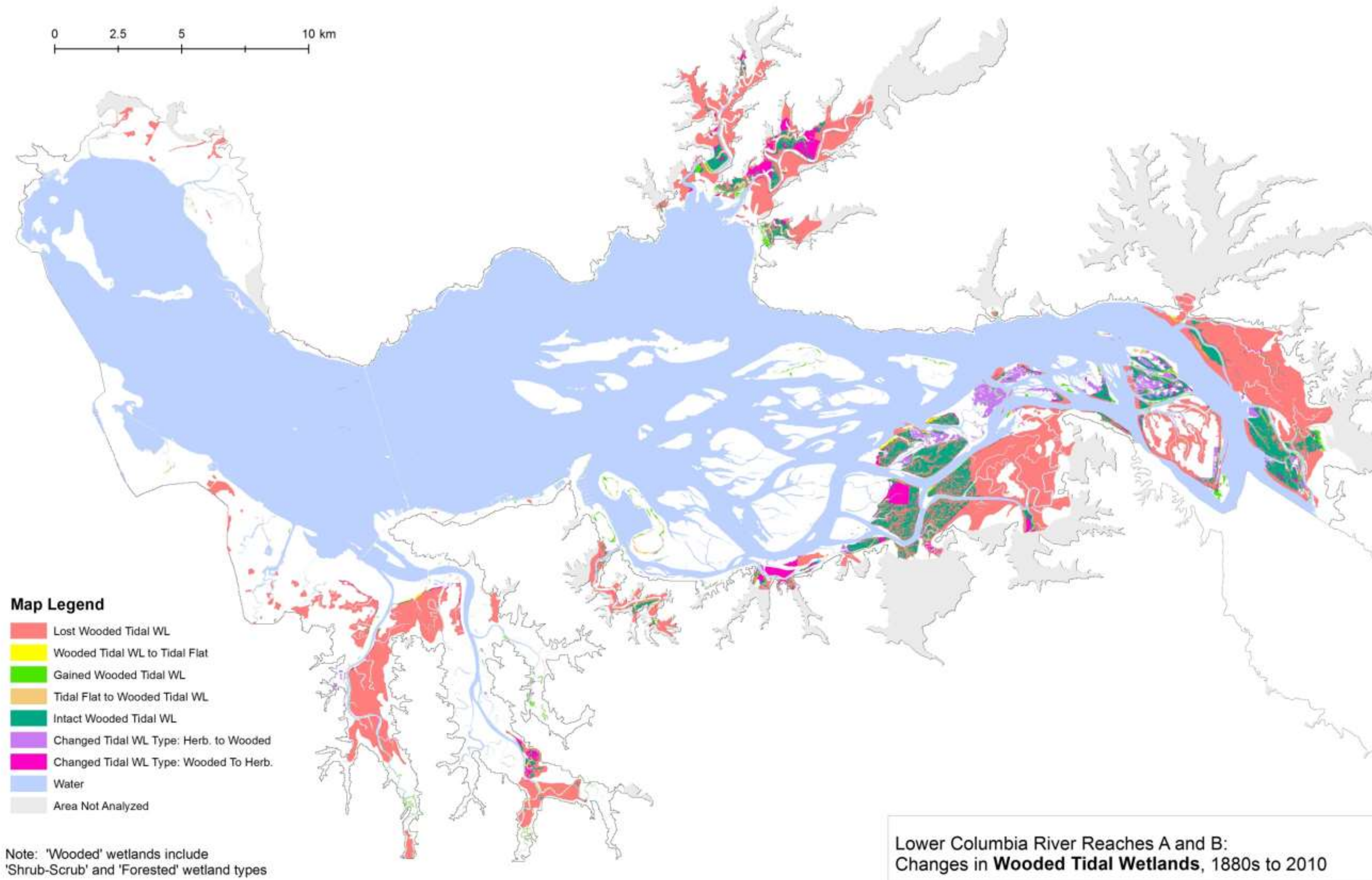


Figure 55. Regional Map – Changes in Wooded Tidal Wetlands, Lower Estuary

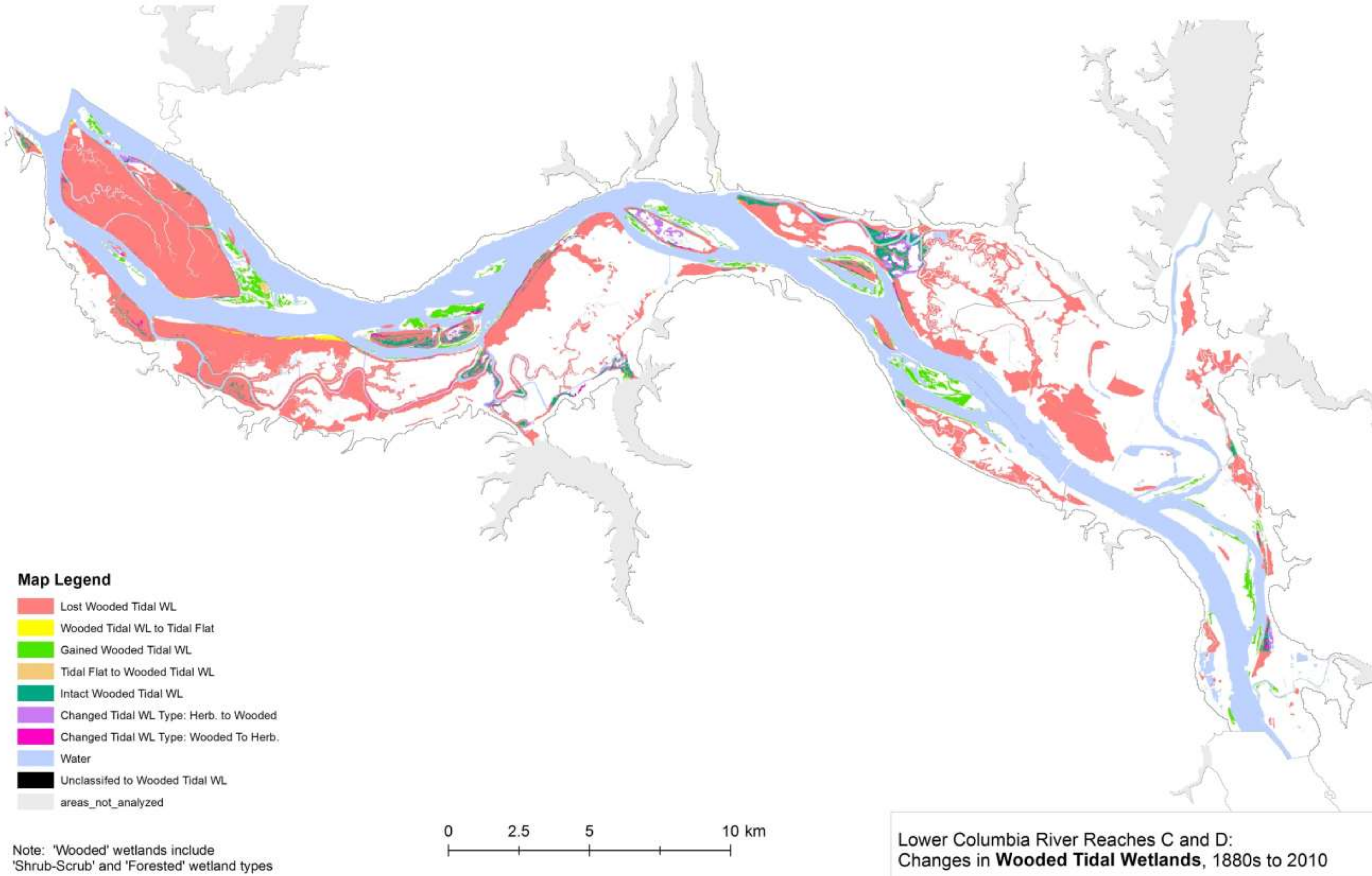


Figure 56. Regional Map – Changes in Wooded Tidal Wetlands, Mid-Lower Estuary

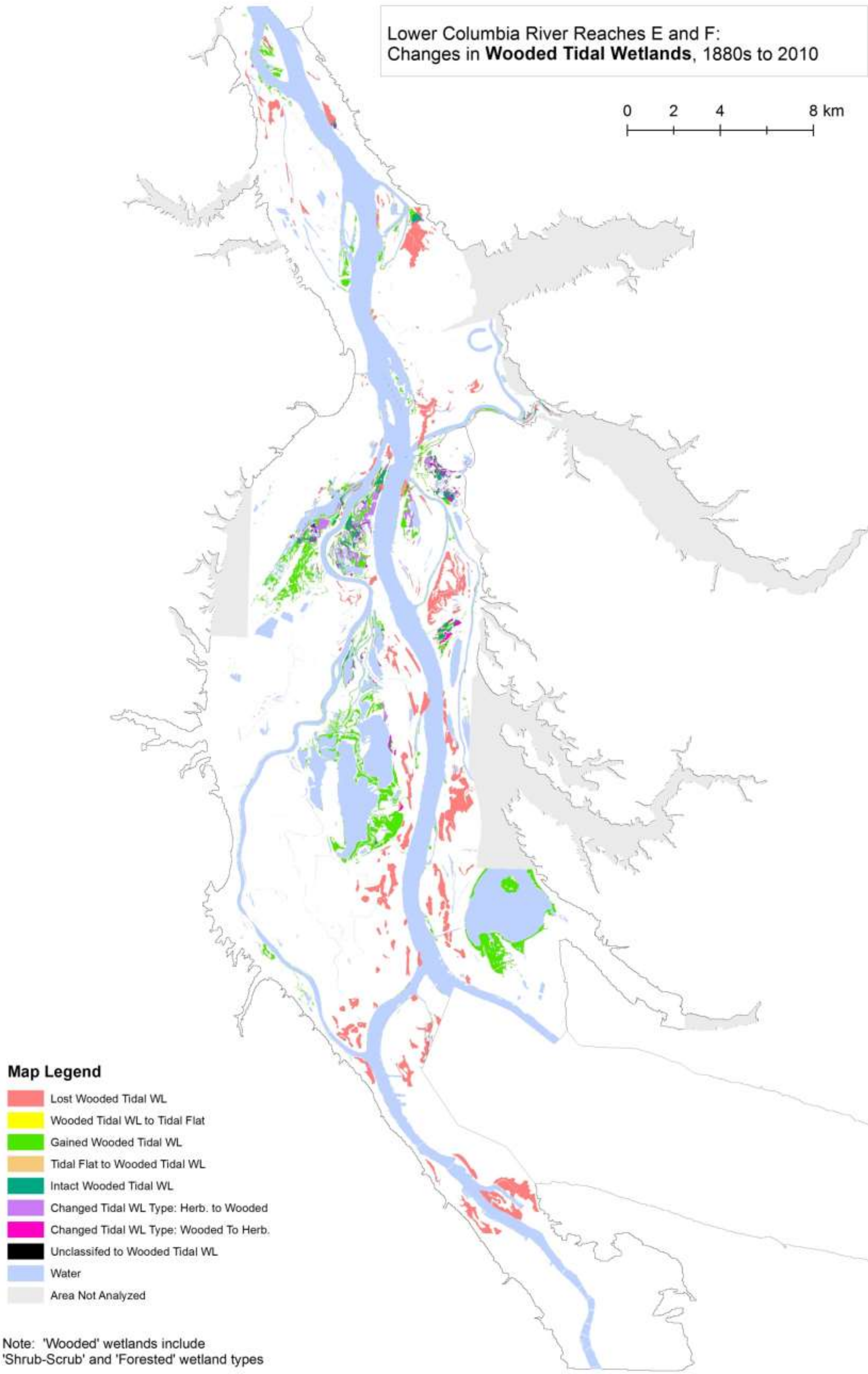


Figure 57. Regional Map – Changes in Wooded Tidal Wetlands, Mid-Upper Estuary

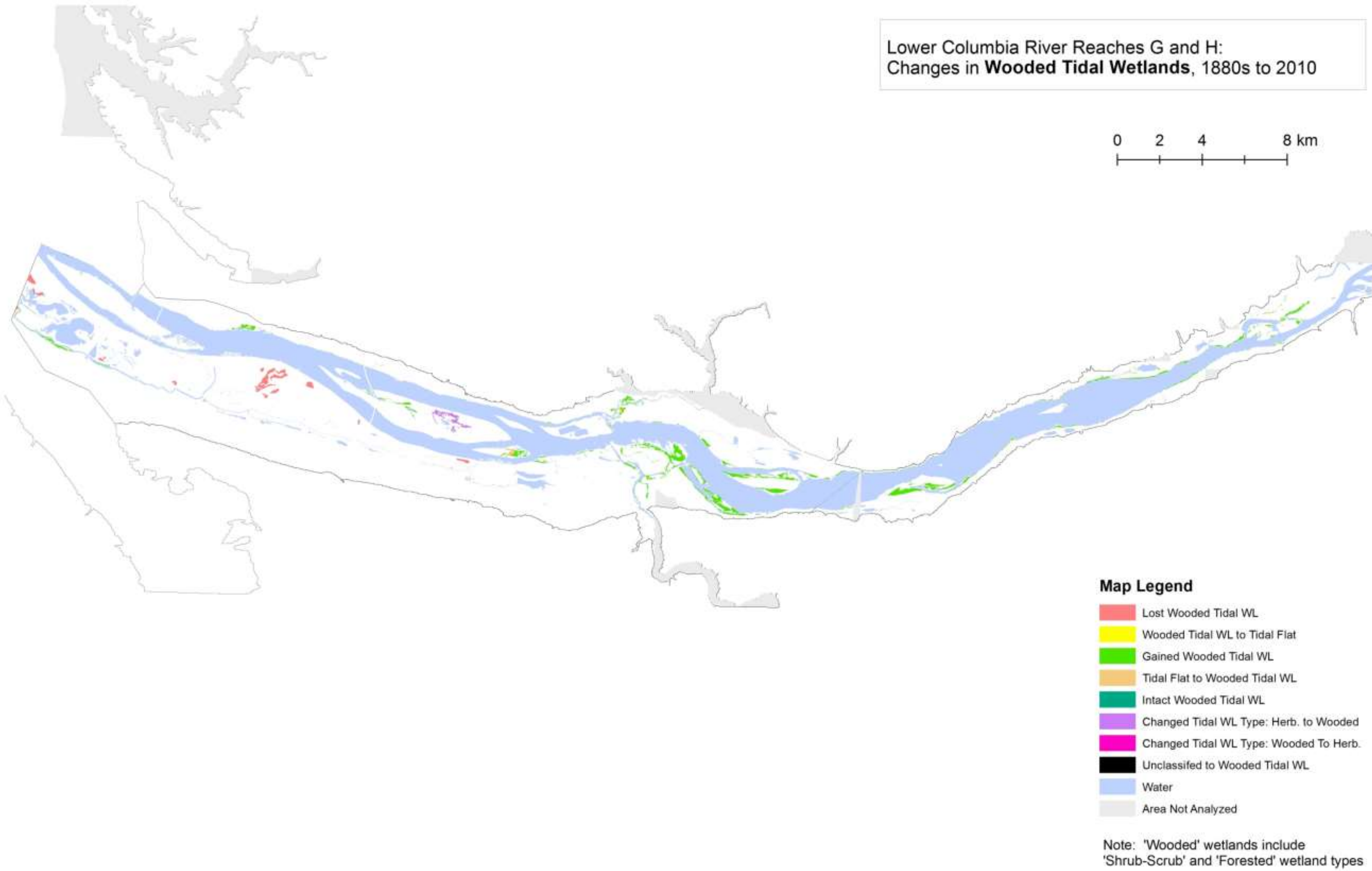


Figure 58. Regional Map – Changes in Wooded Tidal Wetlands, Upper Estuary

Appendix C

Tables and Figures Summarizing Descriptive Analyses of Chemical Contaminant Data Compiled in Lower Columbia River