AN ABSTRACT OF THE DISSERTATION OF

Tracy Hunter Allen for the Degree of Doctor of Philosophy in Geography. Presented on May 7, 1999. Title: Areal Distribution, Change, and Restoration Potential of Wetlands within the Lower Columbia River Riparian Zone, 1948-1991.

Abstract approved:

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The lower Columbia River (LCR) riparian zone is rich in habitat diversity. However, the natural beauty and species diversity along the river have increasingly become affected by human activity. This study quantifies the areal extent and degree of wetlands change and associated causes along the LCR over the past 44 years. This research examines the distribution of wetland types and their patterns of change, developing regional models which rank areas most conducive to potential wetland recovery or restoration efforts.

The length of the study area totals 234 river kilometers, from the mouth of the Columbia River to Bonneville Dam. The width includes the active channel and an approximately three-kilometer swath on either side of the river. Aerial photography was the primary means for interpreting historical extent of wetlands, using five photo

dates (1948, 1961, 1973, 1983, and 1991), based upon their time interval, coverage, and photo quality. For each photo throughout the entire study site, land uses and wetland habitats greater than one hectare were identified and classified. Each classified polygon was digitized and spatially analyzed using a Geographic Information System.

This study indicates that wetland habitats which were once contiguously draped upon the linear features of the river are decreasing in size and becoming fragmented. There have been both increases and decreases in specific wetland habitat areas which vary by river reach, even though wetlands have diminished overall. The estuarine section of the LCR experienced a 25% net decrease in wetland area between 1948 and 1991, while the riverine tidal section fostered a 1% increase. The riverine lower perennial section sustained the greatest loss of wetlands, which decreased by 37%. Causes for wetland losses in the estuarine section were largely related to in-water activities, such as channelization, while the causes for declines in the riverine lower perennial section were correlated with rapid urbanization. Wetland increases in the riverine tidal section were generally influenced by significant growth in palustrine and forested wetlands associated with the establishment of wildlife refuges and the incremental increase of upstream flood storage capacity.

This research provides a template for identifying degraded or displaced wetlands. Through the use of a GIS, each historical wetland was ranked in either low, moderate, or high categories for restoration potential. GIS technology permits focused, sequentially-refined queries to identify potential restoration or recovery sites. In the estuarine section, 74 historical wetland sites were ranked high for restoration potential, while in the riverine tidal and riverine lower perennial sections, there were 178 and 105, respectively. Overall, these sites represent only 25% of the area occupied by wetlands in 1948. While this study advocates restoration potential, restoration is not a surrogate for responsible ecosystem-wide stewardship of the riparian zone. Restoration will not succeed unless degrading factors are mitigated or eliminated.

Areal Distribution, Change, and Restoration Potential of Wetlands within the Lower Columbia River Riparian Zone, 1948-1991

By

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APPROVED:

Major Professor, representing Geography

Chair of Department of Geosciences

Dean of Graduate School

I understand that my dissertation will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my dissertation to any reader upon request.

Tracy Hunter Allen, Author

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As this dissertation grew, so did the list of people to whom I was indebted. The data for this dissertation was gathered under a grant given to Bohica Enterprises by the U.S. Army Corp of Engineers, Portland, Oregon, District. The detailed information derived from an enormous study site, coupled with the extra dimension of a time line, would have precluded the fate of a non-funded project to incompletion. Using the funds provided by the grant, twenty graduate students from the Department of Geosciences at Oregon State University helped compile raw data in a timely fashion via photo interpretation.

I am indebted to my Major Professor, Dr. Charles L. Rosenfeld, for his overall guidance graciously given to me and this dissertation. Most importantly, I thank Dr. Rosenfeld for our weekly meetings, without which my focus for completing my degree may have wandered to Nepal, Alaska, Kilimanjaro...Dr. Rosenfeld's vision and great knowledge are clearly visible in this work.

Graduate committee members, Dr. Charles L. Rosenfeld, Dr. Philip L. Jackson, Dr. Keith W. Muckleston, Dr. Monte L. Pearson, and Graduate Representative, Dr. Steven C. Rubert, each played a key role in shaping this dissertation. I especially thank each member for supplying his expertise. This study was better developed by information provided by: Dr. Rosenfeld on geomorphology, Dr. Jackson on land use/landcover, Dr. Muckleston on water resources, and Dr. Pearson on river processes.

The GIS portion of this study required considerable knowledge of ArcInfo™, ArcView™, and several database structures. In technical matters, where I found a need, but had not an answer, I largely turned to Charles Barrett. Charlie found the time to help me dig myself out of several technical errors. With a great store of GIS knowledge, Charlie writes AML (ARC/INFO Macro Languages) with unparalleled completeness and speed. I also wish to thank Douglas Oetter for his help in technical GIS and UNIX matters.

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DEDICATION

While writing, it was with sadness that I was informed of the death of my mentor, Dr. Alice Andrews. Dr. Andrews saw the unfulfilled potential of a student. She made me think and filled me with inspiration. I am, at this point in life, writing these words because she cared. A finer teacher would be hard to find.

I dedicate this dissertation to my wife, Melissa W. Allen; our new baby, Madison M. Allen; and, my parents, Marlyn and Sue Allen. My parents have supported me in all of my fruitful, as well as dim-witted, endeavors, from childhood to adulthood. Melissa has persevered with me during the long days and months of compiling this project. I thank Melissa for her numerous proofreading episodes. Without question, Melissa is a superb editor. Madison was born three years into my degree at Oregon State University. She was born in Oregon; thus, I have deprived her of her right to be a "true" Southerner. But, as are most Southerners, she is still persistent. No matter how many times I said, "No", she would still beat on my keyboard, often deleting or changing important information in my dissertation. I took this as a cue to finish.

Areal Distribution, Change, and Restoration Potential of Wetlands within the Lower Columbia River Riparian Zone, 1948-1991

CHAPTER I. INTRODUCTION

Problem Statement

The lower Columbia River (LCR) ecosystem is rich in habitat diversity. Few places in the United States so strongly emanate a sense of naturalness and tranquility. However, the natural beauty and habitat diversity along the river are increasingly compromised. The LCR, like all other rivers, changes with time. This progression naturally alters the physical features and biological structures of riparian systems, causing distinct ecological areas or habitat types to evolve. Natural alterations to riparian ecosystems most commonly occur over long periods of time, spanning many hundreds or thousands of years. Human occupance and intervention has dramatically accelerated the rate of wetland habitat change along the LCR.

The vitality of the riparian ecosystem has not kept pace with rapid human change. Most of the riparian zone and the wetlands therein have been impacted and are no longer fully functional. Certainly, the changes to the LCR riparian zone have resulted in many benefits to the people of Washington and Oregon. Productive timber and agricultural harvests have long been a cornerstone of the local economy. The transportation network of river, rail, and road, has linked the region to a global hinterland. The continued growth of the area attracts development and investment from around the world. Cities and suburbs which reflect a high standard of living dominate the cultural landscape. The ecological resources of the riparian zone have only recently gained public recognition; consequently, the ecological and associated economic costs of full scale "progress" along the LCR are considerable.

On occasion, riparian ecosystems, particulary within the floodplain, will experience accelerated change due to natural events, such as flooding, or other less likely events, such as landslides or volcanic eruptions. Unlike alterations induced by humans, these changes are considered a natural process which becomes an integral part of the dynamic ecosystem. Human activity within the riparian zone may accelerate habitat change to the point where some habitats no longer exist, let alone naturally develop. Riparian ecosystems are among the most threatened environments on Earth, and the lower Columbia ecosystems are no exception. Water sustains all life. Invariably, competition to occupy and dwell at the river's edge is intense. Plants, animals, and humans vie for space. It is important to understand how human activity over the past 44 years has impacted the LCR riparian zone. Whether humans have had an impact is not in question, rather, to what extent human intervention has caused the loss or gain of riparian habitats. Based upon a history of rapid development along the LCR, the stage is set for continued growth. A balance between natural and human development needs to be reached.

This study identifies changes in wetland habitats from 1948 to 1991 and discusses factors which influenced these changes. Because wetlands are valuable to humanity and, as a habitat, are unsurpassable in biological productivity, they are identified as important areas. Depending upon the extent and circumstances of habitat loss within these important areas, restoration of particular wetlands may be possible. Lost riparian wetland habitats are ranked according to their likelihood for restoration. By eliminating those areas with little potential for restoration, future restoration efforts may be focused upon locations which demonstrate the greatest potential for recovery.

Objectives of Study

The purpose of this study is to: a) quantify the extent and location of habitat change along the LCR riparian zone from 1948 to 1991; b) determine the factors and patterns which influence significant wetland habitat change; and, c) develop regional wetland habitat models which rank areas most conducive for potential restoration.

Significance of Research

The Columbia River plays an important role in the development of both Oregon and Washington. The river is a corridor of settlement which provides many major functions, including: navigation and bulk transport, intensively farmed land, livestock pasturage, upstream hydroelectricity production, waste disposal, and industrial and recreational uses. These activities have long been the infrastructure of a stable and growing economy along the LCR corridor. With so many demanding and often conflicting functions, it is not surprising that the ecosystem has become "stressed". The Columbia River has experienced sustained human disturbance; however, riparian ecosystems are extremely resilient.

The scale balancing the natural and human environments has largely been tipped toward development. In reaching a partnership between essential development and habitat protection, it is necessary that key aquatic and terrestrial areas along the river be identified, maintained, and restored. This research documents the degree of wetland habitat change and provides insight as to why changes occurred. Not only is it important to understand how habitat areas were negatively impacted, but positive impacts should, likewise, be studied.

Wetland Habitat Value

Wetland habitats have ecological and economic value. The riparian zone in its natural state absorbs potentially destructive flood waters, attracts tourism, and filters harmful pollutants. Perhaps most importantly, riparian wetlands are biologically diverse. While the potential for biologically diverse areas is not fully recognized, they are essential natural resources. Diversity provides for a sustainable environment. Directly or indirectly, humans are reliant upon the contribution of numerous plants and animals for survival. As riparian habitats are developed, certain species may become threatened, endangered, or extinct. Thus, both the resource and its potential as a future resource may be lost.

The LCR is one of the most biologically rich natural resources in the world (Garrett 1998). However, diking, upstream damming, channelization, farming, timber harvesting, road construction, waste disposal, and rural and urban development have altered or destroyed most of the natural habitat. The LCR no longer sustains the species diversity it once did. The Chinook salmon and steelhead runs on the Columbia were among the world's largest. Now the Snake River (a major tributary of the Columbia) Chinook Salmon and the Lower Columbia River Steelhead are listed as Endangered and Threatened Species (Garrett 1998). With the continued encroachment of humans and non-native species, what little natural habitat remains is likely to change.

Population growth and subsequent development will continue to increase along the LCR. What is important is how the growth proceeds. This research produces information regarding habitat modification on the LCR. It seeks to answer questions integral to building comprehensive management policies.

Supporting Policies

Since Euro-American settlement, more than 65% of the wetlands found in the study site have disappeared; yet, wetland habitats still comprise a considerable part of the total area. Many biologists recognize the value of wetlands and label them as important habitats. These often highly impacted habitats play a critical role in defining the general well-being of the LCR.

Figure I.1: Wetlands Functions

‣ Biologically productive habitats ‣ Groundwater charge and discharge ‣ Flood protection and conveyance ‣ Erosion minimization ‣ Basin for settling and filtering pollutants ‣ Nutrient retention and removal

Western culture has perceived wetlands as worthless swamps, valuable only if drained. The functions and values of wetlands have often been ignored. Exactly how valuable are phargmites, bottombushes, and dragonflies, and what functions do they provide within their niche? Wetlands are undeniably necessary for a healthy environment (see Figure I.1). They are the most biologically productive habitats in the world (Heinzenknecht and Paterson 1978). Not only is it important to identify and protect currently existing wetlands, but, in some circumstances, it is necessary to provide suitable conditions for wetland creation and growth. In light of the plethora of evidence warning of the long term ecological impact from damaging riparian habitats (especially wetlands), management policies at federal, state and local levels have been developed. At the federal level, the no-net-loss concept and the Wetlands Protection and Regulatory Reform Act of 1991 are but two important examples of the many activities designed to curb wetland habitat degradation. Another is the National Estuary Program (NEP), which was established in 1987, amending the Clean Water Act. The goal of the program is to protect estuaries that are threatened by human activities. The acceptance of the LCR into the NEP acknowledges that its natural habitats are in jeopardy. More information needs to be collected on how wetlands change over time due to human activities on the LCR. New data could serve to strengthen existing policies and programs and benefit future actions. The biological health of the natural resources found in this area lies in protective policies. Without sound scientific data illustrating how these resources are effected, policies may be loosely formulated and enforced.

Public Concern

In a survey compiled by the Lower Columbia River Estuary Program's science and technical work group, citizens and technical experts were asked to prioritize the greatest problems facing the LCR. More than 1,300 people responded. According to the survey, of primary concern is the loss of wetland habitats within the LCR riparian zone.

There have been no studies on the LCR which investigate the temporal changes of habitats on a large landscape scale. Further, no previous studies on the LCR have incorporated a GIS database to simultaneously examine the changing patterns of habitats in time and space and prioritize potential restoration efforts. This research directly addresses the public's primary concern regarding problems along the LCR.

CHAPTER II. STUDY SITE

General Site Description

The LCR is a system of interconnected physical and biological processes; therefore, it is fitting that it should be studied from an ecosystem perspective. This approach gives rise to an unusually large study site. The site is situated within the historical and active floodplain and active channel of the LCR. The Colombia River watershed is largely located in the Pacific Northwest, where it forms roughly a 500 kilometer border between northern Oregon and southern Washington. In terms of total water discharge, the Columbia River ranks as the second largest river in the United States. The river is 1,950 kilometers in length and drains an area equal to the size of Oregon, Washington, Idaho, and California combined (approximately 667,000 square kilometers).

The length of the study site totals 234 river kilometers, from the mouth of the Columbia River to the Bonneville Dam. The width includes the active channel and a three kilometer swath on either side of the river, or the extent of the aerial photography. The three kilometer zone on either side of the lower river is an arbitrary boundary established as a response to the need to qualify the riparian zone. In reality, there is much debate in the literature as to what defines the riparian zone. Riparian zones have been defined based on hydrologic, topographic, edaphic, and vegetative criteria (Gregory et al. 1991). This study adopts an ecosystem perspective, as discussed by Gregory et al. (1991), and defines the riparian zone as the interface between terrestrial and aquatic ecosystems. The point landward from the river in which the aquatic and terrestrial ecosystem interface is completely uncoupled is not known. The three-kilometer boundary on either side of the Columbia should capture, at a minimum, 90% of the aquatic and terrestrial interrelationships.

Highly mobile animals, such as bird, bear, and deer species, have greater habitat ranges than the three kilometer boundary adjacent to the river. A "true" riparian habitat zone would incorporate the full habitat range of all its inhabitants. However, by incorporating the full range of animals such as a hawk or an eagle in the riparian zone, the study site would no longer approximate the linear features of the river. Perhaps, "riparian ecotone" is a better term than "riparian zone". "Riparian zone" implies that a zone exists with well-defined, measurable boundaries. A riparian zone would have to be adjusted on a case-by-case basis. An "ecotone" suggests that a range, rather than a distinct border, is needed to define the extent of the aquatic and terrestrial interface. For purposes of analysis in this study, a defined zone is necessary. Therefore, the term "riparian zone" is utilized, with the understanding that the larger area needed for some habitats may not be fully represented.

Regional Descriptions

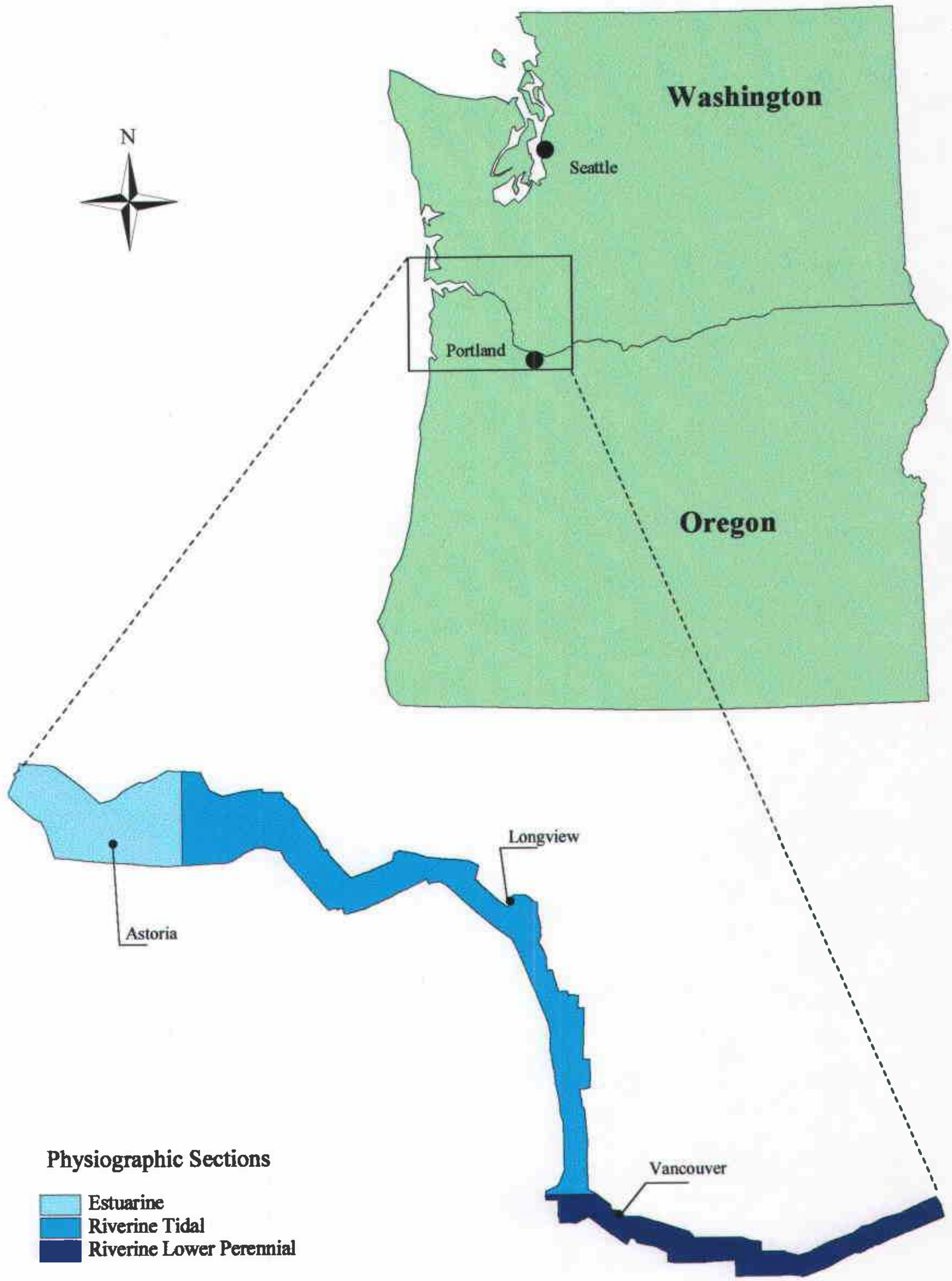
The study site was divided into three regions largely based on physiography. The regions are: estuarine, riverine tidal, and riverine lower perennial (see Figure

II.1). These regions are, in effect, sub-regions or sections of the greater study site region. A formal region is defined as an area throughout which features of such uniformity are found that it can serve as a contrast to other adjacent areas. While each of the three regions has distinct physical characteristics, similarly, the areas could be broken into sections based upon cultural uniformities.

It was necessary to sectionalize the study site according to specific geographic features. Overly generalized data attributed to the entire site may be misleading. For example, it may be shown that the total acreage of wetland habitats has generally declined for the whole LCR; however, palustrine wetlands may, in fact, have increased within the estuarine region. Urbanization trends can be used to illustrate another example. Over all, urbanization is on the increase; but, the trend is especially apparent in the riverine tidal region. Such information is lost when analyzing the study site as a single large region. It is not always necessary, however, for a study site to be regionalized to deduce information. In some cases, prevailing trends across the three areas may be investigated.

For discussion purposes each of the three regions is referred to as a section. The use of the term "section" indicates that the greater region of the LCR has been divided into separate parts representing in natural sections. A section is a geographically contiguous portion of the whole. It better conveys the concept that the entire area is linked, yet is hierarchically structured within a larger region.

Figure II.1: Study Site Locator Map with Major Physiographic Sections



The sections form a system of wetlands, deepwater, and upland habitats that share similar biological, geomorphologic, and hydrologic variables.

Section One: Estuarine

From the ocean heading inland (east), the first section of the study site encountered is the estuarine area. Cowardin et al. (1979) defines an estuary as "consisting of deepwater tidal habitats and adjacent tidal wetlands that are usually semi-enclosed by land but have open, partly obstructed, access to the ocean, and in which water is at least occasionally diluted by freshwater runoff from the land". The features of the estuarine system primarily define the section. But, as a section, it also includes upland areas. The estuarine section in this study has a width which includes the active channel and a three kilometer swath on either side of the river, or the extent of the aerial photography. At the mouth of the estuary, this section measures its narrowest at seven kilometers. The length of the estuary section is 38 kilometers. A line which separates estuarine from riverine tidal at the 38 kilometer mark was drawn. While the line dividing the two sections was established partly upon gradual changes in geomorphology, it is largely defined by salinity levels. The estuarine system extends landward to the point where ocean derived salts are less than 0.5 parts per thousand (ppt) during average annual low flow (Cowardin et al. 1979). Based upon studies completed by the Columbia River Estuary Data Development Program, salinity levels are less than 0.5 ppt during annual low flow between 35 and 40 kilometers inland (Fox et al. 1982). In reality, this line is a transitional zone, ranging over approximately five kilometers. Yet, it was necessary to establish a stationary boundary for analytic purposes.

In comparison to the other two study site sections, the estuarine section is small. Salinity circulation is controlled mostly by tidal and river discharge influences. The section is limited in length because the Columbia River has a greater range between high and low tides and receives larger river discharges than most any river in the United States (Fox et al. 1982). Even at low annual flow, strong river currents of fresh water from upstream push the incoming saltwater oceanward.

The climate of the estuarine section is classified as Marine West Coast. In the winter, the area experiences cool temperatures with steady, drizzly conditions brought on by relatively warm oceanic air masses flowing onshore. The summer months are comparatively dry with moderate temperatures. The average annual temperature for the area is 10.3 degrees Celsius and the average annual precipitation is 168.4 centimeters (U.S. Department of Commerce 1975). Climatically, the chief differences between the estuarine, riverine tidal, and riverine lower perennial sections are slightly decreasing temperatures and precipitation with increasing distances from the ocean.

The estuary is situated within a valley cut by the river and is underlain by sedimentary and basaltic bedrock. Volcanic basalt intrusions occur in various parts of the section. The highest ridges and prominent headlands are formed from this harder, more resistant material. The bedrock floor is a catchment basin which has accumulated sediment. The estuarine section is the scene of currents and sediment in a constant state of flux; however, recent rates of sediment accumulation are unusually high (Fox et al. 1982). Large quantities of sediment are transported and come to rest in the protected embayments of the estuary.

Section Two: Riverine Tidal

The principal factor used to define the riverine tidal section is the extent of tidal action identified by aerial photography. The length of the section from the estuary to its upstream boundary is 124 kilometers. A line representing the upstream extent was established at the point where tidal levels could no longer be clearly identified using areal photography at a scale of 1:48,000. In reality, minor tidal activity monitored on sight is discernable as far inland as Bonneville Dam; but, this activity cannot be accurately identified and classified as a specific habitat type using medium scale areal photography. The section has a width which includes the active channel and a 3 kilometer swath on either side of the river, or the extent of the aerial photography. The maximum width of the riverine tidal section is greatest where it meets with the estuarine section and generally decreases heading upstream.

The area is further characterized by changes in climate, geology, geomorphology, and hydrology not found in the adjacent estuarine and riverine lower perennial sections. The climate is moderated by the ocean. In the winter, low pressure systems form in the Gulf of Alaska and bring steady precipitation (mostly in the form of rain). The area receives slightly less precipitation than does the estuary section, since some of the moisture has already been removed from the system.

The river valley in this section is less submerged, forming a broad floodplain rather than an estuary. Following the last glacial advance, sea level rose. Some 9,000 years ago, the entire area was a part of a drowned river valley. Two major ongoing processes occurred which led to the eventual draining of this section of the drowned river valley: the sea level stabilized and tectonic uplift. Sea level in the area stabilized about 5,000 years ago and has been rising slowly on the order of one or two millimeters per year since (Fox et al. 1982). The coastal area of Oregon and Washington has been rising due to tectonic uplift. In effect, the uplift has superceded the effects of changes in sea level relative to the adjacent land. With the relative retreat of sea level, large quantities of sediments accumulated, partially resulting in the large quantities of sediments still found in the section today. Locals refer to the sediment as "Portland silts".

As tectonic uplift continues, the submerged river valley retreats oceanward. The onetime estuarine features of the riverine tidal zone have slowly given way to today's features and processes which are more riverine. With increasing distance and gradient upstream, the width of the active channel begins to narrow. The overall width of the section reflects these changes and narrows. At its most narrow point, the section is only four and one half kilometers wide.

Where a drowned sea valley once was, now resides an extensive floodplain. Perhaps the most clear relationships between the aquatic and terrestrial environment develop in large river floodplains. The floodplain has components of both systems. Floodplains are the lowlands adjoining a river which experience periodic inundation by floodwaters. The river's gradient and discharge generally decrease, cutting broad meanders in the floodplain of this section. However, the meanders are not as well developed as one would expect of such a large lowland river. The river's comparatively high discharge rates impede the growth of this formation. The alluvium in the floodplain rests on bedrock made up of repeated basalt flows. Flows which are 50 million years old are capped by newer Miocene flows (Alt and Hyndman 1992). The old basalt is eroding and contributes to the sediments found in the floodplain.

The unconstrained active floodplain is girded by older, abandoned floodplains. Under "normal" precipitation conditions, the active channel is constrained by natural levees. However, during periods of intense or continuous precipitation events or snowmelt, the levees may be crested and the floodplain becomes inundated. During inundation, aquatic organisms migrate out of the active channel and onto the floodplain to utilize the newly available resources and geomorphic refuge (Johnson, et al. 1995).

Section Three: Riverine Lower Perennial

Numerous physiographic characteristics are combined to form the riverine lower perennial section. The length of the section is 72 kilometers, stretching from the upstream boundary of the riverine tidal section at the mouth of the Willamette River to Bonneville Dam. The width includes the active channel and a three kilometer swath on either side of the river, or the extent of the aerial photography. The section ranges from wide floodplains in the downstream area to relatively narrow canyons in the upstream segment.

The downstream portion begins where tidal influences cannot be detected using aerial photography. The floodplain in this section is well developed. The channel substrate consists mainly of sand and mud. Beyond the channel lie numerous lakes, marshes, oxbows, and standing water. Within 20 kilometers of its downstream border, the section's appearance begins to change. From the mouth of the Sandy River to Bonneville Dam, the Columbia becomes confined. This section of the river is a portion of the Columbia River Gorge. Unlike the study site, the dam is not at the terminus of the gorge, for it continues upstream to the Dalles. The features of the gorge largely characterize the riverine lower perennial section.

The geomorphology of the area is unique. The gorge walls are dominated by Columbia River basalt (Galster and Imrie 1989). Mudstone, sandstone, and conglomerate fill the structural depressions of the section and are underlain by thick layers of basalt. About 20 million years ago, the flood basalt flows extruded layer upon layer of lava over a wide area (Alt and Hyndman 1992). Concurrently, the Cascades were experiencing tectonic uplift. The river was able to maintain its course through basalt plateau, incising rapidly as the mountains rose. Many small tributary streams, lacking sufficient discharge, could not incise in pace with the uplift and extruding lava flows (Dicken 1973). Today these streams which were left "hanging" form the numerous falls of the Columbia Gorge. Multnomah Falls is perhaps the most widely visited example.

A factor contributing to the unique geography of the estuarine, riverine tidal, and riverine lower perennial sections was cataclysmic outburst flooding. The Missoula floods broke through an ice dam, rapidly draining a large, glacially ponded lake, leaving extensive and enduring erosional and depositional features. Between 12,800 and 15,000 years ago, at least 50 floods of immense proportion swept across the Columbia River drainage basin. Each flood resulted in the release of as much as 611 cubic kilometers of ice-choked water (Allen et al. 1986). Although the floods occurred long ago, they left a legacy on the LCR. The channel of the LCR was scoured and filled during these floods and has since been incising through loosely consolidated material deposited during the floods. Boulders, gravel, silts, sands and loess material from central Washington were deposited in the channel and floodplain of the LCR in the wake of the Missoula floods. The depositional material from the floods contributes to the abundant amount of sediment found in the river today (Baker and Nummedal 1978).

CHAPTER III. LITERATURE REVIEW

Preface

The large scale approach of this research is unique. Few large river, riparian habitat studies have been undertaken. However, there are numerous studies on the use of a Geographic Information System (GIS) and aerial photography for resource management, ecosystem analysis, landcover and wetland classification, habitat change analysis, and wetland restoration. This study is largely comprised of each of the above components; therefore, a literature review of each factor as it relates to this project is necessary.

Geographic Information System

A GIS provides a means to manage complexity. Given the size of watersheds, the multitude of conflicting interests, and the diversity of resources, "the quantity of information exceeds the capacity of a manual system to effectively produce relevant information for decision making" (Levinsohn and Brown 1991). A GIS is composed of "computer hardware and software that provide a set of tools for collecting, storing, retrieving, transforming, and displaying spatial data" (Burrough 1986). Processing spatial data with regard to resource management has been facilitated through the use of GIS. Dick (1990) used a GIS as his primary tool for identifying and modeling riparian buffers. The research focused upon the development of a cartographic model that would display temperature buffers for fish habitats. By incorporating a GIS, the author was able to design temperature buffers using a rational, systematic, and quantitative management approach.

A GIS is a useful tool for monitoring changes in habitats. Holt (1990) incorporated a GIS to show human encroachment on bear habitat. He showed that, by employing a GIS, specific habitat types can be identified and managed. The GIS, using "cover type" as the base, enabled Holt to determine range sizes, habitat preferences and needs, and population dynamics of the black bear. The GIS acts as an updatable central reference system for all information. Similarly, Gagliuso (1990) incorporated a GIS in his research concerning the impacts of human activity on cougar habitat in Oregon's North Umpqua River drainage. Numerous layers were digitized into the GIS for analysis, including riparian zones, forest road systems, human disturbances, and permanent residences. The GIS was used to measure distances relative to cougar habitat and human disturbance, furnishing wildlife managers with highly accurate movement patterns. Eng et al. (1990) suggests that a GIS could greatly aid in the effort to manage habitats. Due to conflict resulting from a lack of integrated planning, wildlife managers frequently do not have control over the timing and placement of habitat changes. The GIS would provide the means to realistically model habitats and react to changes in real time. Eng et al. concludes by indicating that the effective use of the technology requires that wildlife managers explicitly state their habitat objectives and develop an approach to successfully compare those objectives.

Aerial Photography

The use of aerial photography as a key tool for riparian wetland habitat identification, delineation, classification, and monitoring has improved over time with the advent of new technology. Aerial photograph interpretation in a riparian system is unmatched by traditional ground-based time- and cost-intensive investigations. According to Tiner, Jr. (1990), stereoscopic interpretation of both large- and small-scale photography, as compared to ground observations, is efficient and cost-effective for identifying, classifying, and inventorying wetlands.

During the late 1960s, numerous studies demonstrated that aerial photography had great promise for wetland identification and subsequent mapping. Several pioneering studies included Olson (1964), Lukens (1968), and Kelly and Conrod (1969). These studies concluded that standing water, hydrophytic vegetation, soil tone and texture, and slope are the principal visible elements in an air photo which lead to wetland identification and delineation. Aerial photography techniques, coupled with reliable ground-truthed data, provide a rational approach for wetland ecosystem classification (Reimold et al. 1973). Wetlands are typically classified loosely by relief (upland and lowland wetlands) and, more specifically, by vegetation type. The source of information for the generation of both systems of classification is aerial photography (Reimold et al. 1973). The evolving necessity to monitor human influences on wetland habitats results in perhaps the greatest application of aerial photography to wetlands (Dahl 1990). Aerial photography provides hard copy "report cards" on the changes of wetlands. The photography shows an historical context in which human impacts can be sequentially monitored and thereby managed (Dahl 1990).

Ecosystem Analysis

The large area of this study lends itself well to a landscape or ecosystem perspective. Troll (1950) described landscape ecology as the study of physical and biological relationships that regulate the different spatial units of a region (Gosselink et al. 1990). It examines the structure, function, and change in a large heterogeneous land area composed of smaller interacting parts. The landscape may be made up of many interacting ecosystems. Natural or cultural patterns on the landscape influence ecological processes (Forman and Godron 1986).

Gosselink et al. (1990) incorporates an ecosystem perspective for wetland management. The article specifically addresses the use of principles of landscape ecology in planning for the cumulative impacts of human activity on the environment in the Tensas River basin, Louisiana. Gosselink et al. identifies areas of restorable and available “bearshed”-sized property to acquire within the watershed. Gregory et al. (1991) provides insight into why an ecosystem approach to riparian change detection and restoration is important. They propose that the riparian zone is the interface between terrestrial and aquatic ecosystems. Riparian zones are not easily delineated, but are comprised of mosaics of landforms, communities, and environments interacting within the larger landscape. Perspectives which isolate specific components of the terrestrial-aquatic interface, such as hydrologic, geomorphic, or vegetative, "are ecologically incomplete and have limited application to understanding ecosystems" (Gregory et al. 1991). Ecological communities and their environments interact and function as a unit, providing the basis for an ecosystem perspective. According to Muller et al. (1993), despite this knowledge, most riparian studies are not analyzed as integrated wholes, but as discrete, disconnected patches, determined by administrative and political boundaries.

Landcover and Wetland Classification

Forman and Godron (1986) define classification as the systematic arrangement of characteristics of objects. The objective of classification is to create order and, ultimately, a sense of understanding. There are numerous landcover and wetland classification systems. Classification systems for describing landcover have been intensively researched and debated for more than thirty years. There is little likelihood that a single landcover classification system will emerge as "the" standard. Hence, there are currently several systems that are used and accepted (Avery and Berlin 1992). The U.S. Geological Survey's *Land Use and Land Cover*

Classification System for Use with Remote Sensor Data developed by Anderson et al. (1976) is widely utilized in the United States, and was modified for purposes of this riparian study along the LCR. Recently, the chief emphasis has been on the development of classification systems that describe land use and landcover by utilizing remote sensor data (Avery and Berlin 1992). Anderson's classification system is amenable to data derived from aerial photography. The system meets the need for overview assessments of landcover, but is flexible enough to allow for a more detailed classification on a case-by-case basis.

Wetlands have been classified by numerous methods since the early 1900s. Classifications based upon vegetative type and hydrologic regime have long been the most widely used systems. In the 1970s, a different approach for classifying wetlands which explored wetland function was developed. Early classifications were developed so that wetlands could be inventoried and drained for human use. Since that time, wetland philosophy has come full circle. Currently, the chief reason for wetland classification is "the protection of multiple ecological values" (Mitsch and Gosselink 1993). A wetland classification system should incorporate the following major objectives:

- to describe ecological units that have certain homogeneous natural attributes;
- to arrange these units in a system that will aid decisions about resource management;
- to identify classification units for inventory and mapping; and,
- to provide uniformity in concepts and terminology (Mitsch and Gosselink 1993).

In 1974 the U.S. Fish and Wildlife Service began a rigorous nation-wide wetland inventory. *Classification of Wetlands and Deepwater Habitats of the United States* (Cowardin et al. 1979) is the classification system developed and adopted for use in this ongoing inventory. This classification system provides a hierarchical inventory of wetlands and deepwater habitats. For purposes of Cowardin's et al. (1979) classification system, wetlands were identified as: (1) at least periodically, the land supports predominantly hydrophytes; (2) the substrate is predominantly undrained hydric soil; (3) the substrate is non-soil and is saturated with water or covered by shallow water at some time during the growing season of each year. The classification system is divided into three levels referred to as system, subsystem, and class. "The term 'system' refers to a complex of wetlands and deepwater habitats that share the influence of similar hydrologic, geomorphologic, chemical, or biological factors" (Cowardin et al. 1979).

Wetland Habitat Change Analysis

There are numerous methods available for assessing historical ecosystem changes. A wetland habitat analysis along the Lower Columbia was completed by Thomas (1983) of the Columbia River Estuary Study Taskforce. The purpose of that study was to assess historical ecosystem changes in the Columbia River Estuary. In San Francisco Bay, Krone (1979) used historical bathymetric surveys to quantify wetland changes due to shoaling and erosion. Atwater et al. (1979) assessed habitat changes in tidal marshes by comparing historical and modern maps, augmented with an examination of fossil roots and stems. No matter what the approach, Thomas's (1983) study indicated that any historical habitat analysis requires the gathering of information on the study site as it was in the past and the comparison of that information with recent data. Thomas used historical documents, such as old maps, navigation charts, and historical accounts for his study, but most heavily relied upon historical aerial photography. Thomas concluded that diking and fills that create artificial uplands resulted in substantial loss of estuarine habitats.

A habitat study by the U.S. Army Corps of Engineers entitled *Inventory of Riparian Habitats and Associated Wildlife Along the Columbia and Snake Rivers* was completed in 1976. The study used aerial photography and fieldwork to identify vegetative types and land form classes. Inventories of big game, birds, furbearers, small mammals, and reptiles and amphibians were conducted. This research was especially useful because it discussed human impacts on wildlife habitat.

Wetland Restoration

The "restoration potential" portion of this study does not seek to identify methods for restoring riparian wetlands; rather, in the human/land and spatial traditions of geography, it does seek to identify areas which have the greatest potential for restoration. Identifying these key areas is the first step in physical restoration. Identification provides a means for focusing restoration efforts.

There is growing literature on wetland and riparian restoration ecology. Kusler and Kentula, eds. (1990), Kentula et al. (1992), and Mitsch and Gosselink (1993) present an overview on the general restoration of wetlands. One of the most complete sources on restoration ecology is *Restoration of Aquatic Ecosystems*, produced by the Water Science and Technology Board of the National Research Council (1992). This book provides an in-depth view of the history and future of restoration. A large portion of the book is dedicated to restoration prospects and implications for lakes, rivers and streams, and wetlands. The role of policy, as it applies to restoration ecology, is thoroughly discussed, and numerous restoration case studies are presented.

Riparian wetland restoration is typically divided into two approaches: the restoration of either small streams or large rivers. Restoration studies on small rivers and streams have been common practice for a number of years, but restoration projects on large rivers are much less frequent (Gore and Shields, Jr. 1995). Heed (1977), Gore (1985), Platts and Rinne (1985), Brookes (1987), Jensen and Platts (1989), Loucks (1990), Heilmeyer (1991), and Newbury and Gaboury (1993) consider small stream or "riverine-riparian" ecosystem restoration, while Sparks et al. (1990), Frenkel and Morlan (1991), Kern (1992), Osborne et al. (1993), Higler (1993), Bayley (1995), Gore and Shields Jr. (1995), and Sparks (1995) discuss large river restoration.

Rivers on the scale of the LCR are often overlooked for restoration, because large rivers intimidate restoration research workers (Power et al. 1995). Although there is a sizable amount of human contact with large rivers, there is little understanding of how human activities influence riparian functions. Restoration of small streams has been practiced for nearly twenty years. Subsequently, there is a considerable body of knowledge on small stream restoration. Large rivers and their lateral floodplains are geomorphologically and biologically more complex than the constrained reaches of small streams. Floodplains are among the most biologically diverse regions of the world; yet, "there is no clear theoretical basis for how large river ecosystems operate" (Johnson et al. 1995, 134).

Identification of the “ideal” site for riparian wetland restoration is critical, as proper site selection may ultimately determine the success or failure of physical restoration. When considering site selection, an historical analysis is necessary, to provide a relatively complete picture of the once natural system (Williams 1995). Appropriate site analysis can maximize the potential for successful restoration. Brodie (1989) discusses how to select and evaluate potential sites for constructed wastewater treatment wetlands. Willard et al. (1989) considers site selection for the creation and restoration of riparian wetlands in the Midwest. While there are multiple factors which must be considered when identifying a site for restoration potential, three are essential for success: 1) locate where wetlands previously existed or area adjacent to or near existing wetlands; 2) determine if the surrounding landcover and land uses are compatible; and, 3) locate an area where natural inundation is frequent (where the soil is saturated for at least part of the growing season).

CHAPTER IV. MATERIALS AND METHODS

Creating a GIS Habitat Database

Building a methodology for this study required a series of hierarchical steps, the first of which was creating a GIS database. Each step in the hierarchy relies upon the completion of the prior step. Without first developing the GIS database, it is certainly not possible to derive methods for quantifying total habitat change or restoration potential. Steps for building a comprehensive methodology for this dissertation are: creating a GIS habitat database, quantifying total habitat change, determining factors which influence wetland habitats' change, and identifying wetland habitats for restoration potential.

Geographic data can be spatially analyzed in a GIS. Due to the immense size of the study site, a manual interpretation of the data would literally take years; however, by using a GIS, the analysis is more inclusive, accurate, and expedient. Changes in habitat type and human development along the river can be measured. Synoptic viewing capabilities and a GIS make it possible to spatially study large ecosystems like the LCR.

Photo Selection

Working in cooperation with the U.S. Army Corps of Engineers, Portland District, it was decided that the best method for documenting habitat change was through the use of aerial photography. Aerial photography provided by the Corps of Engineers was the primary means for identifying historical river habitats on the LCR. Five photo dates were selected, based upon their degree of representativeness, spanning approximately 44 years of habitat change. The selected photo acquisition dates were: 1948, 1961, 1973, 1983, and 1991.

While the objective was to acquire photography taken during the same time frame for each year, ultimately the photos ranged from August to November. All photo prints were black and white, with the exception of the 1983 photos, which were color infrared. Scale ranged from 1:12,000 to 1:48,000. Most of the photography was at a scale of 1:24,000.

Generalized Landcover Classification Criteria

In order to optimize habitat delineation, two classification systems were created. The first classification system identifies landcover, while the second classification system identifies wetland morphology. The landcover classification is a modified version of Anderson's et al. *Land Use and Land Cover Classification System for Use with Remote Sensor Data* (1976). This study utilizes the system primarily in order to identify landcover and, to a lesser degree, to distinguish general land uses associated with human occupance. Each landcover unit is, likewise, a habitat unit for both aquatic and terrestrial fauna and flora. Landcover delineation was limited to:

1. Barren Land -- Sand dunes, rock lands, sandy beaches, dredged material disposal sites, and quarries (95% barren)

2. Water Resources -- Ponds, lakes, rivers, sloughs, ox-bow lakes, backwaters, side-arm channels, and artificially cut-off meanders (deep -- open water at least 2 meters -- and are bodies of water with less than 10% emergent vegetation)

3. Grassland -- Cannery reed grass (95% grassland)

4. Wetland/Marsh -- Tidal and non-tidal, cattail, sedge, grass, ponds, shallow lakes, shallow sloughs, backwaters, oxbows, salt marsh, freshwater marsh; the water is shallow enough to support emergent vegetation (usually shallower than 2 meters)

5. Shrub/Scrub -- 95% shrub/scrub; power lines, clear cuts

6. Savanna-like -- Grassland with scattered trees (75% grasses with < 25% trees)

7. Forest including: Coniferous forest -- Sitka spruce, Douglas fir, western red cedar; Broad-leaf forest -- Cottonwood, red alder, ash, white oak, big leaf maple, vine maple; Mixed forest

8. Agricultural Land -- Field crops, orchards, pasture

9. Urban/Developed Land -- Residential, industrial, transportation, mining operations

10. Forested Wetland -- Wetland/Marsh areas which contain 25% or greater forest density

Generalized Wetland and Deepwater Habitats Classification Criteria

The wetland and deepwater classification system used in this study is a modified version of the U.S. Fish and Wildlife Service's *Classification of Wetlands and Deepwater Habitats of the United States* (1979). This classification system provides a hierarchical inventory of wetlands and deepwater habitats. Ultimately, it is an attempt to classify wetland habitats indicated by the surficial structure or form of the LCR Valley. Areas are classified based upon the degree of structural similarity. This system of classification satisfies two critical needs: it refines the general wetland delineation of the landcover classification system; and, it includes areas of deep water, which historically have not been classified as wetlands. Topographic areas which are similar in form are, likewise, similar in function. Similar topographic form and function often provide a niche for specific habitat types. This classification system, utilized over a period of time, provides the means to monitor changes in particular wetland habitats. Wetland and deepwater habitat delineation were limited to:

Marine (M)

From the open ocean (Continental shelf) shoreward. Limits include: a) to the landward splash zone of breaking waves; b) to the seaward limit of emergent vegetation.

Marine subtidal (Ms) -- Continuously submerged

Marine intertidal (Mi) -- Exposed and flooded by tides

Estuarine (E)

Tidal deepwater and wetlands that are semi-enclosed by land with access to the open ocean. Limits include: a) upstream and landward to where ocean salts measure less than .5%; b) seaward to a line closing the mouth; c) to the seaward limit of the wetland.

Estuarine subtidal (Es) -- Continuously submerged

Estuarine intertidal (Ei) -- Exposed and flooded by tides

Riverine (R)

All wetlands and deepwaters contained within channels and are downriver of the saline (7.5%) estuarine environment. Expect a transition zone. Typically, the riverine system is flowing. If persistent emergents (plants that are not periodically washed away) occur within the channel, the classification will not be riverine.

Riverine tidal (Rt) -- Gradient is low, water velocity fluctuates, and is influenced by tides

Riverine lower perennial (Rl) -- Gradient is low, water velocity is not influenced by tides, and some water flows throughout the year

Upper perennial (Ru) -- Gradient is relatively high, velocity is fast and not influenced by tides, and some water flows throughout the year

Lacustrine (L)

All wetlands and deepwaters which include the following characteristics (typically lacustrine refers to lakes): a) situated in a topographic depression; b) lacking persistent emergents (at least 70% of the water must be too deep to support emergents; c) total area must exceed 8 hectares (however, if the lacustrine system is very deep -- 2 meters -- and it does not support emergents, the system is still classified as lacustrine).

Lacustrine limnetic (Ll) -- All deepwaters within the lacustrine system

Lacustrine littoral (Lt) -- Shallow wetlands (< 2 meters) which extend from the shore to the non-persistent emergent deepwaters; this is a potential 30% of the lacustrine system, which is typically found along the shoreline

Palustrine (P)

All non-tidal wetlands documented by persistent emergents, trees, or shrubs; examples may include backwaters, ox-bows, and ponds; also includes the following characteristics: a) areas less than 8 hectares with emergents; b) areas in which the water depth is shallow (< 2 meters); these areas may include areas which are greater than 8 hectares, if emergents persist (marshes and swamps); c) palustrine areas in the tidal zone must contain less than 0.5 parts per thousand salinity.

Photo Interpretation

All landcover and wetland and deepwater habitats were identified and classified using aerial photograph interpretation. Areas greater than 1 hectare were classified, provided that adequate photo resolution exists. Landcover and habitats smaller than roughly 1 hectare were "lumped" with adjacent, larger units. Linear features which were less than 1 hectare and were easily identified were delineated. In all, more than 1,750 photos were delineated and classified. The following is a list of steps which establishes the basis for how each photo for the selected dates was prepared and interpreted:

1. All photos were arranged in adjacent flight lines for a given reach of the river. The selected dates began with 1948. This allowed for a determination of which photos to pair as stereo pairs and which photo in a pair should be overlaid with mylar. It was necessary to look at photos in adjacent flight lines to avoid creating gaps in interpretation.

2. Mylar was attached to one photo in each photo pair. The photo number and date were written on the edge of each mylar overlay.

3. The mylar was registered to the photo.

4. The effective area boundaries were drawn. This was done by locating points which could be recognized on both the photo and on the adjacent photo. The effective area boundaries were drawn as small and as close to the center portion of the photograph as possible. Aerial photographs are progressively more distorted from the photo's principal point or center towards the outside edges.

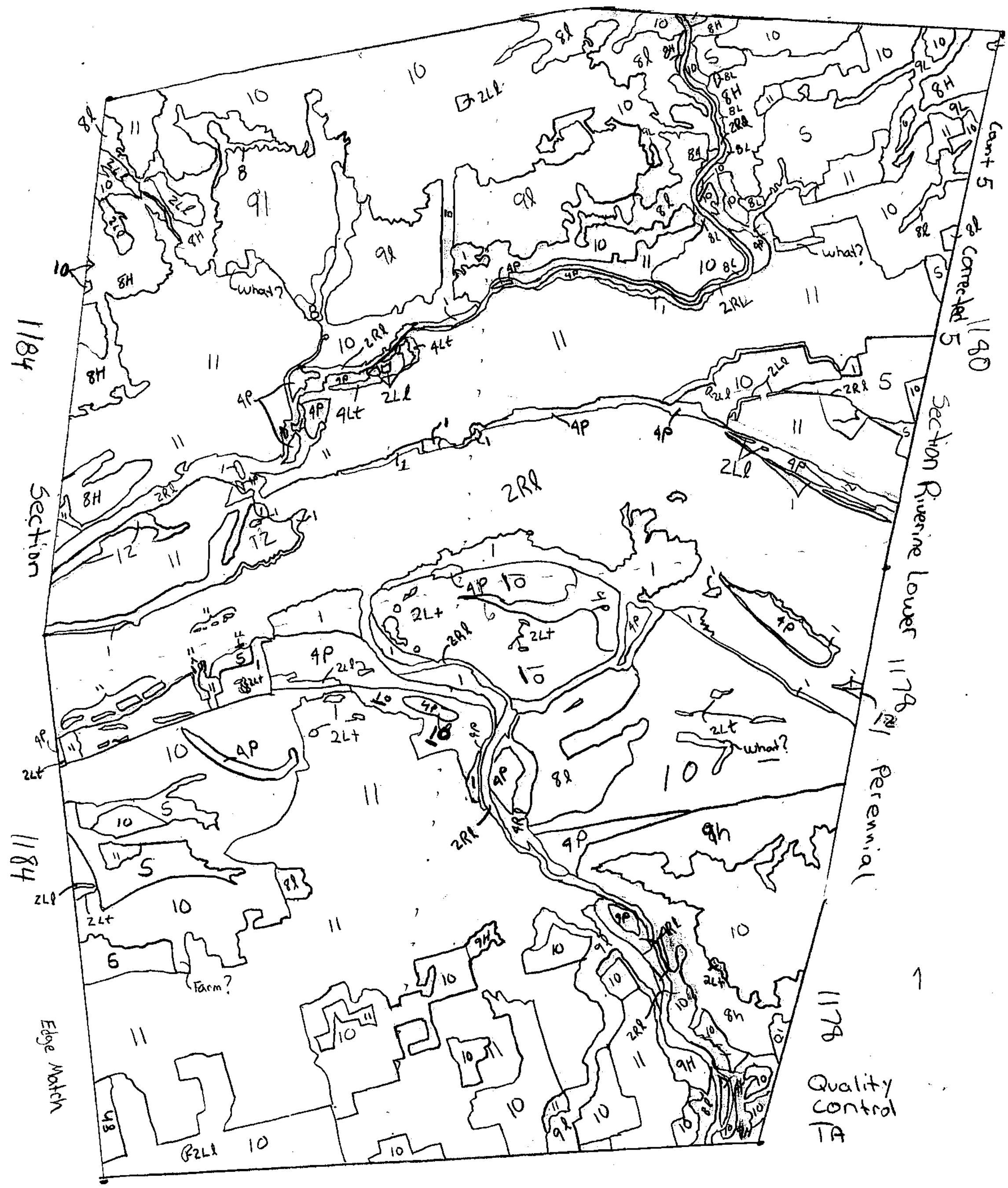
5. All polygons situated in the study site on each photo were delineated using the 3-D viewing capabilities of stereo scopes. Polygons smaller than 1 hectare were not delineated.

6. All polygons were placed within a classification.

Combining the landcover and wetland and deepwater habitat classifications resulted in a hybrid system that provided more information about each classified polygon. Each polygon was given a classification attribute according to its general landcover and, where appropriate, was further classified as a specific type of wetland. For example, a polygon interpreted as a water resource and as riverine lower perennial would be given an attribute combining the two classes conveyed as a 2Rl. A polygon classified as 4Ei denotes wetland esturine intertidal. The number in the classification refers to the landcover while the second two characters refer to the specific type of wetland habitat.

The following illustration is a copy of a mylar overlay as it was delineated and classified from a photo pair. Each polygon has an attribute (see Figure IV.1). The scale of the classified overly is 1:48,000. Mapping habitats to 1 hectare from aerial photographs at such a small scale required magnification. Narrow linear habitats, such as those found along the banks of streams or around the margins of islands were the most difficult to delineate. The cultural landscape, such as urban, agriculture and timber harvest area were less difficult to classify, because their borders were often geometric.

**Figure IV.1: Example of Habitat Mapping
from Aerial Photography**



1983 Photo

Photo Transfer

Because scale varied within and between photo dates, it was necessary to create a uniform series of interpreted photo pairs. Using Zoom Transfer Scopes, photo images were visually superimposed onto United States Geological Survey 7.5' quadrangle maps. A total of 41 7.5' maps cover the study site. Photos were superimposed onto quads for all five photo sets.

Digitization

The U.S. Army Corps of Engineers, Portland District, digitized the classified habitat polygons. 7.5' mylar overlays for each of the five photo sets, containing visually superimposed, delineated and classified polygons, were digitized. All or portions of 204 7.5' mylar sheets were digitized. The digitized data can be spatially analyzed in a GIS.

Quantifying Total Habitat Change

The previously created GIS database provided the means to quantify habitat change. The objective was to develop a methodology that would accurately determine total landcover and wetland habitat acreage for each of the five selected years. A comparison of acreage totals between each of the selected years would provide crude habitat change data. The following five steps were employed in order to achieve this objective: editing and constructing topology, fieldwork, establishing common boundaries, preparing data for export, and illustrating the data.

Editing and Constructing Topology

The GIS platform used to analyze the spatial data was ARC/INFO version 7 for UNIX. To secure the digitized data in a usable format, topology was constructed. Topology is the spatial relationship formed between connecting or adjacent coverage features. It specifies the relationship between points, arcs, nodes, and polygons. The ARC/INFO command used to construct topology was "Build". The "Build" command checks for arc connectivity and contiguity and creates a feature attribute table for the specified coverage. Upon constructing topology, each of the five coverages were extensively checked for spatial errors. Missing features were added; polygons missing an identity were assigned a new identity or attribute; polygons marked with incorrect attributes were corrected; unclosed polygons were closed; and, overshoots were deleted. Finally, the borders for the sections of the larger region (estuarine, riverine tidal and riverine lower perennial) were overlain onto the coverages. Topology was then reconstructed on the newly edited data.

Fieldwork

Fieldwork was the primary means for determining the accuracy of the GIS coverages. Maps were printed from the 1991 coverage and used to spot check actual habitats in the field. Fieldwork as a means to assess accuracy for the earlier coverages was not realistically an option. Rather than fieldwork, the earlier coverages were compared against historical habitat studies conducted within the region. The two principal habitat mapping studies used were conducted by the U.S. Army Corps of Engineers (1973) and by Thomas (1983).

Using a handheld Global Positioning System and U.S. Geological Survey topographical maps, the exact position and classification of features in the 1991 coverage could be checked as "correct" or recorded as "incorrect to be fixed". Those areas with easier access were more heavily verified than others. Roads along the Washington and Oregon border such as State Route 4, US Route 30, and Interstate Routes 5 and 84 were used as corridors for field verification. In an effort not to preclude the remote features within the river's channel from field verification, a canoe was employed. An eighty kilometer route within the riverine tidal and riverine lower perennial sections was checked. Generally, the spot checking demonstrated that the location and classification of landcover and wetland habitats were accurate. Certainly, errors were found, especially within the river's channel. Some of these errors could be attributed to the dynamic state of the river and the changes incurred since 1991.

The data collected during fieldwork were input into the GIS. By editing the spatial features of the coverages, the topology was altered; therefore, topology was reconstructed.

Establishing Common Boundaries

Each of the five photo dates (1948, 1961, 1973, 1983, and 1991) contained varying ranges of coverage. While those areas within three kilometers on either side of the river were the objective coverage, actual photo coverage did not always allow for such consistency. For example, the 1948 coverage incorporated the full 3 kilometers on either side of the river, while in places, the 1961 coverage captured considerably less than the full extent. A comparison between the two coverages would erroneously imply a great deal of habitat change. There would be more habitat in the 1948 coverage simply because the geographic area of the coverage was much greater. In order to achieve a meaningful comparison between the habitats in each of the five years, the coverages had to be limited to the greatest area common to all coverages. By utilizing the identity command in Arc/Info, all five photo coverages, in effect, would be "clipped" to fit the same geographic area. The identity command was used to compute the geometric intersection of the two coverages. The output coverage preserved all of the input and overlap features. "Input features, preserved in the output data set, received attributes of the polygons they intersect" (GeoInformation International 1995).

Preparing Data for Export

When exporting GIS coverages, it is best to transfer only pertinent information. To increase the speed and accuracy of the transfer and to remove unwanted arcs, the size of the coverage files were reduced. The coverages were prepared for export into ArcView[R]. The ease and functionability of ArcView make it an attractive option for general GIS analysis and map design. ArcView version 3 will only accept 10,000 arcs for import per coverage. Two commands were used to remove nonessential arcs and sliver polygons: dissolve and eliminate. The dissolve command removes boundaries between adjacent polygons that have the same value. The eliminate command removes polygon slivers. All slivers less than .5 hectares (number specified by user) were automatically dissolved into the neighboring polygon with which it shared the longest border. Classified polygons which were less than .5 hectares imply a level of accuracy beyond that which was sought in this study.

Statistical information, such as frequency, standard deviation, sum hectares, and mean hectares per coverage, was calculated. This tabular data was exported into a database for analysis. Using ARC Macro Language (AML) many of the redundant commands, such as the statistics command, were written as a macro to be processed in turn without assistance (see Appendix Example One). The AML is a "high-level, algorithmic language that provides full programming capabilities and a set of tools for building menus to tailor user interfaces for specific applications" (GeoInformation International 1995).

Illustrating the Data

Using the ARC/INFO dissolve command, the 1948, 1961, 1973, 1984, and 1991 coverages were each extracted from the larger file containing all the coverages. The coverages were imported into ArcView. Tabular data for each coverage were imported into Quattro Pro. Maps illustrating habitats and landcover of the LCR for each coverage were produced for spatial analysis (see Figures IV.2-6). To generate additional site-specific information, maps and tabular data for each section of the river were created. Visual interpretation of the maps was limited, due to the large number of polygons; therefore, pie charts representing the total area of habitat and landcover for each coverage were generated.

The maps, tables, and charts of each of the five coverages, starting with the year 1948 were systematically compared. By comparing 1948 data with 1961 data and then 1961 data with 1973 data, etc., cumulative changes (gains or losses) between years and sections were measured. A comparison of 1943 data with 1991 data revealed both net gains and losses of wetland habitat types.

Determining Factors Which Influence Wetland Habitat Change

The methodology used to determine factors which influence wetland change builds upon the methods from the previous sections. The objective was to create a methodology that would identify the linkages between wetland habitat change, associated resources and functions, and the causes for change. A better understanding

Figure IV.2: Habitats and Landcover of the Lower Columbia River, 1948

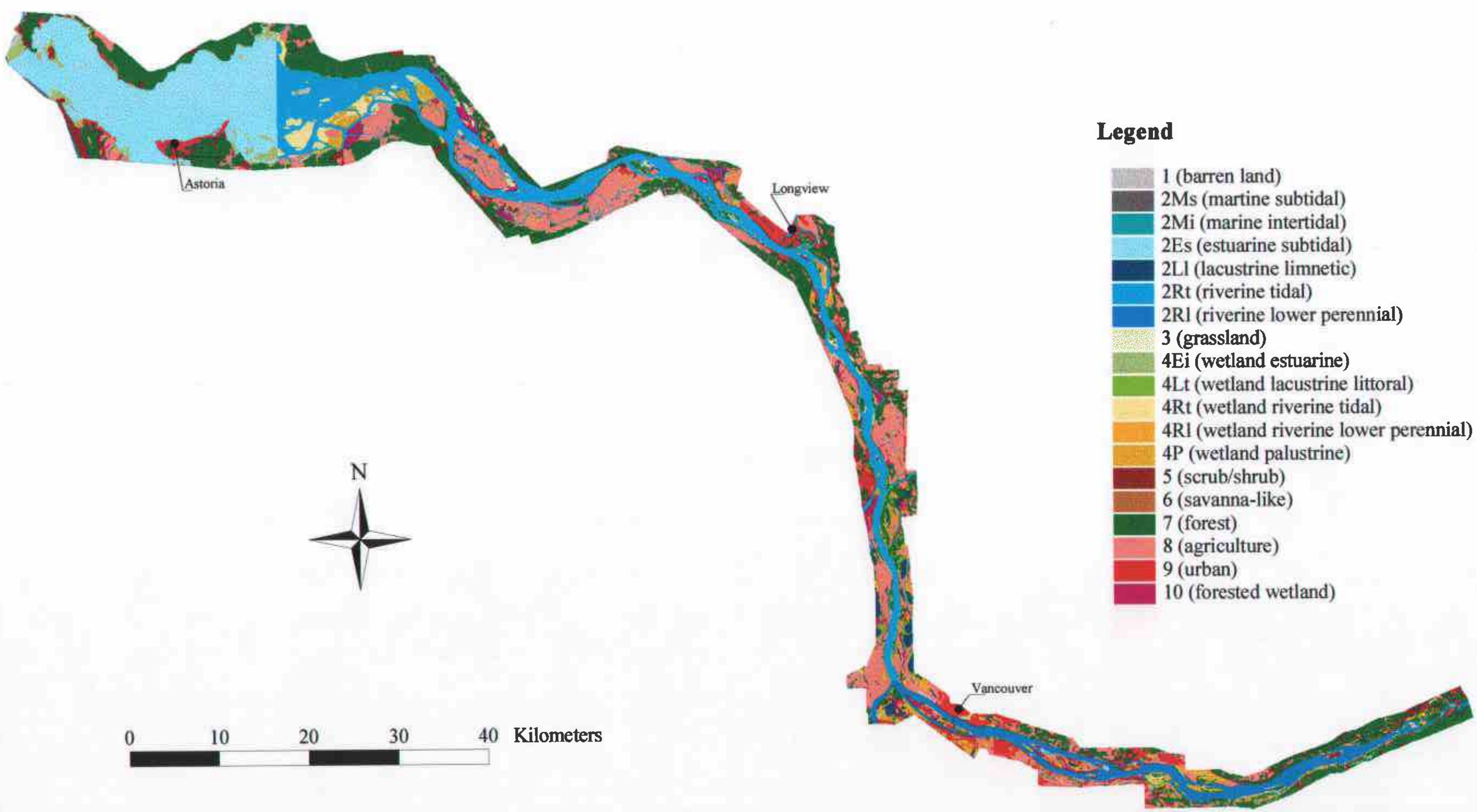


Figure IV.3: Habitats and Landcover of the Lower Columbia River, 1961

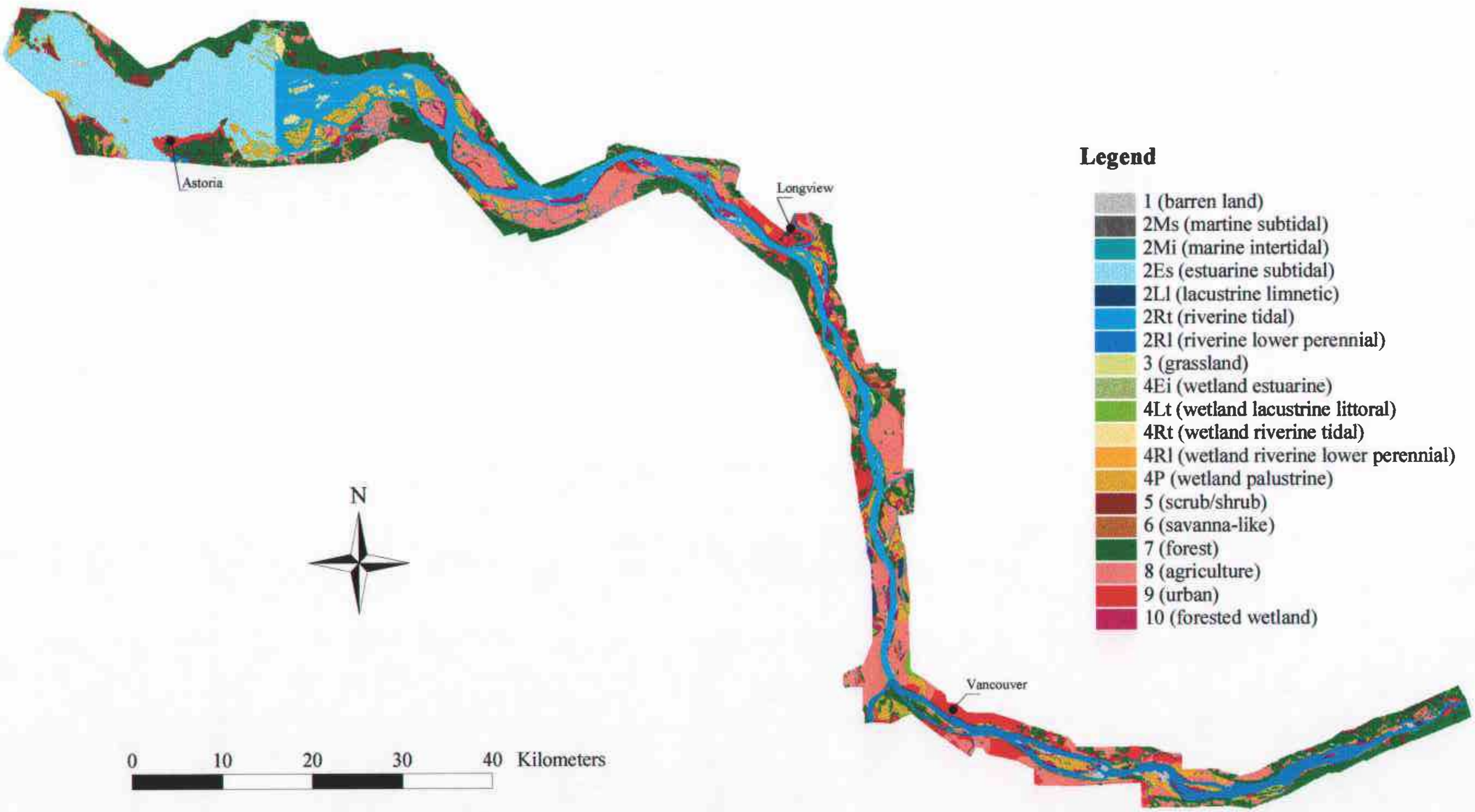


Figure IV.4: Habitats and Landcover of the Lower Columbia River, 1973

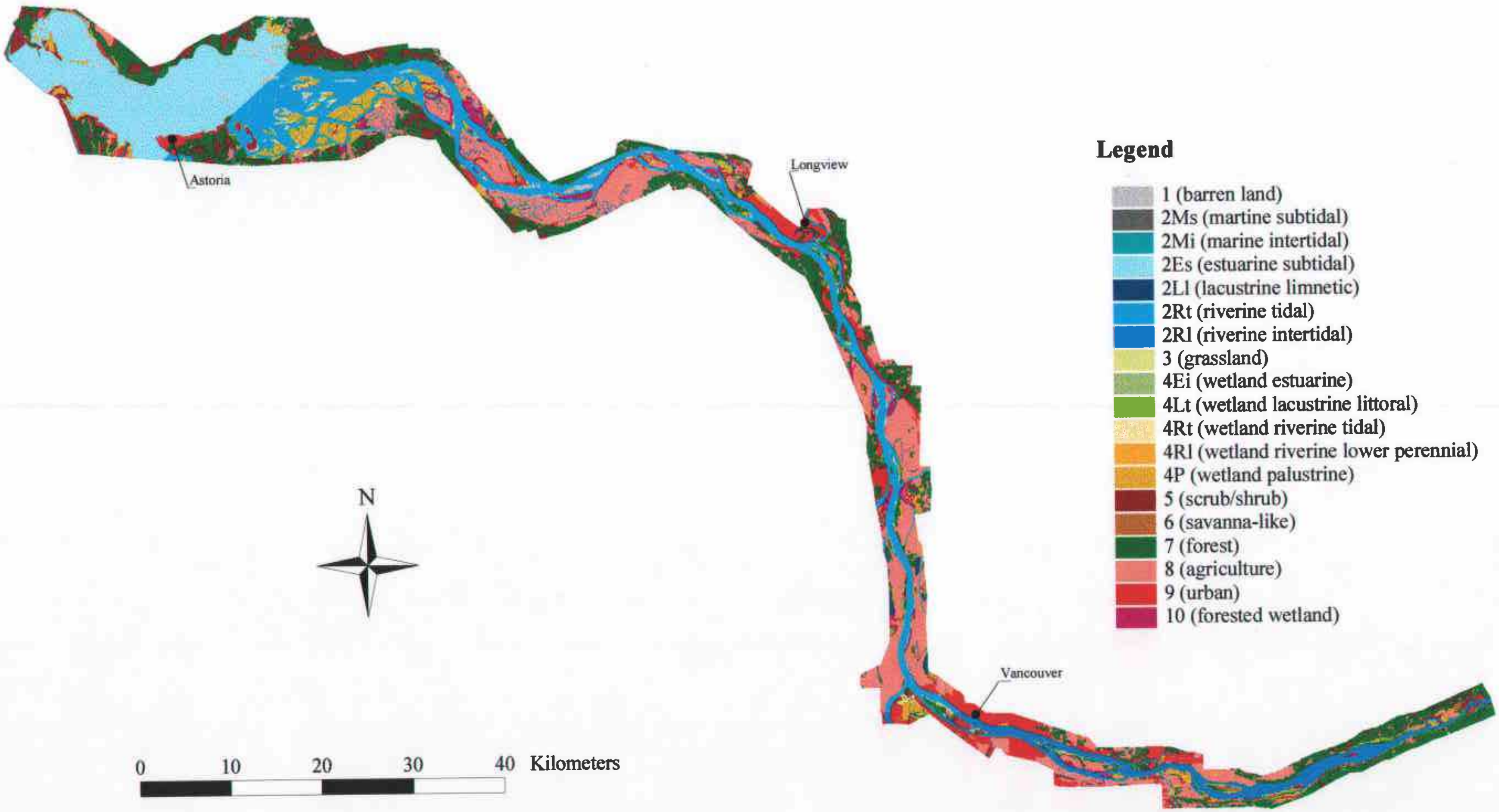


Figure IV.5 Habitats and Landcover of the Lower Columbia River, 1983

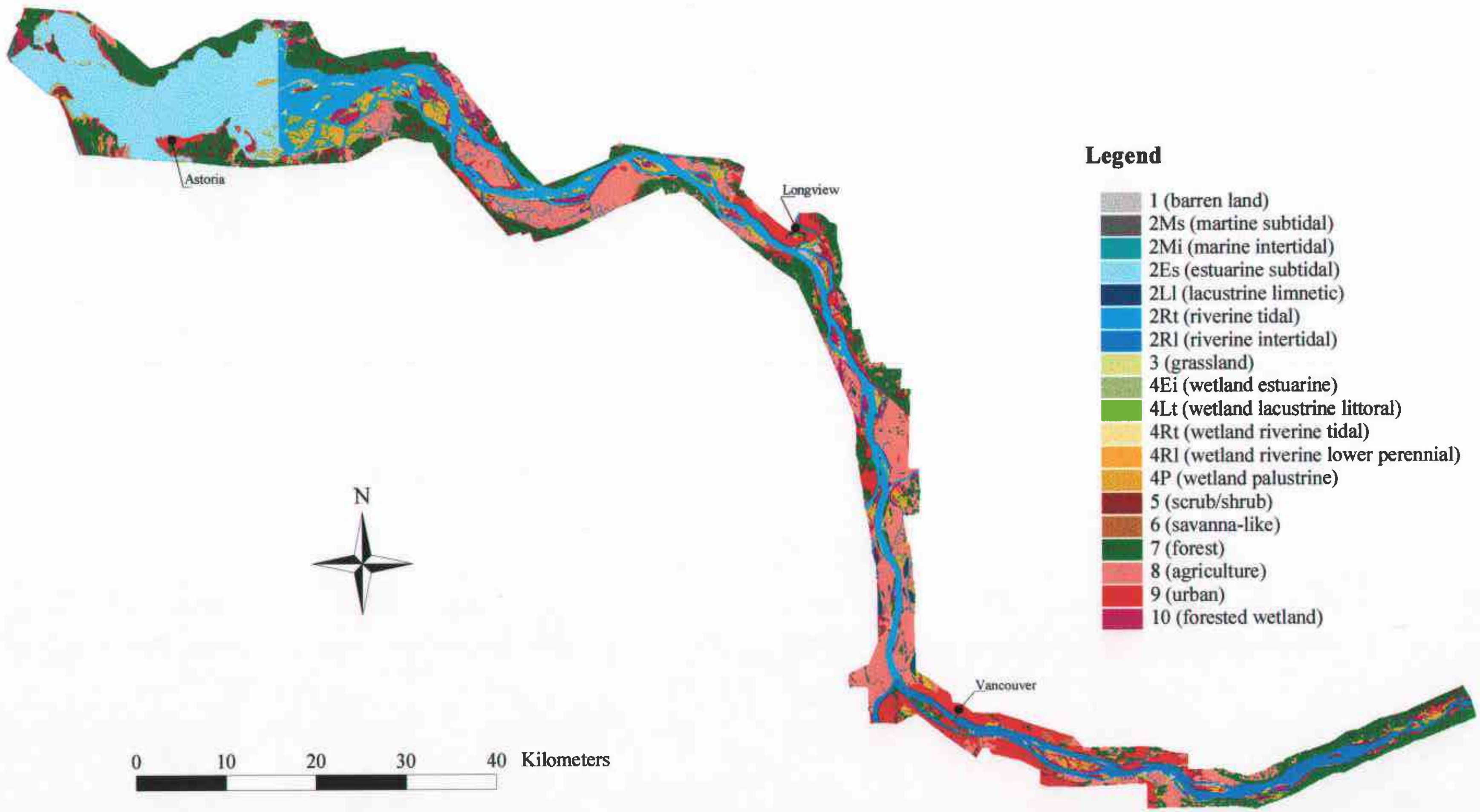
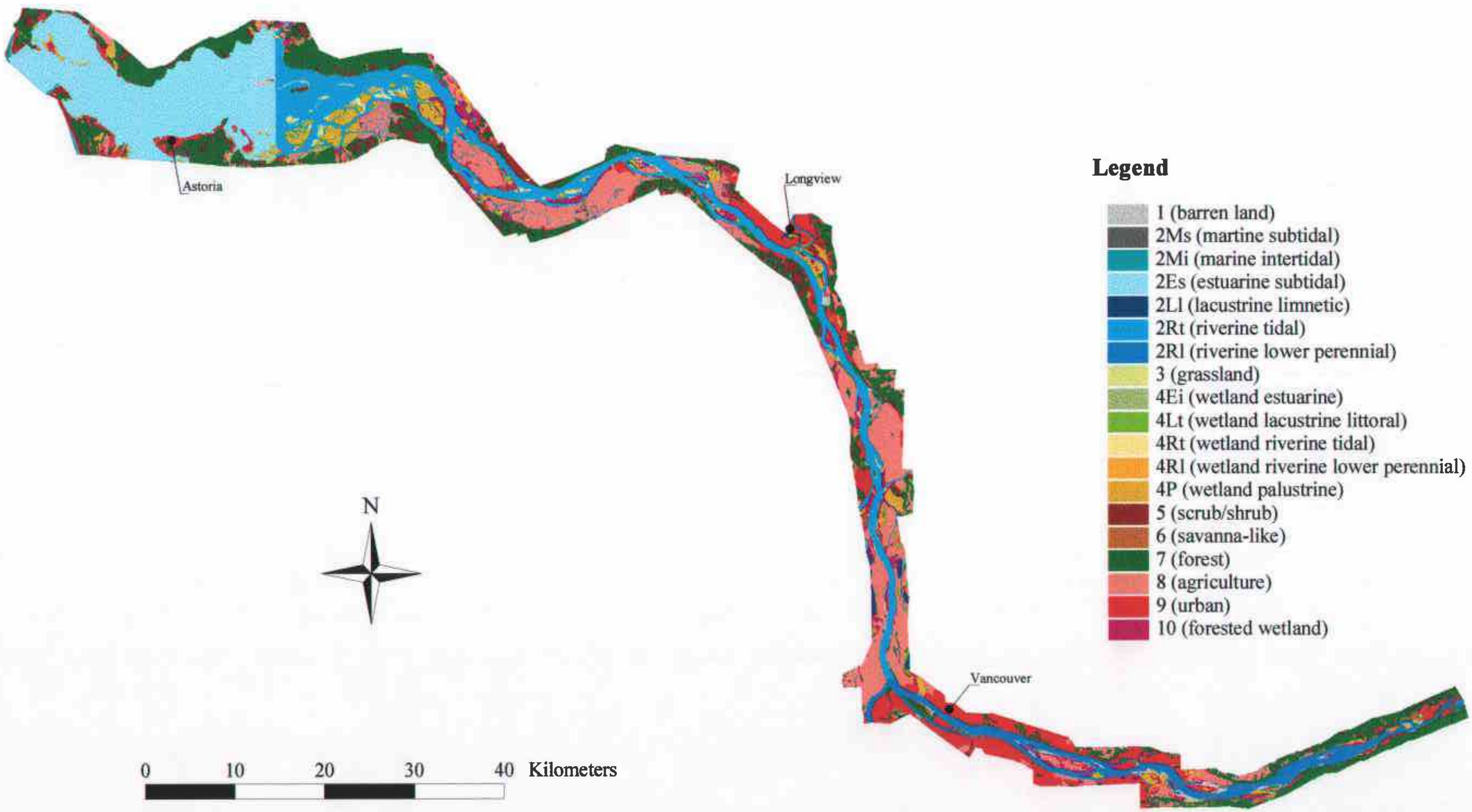


Figure IV.6: Habitats and Landcover of the Lower Columbia River, 1991



of these changes provides fundamental information for management planning. The objective was not to simply show a picture of the state of past habitats; rather, to provide an understanding of how principal variables which effect wetland habitats have been altered over time.

It is necessary to recognize that landcover, such as urban areas or forest habitats, has changed along the LCR. However, landcover, as it relates to wetlands, is the focus of this study. The landcover classification provides the backdrop for which changes in wetland functions and associated resources can be identified. For example, visual interpretation of the maps produced in the prior section (Figures IV.2-6) reveals that the urban landcover has experienced considerable growth. Certainly, the growth drew upon multiple landcovers; yet, at issue is how the growth specifically impacted wetland habitats. The methodology of this section lends itself to how and why wetlands changed.

Researching Historical Wetland Habitat Change

The primary factors which influence wetland habitat change were identified through change detection tables and library research. The LCR provides a wealth of resources to Oregon and Washington. The value of its rich heritage and natural resources has not been overlooked by previous researchers. Numerous studies have been conducted on various sections of the region. From the river's Euro-American "discovery" by Captain Robert Gray in 1792 to the present, changes to the river have been documented. Historical materials, such as maps, journals, and photographs were examined to piece together the past natural conditions of the LCR. Scientific research conducted within the past 50 years was the primary means for identifying the causes for change. Most of the studies examined were compiled by the U.S. Army Corps of Engineers, Columbia River Estuary Data Development Program, and Lower Columbia River Bi-State Program. In addition, scientific studies addressing habitat change on other rivers, especially large rivers, were utilized.

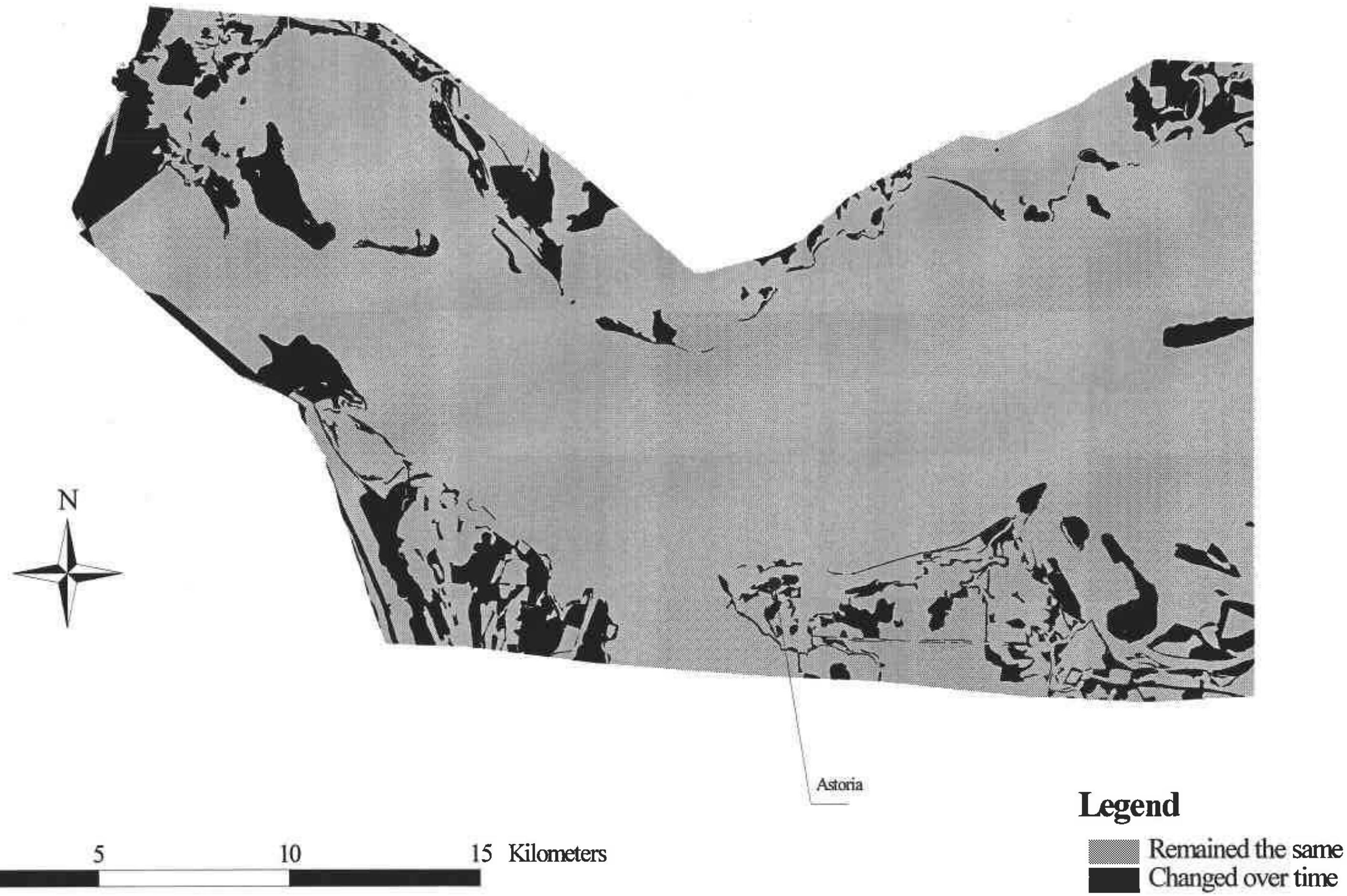
This information base was used to determine the foremost factors which influence wetland habitat change. Human activities, such as agriculture, diking, dam construction, jetty building, dredging and dredge disposal, urban and rural development, timber harvesting, and public policies were the chief causal factors considered. The dominant natural processes assessed were flooding, volcanic eruption and shoaling.

Identifying Patterns of Historical Wetland Habitat Change

Providing information on patterns of wetland change is useful for developing a wetlands management plan. Trends that show which landcover is most likely to degrade or replace a wetland or which wetland type is the most susceptible to change, pinpoint specific environs around which management and additional research should revolve. Wetland data collected over a lengthy time span provides insight on questions, such as: Do specific wetland habitats consistently change to another wetland or landcover?; and, What wetland habitat types regularly show regional gains or losses?. Methods were developed which identified historical landcover types and determined what they became.

Using ARC/INFO, all landcover and wetland habitat polygons for 1948 were overlain onto the landcover and wetland habitat polygons for 1991. A new combined coverage was created. The ARC/INFO Statistics command was used to generate summary information displaying changes between 1948 and 1991. The coverage was split into the three sections of the LCR. Figure IV.7 illustrates these changes for the estuarine section. All possible changes between 1948 and 1991 were recorded as "changed over time". The Figure depicts extensive change in the estuarine section. The changes were saved as an INFO data file and were later exported to Quatro Pro. All 10 classes of landcover and the 10 subclasses of wetland habitats were individually selected from the new data file containing the "changed over time" data. All possible classification combinations for 1948 polygons which were historically one type of landcover or wetland habitat, but became another in 1991, were identified. The total area representing the amount of change for all classified polygons was calculated. An example of this methodology is as follows: areas within the landcover classification, wetland/marsh (4) and the subclassification wetland palustrine (P) for the estuarine section of the river, changed over time; changes were listed according to what they changed to in 1991; the amount of change was measured. The methods

Figure IV.7: Habitat and Landcover Changes from 1948 to 1991, Estuarine Section



used to identify the changed 1948 polygons were written as an AML (see Appendix, Example Two: Factors Which Influence Wetland Habitat Change).

The combined 1948 and 1991 coverage (for each section of the river) was exported to ArcView. Using the database file as a guide, wetland polygons which displayed change were analyzed and mapped. New fields were added to the coverage which displayed wetland changes. Any 1948 polygon which was a wetland but became a different classification value was added to a field according to its new classification. An example of the query command syntax which displayed changes for 1948 forested wetlands that became agriculture is: ([1948] = "10") and ([1991] = "8"). "1948" was the year, "10" was forested wetlands, "and" was the operator, "1991" was the year of the changed value, and "8" was agriculture. As such, the new field contains all 1948 polygons which were equal to forested wetlands, but were changed in 1991 to equal agriculture. All possible combinations of forested wetland change were added to the field by systematically replacing the agriculture value in the query command with the remaining classification values, such as barren land, urban, or palustrine wetlands. This procedure was repeated for each of the wetland habitat classes for each section of the river.

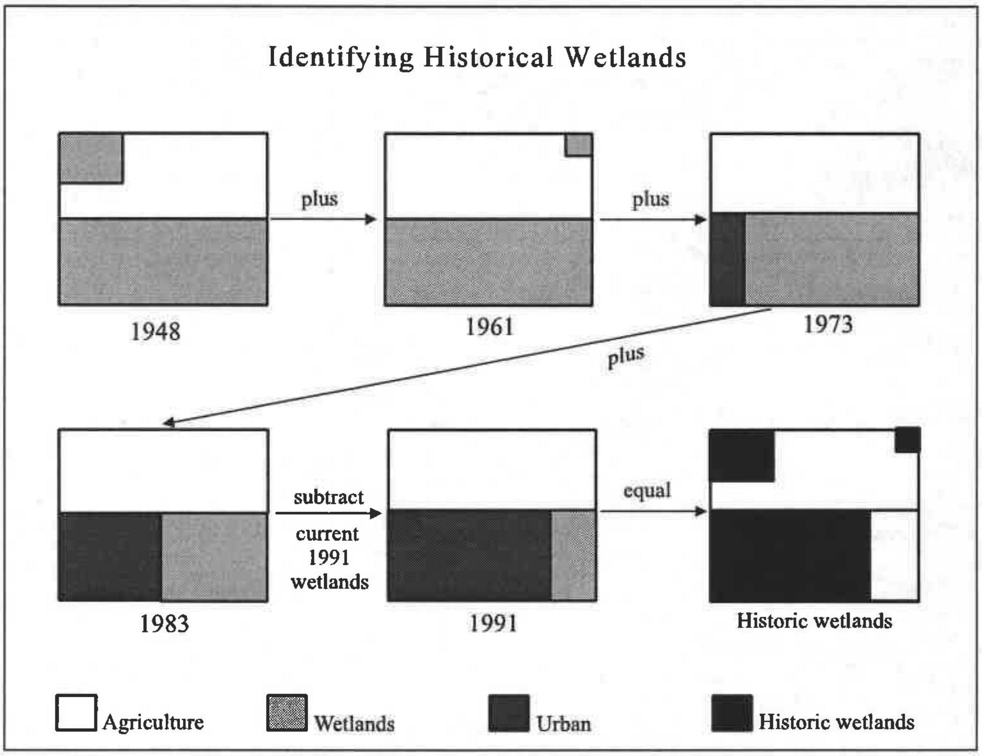
Identifying Wetland Habitats for Restoration Potential

The process of restoring wetland habitats presents myriad problems. Restoration or even partial restoration is not certain. It is costly, resource consuming, and labor intensive. Restoration removes the area in question from its current use and may impede it from further development. For these reasons, once regional wetland restoration is generally agreed to be necessary and viable, great care must be taken to select areas which are the best suited for recovery. Accurate site selection is one of the most important steps in wetland restoration. The objective in this section was to develop methods to identify wetland habitats for restoration potential. For the habitats identified, methods were developed to refine the selection according to varying degrees of plausibility. In this manner, restoration efforts can focus on the most crucial areas. Realistically, the drive for development along the LCR would not allow for large-scale habitat restoration. By limiting the areas deemed important for restoration, development can continue only slightly hindered.

Querying the Data

The data was prepared for querying. All areas which were historically a wetland were identified. Wetlands, including estuarine, riverine tidal, riverine lower perennial, lacustrine littoral, palustrine, and forested, were selected from the 1948, 1961, 1973, and 1983 coverages (see Appendix Example Three: Restoration Potential). These coverages were combined to form one coverage containing all historical wetlands. The new coverage was joined with the 1991 coverage, which contained both landcover and wetland habitat areas, rather than solely wetlands. The 1991 coverage was added because it provided a means by which the previous years of

Figure IV.8: Method for Identifying Historical Wetlands



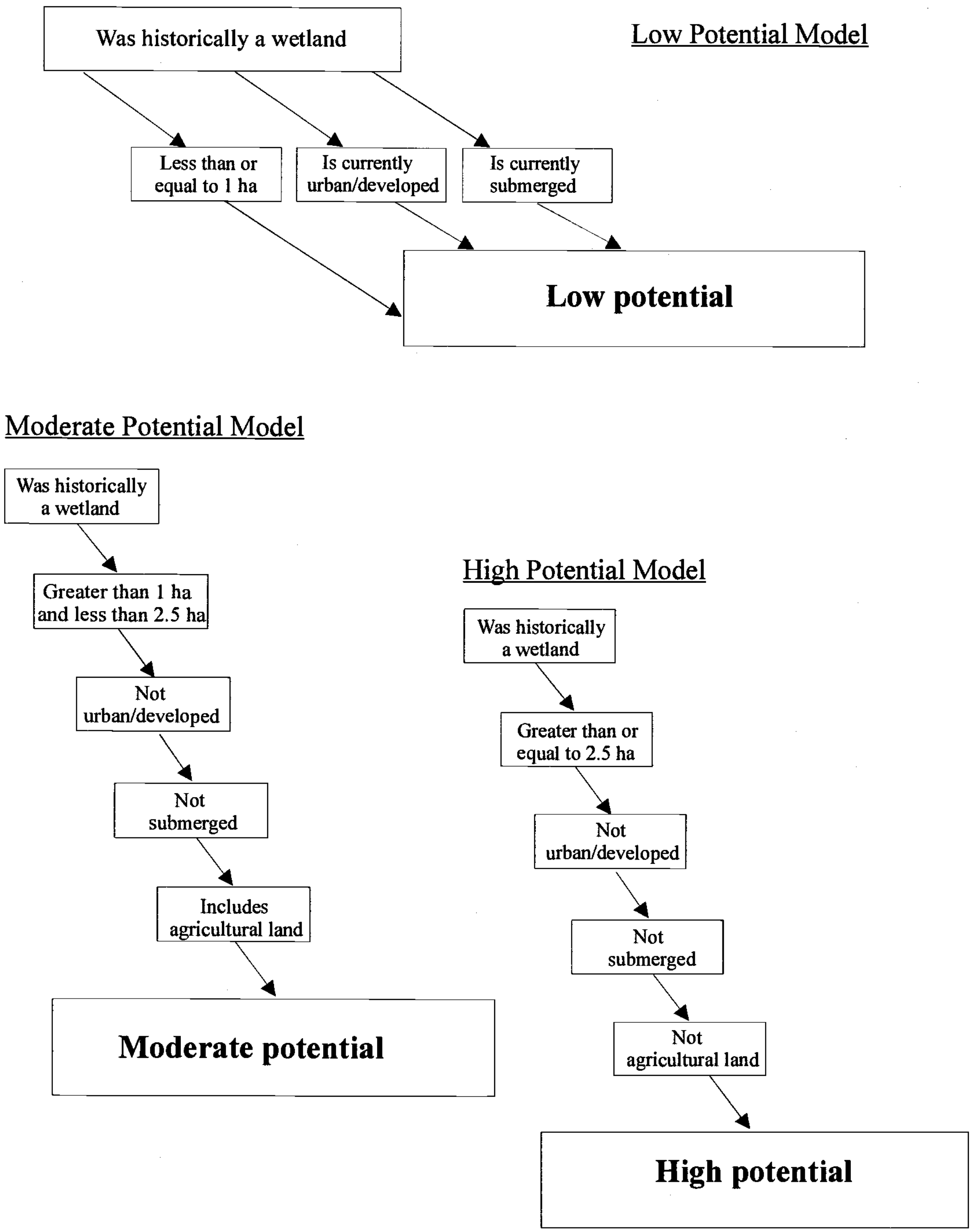
data could be compared. Historical wetlands which became another landcover or habitat were identified. It is necessary to know if some areas remained wetland in 1991 or changed to another classification value. Areas which remained as a wetland did not require analysis for restoration purposes (see Figure IV.8). Areas which originally were not wetlands, but became wetlands and then changed again to a non-wetland landcover by 1991, were represented as historic wetlands. In this manner the current classification of any historical wetland, as well as the specific type of historical wetland, could be identified.

A second coverage was created displaying the outline of the river. This coverage was not needed for analysis purposes, yet was useful as a location guide. Sliver and overlapping polygons were removed from the two new coverages.

ArcView was used to further the querying process. In order to improve the accuracy of the coverage and remove unwanted small polygons, all historical wetlands less than or equal to .5 hectares were removed. Using the field "historical wetlands less than or equal to .5 hectares" as an initial query, three ranked area models were developed for purposes of identifying potential wetland restoration sites (see Figure IV.9). Recall that the study site was regionalized into three sections: estuarine, riverine tidal, and riverine lower perennial. For each of these sections, historical wetlands were ranked based upon low, moderate, or high potential for restoration. Each model was queried separately. For example, in the estuarine section, there were 1149 historical wetlands. Each model was queried, where the initial query was the total number of 1149 historical wetlands. In this manner all historical wetlands have a low, moderate, or high value. No single historical wetland can have more than one value.

Low Potential - Historical wetlands which were identified as low potential were ranked as such because the variables which preclude restoration were formidable. The query criteria for historical wetlands with low potential for restoration were: "less than or equal to 1 hectare", "is currently urban/developed", or "is currently submerged". Historical wetlands less than or equal to 1 hectare in area

Figure IV.9: GIS Query Models for Developing Ranked Area Maps for Potential Wetland Restoration



should receive less attention with regard to restoration than larger areas. The cost in terms of time and labor may exceed the benefits. With an abundance of larger historical wetlands from which to choose, the focus of restoration was swayed to larger, potentially more productive sites. Additionally, the level of detail implicit to identifying small areas was not warranted or possible in this study. On average, the spatial resolution allowed by the aerial photography for identifying habitats was less than 1 hectare. The process of overlaying coverages created smaller polygons. Many of these insignificant polygons were created in error as a bi-product of commands used to shape the data. Commands, such as Build, Clean, and Identity, generated small, unwanted sliver polygons.

Areas which are identified as currently urban/developed have a low potential for restoration. There is little likelihood that a home, business, or road will be dismantled to restore a wetland. Such developed areas retain very little of their historical wetland character, and would require an extensive restoration efforts. It is unrealistic to consider restoring wetlands that are now developed, particularly when other more easily restorable historical wetlands are present.

Historical wetlands which were submerged, becoming deepwater habitats as of 1991, were considered low potential for restoration. These areas were assessed to be ecologically necessary, warranting no restoration intervention. According to Cowardin et al. (1979) deepwater habitats are ecologically related to wetlands. Values associated with wetlands were lost when they became submerged; yet, the interconnectedness of wetland and deepwater habitats remained strong. The highly dynamic nature of the LCR creates and deposes wetlands through accretion and submersion. While this process has been influenced by humans, it is also quite natural. To restore an historical wetland that has become submerged would be largely futile, as it is most likely to change again. Drastic intervention could almost certainly assure that the restored wetland remain a wetland. But the damages of structural engineering on downstream habitats would outweigh the potential benefits of the wetland. Because deep water habitats were considered ecologically necessary, highly transitional, and cost prohibitive to convert to a wetland, the restoration potential was ranked as low.

The three queries, "less than or equal to 1 hectare", "is currently a wetland", and "is currently submerged", were performed in the Tables window of ArcView. The query builder syntax for each query were: ([historicalwetlands] >= 1ha, ([historicalwetlands]) = ([currenturban]), and ([historicalwetlands]) = ([currentsubmerged]), respectively. The data indicated between the closed brackets represent a field within ArcView. Each of the above fields and the query results were mapped for analysis purposes. The "[currentsubmerged]" field was created by combining all possible deepwater habitats, such as estuarine subtidal, lacustrine limnetic, or riverine tidal. Based upon this methodology, maps indicating low potential for restoration were produced for each section of the river.

Moderate Potential - Unlike the low potential model for restoration, the moderate potential model relies on a series of hierarchical queries. In the low potential model, historical wetland habitats which were characterized as "is currently submerged", were marked as low potential for restoration without regard to the remaining queries in the model. In the moderate potential model, historical wetlands were labeled as moderate potential for restoration, based upon the condition that each query in sequence was true. As such, the number of historical wetlands with potential for restoration at the beginning of the query sequence is high. By progressing through the sequence, the number of historical wetlands was reduced. For example, there were 1149 historical wetland habitats in the estuarine section of the Columbia. Of these, only 169 habitats meet the cumulative conditions of the moderate restoration potential ranking.

The queries in the moderate potential model were increased and refined, allowing for fewer habitats to be considered for restoration, than did the low potential model. The data were queried for historical wetlands greater than 1 hectare and less than 2.5 hectares. This refined condition required that wetland habitats had to have more area to be considered for restoration than low potential wetland habitats. Larger areas are more amenable to restoration efforts. The initial costs for restoring an historical wetland are high. Often restoration may be accomplished by removing a dike or berm, and simply allowing nature to take its course. Generally, this cost will not greatly fluctuate for small or large restoration sites. Certainly, larger restoration sites would provide greater habitat value than smaller sites. Unfortunately, there are fewer large tracts of wetland; thus, the returned value, in terms of wetland functions, would be greater on larger restoration sites.

The low potential model identified historical wetlands which were urban/developed and submerged as of 1991. Unlike this model, the moderate potential model was queried to identify historical wetlands which were not urban/developed and were not submerged. Historical wetlands with these qualities were considered to have more potential for restoration.

The command syntax used to express the queries in the moderate potential model were similar to the commands discussed in the low potential model. The exception was the use of the "not equal to" (<>) operator applied to the queries "not urban/developed" and "not submerged". For example, the query commands, ([historicalwetlands] = [hectares] >1<2.5) and ([currenthabitats] <> "urban/devloped") and ([currenthabitats] <> "submerged") were run to specify all historical wetlands greater than 1 and less than 2.5 hectares, which were also not urban or submerged in 1991. Moderate potential maps were produced for each of the three river sections in the study site.

High Potential - The differences between the moderate potential model and the high potential model appear to be slight. The high potential model refined the area query to include larger historical wetlands, and incorporated an additional query regarding agricultural land. The two queries applied were "greater than or equal to

2.5 hectares" and "not agricultural land". While only two changes were made, the results of these queries were substantial. There were a significant number of larger historical wetlands in the study site. Within the riverine tidal section alone there were 753 historical wetland habitats greater than or equal to 2.5 hectares. The low, moderate, and high potential models systematically increased the size of acceptable historical wetlands from less than or equal to 1 hectare, to greater than 1 hectare and less than 2.5 hectares, to greater than or equal to 2.5 hectares, respectively. Three reasons were used to rationalize the amount each model would increase the size of admissible wetlands: larger wetlands are often better, the number of wetlands are systematically decreased from the low to high potential model, and the models conform to a system of natural breaks.

The single greatest cause of the loss of wetland habitats in the United States is their conversion to agricultural use (Mitsch and Gosselink 1993). Since 1890, more than 45 million hectares have been drained for agricultural purposes. Of this amount, at least 65% of the drained land was wetlands (Office of Technology Assessment 1984). Consistent with national wetland losses, the conversion of wetlands along the LCR to farmland has been the chief contributor to wetland habitat depletion. By querying to remove agricultural lands from the areas with potential for restoration, the study focuses on far fewer historical wetlands. In 1991, agricultural land composed 16.5% of the total land area in the study site. Given this large percentage, it was hypothesized that much of this riparian farmland was once wetland. The primary focus for building the high potential model was to gauge the impact of agriculture on habitats. Thereby, the data were queried to identify and unselect agricultural land from the declining number of potential historical wetland restoration sites. Maps displaying high potential for restoration efforts were made for each section of the river. Low, moderate, and high potential maps were combined to form a single definitive ranked area map for each river section.

Methods for Future Research

The following example with regard to refining the querying process demonstrates the possibilities of this research for future studies. It defines how a methodology could be developed to identify wetland habitats with potential for restoration for specific applications. The querying process was refined to address a specific purpose. The purpose was to create wetland corridors forming a continuum of linked habitats. The objectives for restoring one historical wetland over another may vary. Nevertheless, the methods for determining which wetlands are most suitable for restoration can be modeled.

The low, moderate, and high potential models were developed based upon a set of queries designed to systematically reduce the number of historical wetlands that have potential for restoration. Each model refined the number of historical wetlands. While the objective of the three models, to generally refine the number of historical wetlands, was accomplished, as many as 74 high restoration potential sites within the estuarine section, 178 sites within the riverine tidal section, and 105 sites within the riverine lower perennial section remained. This number of high restoration potential sites is relatively small, considering that the total number of historical wetlands for all sections was 7397. The high potential model provides a culled number of restoration sites spread evenly across the study site. Yet, for some applications, the high potential model may yield too many possible restoration sites. Considering that most restoration programs have a limited amount of resources, narrowing the scope of historical wetlands to a number which could be reasonably field checked for restoration potential may be desirable. The more specific the querying process becomes, the fewer the number of restoration sites.

An important variable for choosing which historical wetlands should be considered for restoration on the LCR was location. The location of an historical wetland in relation to a current wetland impacts the size and functionability of a potentially restored area. Historical wetlands adjacent to current wetlands were preferred.

In the Tables window of ArcView, a new coverage containing only current wetland habitats was created. Using the Query Builder function, the query command was written as: ([currentwetlands] = "4Ei" and "4Lt" and "4Rt" and "4Rl" and "4P" and "10". A second coverage of all historical wetlands greater than or equal to .5 hectares was added to the View. A map illustrating historical and current wetlands displayed together was made for each section of the river.

An adjacency analysis was performed. All current wetlands were selected as the active coverage. Historical wetlands within a selection distance of "0" (adjacent to) from the active coverage were identified as a New Set. The New Set was converted into a coverage. A map of all historical wetlands adjacent to current wetlands was developed for each section of the river. Important for analysis purposes, the individuality or value of each adjacent historical wetland remained intact. Any polygon could be identified according to its value, i.e., palustrine or forested wetland. Building upon the high potential model for restoration, the adjacency analysis was refined. The 1991 wetland coverage was queried to select only those wetlands which were greater than or equal to 2.5 hectares. A new set containing all historical wetlands that are adjacent to current wetlands greater than or equal to 2.5 hectares was derived. This process eliminated all small current wetlands and the adjacent historical wetlands. By coupling the results of the new set with the high potential model, five queries were combined to limit the number of historical wetlands. This coverage was called "historical wetlands with the highest potential for restoration". The five queries used to refine the adjacency analysis were: 1) select historical wetlands greater than or equal to 2.5 hectares; 2) of these, select historical wetlands which did not become urban; 3) of these, select historical wetlands which did not become submerged; 4) of these, select historical wetlands which did not become agricultural land; and, 5) of these, select historical wetlands which are adjacent to current wetlands greater than or equal to 2.5 hectares. A map illustrating historical wetlands with highest potential for restoration was made for each section of the river.

The methods used in the adjacency analysis demonstrate how the LCR GIS database could be queried according to a specific purpose for future research. Depending upon the purpose (e.g., establishing a corridor, restoring specific wetland types, creating a mitigation bank, or reestablishing salmon rearing habitat), the possibilities for refining the number of historical wetlands with potential for restoration are extensive. With each query, the number of historical wetlands are reduced. The final query should result in a manageable number of historical wetlands with high potential for restoration.

CHAPTER V. RESULTS OF ANALYSIS ON QUANTIFYING TOTAL HABITAT CHANGE

Preface

The purpose of this chapter is to describe the extent and location of habitat change along the LCR riparian zone. The chapter following will build upon these results and determine the trends and causes of habitat change as they apply to wetlands. Habitat maps are used to identify the location of change. Habitat summary tables are the means by which total wetland habitat change is measured. The LCR riparian zone is discussed in this chapter by section. The sections are: estuarine, riverine tidal, and riverine lower perennial. A discussion of habitat change which focused upon the entire study site would be too general. By sectionalizing the LCR, specific changes are associated with specific geographic areas. For example, the study site as a whole might indicate a decrease in a particular wetland type over time. However, a regional approach would indicate that, while the wetland type in question generally decreased, it increased within a specific region.

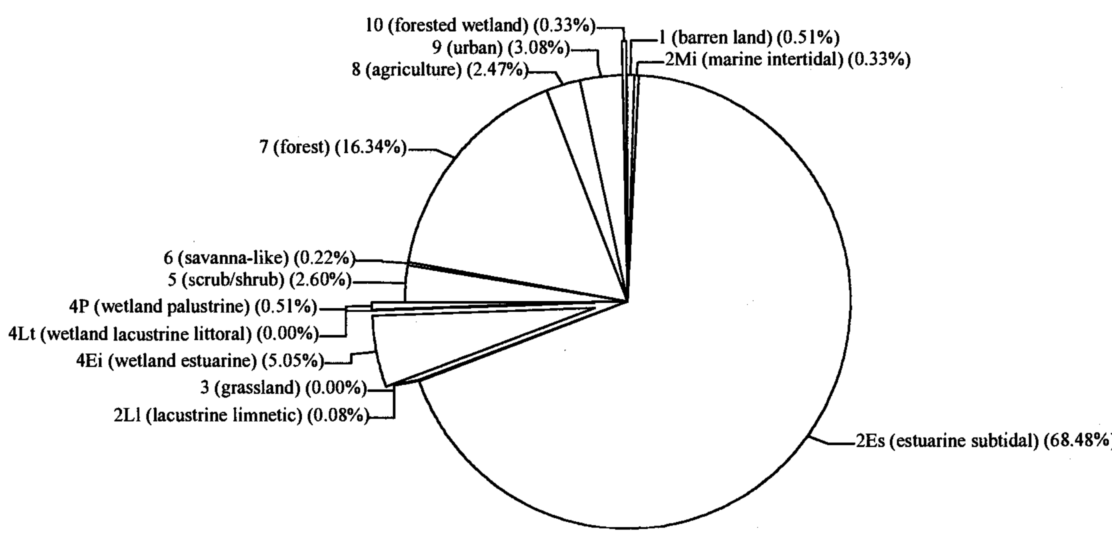
Section One: Estuarine

Table V.1 and Figure V.1 provide summary information on habitat and landcover areas for the 1948 estuarine section. Figure V.2 is a map of the locations of the 1948 habitats and landcover. The largest habitat in this section was estuarine

Table V.1: Summary Data for the LCR, Estuarine Section, 1948

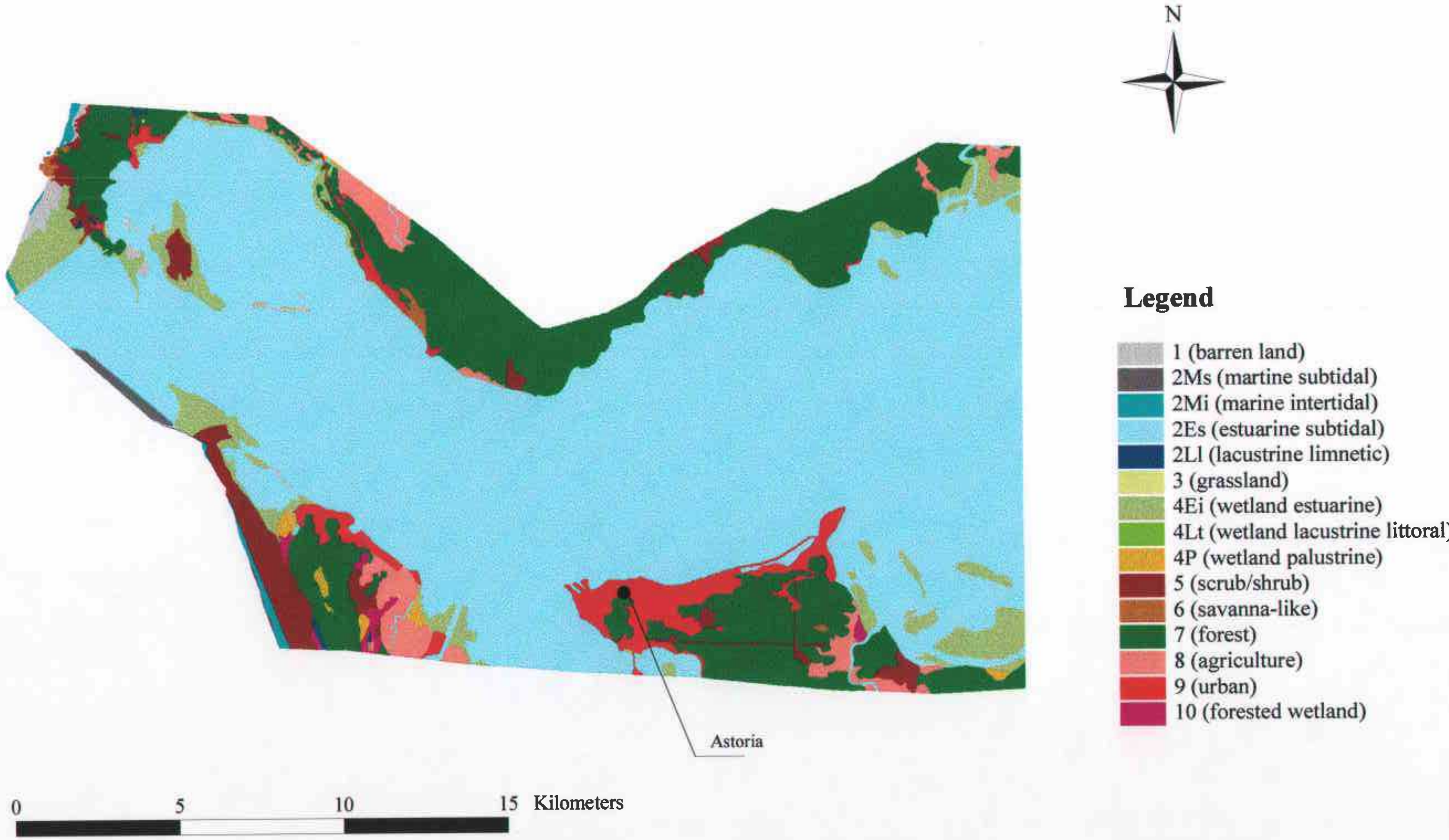
HABITAT/LANDCOVER	SUM HECTARES	MEAN HECTARES	FREQUENCY
1 (barren land)	196.8	15.1	13
2Mi (marine intertidal)	127.1	18.2	7
2Es (estuarine subtidal)	26534.1	3316.8	8
2Ll (lacustrine limnetic)	32.7	5.4	6
3 (grassland)	1.1	1.1	1
4Ei (wetland estuarine)	1958.3	46.6	42
4Lt (wetland lacustrine littoral)	1.7	1.7	1
4P (wetland palustrine)	198.0	24.8	8
5 (scrub/shrub)	1007.0	56.8	19
6 (savanna-like)	83.8	27.9	3
7 (forest)	6329.5	226.1	28
8 (agriculture)	955.7	41.6	23
9 (urban)	1195.2	66.4	18
10 (forested wetland)	126.0	25.3	5

Figure V.1: Area Summaries for the LCR Estuarine Section, 1948



Note: All wetland classifications are exploded from the chart.

Figure V.2: Habitats and Landcover of the LCR, Estuarine Section, 1948



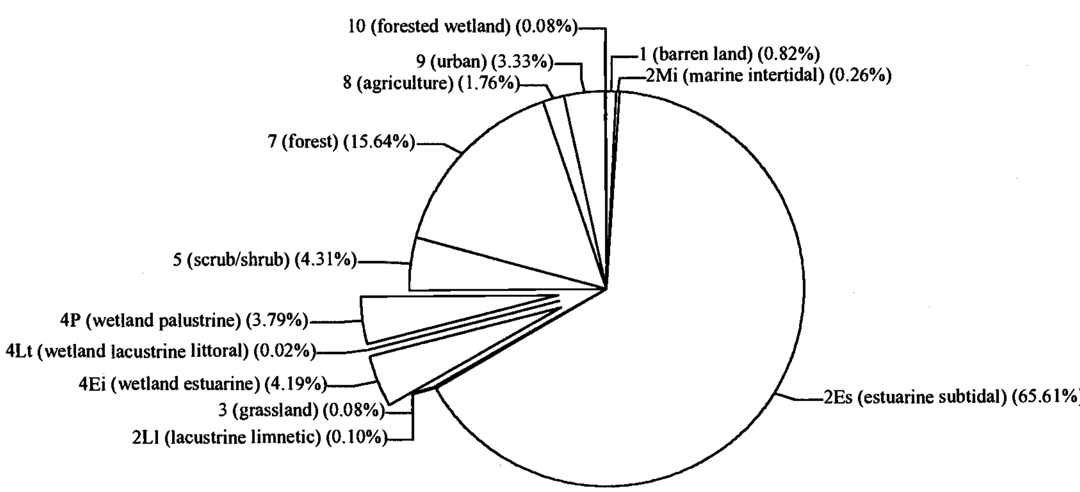
subtidal, consisting of 68.5% of the total area. Forested land incorporated 6329.5 hectares or 16.3% of the total area. Most of the wetlands found in the site were wetland estuarine, comprising 5.1% of the total area. The remaining wetlands contained less than 1% of the area. In 1948, all wetlands combined consisted of 2284 hectares. The greatest concentration of wetlands was found on islands and along the mouth of rivers dumping into the estuary. Agricultural land largely competed for wetland habitats along or near the mouth of river valleys. Surprisingly, agriculture and urban landcover made up very little of the total area, totaling 5.6%. The greatest concentration of urban development was in and around Astoria and along the estuary's shoreline.

By comparing the 1948 and 1961 estuarine sections, several significant changes are revealed. In 1948, there were 1958.3 hectares of the habitat wetland estuarine; but, in 1961 there were 1624.3 hectares (see Table V.2). Estuarine wetlands decreased by 17%. Most of this change occurred within the islands in the southwestern portion of the section. Estuarine wetlands on the islands changed to palustrine wetlands. By 1961, palustrine wetlands increased by 86.5% over 1948. Agricultural land decreased from 2.5% of the total habitat and landcover area in 1948 to 1.8% in 1961, while urbanization accounted for a small gain in urban area (see Figure V.3). Forested habitat decreased slightly, with most of the change taking place near Astoria (see Figure V.4). There is evidence of the dynamic nature of the silt

Table V.2: Summary Data for the LCR, Estuarine Section, 1961

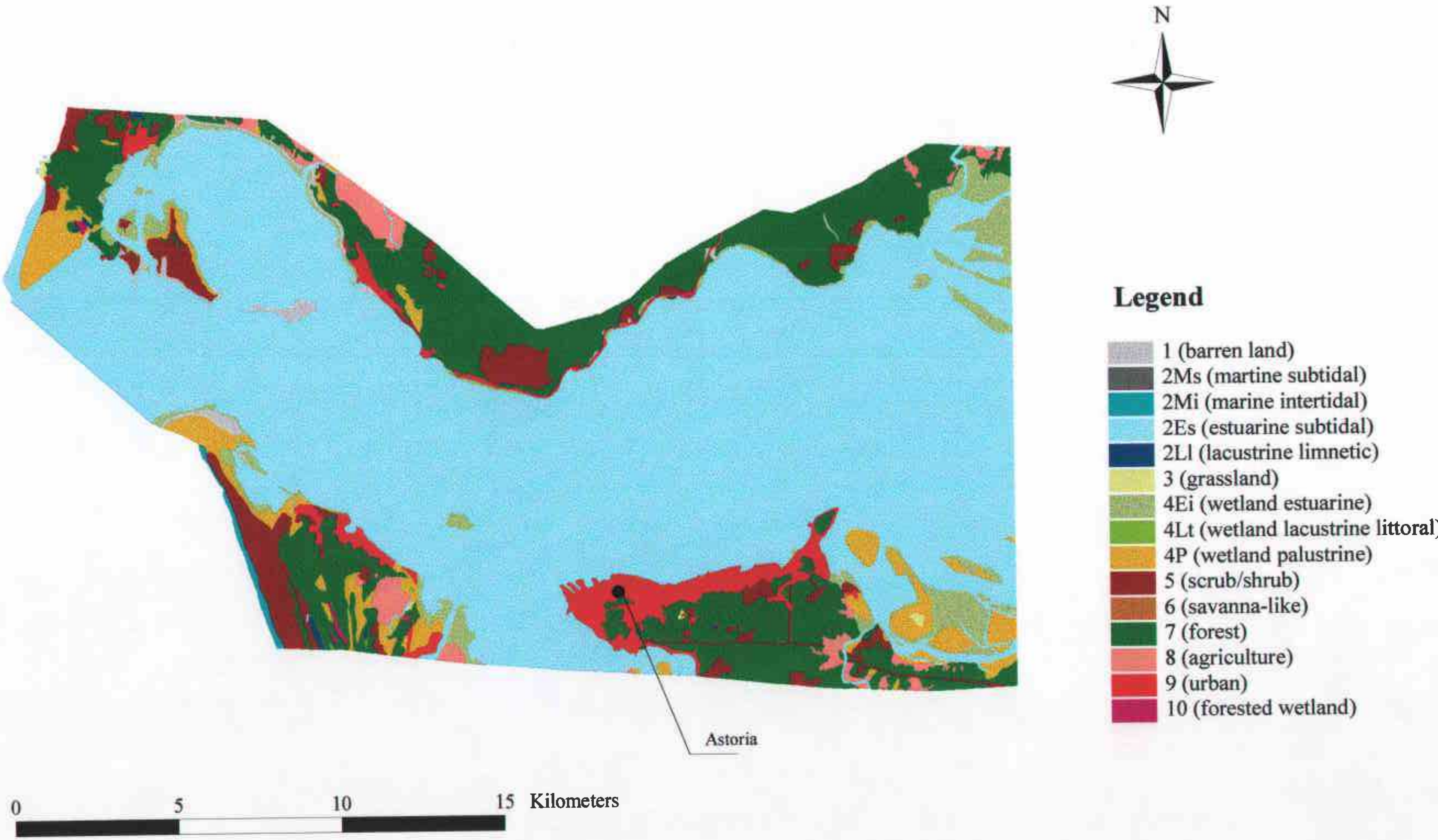
HABITAT/LANDCOVER	SUM HECTARES	MEAN HECTARES	FREQUENCY
1 (barren land)	318.1	12.2	26
2Mi (marine intertidal)	99.5	99.5	1
2Es (estuarine subtidal)	25422.6	1694.8	15
2Ll (lacustrine limnetic)	38.4	5.5	7
3 (grassland)	32.0	6.4	5
4Ei (wetland estuarine)	1624.3	31.8	51
4Lt (wetland lacustrine littoral)	6.0	1.2	5
4P (wetland palustrine)	1470.2	40.8	36
5 (scrub/shrub)	1671.6	37.2	45
7 (forest)	6060.0	126.2	48
8 (agriculture)	681.6	21.3	32
9 (urban)	1289.9	61.4	21
10 (forested wetland)	32.1	8.0	4

Figure V.3: Area Summaries for the LCR Estuarine Section, 1961



Note: All wetland classifications are exploded from the chart.

Figure V. 4: Habitats and Landcover of the LCR, Estuarine Section, 1961



laden LCR. Figure V.4 indicates that several new islands were created, while other islands were reworked with accumulating sand.

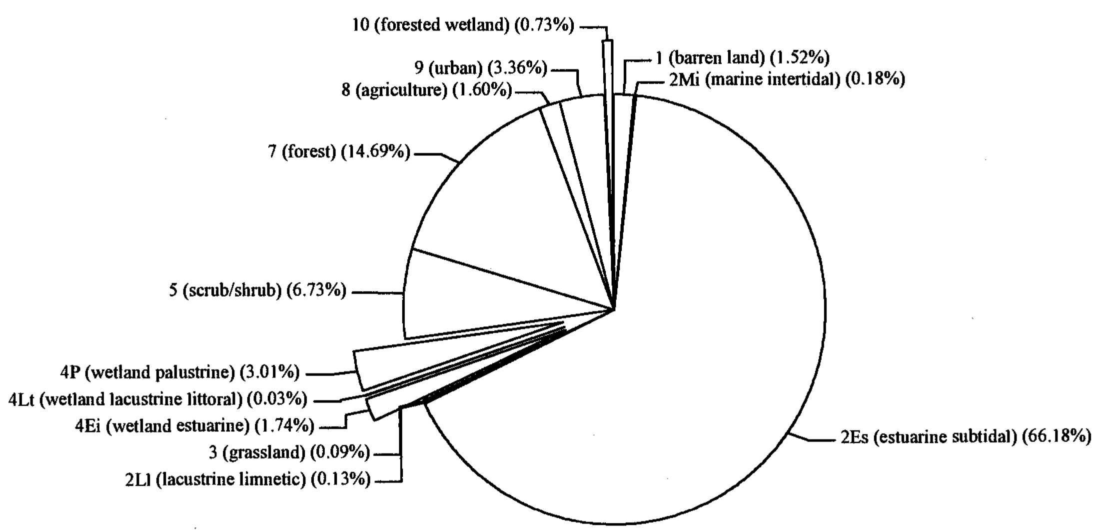
From 1961 to 1973, the estuarine section of the LCR experienced minimal change (see Table V.3). Most of the changes in 1973 occurred in the wetlands category. Estuarine wetlands decreased from 1624.3 hectares and 4.2% of the total area in 1961 to 673.7 hectares and 1.7% of the total area in 1973 (see Figure V.5). Palustrine wetlands changed from 1470.2 hectares in 1961 to 1167.4 hectares in 1973. Figure V.6 indicates that the changes to palustrine wetlands occurred scattered across the section rather than in a concentrated area. Forested wetlands grew by 88.6% in 1973 over the 1961 total. By visually comparing the 1961 and 1973 habitat area maps, it is apparent that many palustrine wetlands became forested wetlands. Several small sand spits were created or exposed in 1973, thereby increasing the amount of barren land by 46%. Agriculture slightly decreased by 1973, and urban areas grew only faintly.

In 1983, wetland habitats continued to change. Estuarine wetlands increased from 673.7 hectares in 1973 to 827.1 hectares in 1983 (see Table V.4). Palustrine wetlands decreased from 3% of the total area in 1973 to 2% of the total area in 1983 (see Figure V.7). Forested wetlands continued a steady growth by nearly doubling in size over 1973. Figure V.8 indicates that most of the increases in forested wetlands occurred when smaller 1973 forested wetland sites grew outward, rather than through the creation of new sites. Forest habitats grew by 15.5% in 1983, indicating that

Table V.3: Summary Data for the LCR, Estuarine Section, 1973

HABITAT/LANDCOVER	SUM HECTARES	MEAN HECTARES	FREQUENCY
1 (barren land)	589.3	13.1	45
2Mi (marine intertidal)	69.8	10.0	7
2Es (estuarine subtidal)	25645.2	2564.5	10
2Ll (lacustrine limnetic)	52.3	6.5	8
3 (grassland)	34.0	11.3	3
4Ei (wetland estuarine)	673.7	12.5	54
4Lt (wetland lacustrine littoral)	10.7	2.7	4
4P (wetland palustrine)	1167.4	22.0	53
5 (scrub/shrub)	2608.2	70.5	37
7 (forest)	5693.4	69.4	82
8 (agriculture)	621.2	23.9	26
9 (urban)	1303.4	38.3	34
10 (forested wetland)	281.0	31.2	9

Figure V.5: Area Summaries for the LCR Estuarine Section, 1973



Note: All wetland classifications are exploded from the chart.

Figure V.6: Habitats and Landcover of the LCR, Estuarine Section, 1973

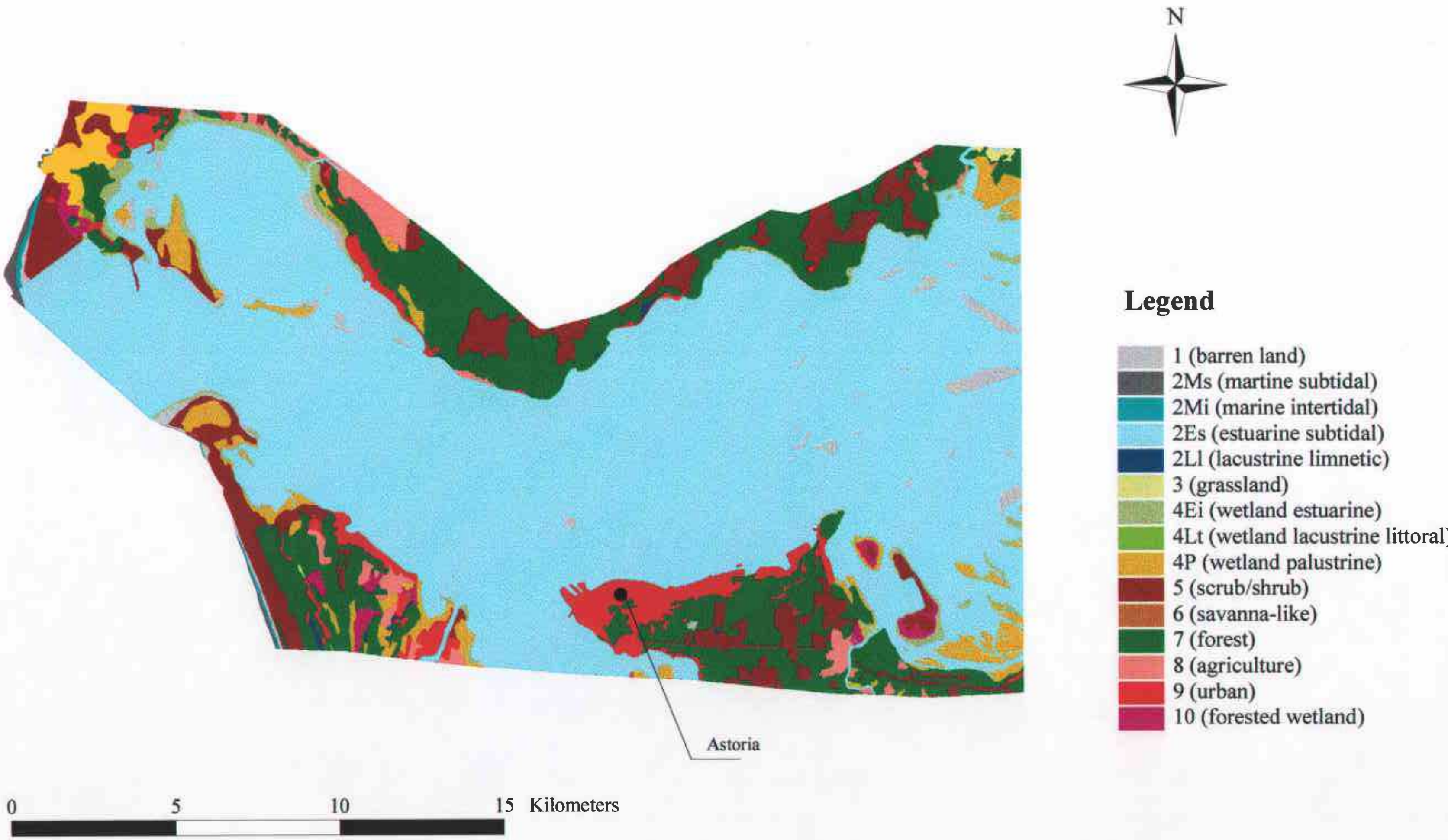
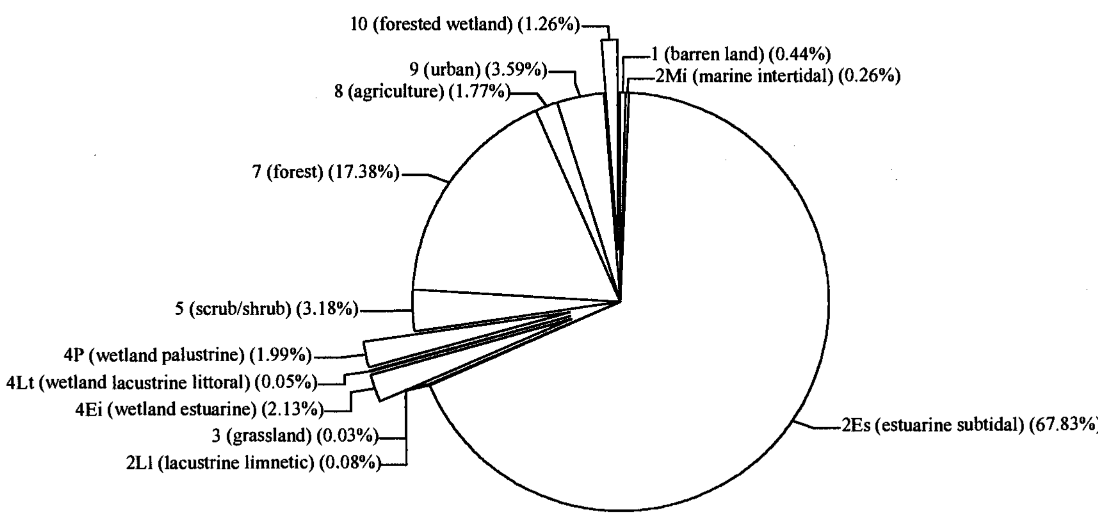


Table V.4: Summary Data for the LCR, Estuarine Section, 1983

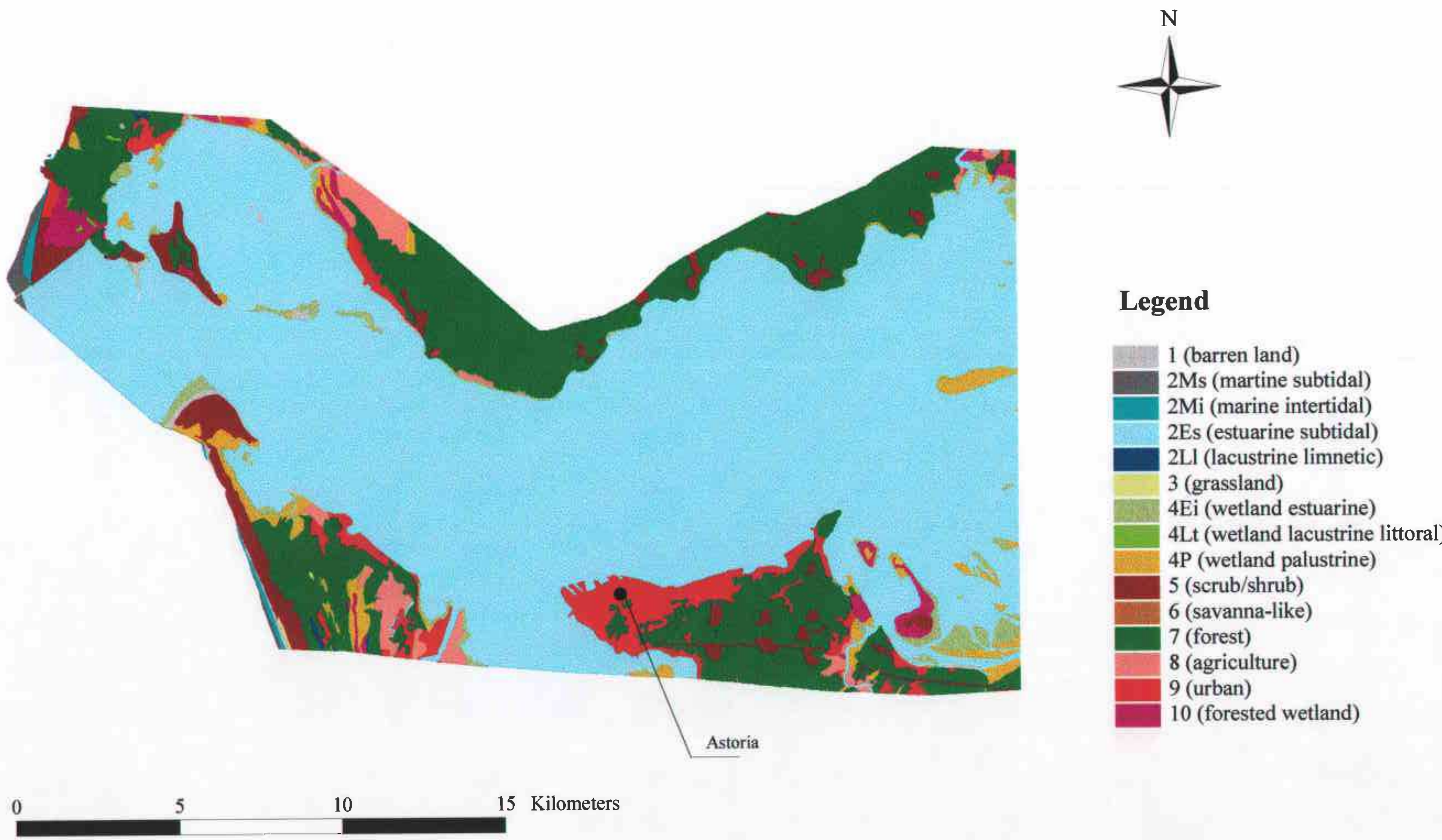
HABITAT/LANDCOVER	SUM HECTARES	MEAN HECTARES	FREQUENCY
1 (barren land)	170.5	6.6	26
2Mi (marine intertidal)	99.5	10.0	10
2Es (estuarine subtidal)	26284.3	5256.9	5
2Ll (lacustrine limnetic)	31.3	3.9	8
3 (grassland)	11.9	6.0	2
4Ei (wetland estuarine)	827.1	14.3	58
4Lt (wetland lacustrine littoral)	17.4	2.2	8
4P (wetland palustrine)	769.7	17.5	44
5 (scrub/shrub)	1233.6	38.6	32
7 (forest)	6735.5	240.6	28
8 (agriculture)	686.0	25.4	27
9 (urban)	1392.5	39.8	35
10 (forested wetland)	488.6	25.7	19

Figure V.7: Area Summaries for the LCR Estuarine Section, 1983



Note: All wetland classifications are exploded from the chart.

Figure V.8: Habitats and Landcover of the LCR, Estuarine Section, 1983



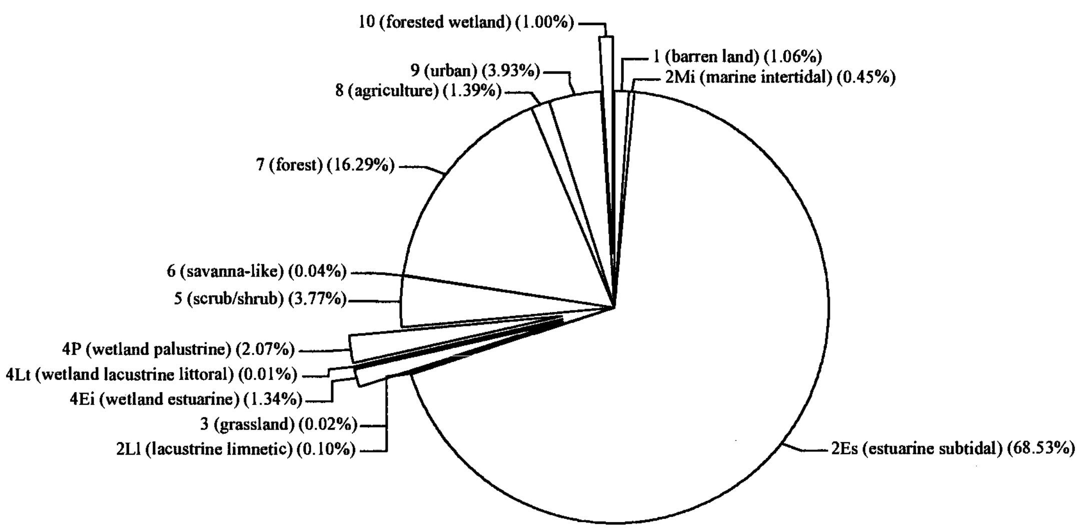
timber harvesting had slowed in the section. Scrub/shrub habitats were fewer in 1983 than in 1973. Generally, an increase in scrub/shrub habitats connotes an increase in forest cutting practices, as scrub/shrub areas are usually cut areas. Scrub/shrub habitats are illustrated on the habitat maps as islands within the forest. The amount of agricultural land remained nearly the same. Urban development continued its slow steady upward growth. Most of the growth occurred along the estuary's shoreline from existing urban areas.

Estuarine wetlands in 1991 sustained heavy losses over 1983. In 1983 estuarine wetlands made up 827.1 hectares; but, in 1991, they consisted of 518 hectares (see Table V.5). From 1983 to 1991, estuarine wetlands decreased by 37.4%, and from 1948 to 1991, they decreased by 73.6%. After 1983, palustrine wetlands increased slightly. After a consistent gain until 1983, forested wetlands experienced a significant drop by 1991. Forested wetlands composed 1.3% of the total habitat and landcover area in 1983; and, in 1991 they consisted of 1% (see Figure V.9). Over all, from 1948 to 1991, forested wetlands increased by 67.6% in the estuarine section. All wetlands combined suffered a total decrease of 22.9% from 1948 to 1991. This amount is somewhat misleading, since it only compares 1948 to 1991 wetlands, without regard to increases or decreases in wetlands which may have occurred between these years. Forest habitats declined from 1983 to 1991 by 424.6 hectares. Scrub/shrub habitats reflected the decrease in forest with an increase of 228.7 hectares. Agriculture continued its small but consistent decline in area. From

Table V.5: Summary Data for the LCR, Estuarine Section, 1991

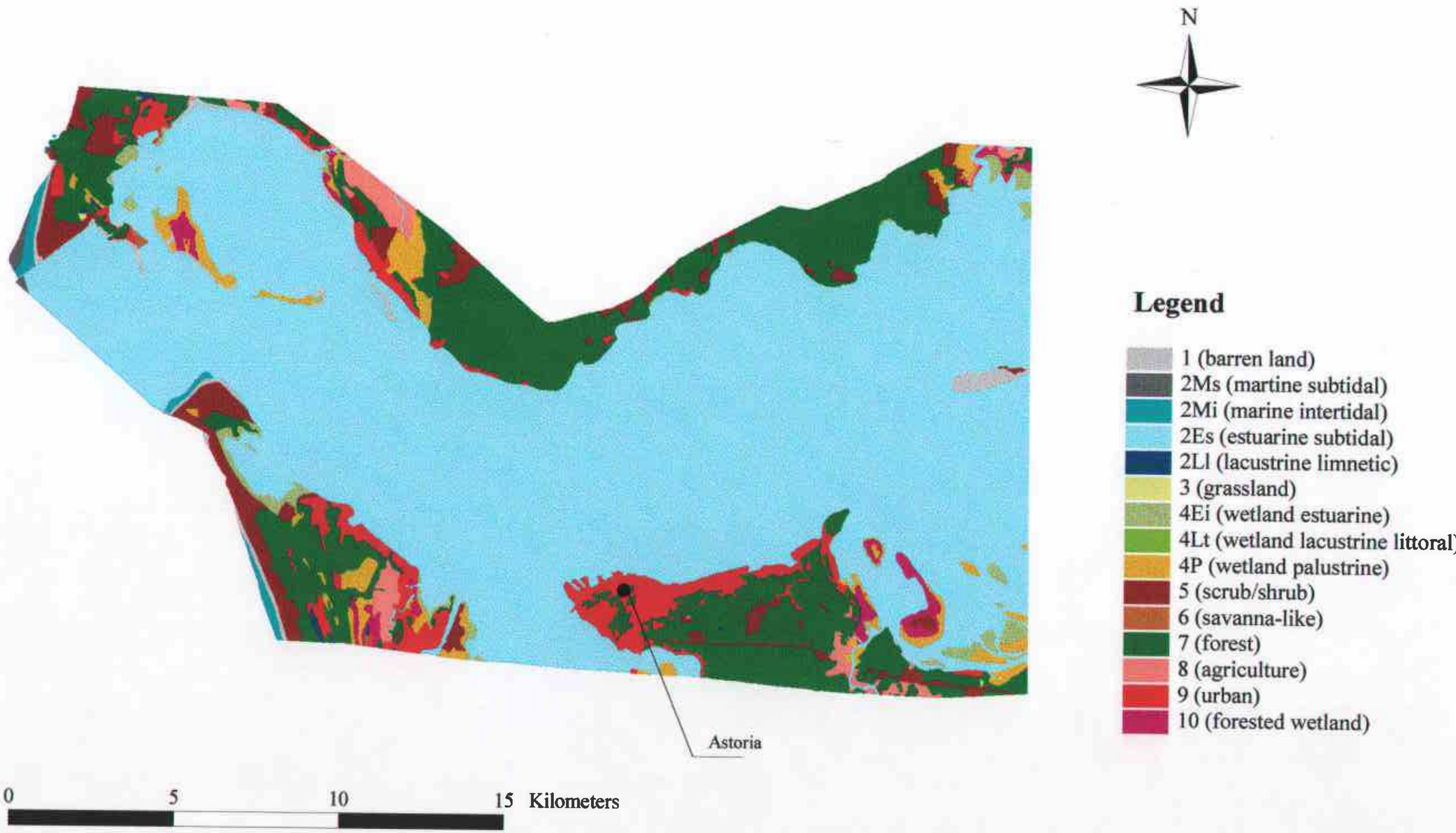
HABITAT/LANDCOVER	SUM HECTARES	MEAN HECTARES	FREQUENCY
1 (barren land)	412.5	17.2	24
2Mi (marine intertidal)	174.0	17.4	10
2Es (estuarine subtidal)	26553.7	5310.7	5
2Ll (lacustrine limnetic)	38.7	3.0	13
3 (grassland)	6.9	3.4	2
4Ei (wetland estuarine)	518.0	16.1	32
4Lt (wetland lacustrine littoral)	2.0	2.0	1
4P (wetland palustrine)	801.4	18.2	44
5 (scrub/shrub)	1462.3	34.0	43
6 (savanna-like)	13.9	13.9	1
7 (forest)	6310.9	180.3	35
8 (agriculture)	538.4	24.5	22
9 (urban)	1523.6	33.9	45
10 (forested wetland)	389.2	25.9	15

Figure V.9: Area Summaries for the LCR Estuarine Section, 1991



Note: All wetland classifications are exploded from the chart.

Figure V.10: Habitats and Landcover of the LCR, Estuarine Section, 1991



1983 to 1991, agriculture decreased by 21.5% and from 1948, decreased by 43.7%. Most of the total change in agriculture occurred along the western banks of Youngs Bay near the town of Warrenton (see Figure V.10). Large portions of the farmland in this area was converted to urban. Urbanization continued, reaching 1523.6 hectares in 1991. Urban landcover in 1991 grew by 131.1 hectares from 1983 and by 328.4 hectares from 1948. Most of the total gain in urban area developed around Astoria, Warrenton, and Ilwaco. The greatest concentration of growth occurred from Fort Stevens to Port of Astoria Airport along the coastline of Youngs Bay. Comparatively, little urban growth took place on the Washington side of the river. The majority of growth in Washington took place from Ilwaco to Knappton along Highway 101.

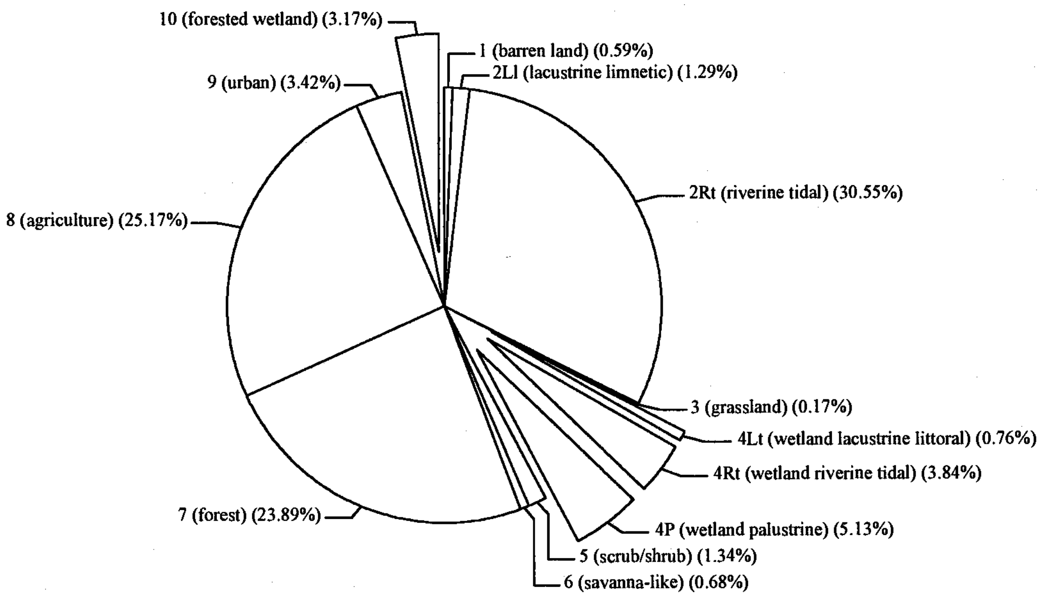
Section Two: Riverine Tidal

With increasing distance upstream, the river narrows in this section and the amount of deep water habitat decreases over that of the estuarine section. In 1948, riverine tidal was the largest habitat, consisting of 23835.8 hectares and 30.6% of the total habitat and landcover area (see Table V.6). Unlike the estuarine section, the riverine tidal habitat was closely followed in size by agriculture, with 19636.7 hectares and 25.2% of the total area (see Figure V.11). Because of the amount of agricultural landcover in the riverine tidal section, it is likely to have a greater impact on other habitats as it changes over time. Forested land was the third largest habitat consisting of 23.9% of the total area. Riverine tidal, agriculture, and forest

Table V.6: Summary Data for the LCR, Riverine Tidal Section, 1948

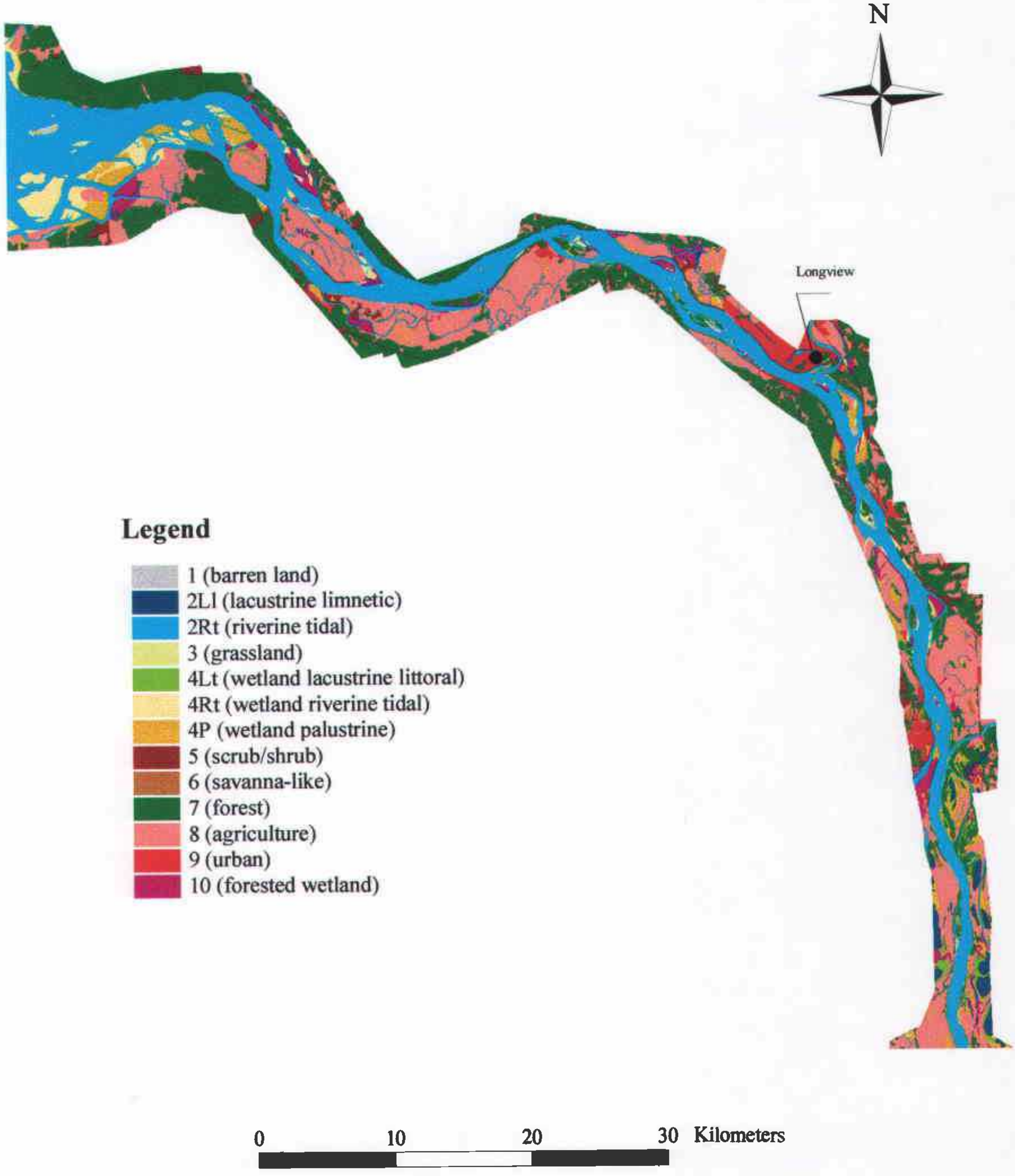
HABITAT/LANDCOVER	SUM HECTARES	MEAN HECTARES	FREQUENCY
1 (barren land)	462.9	4.2	111
2Ll (lacustrine limnetic)	1006.7	22.9	44
2Rt (riverine tidal)	23835.8	450.0	53
3 (grassland)	133.0	6.6	20
4Lt (wetland lacustrine littoral)	595.6	18.6	32
4Rt (wetland riverine tidal)	2992.7	24.1	124
4P (wetland palustrine)	4002.4	25.2	159
5 (scrub/shrub)	1042.8	14.9	70
6 (savanna-like)	531.0	12.1	44
7 (forest)	18640.3	61.1	305
8 (agriculture)	19636.7	80.1	245
9 (urban)	2664.7	54.4	49
10 (forested wetland)	2476.0	20.5	121

Figure V.11: Area Summaries for the LCR Riverine Tidal Section, 1948



Note: All wetland classifications are exploded from the chart.

Figure V.12: Habitats and Landcover of the LCR Riverine Tidal Section, 1948



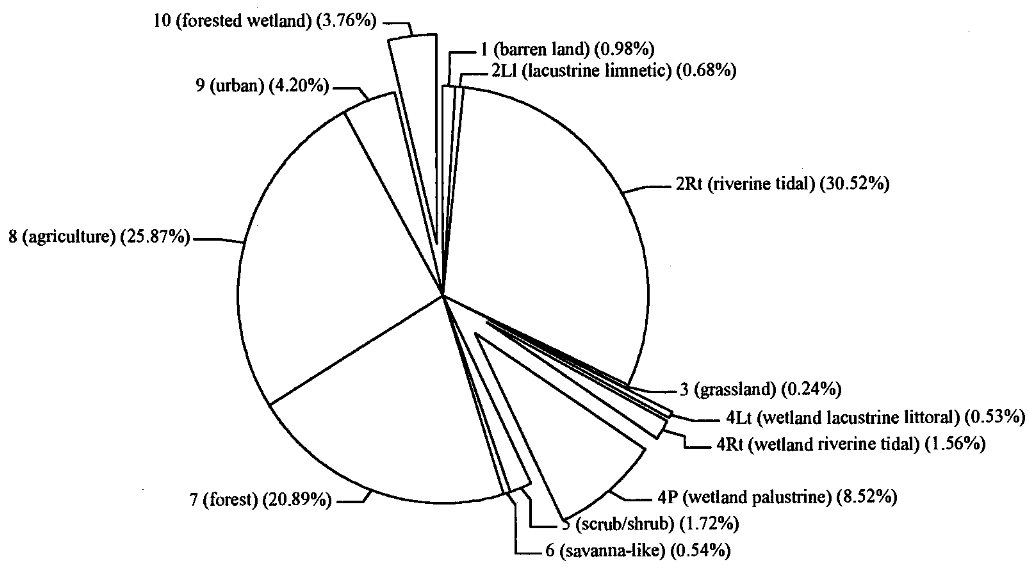
landcovers composed 79.6% of the total area in 1948. Figure V.12 reveals that agriculture in 1948 was situated to take advantage of the river's rich alluvium deposits. Agricultural land was largely located along the river's edge, on meander loops and on broad islands. The greatest concentration of forested land in 1948 was found on the Washington side of the river's northwest region. Palustrine wetlands were the fourth largest habitat in the section, closely followed by wetland riverine tidal, urban, and forested wetlands respectively. Wetlands combined to form 12.9% of the total area. In 1948, urban landcover consisted of 2664.7 hectares. Barren land and grassland constituted very little of the total habitat and landcover in the section.

From 1948 to 1961, wetland habitats sustained significant changes. Wetland habitats increased by 1141.4 hectares or 10.2% (see Table V.7). Most of the increase occurred within the wetland palustrine habitat. By 1961, palustrine wetlands grew by 2644.6 hectares, and forested wetlands increased by 460.2 hectares. However, both riverine tidal wetlands and lacustrine littoral wetlands decreased in size. Riverine tidal wetlands decreased by 59.4% and lacustrine littoral wetlands were diminished by 31.2%. The changes to lacustrine littoral wetlands reflected the nearly 50% decrease in area of lacustrine limnetic habitats. As lakes were reduced in number and size, naturally, the total area of littoral wetlands decreased. Forest habitats declined by 3% of the total area (see Figure V.13). Agriculture changed very slightly from 1948 to 1961. A comparison of 1948 and 1961 habitat maps illustrates a noticeable increase

Table V.7: Summary Data for the LCR, Riverine Tidal Section, 1961

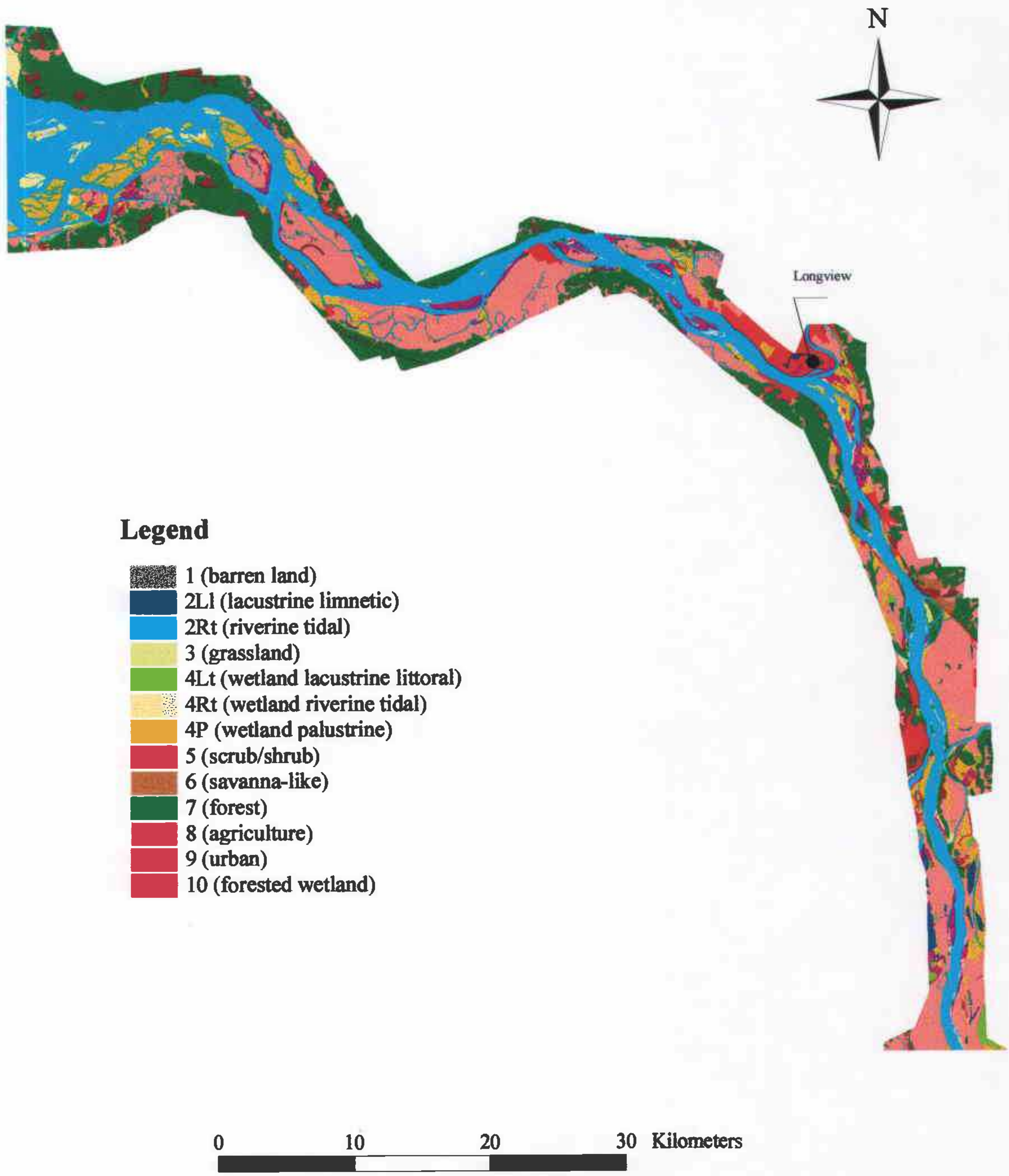
HABITAT/LANDCOVER	SUM HECTARES	MEAN HECTARES	FREQUENCY
1 (barren land)	765.8	8.2	93
2Ll (lacustrine limnetic)	530.7	18.3	29
2Rt (riverine tidal)	23809.0	566.9	42
3 (grassland)	183.8	9.7	19
4Lt (wetland lacustrine littoral)	409.8	13.7	30
4Rt (wetland riverine tidal)	1215.1	10.8	112
4P (wetland palustrine)	6647.0	36.9	180
5 (scrub/shrub)	1339.3	23.5	57
6 (savanna-like)	422.3	35.2	12
7 (forest)	16295.1	106.5	153
8 (agriculture)	20185.3	112.1	180
9 (urban)	3279.5	117.1	28
10 (forested wetland)	2936.2	21.9	134

Figure V.13: Area Summaries for the LCR Riverine Tidal Section, 1961



Note: All wetland classifications are exploded from the chart.

Figure V.14: Habitats and Landcover of the LCR Riverine Tidal Section, 1961



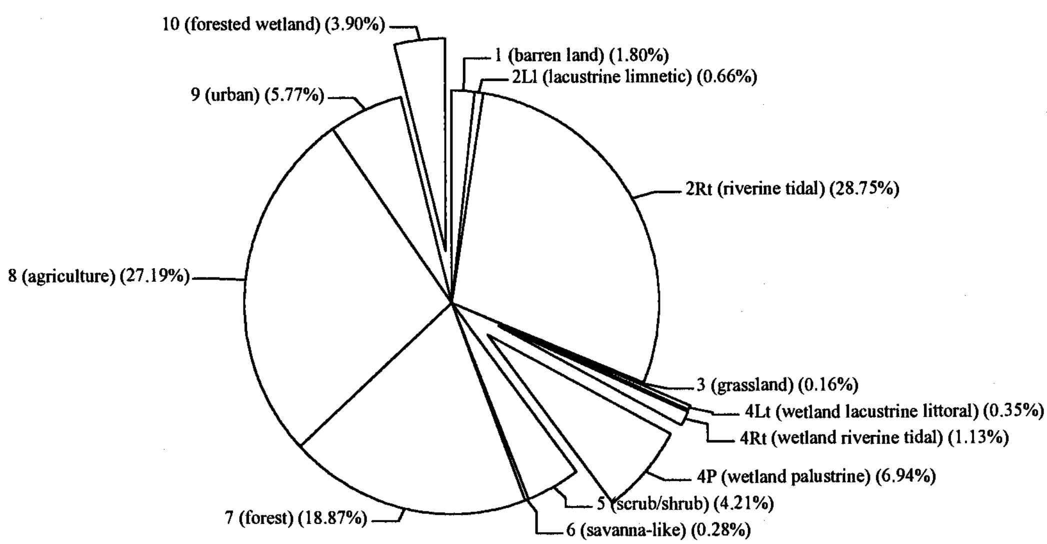
in urban landcover, especially on Sauvie Island (see Figures V.12 and V.14). Urban landcover increased by 614.8 hectares.

In total area, wetland habitats decreased from 1961 to 1973, with the exception of a small increase in forested wetlands (see Table V.8). Forested wetlands increased by .1% of the total landcover and habitat area (see Figure V.15). After 1961, riverine tidal wetlands declined by 329.8 hectares. Most of this change can be visually interpreted from the 1961 and 1973 habitat map (see Figures V.14 and V.16). On the islands within the present day Lewis and Clark National Wildlife Refuge, areas adjacent to the tidal waters of the river experienced a change largely to palustrine wetlands from 1961 to 1973. Regardless, palustrine wetlands over the entire section for 1973 decreased. Palustrine wetlands lost 1236 hectares. Lacustrine littoral wetlands continued their steady decline. This habitat lost 33.8% after 1961. Barren land increased by nearly half, most of which occurred by the reworking of sand spits. The apparent stability of agriculture in this section of the river was exhibited by an increase in landcover by 1024.7 hectares in 1973. Forest habitat dwindled by 1572.9 hectares, while scrub/shrub mirrored this change, as it expanded by 1944 hectares. Scrub/shrub habitats are largely timber clear-cuts. Urbanization lays claim to one of the most significant landcover increases in the section. In 1961, urban landcover measured 3279.5 hectares, and, in 1973, urban areas measured 4501.2 hectares, for a growth of 1221.7 hectares.

Table V.8: Summary Data for the LCR, Riverine Tidal Section, 1973

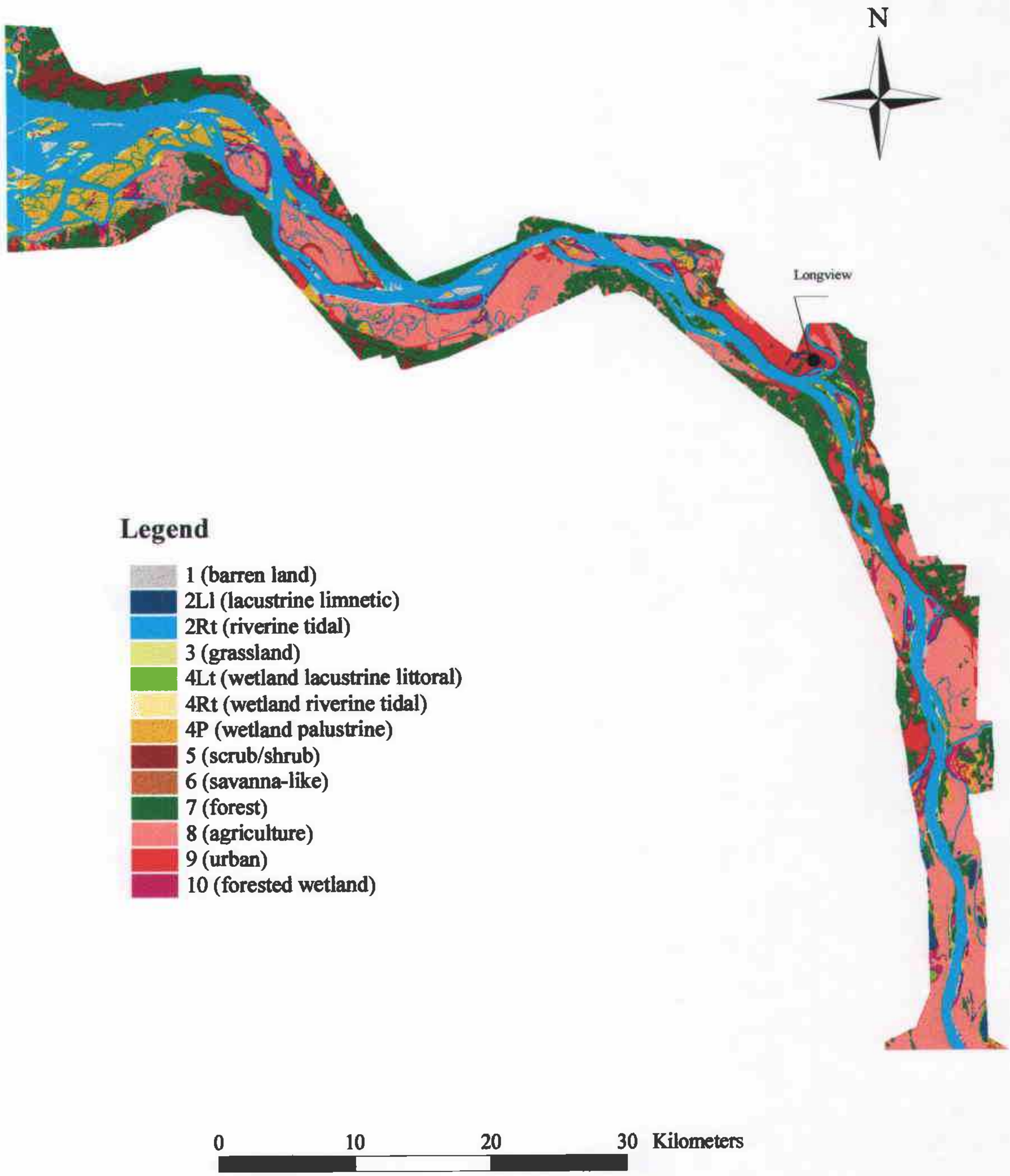
HABITAT/LANDCOVER	SUM HECTARES	MEAN HECTARES	FREQUENCY
1 (barren land)	1401.9	12.2	115
2Ll (lacustrine limnetic)	517.5	15.2	34
2Rt (riverine tidal)	22426.8	457.7	49
3 (grassland)	124.2	10.3	12
4Lt (wetland lacustrine littoral)	271.2	7.1	38
4Rt (wetland riverine tidal)	885.3	7.4	120
4P (wetland palustrine)	5411.0	24.0	225
5 (scrub/shrub)	3283.3	36.1	91
6 (savanna-like)	220.3	12.2	18
7 (forest)	14722.2	47.2	312
8 (agriculture)	21210.0	103.0	206
9 (urban)	4501.2	57.7	78
10 (forested wetland)	3043.8	17.6	173

Figure V.15: Area Summaries for the LCR Riverine Tidal Section, 1973



Note: All wetland classifications are exploded from the chart.

Figure V.16: Habitats and Landcover of the LCR Riverine Tidal Section, 1973



From 1973 to 1983, wetland habitats generally underwent an increase. As habitat summary data for both the estuarine and riverine tidal sections indicate, forested wetlands continued their consistent gain in area. Forested wetlands increased by 33.6% or 1540.7 hectares from 1973 to 1983 (see Table V.9). Palustrine wetlands gained nearly a 1% change for the total landcover and habitat area, and lacustrine littoral wetlands, likewise, grew by a small amount (see Figure V.17). Many of the palustrine wetlands and forested wetlands are adjacent to one another (see Figure V.18). Changes in one wetland type often reflected a change in another. The only wetland type to decrease was riverine tidal wetlands. By 1983, this habitat lost 220.6 hectares. While grassland makes up very little of the LCR, between the years 1973 and 1983, grasslands endured considerable change. Grasslands decreased by 96.9% by 1983. Forest habitats declined slightly, as did agriculture. Agriculture lost only 5.1% of its landcover. Urban landcover continued to increase, however, at a slower pace between the years of 1973 and 1983. Urban landcover grew by only 7.2%.

A comparison of 1983 to 1991 wetlands reveals that wetlands as a whole decreased by 1470.1 hectares or 12.5% (see Table V.10). Between 1948 and 1991, all wetland habitats combined increased by .9%. The .9% value representing total wetland change is vague. The increase or decrease in wetlands between these years is not factored. For example, the increase in wetlands between 1948 and 1961 was 1141.4 hectares. Total wetland change between 1961 and 1991 was 9.4%.

Table V.9: Summary Data for the LCR, Riverine Tidal Section, 1983

HABITAT/LANDCOVER	SUM HECTARES	MEAN HECTARES	FREQUENCY
1 (barren land)	852.9	11.5	74
2Ll (lacustrine limnetic)	755.9	9.3	81
2Rt (riverine tidal)	23290.0	431.3	54
3 (grassland)	3.8	3.8	1
4Lt (wetland lacustrine littoral)	354.5	6.0	59
4Rt (wetland riverine tidal)	664.7	7.1	94
4P (wetland palustrine)	6026.1	24.6	245
5 (scrub/shrub)	1992.3	20.1	99
6 (savanna-like)	2.8	2.8	1
7 (forest)	14442.2	83.5	173
8 (agriculture)	20197.8	118.8	170
9 (urban)	4851.3	57.8	84
10 (forested wetland)	4584.5	21.9	209

Figure V.17: Area Summaries for the LCR Riverine Tidal Section, 1983

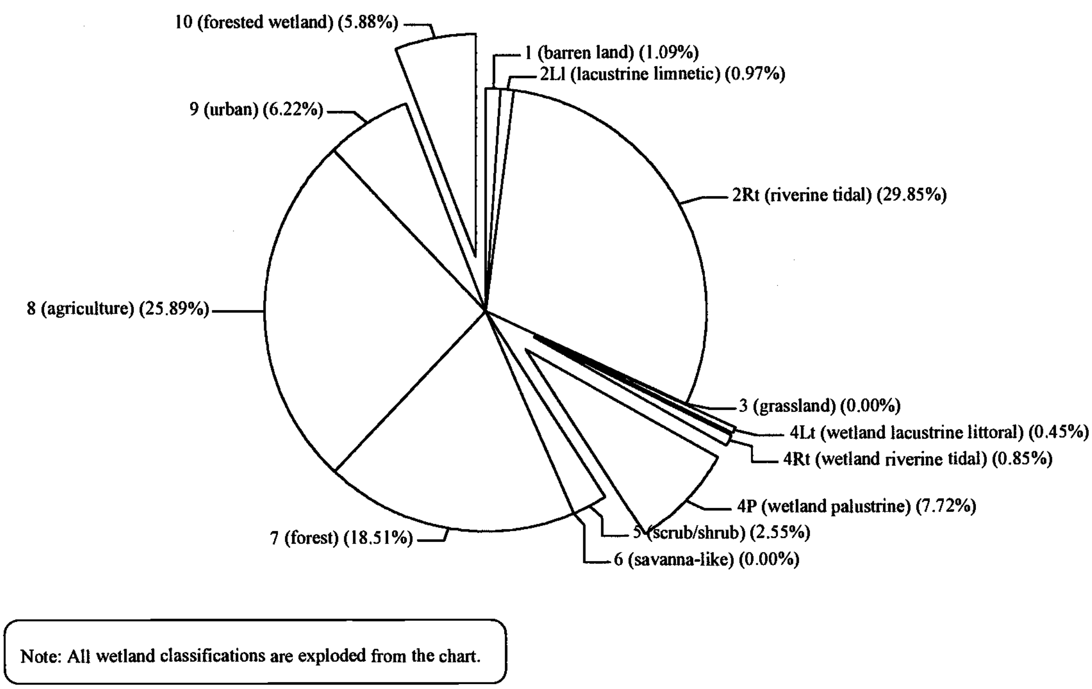


Figure V.18: Habitats and Landcover of the LCR Riverine Tidal Section, 1983

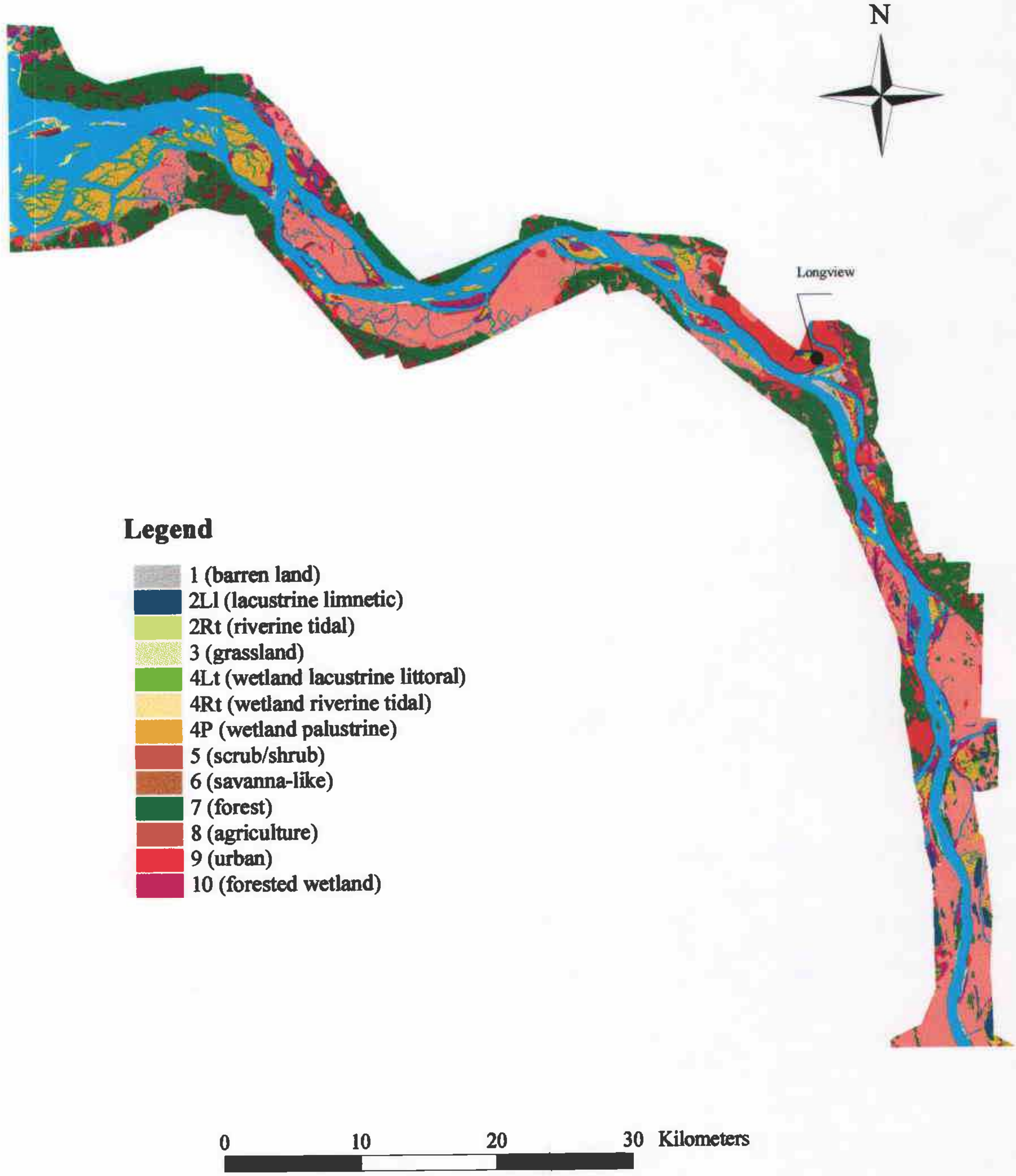
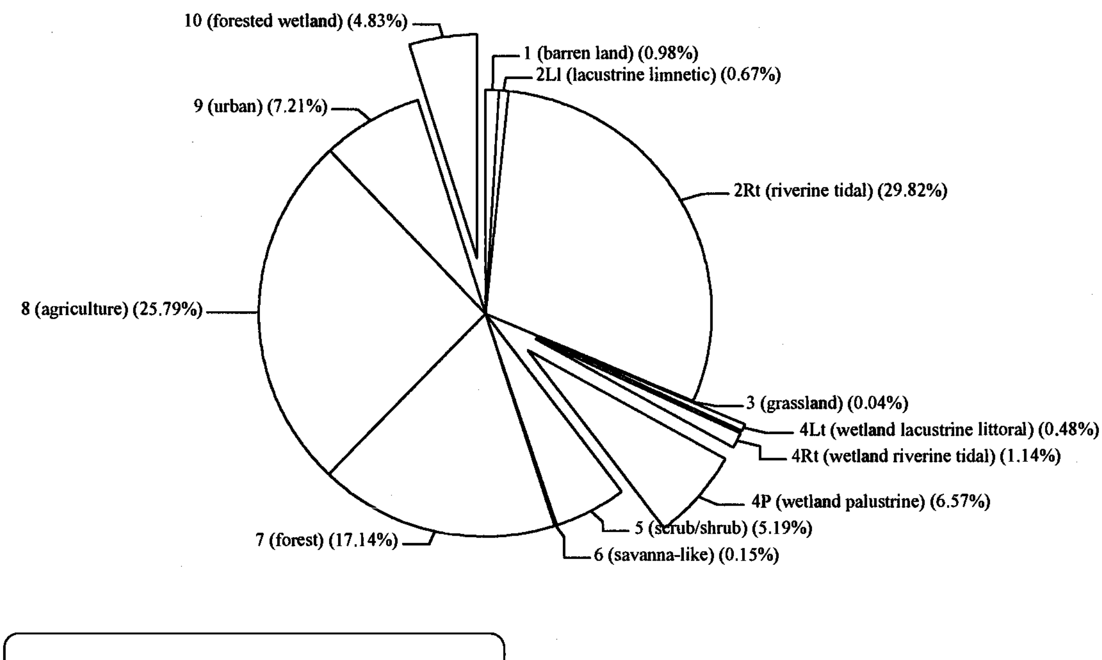


Table V.10: Summary Data for the LCR, Riverine Tidal Section, 1991

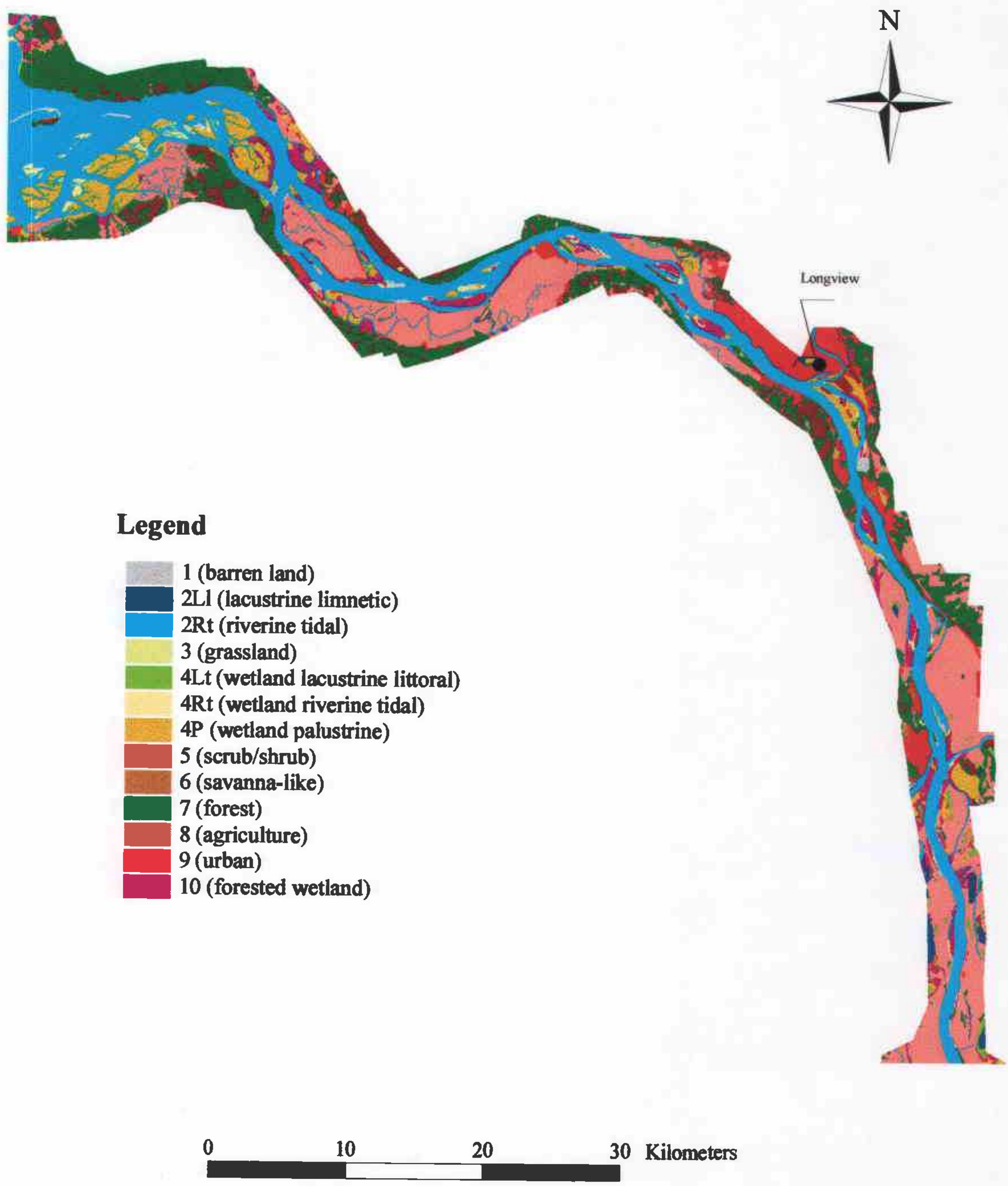
HABITAT/LANDCOVER	SUM HECTARES	MEAN HECTARES	FREQUENCY
1 (barren land)	760.9	9.2	83
2Ll (lacustrine limnetic)	520.7	18.6	28
2Rt (riverine tidal)	23264.2	684.2	34
3 (grassland)	33.6	5.6	6
4Lt (wetland lacustrine littoral)	376.3	10.8	35
4Rt (wetland riverine tidal)	889.4	7.5	118
4P (wetland palustrine)	5124.5	29.0	177
5 (scrub/shrub)	4046.2	34.0	119
6 (savanna-like)	118.7	29.7	4
7 (forest)	13370.1	85.2	157
8 (agriculture)	20120.1	138.8	145
9 (urban)	5624.6	57.4	98
10 (forested wetland)	3769.5	23.4	161

Figure V.19: Area Summaries for the LCR Riverine Tidal Section, 1991



Note: All wetland classifications are exploded from the chart.

Figure V.20: Habitats and Landcover of the LCR Riverine Tidal Section, 1991



Additionally, without understanding why wetlands increased between 1948 and 1991 the value is misleading.

Uncharacteristically, forested wetlands were diminished by 815 hectares between 1983 and 1991. Previous trends indicate steady increases in forested wetlands. Between 1948 and 1991 forested wetlands increased by 34.3%. These increases were spread evenly across the section. Lacustrine littoral wetlands experienced little change between 1983 and 1991. In 1983, lacustrine littoral wetlands made up .45% of the total habitat and landcover area and .48% in 1991 (see Figure V.19). Riverine tidal wetlands increased between 1983 and 1991 by 224.7 hectares. However, from 1948 to 1991, riverine tidal wetlands decreased by 70.3%. Most of the decreases in wetlands between 1948 and 1991 occurred within riverine tidal wetlands (see Figure V.20).

An increase in scrub/shrub habitat in 1991 indicates a decrease in forest habitats. Forest habitats decreased by 1072.1 hectares after 1983. From 1948 to 1991, forested habitats decreased by 28.3%. The 1991 habitat map displays that much of the change in forest occurred in Washington in the northwest portion of the section and in Oregon in the area across the river from Longview. From 1983 to 1991, agricultural land changed only slightly. Similarly, total changes in agricultural land from 1948 to 1991 were small. In total area, agricultural land rose by 1%. Many of the changes in agriculture occurred within the islands of the Lewis and Clark National Wildlife Refuge. In 1948, parts of the present day refuge were farmland;

therefore, as the land was converted to the refuge, the amount of agricultural land between 1948 and 1991 should reflect a significant decrease (see Figures V.12 and V.20). Yet, as noted above the total changes in agriculture were limited. While agricultural land decreased within the refuge, it increased in the southern portion of the section (south of Woodland, Washington, and St. Helens, Oregon). Lacustrine limnetic habitats decreased by nearly 50% between 1948 and 1991. The majority of this habitat became agriculture (see Figure V.20). The decrease in lacustrine limnetic habitats accounts for an increase in agriculture. 1991 urban landcover was marked by continued rapid growth. In 1983 urban areas accounted for 4851.3 hectares. By 1991, there were 5624.6 hectares. From 1948 to 1991, urban landcover grew by 52.6%. While most of this growth occurred near Longview, Figure V.20 reveals that urbanization was spread patchwork across the section. There were many newly formed small urban areas in 1991.

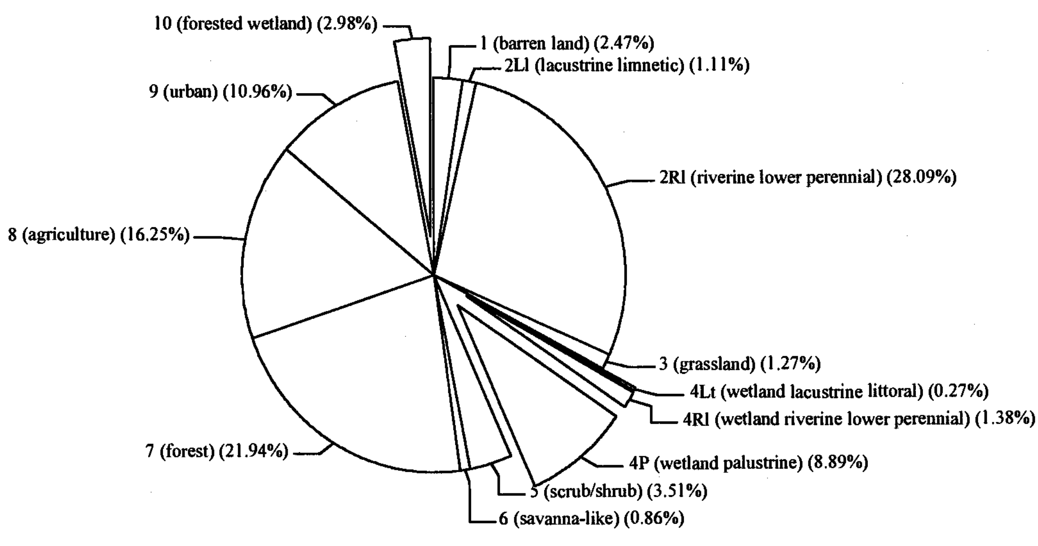
Section Three: Riverine Lower Perennial

Table V.11 and Figure V.21 provide information on habitat and landcover areas for the 1948 riverine lower perennial section of the LCR. The deepwater habitats of the riverine lower perennial area constituted, by far, the largest habitat within this section of the river, at 8843.2 hectares or 28.1% of the total area. The riverine lower perennial habitat was followed by forest, agriculture, urban, and wetland palustrine habitats and landcover to make up the bulk (58%) of the total area.

Table V.11: Summary Data for the LCR, Riverine Lower Perennial Section, 1948

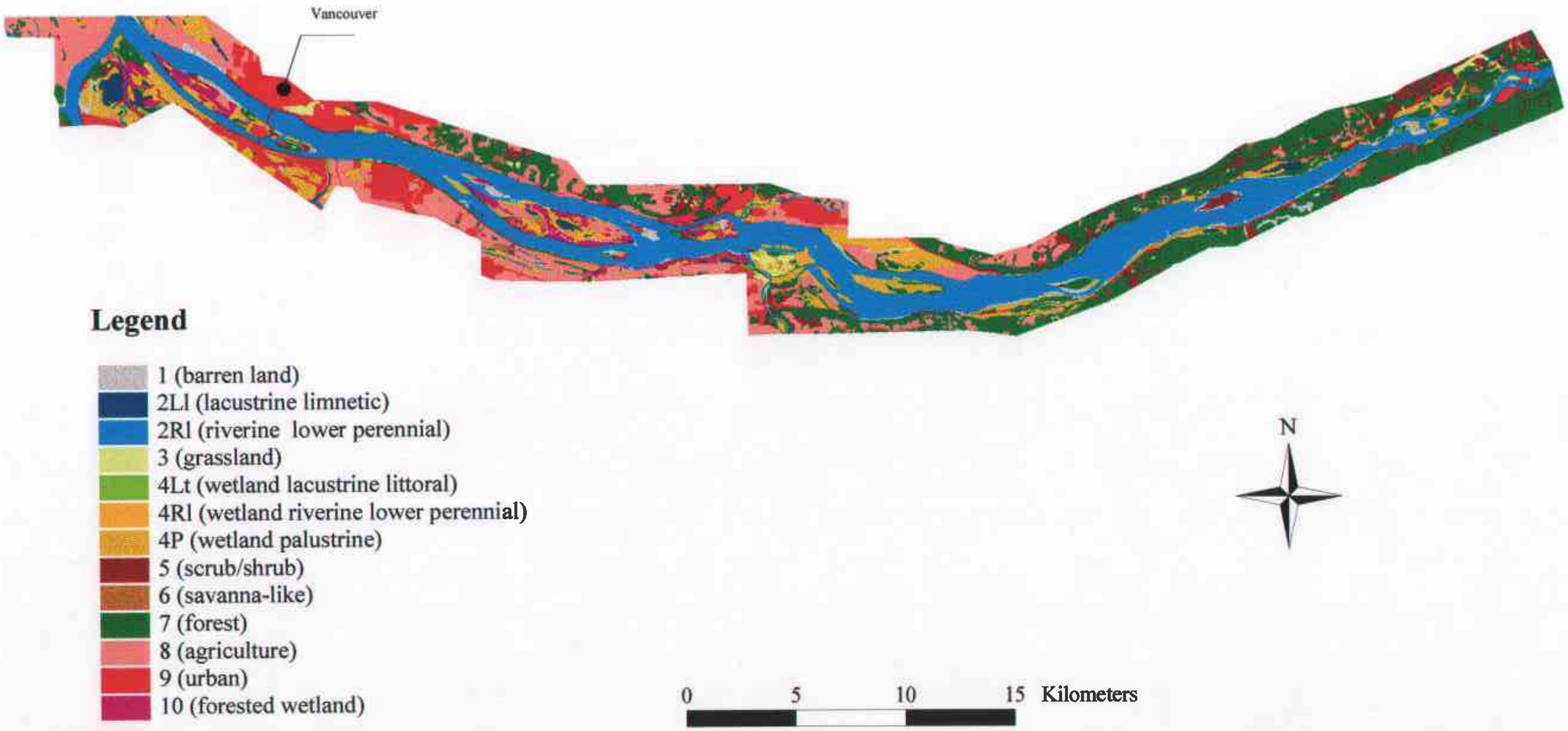
HABITAT/LANDCOVER	SUM HECTARES	MEAN HECTARES	FREQUENCY
1 (barren land)	776.3	9.2	84
2Ll (lacustrine limnetic)	350.7	9.0	39
2Rl (riverine lower perennial)	8843.2	520.2	17
3 (grassland)	399.3	6.1	66
4Lt (wetland lacustrine littoral)	84.7	4.5	19
4Rl (wetland riverine lower perennial)	435.1	8.4	52
4P (wetland palustrine)	2798.5	18.2	154
5 (scrub/shrub)	1106.4	9.5	116
6 (savanna-like)	271.7	7.1	38
7 (forest)	6905.7	30.3	228
8 (agriculture)	5114.7	35.8	143
9 (urban)	3451.0	46.6	74
10 (forested wetland)	939.4	15.7	60

Figure V.21: Area Summaries for the LCR Riverine Lower Perennial Section, 1948



Note: All wetland classifications are exploded from the chart.

Figure V.22: Habitats and Landcover of the LCR, Riverine Lower Perennial Section, 1948



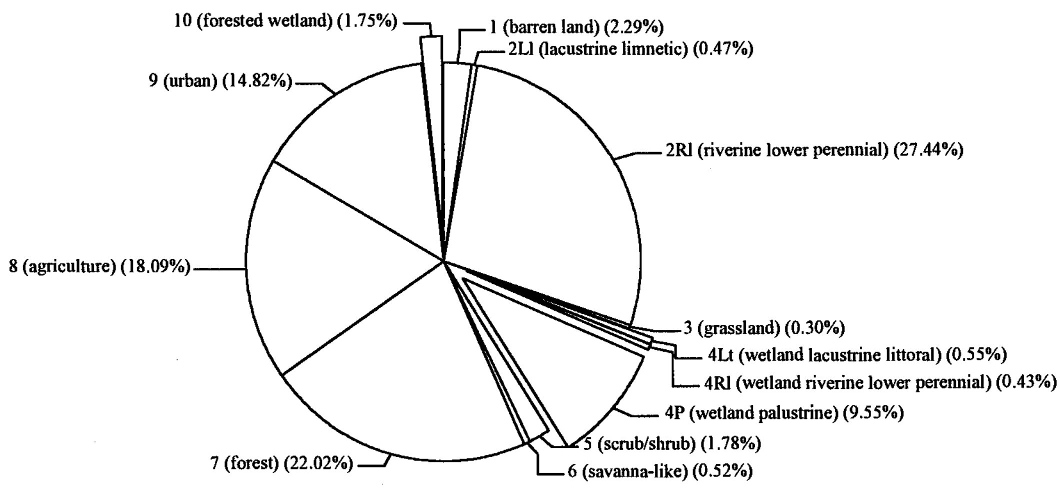
In 1948, agricultural land constituted 16.3% and urban 11% of the total area in the section. Agriculture and urban were the most prominent terrestrial features in the western part of the section (see Figure V.22). As a percent of total area, 1948 urban landcover within the riverine lower perennial section was comparatively much greater than urban coverage in the estuarine and riverine tidal sections. Heading east, at approximately the midway point in the section, agriculture and urban cover gave way to forest and scrub/shrub habitats. The forested land within this section coincided with a more narrow floodplain, as the river increasingly became channelized. From approximately the Sandy River eastward, the geomorphology of the Columbia River Gorge dominated. Forested land composed 21.9% and scrub/shrub 3.5% of the total area in the riverine lower perennial section. The fifth largest habitat in the section was wetland palustrine, claiming 2798.5 hectares. This habitat was spread sporadically across the section, with a concentration along the river's edge near Washougal and Troutdale. All wetlands combined constituted 4257.7 hectares.

By comparing 1948 and 1961 wetland habitats, significant changes are revealed. Generally, wetlands decreased in the riverine lower perennial section by 9.2%; however, the changes in specific wetland habitats were much greater (see Table V.12). Between 1948 and 1961, forested wetlands lost the most habitat of all the wetland types. Forested wetlands dwindled by 389.6 hectares of habitat. While forested wetlands decreased the most as a total percent of area, riverine lower perennial wetlands experienced the most change. Riverine lower perennial wetlands

Table V.12: Summary Data for the LCR, Riverine Lower Perennial Section, 1961

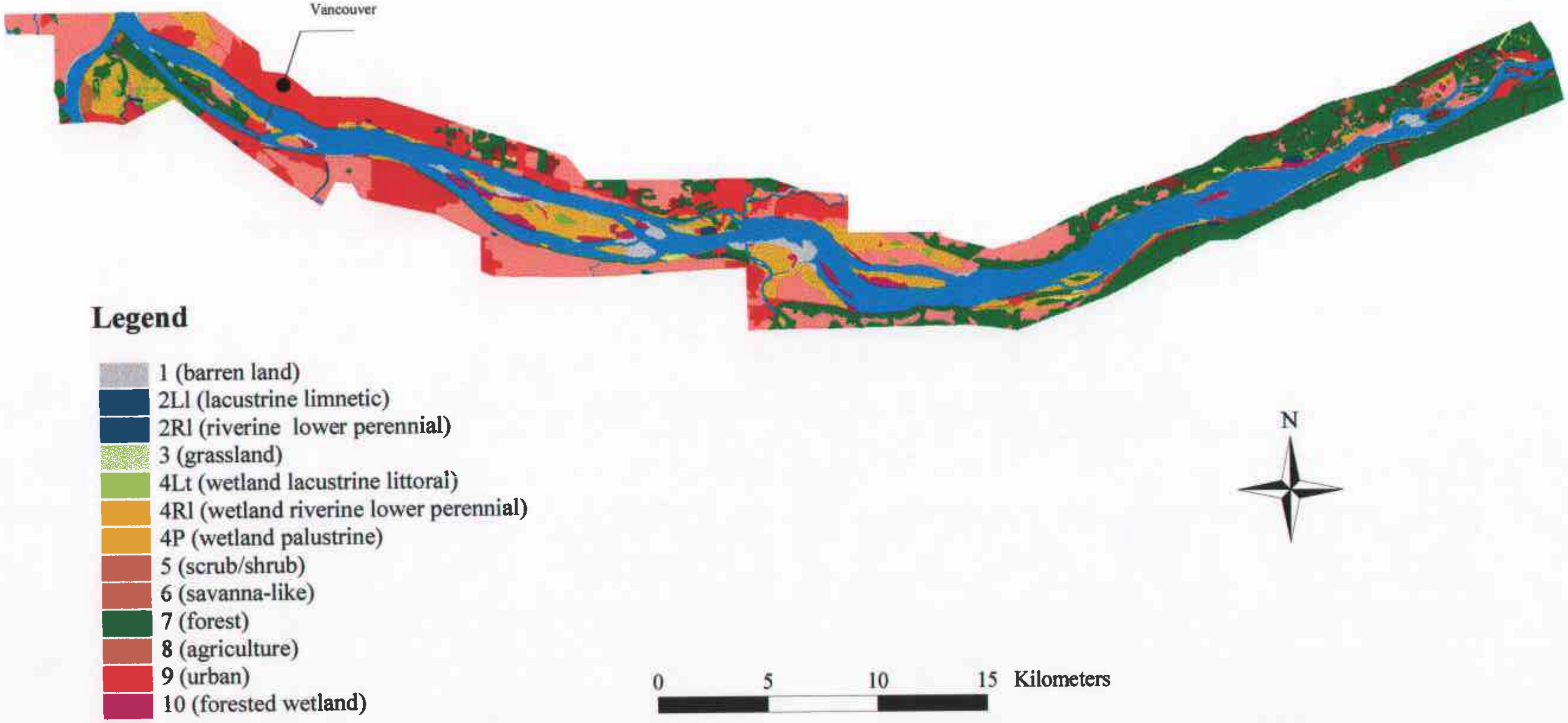
HABITAT/LANDCOVER	SUM HECTARES	MEAN HECTARES	FREQUENCY
1 (barren land)	721.9	14.7	49
2Ll (lacustrine limnetic)	147.8	7.4	20
2Rl (riverine lower perennial)	8636.8	719.7	12
3 (grassland)	93.8	9.4	10
4Lt (wetland lacustrine littoral)	172.8	9.1	19
4Rl (wetland riverine lower perennial)	136.7	19.5	7
4P (wetland palustrine)	3007.2	47.7	63
5 (scrub/shrub)	559.1	15.1	37
6 (savanna-like)	162.9	27.1	6
7 (forest)	6931.9	87.7	79
8 (agriculture)	5693.0	69.4	82
9 (urban)	4663.5	245.4	19
10 (forested wetland)	549.8	18.3	30

Figure V.23: Area Summaries for the LCR Riverine Lower Perennial Section, 1961



Note: All wetland classifications are exploded from the chart.

Figure V.24: Habitats and Landcover of the LCR, Riverine Lower Perennial Section, 1961



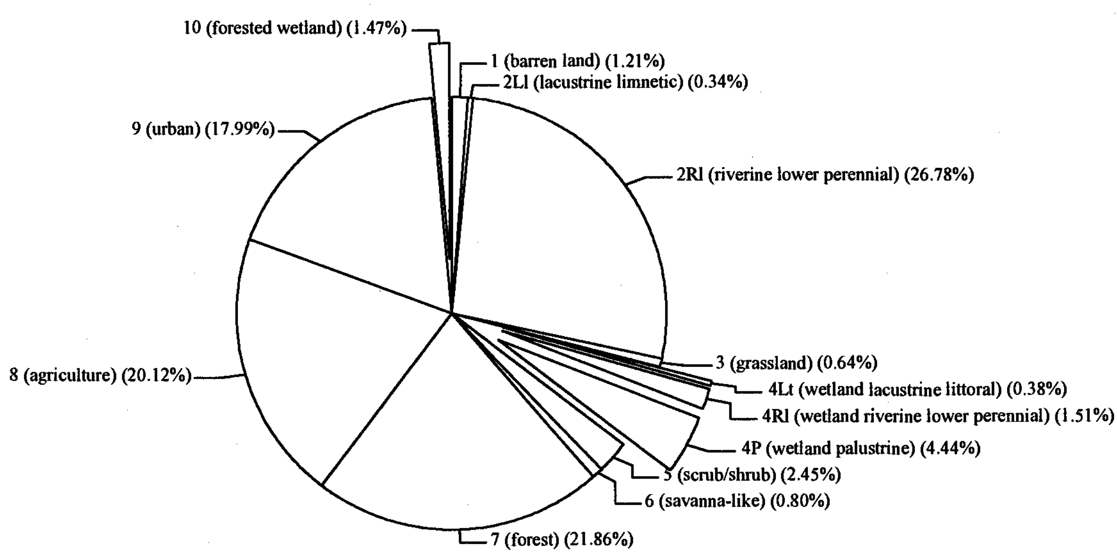
were diminished by 68.6%. Palustrine wetlands grew by 208.7 hectares or .66% of the total area (see Figure V.23). Likewise, lacustrine littoral wetlands increased between 1948 and 1961. Lacustrine littoral wetlands gained 88.1 hectares. Forest habitats saw little change, increasing slightly. Agricultural land also increased. It rose by 10.2% over 1948. Most of this change occurred in the far eastern portion of the section in Washington (see Figure V.24). Urban landcover boomed markedly. From 1948 to 1961, development accounted for 1212.5 hectares of urban growth.

Between 1961 and 1973, palustrine wetlands suffered tremendous losses. In 1961, palustrine wetlands peaked in the riverine lower perennial section at 3007.2 hectares. By 1973, there were 1397.9 hectares (see Table V.13). More than half of the original habitat was lost. As a percent of total area, palustrine wetlands were diminished by 5.1% (see Figure V.25). The location of the losses was largely situated on Government Island (see Figure V.26). Forested wetlands decreased by 85.8 hectares from 1961 to 1973. Similarly, lacustrine littoral wetlands decreased by 54.7 hectares. The only wetland type to gain habitat during this time frame was riverine lower perennial wetlands. These wetlands increased by 340 hectares. Barren land decreased by nearly 50%. Sand accumulation on the eastern portion of several large islands in 1961 was depleted or submerged by 1973. Grasslands increased by 107.2 hectares, representing a sizable increase for a habitat which constituted very little of the total area. Savanna-like habitat increased by 87.8 hectares. Much as forest habitat

Table V.13: Summary Data for the LCR, Riverine Lower Perennial Section, 1973

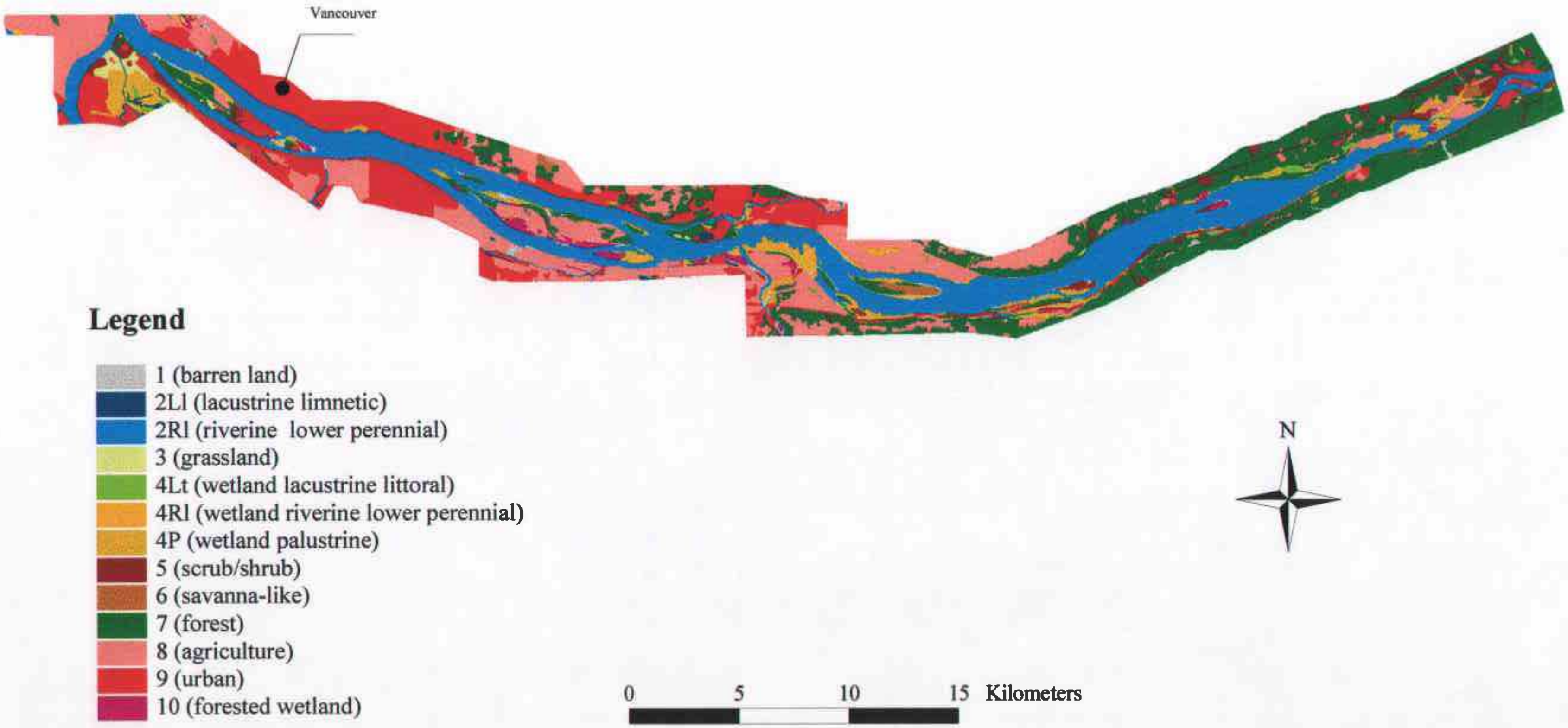
HABITAT/LANDCOVER	SUM HECTARES	MEAN HECTARES	FREQUENCY
1 (barren land)	380.6	4.9	77
2Ll (lacustrine limnetic)	108.5	4.0	27
2Rl (riverine lower perennial)	8428.2	702.4	12
3 (grassland)	201.0	14.4	14
4Lt (wetland lacustrine littoral)	118.1	5.6	21
4Rl (wetland riverine lower perennial)	476.7	19.1	25
4P (wetland palustrine)	1397.9	20.3	69
5 (scrub/shrub)	772.7	17.2	45
6 (savanna-like)	250.7	20.9	12
7 (forest)	6880.4	43.8	157
8 (agriculture)	6334.6	67.4	94
9 (urban)	5663.7	115.6	49
10 (forested wetland)	464.0	10.5	44

Figure V.25: Area Summaries for the LCR Riverine Lower Perennial Section, 1973



Note: All wetland classifications are exploded from the chart.

Figure V.26: Habitats and Landcover of the LCR, Riverine Lower Perennial Section, 1973



changed little between 1948 and 1961, changes between 1961 and 1973 forest habitat were similarly limited, decreasing by less than 1%. Agriculture continued to steadily grow, increasing by 10.1% after 1961. Urban landcover increased considerably between 1961 and 1973. Urban development accounted for 1000.2 hectares of growth. Urbanization within the riverine lower perennial section took place much more rapidly than in the esturine and riverine tidal section.

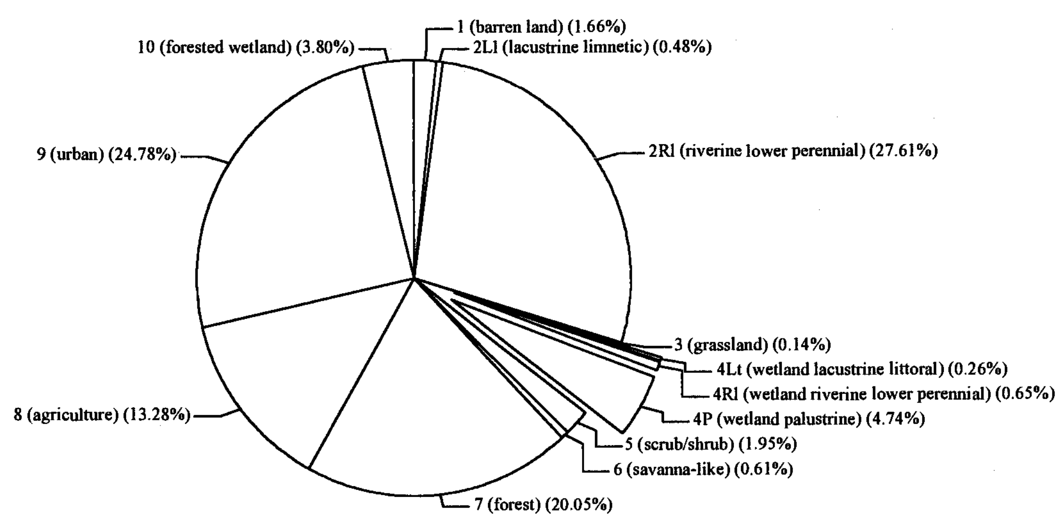
Between 1973 and 1983, wetland habitats experienced minimal change, with the exception of forested wetlands. Forested wetlands grew by an unprecedented amount. In 1973 forested wetlands consisted of 464 hectares, and in 1983, there were 1195.3 hectares (see Table V.14). In the riverine lower perennial section, unlike the estuarine and riverine tidal sections, forested wetlands decreased in area until 1973. In 1983, palustrine wetlands contained 4.7% of the total area (see Figure V.27). This amount increased from 4.4% in 1973. The increases in palustrine wetlands were largely confined to islands (see Figure V.28). Lacustrine littoral wetlands decreased by 36.6 hectares from 1973 to 1983; yet, lacustrine limnetic habitats increased by 43.8 hectares. Riverine lower perennial wetlands decreased by 272.4 hectares.

There were considerable changes in non-wetland habitats and landcover between 1973 and 1983. While agriculture in this section maintained little change in the past, between 1973 and 1983 it decreased by 2153.5 hectares. Suburbanization adjacent to Vancouver and Portland accounted for most of the decline in agricultural land. Forest habitats decreased by 8.3% from 1973. Urban landcover continued to

Table V.14: Summary Data for the LCR, Riverine Lower Perennial Section, 1983

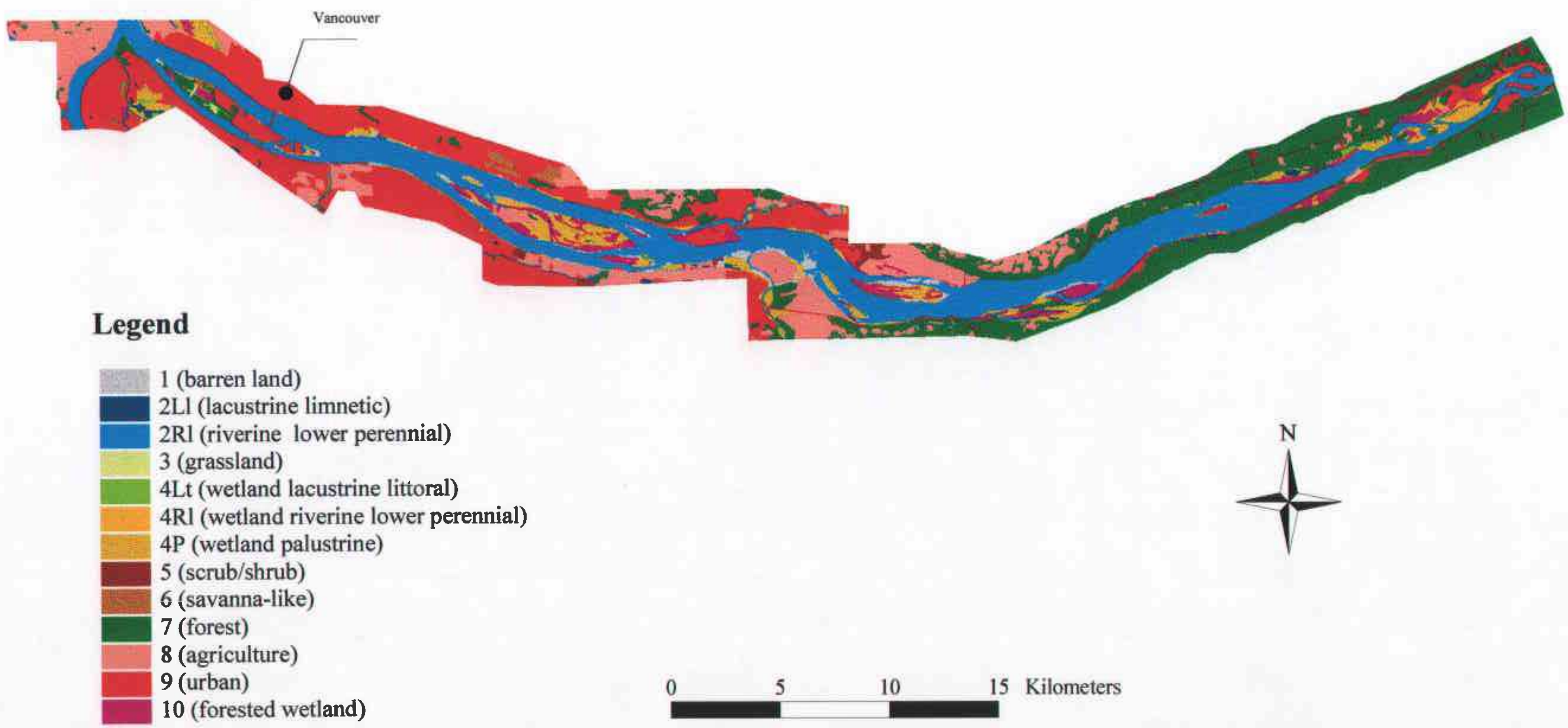
HABITAT/LANDCOVER	SUM HECTARES	MEAN HECTARES	FREQUENCY
1 (barren land)	522.0	8.0	65
2Ll (lacustrine limnetic)	152.3	2.8	55
2Rl (riverine lower perennial)	8691.1	724.3	12
3 (grassland)	44.3	22.2	2
4Lt (wetland lacustrine littoral)	81.5	3.5	23
4Rl (wetland riverine lower perennial)	204.3	7.6	27
4P (wetland palustrine)	1491.0	16.9	88
5 (scrub/shrub)	612.8	14.3	43
6 (savanna-like)	190.5	19.1	10
7 (forest)	6310.2	85.3	74
8 (agriculture)	4181.1	55.7	75
9 (urban)	7800.1	200.0	39
10 (forested wetland)	1195.3	19.9	60

Figure V.27: Area Summaries for the LCR Riverine Lower Perennial Section, 1983



Note: All wetland classifications are exploded from the chart.

Figure V.28: Habitats and Landcover of the LCR, Riverine Lower Perennial Section, 1983



increase rapidly. From 1973 to 1983, urban landcover grew by 2136.4 hectares. Suburbanization and satellite cities of Vancouver and Portland expanded the range of urban landcover in the eastern half of the section.

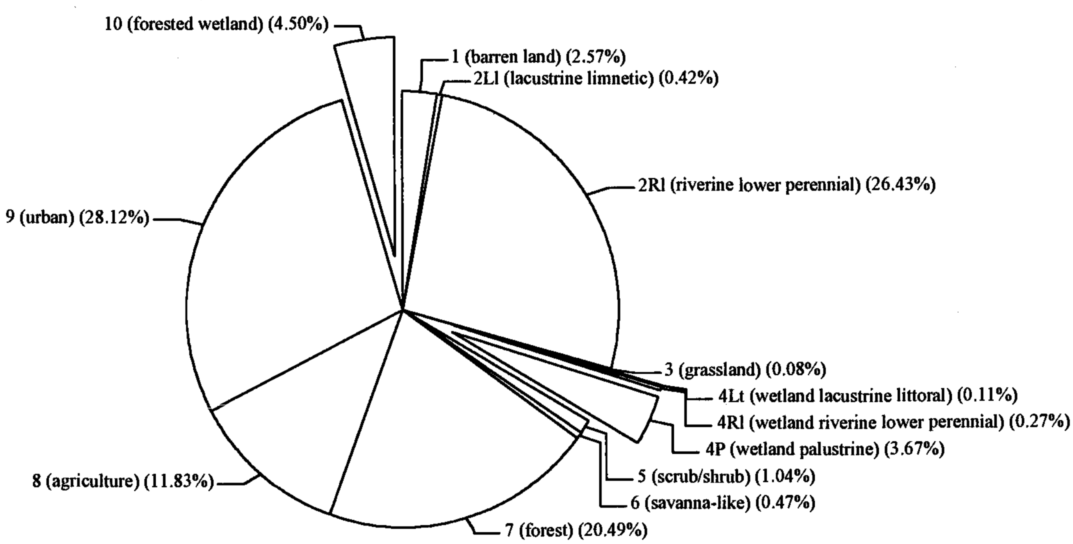
Much like wetlands between 1973 and 1983, wetland habitats generally decreased between 1983 and 1991, with the exception of forested wetlands. All wetlands combined decreased by 9.4% (see Table V.15). In 1991, wetlands comprised 8.6% of the total habitat and landcover in the section, down from 1983 by nearly 1% (see Figure V.29). From 1983 to 1991, lacustrine littoral wetlands were diminished by 47.8 hectares, riverine lower perennial wetlands by 117.7 hectares, and palustrine wetlands by 337.3 hectares. Forested wetlands continued a sharp increase in habitat, growing by 15.7% over 1983. Most of the forested wetlands in 1991 were consistently situated adjacent to the river's banks (see Figure V.30). Forested wetlands between 1948 and 1991 gained 33.7% more habitat. In total, wetlands decreased by 36.8% from 1948 to 1991. Wetlands in the riverine lower perennial section experienced more change than did wetlands in the estuarine and riverine tidal sections.

From 1983 to 1991, urban and forested areas increased, while agriculture decreased. Forest habitat grew by 2%, while urban increased by 1050.6 hectares or 12%. While the estuarine and riverine tidal sections sustained steady growth in urban landcover, the riverine lower perennial section experienced unparalled large gains. Between 1948 and 1991, urban landcover expanded by 5399.7 hectares, more

Table V.15: Summary Data for the LCR, Riverine Lower Perennial Section, 1991

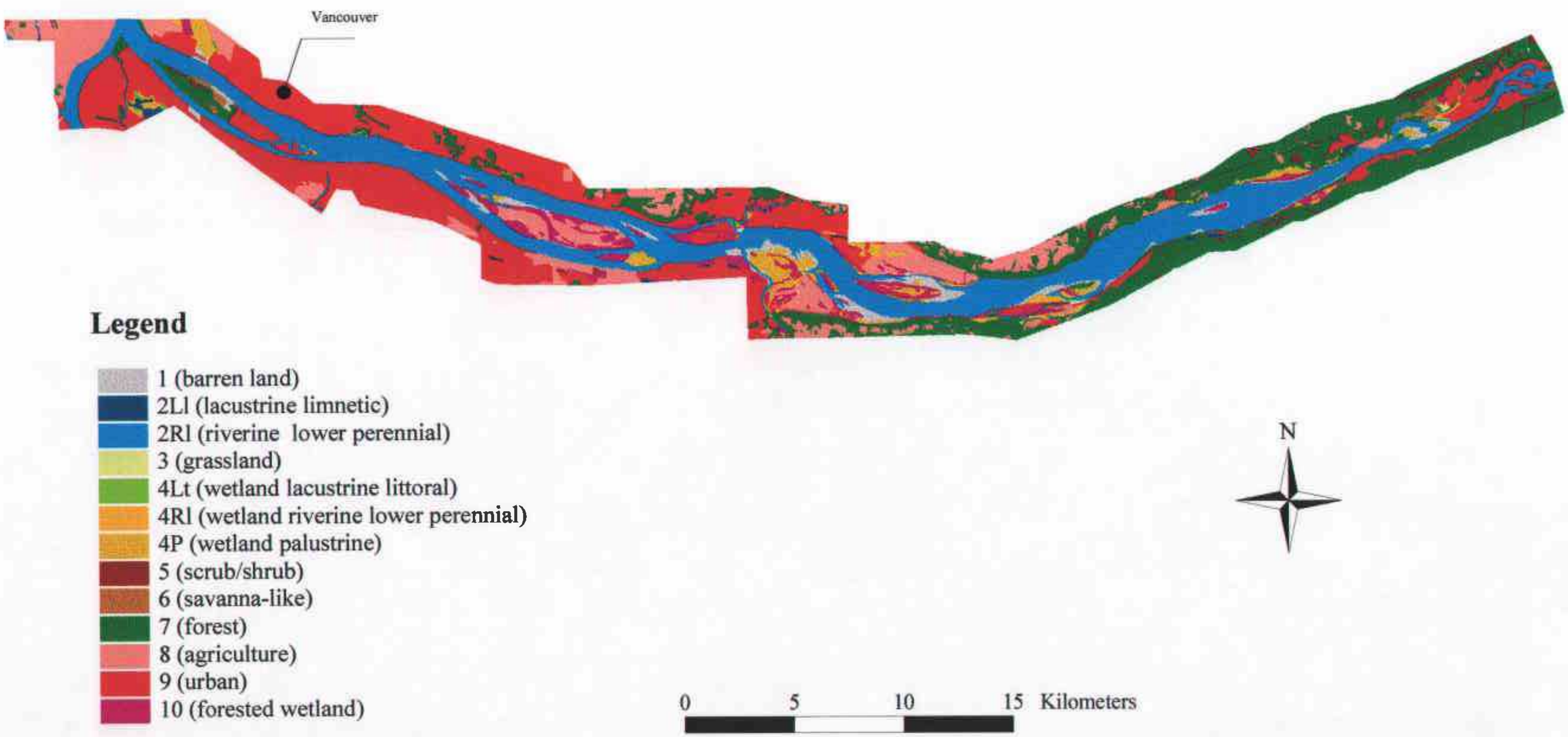
HABITAT/LANDCOVER	SUM HECTARES	MEAN HECTARES	FREQUENCY
1 (barren land)	810.4	23.8	34
2Ll (lacustrine limnetic)	131.4	6.0	22
2Rl (riverine lower perennial)	8320.4	832.0	10
3 (grassland)	26.3	6.6	4
4Lt (wetland lacustrine littoral)	33.7	3.1	11
4Rl (wetland riverine lower perennial)	86.6	10.8	8
4P (wetland palustrine)	1153.7	19.6	59
5 (scrub/shrub)	328.3	11.3	29
6 (savanna-like)	146.4	48.8	3
7 (forest)	6448.6	66.5	97
8 (agriculture)	3722.8	40.5	92
9 (urban)	8850.7	245.9	36
10 (forested wetland)	1417.7	17.1	83

Figure V.29: Area Summaries for the LCR Riverine Lower Perennial Section, 1991



Note: All wetland classifications are exploded from the chart.

Figure V.30: Habitats and Landcover of the LCR, Riverine Lower Perennial Section, 1991



than doubling in size. From the mouth of the Willamette River upstream to Camas, the 1991 urban landscape was nearly unbroken. Agriculture decreased between 1983 and 1991 by 458.3 hectares. As a whole, between 1948 and 1991, agricultural lands were reduced by 1,391.9 hectares.

Combined Total Wetland Change

Until this study, there had been little research comparing the extent and distribution of wetland habitat changes over a period of time along the LCR. According to the Reconnaissance Survey of the Lower Columbia River, extensive losses to wetlands have been well documented throughout the United States; yet, regional losses along the LCR are less know (Lower Columbia River Bi-state Program 1993). Identifying and mapping regional riparian habitat gains and losses along the LCR provides new information which may lead to greater habitat protection.

The dynamic nature of the Columbia River, coupled with the relentless ability of humans to transform their environment, has left the LCR riparian zone in a state of constant change. Between 1948 and 1991, wetlands decreased in the estuarine section by 25.1%, increased in the riverine tidal section by 1%, and decreased in the riverine lower perennial section by 36.6%. In total, wetlands habitats within the LCR riparian zone decreased by 12% (see Table V.16).

Table V.16: Total Wetland Habitat Change from 1948 to 1991

Section	**1948**	**1991**	**Habitat Change**
Estuarine	2,284.0	1710.6	25% decrease
Riverine Tidal	10,066.7	10,159.7	1% increase
Riverine Lower Perennial	4,257.7	2691.7	37% decrease
Total wetland area Lower Columbia River	16,608.4	14,562.0	12% decrease

CHAPTER VI. RESULTS OF ANALYSIS ON FACTORS WHICH INFLUENCE WETLAND HABITAT CHANGE

Preface

This chapter examines the patterns and factors which influence wetland habitat change along the LCR riparian zone. Assessment of the extent, distribution, and type of wetland habitats over time is necessary to understanding the health, values, and functions of the LCR. Habitats previously identified as experiencing considerable changes over time will be discussed by River section. The focus is on wetlands, rather than on other habitats or landcovers. Only those habitats which are presently wetlands or can be linked to influencing a change in wetlands will be discussed.

This chapter is divided into three major parts which correspond to the three sections of the LCR riparian zone. Changes which are site specific to each section will be discussed in terms of why change occurred. For each section of the river, three dimensional area graphics which illustrate principal changes over time and tables which display trends for specific habitat types are employed to aid analysis and discussion. As one habitat consistently replaces another, trends begin to form. Such trends reveal important information on the causes of wetland habitat change. Nevertheless, many changes to wetlands cannot be gathered from this type of study; thus, other research concerning the riparian zones of large rivers are required as an essential tool for deconstructing wetland habitat change.

Much of the discussion in this chapter relies on the understanding that changes in riparian geomorphology impact a change in wetland biology. Geomorphology can be a predictor of community types. The geomorphic structure of valley floors and river channels results from the interaction of basin geology, channel hydrology, and organic mater. As such, basin morphology shapes the development of stream plant communities and aquatic biota (Gregory, et al. 1991). Geomorphology largely determines habitat diversity and ecological functions (Petts, et al. 1992). For example, an oxbow lake or side arm channel is the functional unit in which species habitats are found. The greater the spatial heterogeneity of geomorphic features, the greater the species diversity and abundance (Poff and Ward 1990). Clearly, river geomorphology and biology are intertwined. Even in severely degraded systems, it is not likely that the physical state and structure of the system are completely altered, such that all ties to the biological environment are severed (Sparks 1995) (Sedell, et al. 1990). Concurrently, both aquatic and basin biota influence geomorphology. Riparian vegetation influences riparian geomorphology by trapping sediment, stabilizing banks, and routing flow (Connin 1991).

The task of determining factors which influence wetlands change is somewhat subjective and speculative. There are many processes at work in the LCR riparian zone. The complexities of these processes are prohibitive to simple cause and effect logic. Therefore, the explanations are focused on dominant wetland changes. Of these major changes, the causative factors discussed are limited to general observations.

Section One: Estuarine

The estuarine section of the LCR was first to witness Euro-American exploration and settlement. Perhaps the earliest account of a possible great river was voiced by Sir Frances Drake. He explored sections of North America's western coastline in 1529. However, it was not until 1792 that a Yankee mariner named Robert Gray made the first historical voyage into the turbulent mouth of the river's estuary (Lyman 1963). Captain Gray's famous ship, the Columbia Rediviva is the river's namesake. On the heels of this great discovery came the 1804-1806 Pacific expedition of Lewis and Clark. At Fort Clatsop, Lewis and Clarke made a wet winter camp on the headlands of the river's mouth (DeVoto, ed. 1953). In search of a better life, the prospect of free land, or simply adventure, nearly half a million people traveled to the river's edge and the Pacific Ocean during the mid-1800's (Garrett 1998). With the fur, salmon, and timber industries booming, Astoria and surrounding towns began to grow. When the seemingly endless bounty of the region began to falter, the local population turned from resource extraction to agriculture. It would seem that the long exploitation of the estuarine region might leave riparian habitats severely diminished. It has -- but, as the data in this chapter indicates, not to the extent that one would anticipate. In 1948, considerable wetlands remained.

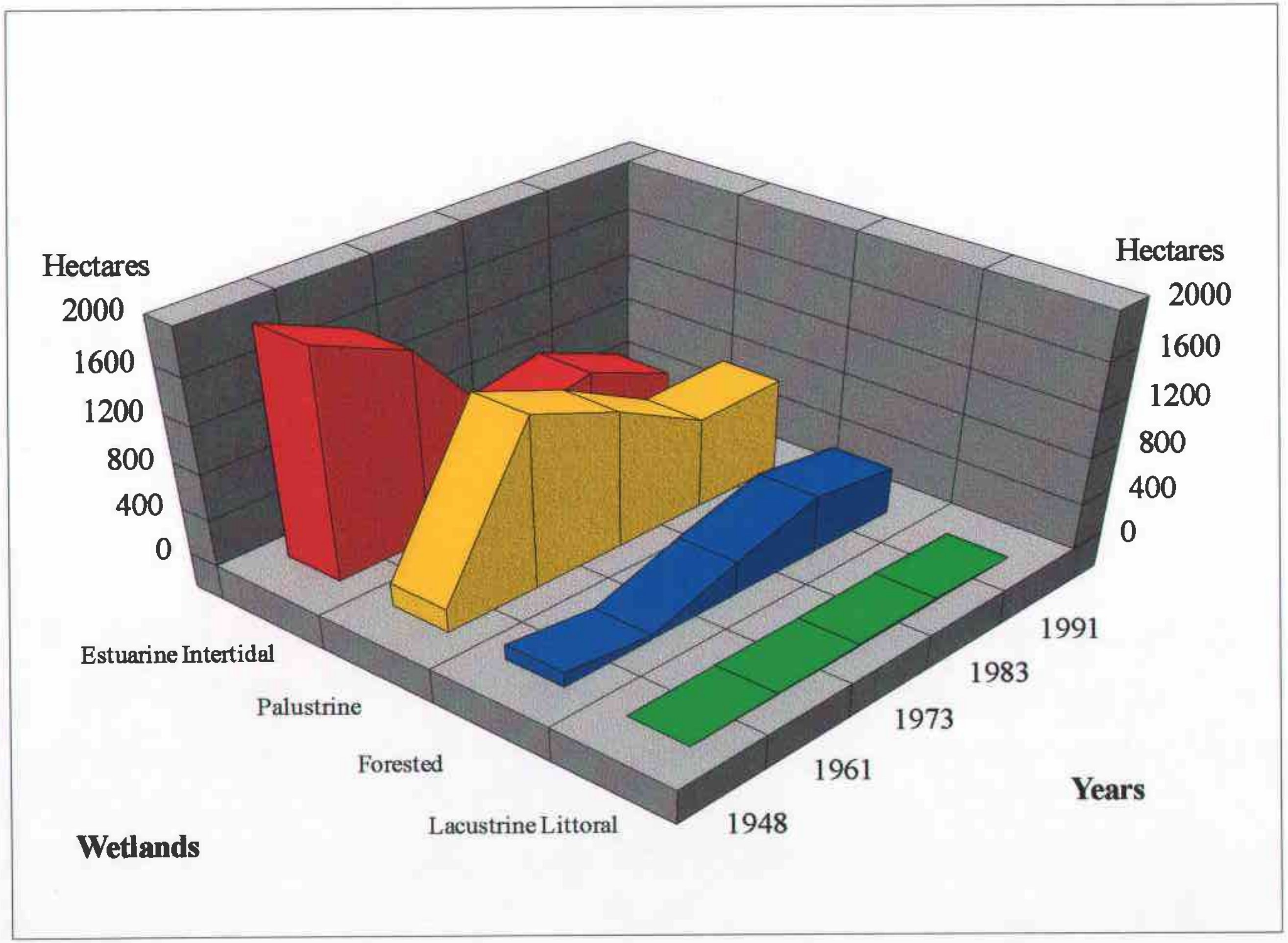
There are four wetland types that are specific to the estuarine section of the LCR. They are: estuarine intertidal, palustrine, forested, and lacustrine littoral wetlands. The probable cause of major changes experienced by each of these wetland types between 1948 and 1991 is discussed.

Estuarine Intertidal Wetlands

Estuarine intertidal wetlands experienced tremendous changes between 1948 and 1991. Most of the 25% decrease in wetlands habitats in the estuarine section occurred within this wetland type. Figure VI.1 illustrates the major changes in estuarine intertidal wetlands for all five habitat coverage dates. In 1948, estuarine intertidal wetlands peaked in terms of total area. By 1973, this wetland type shrank to its lowest point before slowly increasing to its 1991 value. In 1948, 1958.3 hectares of estuarine intertidal wetlands was abnormally high, compared with other years. Extensive flooding in 1948 contributed to the large amount of estuarine intertidal wetlands.

The habitats for this study were mapped in the aftermath of one of the largest floods on record for the LCR. As a result of the excessive rain and thaw in June, the measured overflow of the Columbia River at its mouth was >28,320 m^3s^{-1}. There are only two other June freshets in recorded history for the LCR which were close to the volume of the 1948 freshet. In 1863 the June freshet was 26,900 m^3s^{-1}, and in 1876, the June freshet was >27,180 m^3s^{-1} (U.S. Army Corps of Engineers, 1996). The 1948

Figure VI.1: Wetland Change, 1948-1991, Estuarine Section



flood was responsible for unprecedented flooding. A flood crest of 8.5 feet or higher at Vancouver Gage is considered a major flood. Only four recorded floods on the LCR reached this level, the flood of 1894 was the largest, followed by the flood of 1948. The two remaining smaller floods occurred in 1956 and 1964 (Federal Emergency Management Agency 1986). River regulating effects of upstream dams were largely not in place by 1948. Bonneville Dam, which was completed in 1938, was not specifically designed for flood control; however, it does impound water in a reservoir, thereby partially moderating minor annual flood events. Greater control was exerted over large flood events, such as the 1948 flood, following the construction of the John Day Dam in 1968, which was designed to control floods.

The flood of 1948 scoured estuarine intertidal wetlands, as well as all other habitats within the river's floodplain. As the flood receded, estuarine intertidal wetlands were the first vegetated habitat to be quickly reestablished. Other areas close to or adjacent to the river, such as palustrine wetlands, forested wetlands, lowland forest, agriculture, or scrub/shrub, were, in part, initially reestablished as estuarine intertidal wetlands. In essence, the 1948 flood partially reset wetland succession. This phenomenon is not uncommon after a particularly large flood (Galat et al. 1998). Before the Great Midwest Flood of 1993, the wetland ecosystems of the lower Missouri River were disconnected from this heavily regulated River. By breaching its channel and levees at flood stage, the river naturally repaired lost links with its floodplain and wetland habitats (Galat et al. 1998).

During the 1948 flood, levees were breached, and protective forests lands were inundated with water, leaving palustrine wetlands vulnerable for replacement. Many palustrine wetlands which were replaced by estuarine intertidal wetlands were situated along the northern and southern banks near the river's mouth, the lowlands of Youngs Bay, and the islands of Cathlamet Bay.

While estuarine intertidal wetlands increased in 1948 directly after a flood event, by 1973 they had decreased sharply. From 1948 to 1973, estuarine intertidal wetlands decreased by 65.6%. Within a pristine river system such a rapid decrease in wetlands over a short period of time is not likely to occur. Directly or indirectly, human activities were the chief cause for the changes. This decline in estuarine intertidal wetlands can be associated with in-water activities, such as channelization, dredging, and annual flood flow regulations. The small increases in wetlands are likewise associated with the same activities, via shoaling and fill deposition and the lack of large flood flow control. Smaller annual floods were regulated by upstream water impoundments reducing the annual reestablishment and growth of emergent wetlands. However, larger floods were not regulated until approximately 1968, as the John Day Dam, designed to control floods, was completed and other impoundments began to increase water storage capacities. Two larger floods greater than 8.4 meters at Vancouver Gage occurred. The floods of 1956 and 1964 were the last large floods to occur during the study period (FEMA 1986). Had these been controlled like the smaller annual floods, it is likely that estuarine intertidal wetlands would have experienced yet greater losses.

The nature of a regulated large river is to become disconnected from its floodplain (Galat et al. 1998). Human intervention outstripped the emergent wetland restorative properties of flooding. Following the flood of 1948, dikes were built higher to protect agricultural land from future large flood events, and channelization, fill disposal, jetty building, continued in earnest. Regulated river flow via increased flood storage capacity increased. These actions guaranteed that the river would resume its pre-flood, highly disconnected state. In the curtailment of annual flooding, exchanges between the river and floodplain pools, lakes, side channels, and sloughs were diminished. Floodplain wetlands are specifically affected by reducing the occurance and duration of flooding. Over a period of 88 years floodplain wetlands along a 145 kilometer reach of the regulated Missouri River were depleted by 67% (Whitley and Campbell 1974).

By 1961, estuarine intertidal wetlands had decreased rapidly, while palustrine wetlands increased sharply, indicating that palustrine wetlands had reclaimed territory which the extremely high waters of the 1948 flood had washed away. While it is simplistic to view wetland succession as systematic, in the estuarine section of the LCR, estuarine intertidal wetlands directly facilitate the growth of other wetland types. According to Connell and Slayter (1977), there are plant species which alter their environment and make it more suitable for other species. One of the most common plant species found within estuarine intertidal wetlands is Lyngby's sedge (Carex lyngbyei) (Thomas 1983). After the 1948 flood, Lyngby's sedge colonized intertidal marsh areas, and sediment became trapped and accumulated, effectively raising the elevation over time. Accompanying the change in elevation was a change in species. Palustrine wetlands were the most common wetland species to follow.

The single greatest activity which contributed to the decline of estuarine intertidal wetlands was channelization for navigation. The consequences of channeling have both increased and decreased estuarine intertidal wetlands; yet, the net effect was a reduction. Channelization was achieved by building jetties and pile dikes and through extensive bar and main channel dredging. Channeling the river resulted in increased current velocities along the length of the channel and corresponding velocity reductions along the outside margins of the channel. Within the channel, high current velocities promoted scouring and the transport of suspended sediments, while velocities dropped elsewhere and sediment accretion occured. Reduced circulation in the estuary led to accelerated shoaling. In areas of slower or slack currents, tidal flats developed and promoted the growth of emergent vegetation. For example, in Baker Bay, sand and mud flats have grown, establishing limited 'fringe' vegetation. As a whole, emergents have generally declined within the bay, while experiencing minimal growth along the shorelines. The flats in the bay were more exposed than the shorelines, thereby, were reworked by tides and currents not allowing emergent vegetation to take hold.

Typically, diking has more of an impact on wetland habitat change than does channelization. According to Thomas (1983), diking along the LCR has caused more changes to habitats than any other single factor. Thomas's study generally compared habitats between 1870 and 1980. However, by 1948, most of the extensive diking systems were already built. Since then, efforts have focused on building the established dikes higher, rather than building new ones. Much like diking, channelization has a long history on the river. However, while the diking boom peaked, channelization continued in an effort to support the demands of more traffic and larger vessels. By 1935, the main channel through the estuarine section to Portland was completed. The depth of the channel was 10.7 meters. Since 1948 channelization projects continued to be developed, thereby influencing dominant changes to estuarine intertidal wetlands.

Between 1948 and 1973, at least seven major channelization projects which had significant impacts on wetland habitats were undertaken in the estuarine section of the LCR. Six of these projects directly impacted the northwest portion of the estuary. The most extensive changes in estuarine intertidal wetlands occurred within and adjacent to Baker Bay and the estuary's mouth. Changes developed along the north jetty to Cape Disappointment to Ilwaco and on West and East Sand Islands. In 1948, three pile dikes on West Sand Island were completed, and a fourth pile dike was added in 1953. In 1948, the Ilwaco west channel was dredged to 2.4 meters, and in 1957, the same channel was deepened to 3.1 meters. Main channel maintenance was carried out through the entire period. The Chinook harbor breakwaters were extended in 1958, and dredge material was disposed on the Sand Islands (U.S. Army Corps of Engineers 1996). By 1973, most of West Sand Island changed from estuarine lowlands to uplands. The extensive estuarine intertidal wetlands along the outside margins of the island changed to scrub/shrub. The four new pile dikes partially eliminated the link between the estuarine and the terrestrial environment. The dredge spoils taken from the Ilwaco channel were deposited as fill on both the East and West Sand Islands. The habitat value created by the deposition of dredge spoils is not as great as the value of naturally occurring emergent wetlands. The nutrient quality of spoils is generally lower and cannot support wetland habitats that are as varied or productive (Slotta et al. 1974). While the fill material did establish colonization of palustrine wetlands on the islands, approximately 160 hectares of estuarine intertidal wetlands were lost. By 1973 extensive scrub/shrub habitats were located on West Sand Island.

Construction was begun on the south jetty in 1895, and on the north jetty in 1913. Therefore, by 1948 the impacts to the surrounding wetland habitats should have stabilized. In reality, the wetlands near the north and south jetties experienced sizable changes between 1948 and 1973. Estuarine intertidal wetlands were heavily diminished. Channelization and continued construction on the jetties may have caused these changes. The River and Harbor Act of 1954 guaranteed the entrance channel to be set at 14.6 meters in depth. The project was finished in 1957. Both jetties were constructed longer and higher on many occasions since their initial construction began, but in 1961 underwent extensive rehabilitated (U.S. Army Corps of Engineers 1996). The jetties are responsible for substantial accretion of sand, which influenced a change from estuarine intertidal wetlands in 1948, to palustrine wetlands in 1961, and scrub/shrub habitat in 1973. Sand deposited along Clatsop Spit near the south jetty and Peakock Spit adjacent to the north jetty, was carried by littoral currents and wind resulting in uplands.

Shoaling and the deposition of dredge material had a negative impact on estuarine intertidal wetlands on the sand and mud flats east of Tongue Point, while positively influencing wetlands of the same type in Grays Bay. Mott and Lois Islands are dredge spoil islands. Where once estuarine intertidal wetlands were found in abundance, the repeated deposition of dredge spoils formed stable upland islands. In 1961, both islands first appeared. The islands changed from shifting estuarine emergents to upland palustrine wetlands. By 1973, the islands continued to change. Very few estuarine intertidal wetlands remained, and the palustrine wetlands were transformed to scrub/shrub and forested wetlands.

Grays Bay is a shallow, sheltered bay, rich in biological habitat. Fox et al. (1982) discussed the importance of the bay's benthic infauna as a critical food source for fish and birds. Despite that, the floodplain was already diked by the early 1900's, and much of the wetlands was changed to pasture. By 1948, the bay remained an important and productive habitat rearing area. Some estuarine intertidal wetlands were established as a result of the long history of diking. In 1948, wetlands were found along the fringes of the dikes. Shoaling decreased the total amount of deepwater habitat and increased shallows and flats. By 1961, estuarine intertidal wetlands had increased by more than 100 hectares expanding away from the dikes and into the bay. Pile dike construction, which reduced circulation velocities, and dredge spoil disposal were the most likely reasons for this increase.

By 1973 nearly 200 hectares of estuarine intertidal wetlands in the Grays Bay region were displaced. Estuarine intertidal wetland losses followed a predictable pattern of change. These wetlands changed to upland palustrine wetlands. Unlike prior trends, estuarine intertidal wetlands did not progress to scrub/shrub habitats. Estuarine wetlands which did not change to palustrine wetlands became barren sand flats. Rice Island provides evidence of shoaling and large scale dredge spoil disposal. In 1948, the island did not exist; but, in 1973, it appeared as a large barren sand swept island. Numerous unnamed sand islands which were not evident in 1948 appeared in Grays Bay or at its mouth by 1973. It is likely that these dredge spoil islands impacted tidal and river currents in the bay by generally reducing current velocities and contributing to increased shoaling and the indirect loss of estuarine intertidal wetlands.

Watershed activities have had minimal effect on the growth or loss of estuarine wetlands. Historically, this phenomenon was not true. The direct and indirect effects of diking on agriculture were inordinately large. The majority of habitat loss was attributed to the need to drain wetlands for pasture. Of the extensive loss of estuarine surface area since the 1870's, diking, most of which occurred between 1880 and 1930, accounted for 85% (Fox et al. 1982). By 1948, most dikes were in place.

Figure VI.2 supports the theory that, while watershed activities in the estuarine section were once the most influential factor on estuarine intertidal wetlands change, they no longer exert the same control. Little change has occurred in such watershed activities as agriculture and urbanization. Bear in mind that wetland habitat changes in this study are not being compared to the state of wetland habitats in 1881 or 1940, but against habitats which existed only as early as 1948. Because many watershed activities were long established before 1948, their impacts will not be identified unless there is a significant increase or decrease in the activity since 1948. Between 1948 and 1991, the amount of land in service for agriculture steadily declined by 43.7%. In reality, between those years, more land changed from agriculture to wetlands than did wetlands to agriculture. A mere 1.6 hectares of 1948 estuarine intertidal wetlands became agriculture by 1991 (see Table VI.1).

Urban areas experienced a small gain of 328.4 hectares between 1948 and 1991. The most extensive population growth in this section occurred between 1870 and 1920; thus, by 1948, the impacts of rapid population growth on estuarine intertidal habitats were largely in place. Little population growth has occurred since

Figure VI.2: Habitat/Landcover Change, 1948-1991, Estuarine Section

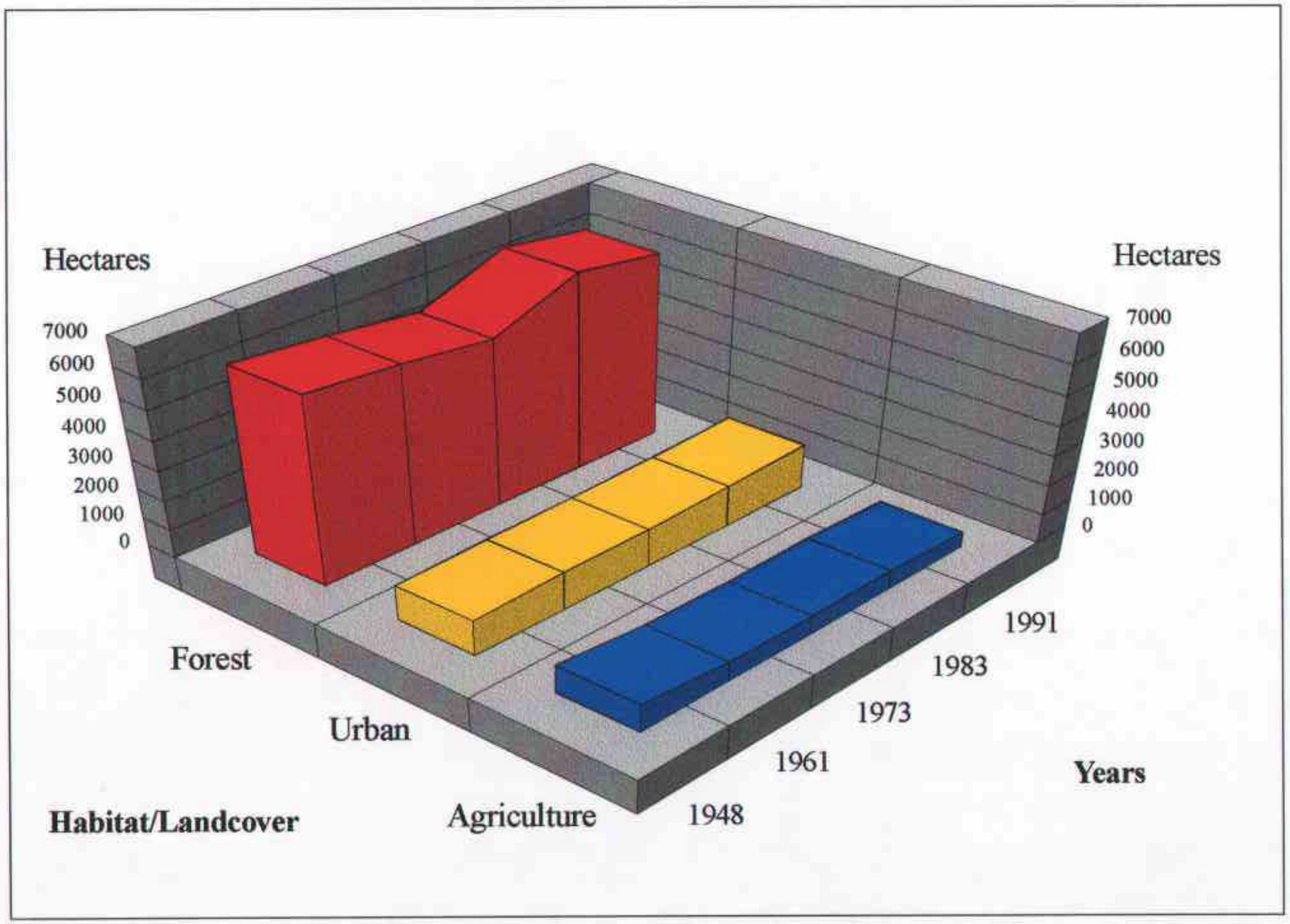


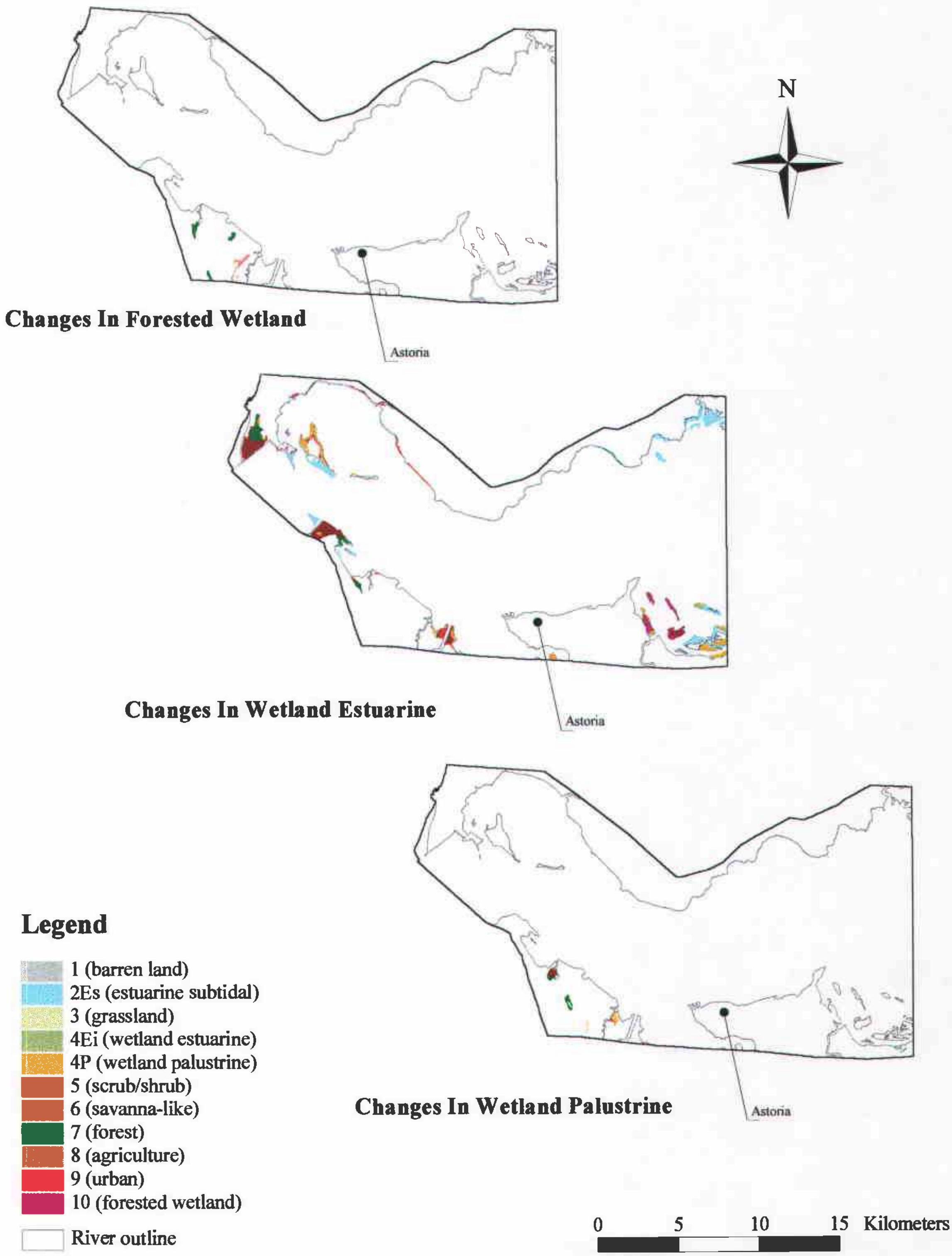
Table VI.1: 1948 Estuarine Intertidal Wetlands Which Became Another Habitat/Landcover by 1991, Estuarine Section

New Habitat/Landcover	Sum Hectares
1 (barren land)	132.2
2Es (estuarine subtidal)	396.5
3 (grassland)	4.8
4P (wetland palustrine)	287.2
5 (scrub/shrub)	348.4
6 (savanna-like)	4.0
7 (forest)	101.2
8 (agriculture)	1.6
9 (urban)	98.5
10 (forested wetland)	102.0

1920. This decline corresponded with a decline in the salmon, fur, and logging industries. Of the current population, 90% is located in Oregon (Fox et al. 1983). Because population growth since 1948 in the section was negligible, little loss of wetland habitats can be directly contributed to urbanization. Urbanization accounts for 70.1 hectares of direct estuarine intertidal wetlands losses (i.e., replacement of wetlands habitat for urban landcover). Rapid runoff and subsequent erosion from urban areas indirectly accounts for estuarine intertidal losses. To determine the amount of wetland losses related to urban erosion in the watershed would be highly speculative.

The most extensive losses of wetland habitat which occurred as a result of urbanization developed along the landward margins of Youngs Bay. On the western shore of the bay, 24 hectares of estuarine intertidal wetlands were replaced by urban landcover (see Figure VI.3). Road expansion projects along the estuary's shores also

Figure VI.3: 1948 Wetland Habitats Which Became Another Habitat/Landcover by 1991, Estuarine Section



accounted for some estuarine intertidal losses. Roads acted much as a dike. As they were elevated, the exchange of estuarine and terrestrial water was restricted. Highway construction promoted erosion which, when coupled with eroding fill material, lead to accelerated accretion and in part, facilitated estuarine intertidal habitat losses. Changes in forest habitats were nominal between 1948 and 1991. This habitat increased slightly by 1983 (see Figure VI.2). Timber harvest practices have the greatest impact on forest habitats. An increase in timber harvesting may effect wetlands via an increase in the amount of sediment carried in tributary streams and the estuary. Further, it can increase the temperature of tributary streams and, subsequently, impact the growing conditions of wetlands. Because forest habitats experienced minimal change, timber harvesting and other forest removal activities in the estuarine section cannot be directly linked to the reduction of estuarine intertidal wetlands. In terms of one habitat replacing the other, minor changes occurred where estuarine intertidal wetlands became forest habitat. There were 101.2 hectares of estuarine intertidal wetlands in 1948 which became forest by 1991 (see Table VI.1).

Palustrine Wetlands

Between 1948 and 1991, palustrine wetlands increased; however, between 1983 and 1991, they decreased (see Figure VI.1). In 1948, palustrine wetlands composed little area, but grew rapidly by 1983. Such a rapid increase likely indicates an abnormal event which had a significant impact upon palustrine wetlands. The flood of 1948 was the most probable event to have such an effect. In the aftermath of the 1948 flood, palustrine wetlands suffered substantial losses. Initially the flood accounted for an increase in estuarine intertidal wetlands, which over time changed to palustrine wetlands. Habitats were interpreted from aerial photos taken four to five months after the flood. Estuarine intertidal wetlands were among the first plant species to recolonize. Palustrine wetlands rebounded from the flood and increased to pre-1948 levels by 1961. Between 1948 and 1961, estuarine intertidal wetlands decreased, reflecting an increase in palustrine wetlands during the same time frame. During this period, estuarine intertidal wetlands most commonly became palustrine wetlands.

Palustrine wetlands decreased in area between 1961 and 1983, and slightly increased between 1983 and 1991. During the period of 1961 to 1983, palustrine wetlands lost 700.5 hectares of habitat. Many of the same activities which caused a reduction in estuarine intertidal habitats, likewise, effected a loss in palustrine wetlands. Dike and jetty systems and dredging had the most significant impacts on these wetlands. Sedell, et al. (1990) concluded that the most damaging anthropogenic impacts on river biology are typically the result of altering the basic structure of the river. Much of the losses of palustrine wetlands were accounted for as these wetlands changed to scrub/shrub habitats. The more highly elevated portions of dredge spoil fills with palustrine wetlands changed within 20 years to become scrub/shrub.

Unlike estuarine intertidal wetlands, which were minimally impacted by the direct consequences of watershed activities, palustrine wetlands were affected to a greater extent by the same actions. Palustrine wetlands are more closely linked to the terrestrial environment for its source of water than are estuarine intertidal wetlands. Some palustrine wetlands in the study site are in uplands areas which have little direct hydraulic connections to the estuary. Such wetlands are certainly impacted by watershed activities to a greater extent than they are effected by in-water activities..

Since the flood of 1948, most dikes were built higher to withstand larger floods; however, some new dikes were built -- especially in the Youngs Bay area. Older low dikes allowed for periodic flooding, which mostly occurred during the Spring, accompanying high precipitation and snow melt. As the old dikes were rehabilitated or new ones were constructed, the palustrine persistent emergents, such as willows, decreased. Dikes interfered with the relationship between the estuary and palustrine wetlands. Backwaters, side-arm channels, ponds, tributary oxbows, and the hyporheic zone connecting the estuary to these wetlands were severed or diminished. Backwaters were reliant on the hydraulic connection to the estuary, and palustrine wetlands in the same locations were reliant on their hydraulic connection to the backwaters. Neither subsurface flow nor inundation recharges were available to the backwaters; therefore, palustrine wetlands had to rely on water purely from external sources, in the form of runoff. Along with these changes, habitat diversity suffered (Gore and Shields Jr. 1995). Palustrine wetland habitats rich in biodiversity changed

Table VI.2: 1948 Palustrine Wetlands Which Became Another Habitat/Landcover by 1991, Estuarine Section

New Habitat/Landcover	Sum Hectares
2Es (estuarine subtidal)	2.8
4Ei (wetland estuarine)	2.0
5 (scrub/shrub)	31.3
7 (forest)	30.2
8 (agriculture)	5.3
9 (urban)	11.4
10 (forested wetland)	19.8

to other habitats or landcover. Most of the change reflects small regional increases inagriculture, urbanization, scrub/shrub habitats, and forest habitats. Long linear palustrine wetlands found directly behind (the landward side) of the dikes decreased in size by 1991, as erosion from agriculture, logging, development, and other watershed activities combined to fill these depressions.

Palustrine wetlands in the estuarine section commonly changed to scrub/shrub habitat between 1948 and 1991 (see Table VI.2). There were 31.3 hectares of palustrine wetlands in 1948 which became scrub/shrub by 1991. Forest followed by forested wetlands accounted for similar minor changes. This small amount of change indicated by Table VI.2 is somewhat misleading, since a comparison revealing 1961 palustrine wetlands which became scrub/shrub in 1991 was much higher. Recall that there were few palustrine wetlands in 1948 against which to compare.

A strict comparison of palustrine wetlands in 1948 and 1991 reveals that this habitat increased in area. Much of the growth was attributed to the succession of

Table VI.3: 1948 Agriculture Which Became Another Habitat/Landcover by 1991, Estuarine Section

New Habitat/Landcover	Sum Hectares
2Es (estuarine subtidal)	11.7
4Ei (wetland estuarine)	1.5
4P (wetland palustrine)	90.6
5 (scrub/shrub)	53.8
7 (forest)	172.0
9 (urban)	170.9
10 (forested wetland)	17.2

estuarine wetlands to palustrine wetlands through sediment trapping. Additionally, newly deposited dredge spoils were partially responsible for increased wetlands. While scrub/shrub habitats were common on filled land, islands largely created by dredge spoils, such as West Sand Island, Lois Island, and Mott Island, support sparsely populated palustrine wetlands. Dredge materials deposited near the mouth of channelized tributary streams, such as at Cullaby Creek, advanced the growth of palustrine wetlands. Finally, the increase may, in part, be attributed to areas of diked floodplains which were abandoned and now support palustrine wetlands. Table VI.3 indicates that 90.6 hectares of agriculture in 1948 became palustrine wetlands by 1991. Therefore, more agricultural land became palustrine wetlands by 1991 than were palustrine wetlands converted to agriculture.

Forested Wetlands

Forested wetlands are largely situated adjacent to or near the estuary and its tributaries. Often, forested wetlands form long linear strips along tributary streams. It is not uncommon for forested wetlands to extend no more than 10 meters on either side of a stream flowing through pasture. Forested wetlands are much less common then either estuarine intertidal or palustrine wetlands. Many of the forested wetlands are located near the estuary and tributary streams because water from theses sources controls the vegetation composition. During periods of high precipitation, exceptionally high tidal influences, and/or spring snow pack melt, forested wetlands may be completely inundated. These wetlands are typically at a sufficiently high elevation that the ground's surface may be dry for most of the year. There are few forested wetlands in this section that are not influenced by the hydraulic link of the estuary or its tributaries. An elevated watertable, a sway or depression, and clay soil pose the most likely conditions for upland forested wetlands. Willows, Sitka Spruce, Red Alder, Ash, and Cottonwoods are common tree species in forested wetlands.

Forested wetlands generally increased in area between 1948 and 1991. The most rapid period of growth was between 1961 and 1973. Before 1948, most of the mature forested wetlands had been removed or greatly disrupted through, diking, draining, logging, and clearing for agriculture (Thomas 1983). However, as diked and drained areas were largely in place before 1948, the initial drastic impact of these actions on forested wetlands is not evident in this analysis. What little decline

Table VI.4: 1948 Forested Wetlands Which Became Another Habitat/Landcover by 1991, Estuarine Section

New Habitat/Landcover	Sum Hectares
1 (barren land)	2.1
4P (wetland palustrine)	8.8
7 (forested)	46.5
8 (agriculture)	19.8
9 (urban)	2.0

forested wetlands experienced was between 1948 and 1961. Interpretation of 1948 forested habitats may have been slightly erroneous, due to the 1948 flood. Floodwaters in forested areas may have remained on the ground's surface, presenting an appearance of forested wetlands. In reality, once the water eventually percolated into the soil or evaporated, forest habitat remained. Because of the regulation of annual flooding, the root zone in forests of these areas may not have been saturated periodically during future growing seasons; therefore, they were not wetlands by definition.

The small decline of forested wetlands can be attributed to one habitat replacing another. Between 1948 and 1991, forested wetlands were most often replaced by forest habitats (see Table VI.4). There were 46.5 hectares of forested wetlands in 1948 which became forest by 1991. Likewise, agriculture accounted for minor changes. There were 19.8 hectares of forested wetlands in 1948 which became agriculture by 1991. The location of these changes was concentrated in the southwest portion of Clatsop Spit (see Figure VI.3).

In total, forested habitats increased by 263.2 hectares. The increase of these habitats was caused by both natural and human influences. As noted before, large tracts of wetlands changed from estuarine intertidal wetlands to palustrine wetlands and then to scrub/shrub habitats. This succession can be attributed to emergent vegetation trapping sediment and increasing its elevation relative to high flows. Channelizing, dredge fill deposition, and watershed erosion accelerated the process of sediment accretion. It is likely that the increases in forested wetlands are an extension of this upland building process.

This theory is best supported by determining what habitat types commonly changed to forested wetlands. The most substantial changes occurred within estuarine intertidal wetlands. There were 102 hectares of estuarine intertidal wetlands in 1948 which changed to forested wetland by 1991. Most of these changes occurred on West Sand Island, Lois Island, Mott Island, along the shoreline south of Tongue Point, and at the mouth of Deep River in Grays Bay. In all cases, regions of theses areas progressed to estuarine intertidal wetlands to palustrine wetlands to forested wetlands or scrub/shrub habitat by 1991. In some areas, the scrub/shrub habitat change to forested wetlands.

An example of the processes which may have increased forested wetlands is as follows: natural mud flats south of Tongue Point began to accumulate additional sediment as a result of increased watershed activities before 1948. Emergent wetland vegetation began to accompany the shoaling. Dredge spoil fills on Tongue Point and on the islands in the vicinity increased the elevation of the emergent wetlands, and palustrine wetlands began to colonize. The accretion of fill material on Tongue Point and its protrusion into the estuary likely increased littoral currents and the subsequent deposition of sediments on its more protected southeast side. Over time, excess water ceased to be the controlling factor in the composition of the vegetation, and scrub/shrub habitats became the dominant cover. If excess water remained the controlling factor on these elevated lands, forested wetlands emerge over a lengthy period of time.

The June freshets which annually flooded the floodplain are largely controlled by many upstream dams. Flood surges no longer inundate the floodplain to the extent of past pre-regulated conditions, except during extremely high precipitation and snow pack thaw events (i.e., the flood of 1948). Emergent wetlands are given the opportunity to grow and progress to other wetland types. In this scenario, early succession wetland species are reduced in number, while late succession species (such as forested wetlands) become more abundant over time. Indeed this pattern of wetland change was commonplace along the entire study site. The increase in forested wetlands was most apparent during the last half of the study period, remaining consistent with the amount of time needed to develop since the flooding of 1948.

Watershed activities, such as logging and agriculture, may have indirectly contributed to minor increases in forested wetlands. There were 62 hectares of

Table VI.5: 1948 Scrub/Shrub Habitat Which Became Another Habitat/Landcover by 1991, Estuarine Section

New Habitat/Landcover	Sum Hectares
1 (barren land)	37.4
2Es (estuarine subtidal)	19.4
2Ll (lacustrine limnetic)	1.4
4Ei (wetland estuarine)	14.3
4P (wetland palustrine)	58.3
7 (forest)	483.6
8 (agriculture)	15.8
9 (urban)	10.5
10 (forested wetland)	62.0

scrub/shrub habitat in 1948 which became forested wetlands by 1991 (see Table VI.5). Scrub/shrub habitats most likely indicate that timber was harvested from the area. Field verification in these sites demonstrated that it was not uncommon for tree limbs, bark, and debris from timber harvests to be pushed into seasonal drainage ditches. Over time, the debris impounded water, forming small, shallow, seasonal ponds. As the trees grew and scrub/shrub habitat returned to forest, pocket forested wetlands in the vicinity of the impoundments often became established.

Agriculture accounted for minor increases in forested wetlands. There were 17.2 hectares of agriculture in 1948 which became forested wetlands by 1991. Pasture land no longer in production was abandoned. Dikes left in ill repair and clogged drainage ditches perpetuated the changes.

Lacustrine Littoral Wetlands

There were no significant changes to lacustrine littoral wetlands in the estuarine section (see Figure VI.1). There were 1.7 hectares of lacustrine littoral wetlands in 1948 and 2.0 hectares in 1991.

Section Two: Riverine Tidal

The riverine tidal section is the largest section in the study site, stretching 124 kilometers. Even though this section is influenced by the ocean to a lesser extent than the estuarine section, many of the changes in wetlands were caused by the same activities previously discussed. The river forms a continuum; thereby, each section of the study site is intricately connected. It would be naive to conclude that the factors which influence wetland changes in the estuarine section only applied to that region. The flood of 1948, upstream damming, and watershed activities had similar impacts on wetlands for the entire study site. Therefore, in those cases where wetland changes occurred because of similar causes, the following discussion will assume that the processes are understood and will be less explanatory.

There are four wetland types found in the riverine tidal section of the LCR. They are: riverine tidal, palustrine, forested, and lacustrine littoral wetlands. The probable cause of the most significant changes these wetlands experienced will be discussed.

Riverine Tidal Wetlands

Wetlands in the estuarine intertidal classification are emergents; similarly, riverine tidal wetlands are composed of emergent plant species. Persistent emergents (plants that are not periodically washed away) are classified as palustrine wetlands. Because the riverine tidal section is large, both physical and biotic conditions vary along its extent. The most apparent differences are those controlled by tidal action. Tidal influences are minimal along the upstream segment, while downstream in Cathlamet Bay, tidal influences are much more pronounced. Generally, there are more riverine tidal wetlands in the more heavily tidal influenced areas.

Shortly following the flood of 1948, riverine tidal wetlands were the first wetland type in this section of the river to become established. Following the receding flood, conditions for rapid riverine tidal wetland growth were ideal. Figure VI.4 illustrates that there were nearly 3,000 hectares of riverine tidal wetlands in 1948; however, by 1961, this amount had dropped to 1,215 hectares. The same trend was noted for estuarine intertidal wetlands. The decline of 1777.6 hectares of riverine tidal wetlands accounts for the majority of all wetland losses in the riverine tidal section. While this decline in wetlands can be partially attributed to the direct and indirect impacts of development, diking, draining, channelizing, and erosional activities, most of the losses were directly accounted for as riverine tidal wetlands changed to other wetland types. Specifically, palustrine wetlands accounted for most of the change. The total number of palustrine wetlands in 1948 was relatively few,

Figure VI.4: Wetland Change, 1948-1991, Riverine Tidal Section

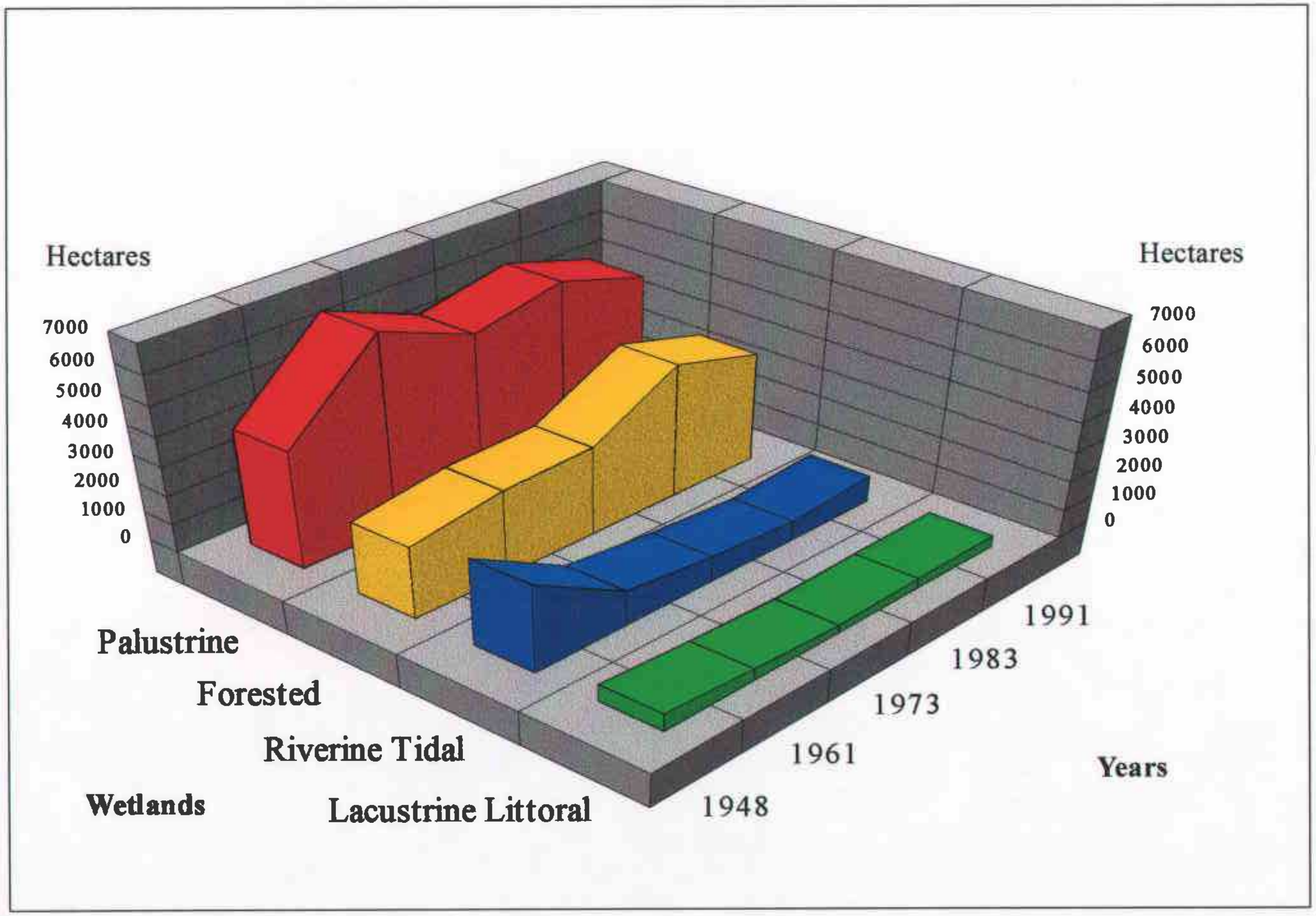


Table VI.6: 1948 Riverine Tidal Wetlands Which Became Another Habitat/Landcover by 1991, Riverine Tidal Section

New Habitat/Landcover	Sum Hectares
1 (barren land)	39.1
2Rt (riverine tidal)	793.3
4P (wetland palustrine)	1064.0
5 (scrub/shrub)	13.0
7 (forest)	56.1
8 (agriculture)	53.8
9 (urban)	38.7
10 (forested wetland)	229.9

yet increased substantially (2644.6 hectares) by 1961. The decline in riverine tidal wetlands reflects the extensive increase in palustrine wetlands.

While it is logical to assume that the decrease in riverine tidal wetlands and the increase in palustrine wetlands were related, it remains an assumption. In order to verify that these events were connected, it must be demonstrated that riverine tidal wetlands changed to palustrine wetlands. Table VI.6 illustrates this point. There were 1,064 hectares of riverine tidal wetlands which changed to palustrine wetlands by 1991. More riverine tidal wetlands changed to palustrine wetlands by 1991 than to any other habitat or landcover. This provides further evidence that regulatory effects on the river contribute to reducing annual flooding and allow emergent vegetation the opportunity to progress to later succession palustrine wetland species.

Downstream, changes to the physical and biological character of the river, floodplain, and near-shore corridor testify to the controversial environmental impacts of Bonneville Dam and other upstream dams (especially those designed for flood control) on the LCR. It is the nature of upstream dams to collect and trap sediment destined for downstream locations. Dams trap sediment in reservoir basins and decrease sediment flow into the ocean. The Aswan High Dam in Egypt traps over 90 million metric tons of silt annually, eliminating the silt enrichment of the Nile floodplains (Petts et al. 1992). Today there are 86 dams on the Columbia River and its major tributaries. Emergent vegetation, such as riverine tidal and estuarine intertidal wetlands downstream from Bonneville Dam, should be deprived of sediment; thereby, the proliferation of wetlands via sediment trapping and accretion would, subsequently, decrease. This process does not hold true on the LCR. Areas within the riverine tidal section, such as Cathlamet Bay, the expanse between the mouths of the Kalama and Cowlitz Rivers, and the vicinity of the mouth of the Lewis River, witnessed an increase in emergent wetlands, palustrine wetlands, and forested wetlands, occurring because of the abundance of sediment in the system. The sediment was largely generated by human activities. Both in-water and watershed activities more than compensated for sediment depletion due to damming. The byproduct of these activities was the inadvertent creation of wetlands. While the upstream dams on the Columbia River and its major tributaries do collect sediment, there is no lack of sediment within the LCR system. According to the Columbia River Estuary Data Development Program (1984), the lower riverine tidal section and the estuarine section combined receive 3.5 million cubic meters of sediment accumulation each year. In 800 years, this region of the LCR would be completely filled with sediment. Clearly, this rate of sediment deposition is abnormally high and can be attributed to human impact on the natural state of the river.

By 1961, riverine tidal wetlands had declined abruptly. These wetlands were generally not replenished by annual flooding. There were, however, minor increases in riverine tidal wetlands following the rapid growth of these wetlands only months after the 1948 flood. Flats which were in shallow water in 1948, especially at or near the mouth of tributary streams, experienced sediment deposition and often formed emergent wetland colonies. Despite small localized increases in riverine tidal wetlands, Figure VI.3 clearly illustrates that these wetlands sharply declined between 1948 and 1961 and then leveled out to a limited reduction between 1961 and 1991. The period between 1948 and 1961 reveals that riverine tidal wetlands decreased by 1777.6 hectares; yet, between 1961 and 1991, they declined by merely 325.7 hectares. The fact that there were no significant variations in riverine tidal wetlands, (rapid increases followed by steady declines) indicates that emergent wetlands were negatively impacted by discharge and flow regulation imposed upon riverflow. As these early successional wetlands continue to change to other habitat types or are directly replaced by an urban or agricultural landcover, riverine tidal wetlands will become increasingly scarce.

With one exception, there were no significant changes where another habitat or landcover became riverine tidal wetlands. There were 68.3 hectares of palustrine wetlands, 23.1 hectares of barren land, 14.1 hectares of forested wetland, 6.6 hectares of agriculture, and 4.2 hectares of urban in 1948 which became riverine tidal wetlands by 1991. These changes were minor and demonstrate that riverine tidal wetlands are not being replenished as they once were. The exception arises from open water riverine tidal habitats changing to riverine tidal wetlands. The process of shoaling in response to large sediment loads within the riverine tidal habitat classification produced the most significant increase in riverine tidal wetlands. Shorelines where dredge spoils were deposited, likewise, contributed to the increase, but to a lesser degree. There were 398.2 hectares of riverine tidal habitat in 1948 which changed to riverine tidal wetlands by 1991.

Channelizing and dredge spoil deposition were responsible for both an increase in estuarine wetlands in some areas (i.e., newly formed or expanded islands) and a decrease in wetlands in other areas. Generally such activities accounted for many more losses than gains. In 1960 the Cowlitz River channel was dredged to 2.7 meters. The loss of riverine tidal wetlands near the mouth of the Cowlitz which appeared in Figure V.14 occurred due to dumping channel dredge material along nearby shallow shorelines. In 1962, it was determined that the LCR needed a deeper main channel. By 1976, the main channel extending from the river's mouth to Portland/Vancouver was dredged to 12.2 meters. The Oregon slough and 18.5 kilometers upstream on the Willamette from the Columbia were, likewise, deepened to 12.2 meters by 1972 (U.S. Army Corps of Engineers 1996). Island and shoreline deposition of dredge material not only contributed to increasing sediment levels in the river, but to the direct filling of shallow emergent wetlands. There were no discernible riverine tidal wetland losses near the mouth of the Willamette River due to channelizing, as the landcover in this area was extensively diked by 1976. Riverine tidal wetlands had already been converted to agriculture.

Another factor which contributed to increased levels of sediment in the riverine tidal section and which both increased and decreased riverine tidal wetlands was the eruption of Mount St. Helens. Mudflows choked the lower Cowlitz River and the Cowlitz/Columbia confluence. Emergent and palustrine wetlands alike were completely buried by this extreme event. Figure V.18 displays extensive deposition of sediment forming barren land habitats. In 1983, between 5 and 11 million cubic meters of material was dredged from the confluence of the Cowlitz and Columbia River (U.S. Army Corps of Engineers 1996). By 1991, most sand barrens along the banks and in the Columbia River which formed in 1980 had changed to palustrine wetlands. Riverine tidal wetlands were found along the margins of the palustrine wetlands. Areas of deposition which had not changed to wetlands remained barren or changed to scrub/shrub habitat.

Palustrine Wetlands

Despite periodic declines in palustrine wetlands and constant decreases in riverine tidal wetlands and lacustrine littoral wetlands, the riverine tidal section of the LCR experienced a 1% increase in wetlands. The growth of palustrine and forested wetlands accounted for the increase. Palustrine wetlands increased between 1948 and 1991 by 1122.1 hectares. Before declining between 1961 and 1973, palustrine wetlands grew by 2644.6 hectares between 1948 and 1961 (see Figure VI.4).

Following the flood of 1948, many palustrine wetlands were washed away, degraded, or filled. The rapid increase in palustrine wetlands between 1948 and 1961 reflected a period of recovery. This time frame represented the greatest increase in wetlands for the riverine tidal section. Palustrine wetlands increased by 2644.6 hectares by 1961. In all wetland types combined, every other increase scarcely exceeded this amount. This large increase supports the theory that palustrine wetlands were recovering from an extreme event. Early succesion riverine emergents were changing to palustrine wetlands. Between 1948 and 1991, 1064 hectares of riverine tidal wetlands changed to palustrine wetlands. It could be assumed that, between 1948 and 1961, this amount was even greater. Most of the changes from riverine tidal wetlands to palustrine wetlands took place in Cathlamet Bay and entirely within the active channel of the river (see Figure VI.5). Increased sedimentation due to channel scouring, watershed activities and dredge disposal, coupled with the minimization of June freshet flooding provided the conditions for the change. Following 1961, there were few fluctuations in the general decrease of palustrine wetlands, indicating that upstream dams were successfully limiting downstream floods.

Figure VI.5: 1948 Wetland Habitats Which Became Another Habitat/Landcover by 1991, Riverine Tidal Section

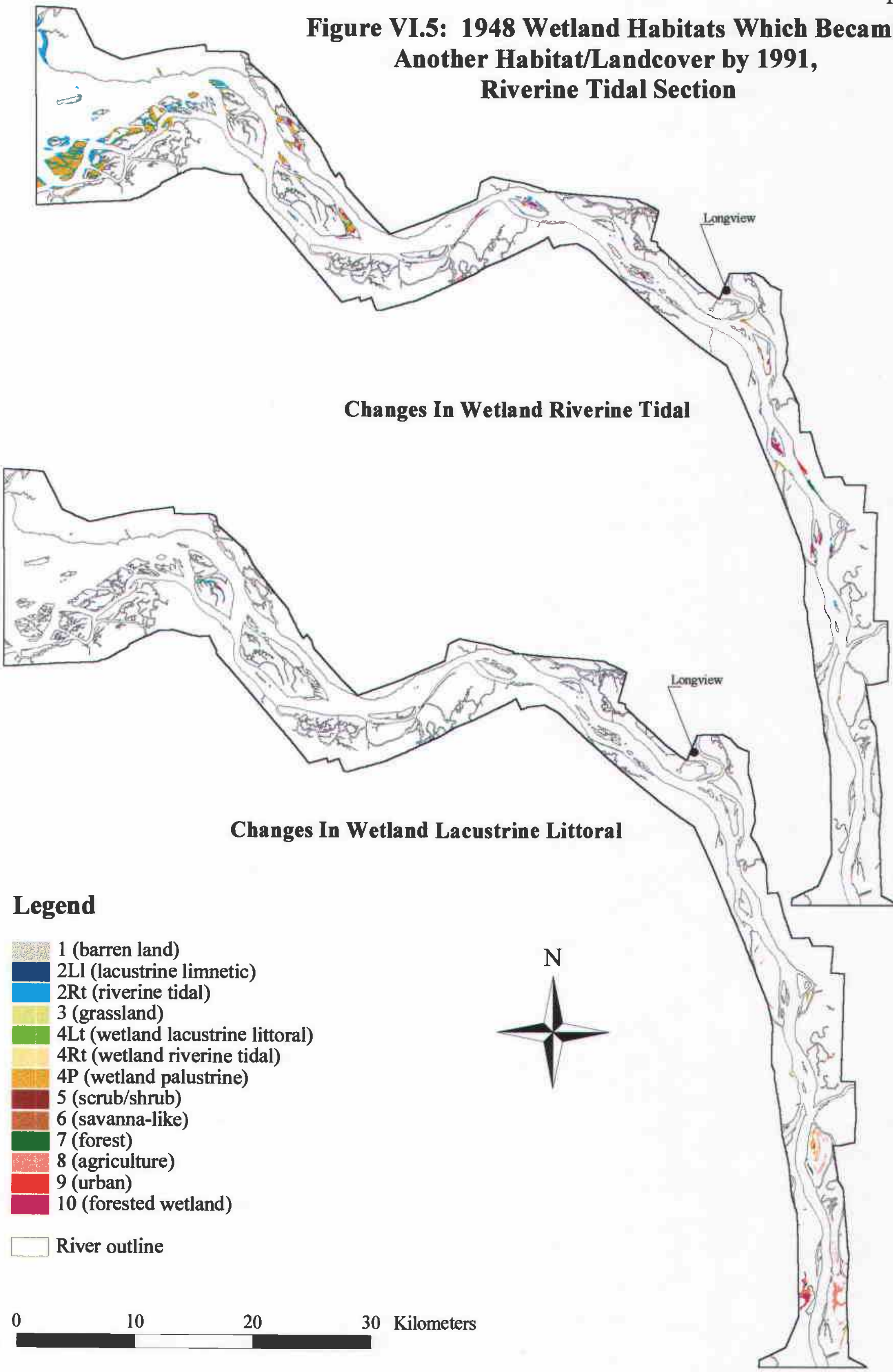


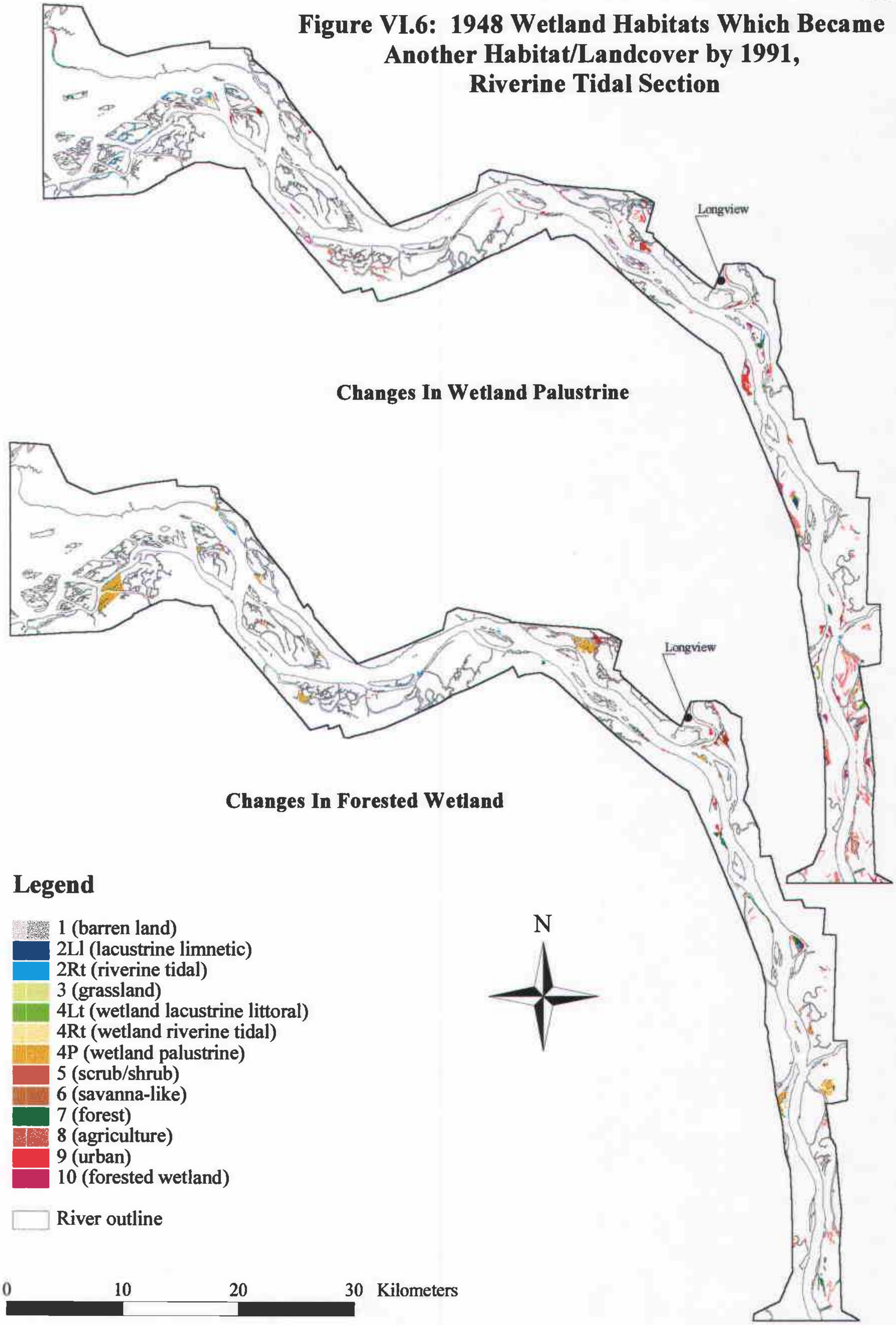
Table VI.7: 1948 Palustrine Wetlands Which Became Another Habitat/Landcover by 1991, Riverine Tidal Section

New Habitat/Landcover	Sum Hectares
1 (barren land)	133.2
2Ll (lacustrine limnetic)	31.4
2Rt (riverine tidal)	120.6
4Lt (wetland lacustrine littoral)	61.7
4Rt (wetland riverine tidal)	68.3
5 (scrub/shrub)	77.6
7 (forest)	116.5
8 (agriculture)	1098.8
9 (urban)	224.8
10 (forested wetland)	309.4

Between 1961 and 1991, palustrine wetlands generally decreased, with the exception of an increase between 1973 and 1983. In total, palustrine wetlands decreased by 1522.5 hectares between 1961 and 1991. Had the flood of 1948 not occurred, it is likely that palustrine wetlands would have decreased from 1948 rather than from 1961, at the fairly consistent rate demonstrated between 1961 and 1991. There were many factors which contributed to the decline of palustrine wetlands. In order to determine the causes of change, exactly to what habitat or landcover palustrine wetlands changed must be ascertained (see Table VI.7).

Agriculture had the greatest impact on the decline of palustrine wetlands. There were 1098.8 hectares of palustrine wetlands in 1948 that changed to agriculture by 1991. Figure VI.6 displays the exact locations where palustrine wetlands were replaced by agriculture. The majority of the change was located in the southern portion of the section, and within this region, much of the change was situated along

Figure VI.6: 1948 Wetland Habitats Which Became Another Habitat/Landcover by 1991, Riverine Tidal Section



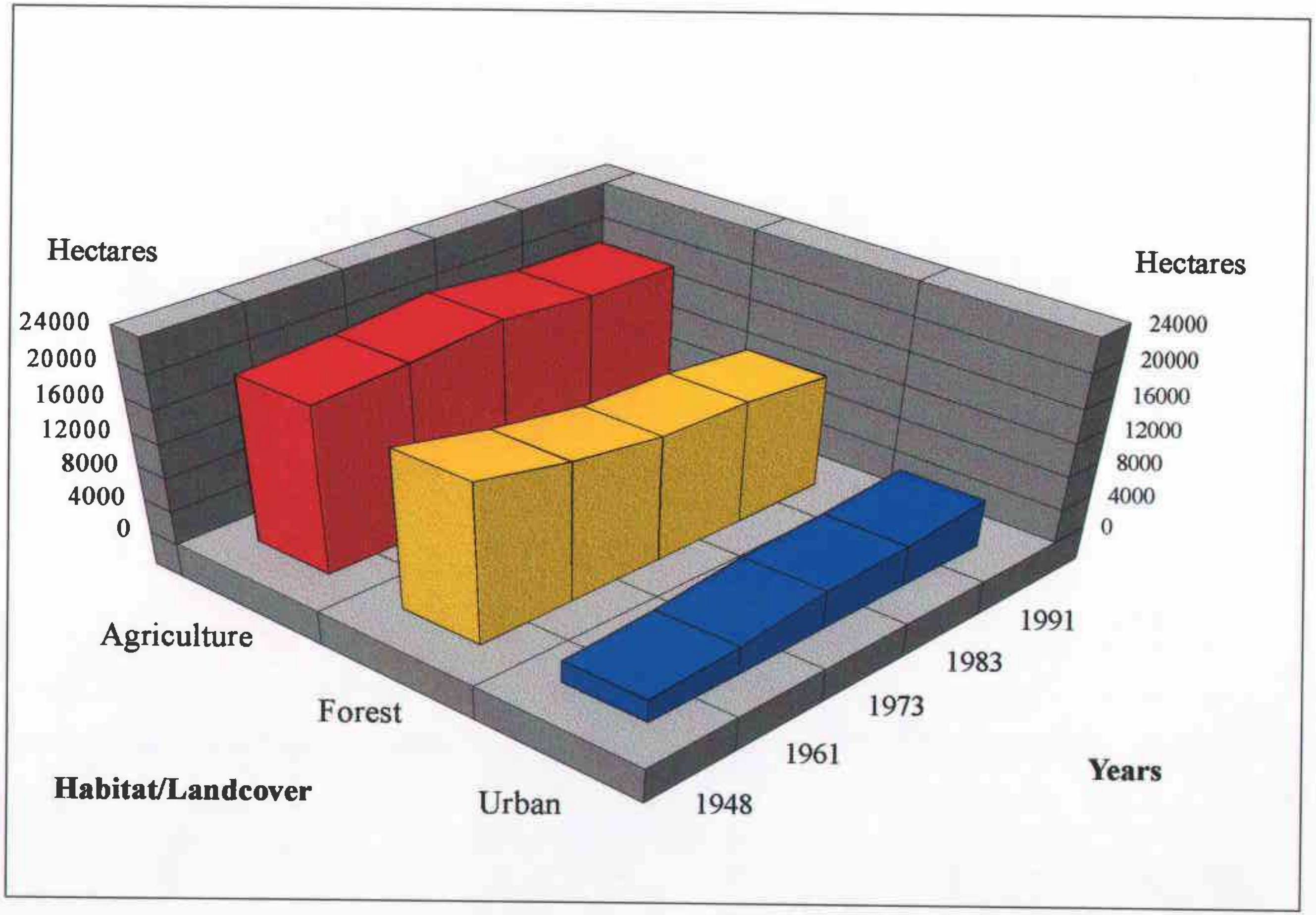
small creeks and canals. Recall that there were considerably fewer wetlands in 1948 than in 1961; therefore, it could be assumed that, in reality, there were far greater losses of palustrine wetlands to agriculture than 1098.8 hectares. Unlike the estuarine section, agriculture in the riverine tidal section was on the increase. In the estuarine section, merely 1.3 hectares of palustrine wetlands in 1948 changed to agriculture. This trend was suspected to remain true for all sections of the LCR, as agriculture across the United States has generally declined over the past 30 years. Farmers were attracted to the riverine tidal and estuarine section of the LCR because of the rich black soil. By 1939, many of the wetlands adjacent to the river had been drained for crop and pasture land.

According to a study produced by the Sea Grant at Oregon State University (1982), the LCR riparian zone was not well suited for farming. The land could not support the numerous and demanding agricultural practices expected of it. Farming became marginally profitable, and many farms suffered and eventually folded (Larison 1982). Certainly, these events were factual (especially in the lower estuarine section), but it appears that as some, possibly family farms collapsed, new agricultural land was brought into service. In the riverine tidal section, much of the new farmland was used for grazing, rather than intensive garden farming. Palustrine wetlands were more heavily impacted by agriculture than were other wetland habitats, because they were relatively abundant and were more easily converted (Thomas 1983). The proximity of palustrine wetlands to the river fostered greater terrestrial qualities than aquatic, making them easier to dike and drain than emergent wetlands.

Forested wetlands claimed the second largest decline in palustrine wetlands. There were 309.4 hectares of 1948 palustrine wetlands that changed to forested wetlands. Forested wetlands are later stage succession habitats than are palustrine wetlands. Wetland succession in the active channel of the river was largely reset following the flood of 1948. As flooding since this time has been greatly controlled, palustrine wetlands, many of which changed from emergent wetlands, became forested wetlands. In those cases where shallow wetlands were buried by excessive deposition of sediment, palustrine wetlands were likely to have emerged for a short time until the hydraulic link was compromised. As shown in the estuarine section, palustrine wetlands often changed to scrub/shrub or forest habitats once the hydraulic link was broken. The same trend remains true in this section. Many hectares of palustrine wetlands which did not become forested wetlands changed to scrub/shrub and forest habitats. In 1948, there were 116.5 and 77.6 hectares respectively of palustrine wetlands which changed to forest and scrub/shrub habitats by 1991.

Urbanization directly displaced 224.8 hectares of palustrine wetlands. The growth of the urban landcover is illustrated in Figure VI.7. Between 1948 and 1991, urban development grew from 2664.7 hectares to 5624.6 hectares. Urbanization in the estuarine section increased by 328.4 hectares, indicating minimal population growth. Urbanization in the riverine tidal section mostly occurred as a result of

Figure VI.7: Habitat/Landcover Change, 1948-1991, Riverine Tidal Section



existing urban areas expanding. Areas adjacent to Longview experienced significant change. Highway construction and subsequent corridor urbanization along the river accounted for much of the palustrine wetland losses.

There were numerous lesser factors which perpetuated the decline of palustrine wetlands. In 1948, there were 133.2 hectares of palustrine wetlands which changed to barren land by 1991. Excessive sediment deposition at the mouth of tributary streams and protected slow or slack current zones, coupled with dredge spoil deposition from channelization were the most probable causes for barren land proliferation. Miller Island was a dredge spoil deposition site. The outside margins of this island changed from palustrine wetlands to barren land in response to spoil deposition. By 1991, the interior would most likely be uniformly upland scrub/shrub, if not for an active on-site restoration program. The changing dynamics of the river, both natural and human-induced, were responsible for 120.6 hectares of 1948 palustrine wetlands becoming riverine tidal habitat. These palustrine wetlands were submerged by 1991. Few areas of palustrine wetlands experienced reversed succession. In 1948, there were 68.3 hectares of palustrine wetlands that changed to riverine tidal wetlands by 1991. By regulating flood events, emergent wetlands were not reestablished in areas adjacent to or near the river, allowing palustrine wetlands to eventually change to other later succession habitats.

Another period of significant increase in palustrine wetlands occurred between 1973 and 1983. Palustrine wetlands grew by 615.1 hectares. This increase was uncharacteristic. After 1961, all wetlands, except for forested wetlands, generally declined. This trend was true for both the estuarine section and the riverine tidal section. Had a major flood occurred, the growth of palustrine wetlands following the event would explain the changes. Large floods were not heavily regulated during this time frame; thus, the explanation lies elsewhere. The reason for these changes, in fact, largely explains why the riverine tidal section experienced an overall 1% growth in wetlands. Currently, there are four locations on the riverine tidal section which have been set aside for wildlife protection. They are: the Lewis and Clark National Wildlife Refuge (river kilometers 27-58), the Julia Butler Hansen Wildlife Refuge for the Columbia White-tailed Deer (river kilometers 56-61), the Ridgefield National Wildlife Refuge (river kilometers 140-150), and the Sauvie Island Wildlife Management Area (river kilometers 138-161). Two of these wildlife areas were largely responsible for the increase in palustrine wetlands between 1973 and 1983.

The Lewis and Clark National Wildlife Refuge was established in 1971, and the Julia Butler Hansen Wildlife Refuge was established in 1972. Historically, portions of both refuges were diked for agricultural purposes -- extensively in the Lewis and Clark National Wildlife Refuge. Areas which were not often inundated by annual flooding and could be converted to agricultural land were diked and drained. By the 1960's, agricultural land on the islands that would later become the Lewis and Clark National Wildlife Refuge was in disuse. A section of 119 hectares of agricultural land on Karlson Island which had been agriculture in 1948 and 1961, changed to palustrine wetlands by 1973, indicating that, even before the island was converted to a refuge, the land was falling into disuse. As both refuges were established in the early 1970's, the impacts of passive restoration were visible by 1983. Over time, agricultural land left in disuse reverted to wetlands. Because the areas which were restored by 1983 were diked and converted to uplands, palustrine wetlands were reestablished, rather than emergent riverine tidal wetlands. The outer margins of the refuge's islands were likely to have become riverine tidal wetlands as wetlands first became reestablished.

Figure VI.7 indicates that agriculture experienced minor changes between 1948 and 1991. The greatest fluctuation occurred between 1973 and 1983, and, as expected, agriculture decreased. Within the refuges, over 600 hectares of agricultural land was converted to palustrine wetlands. Most of the change occurred on Tenasillahe Island. Between 1973 and 1983, agriculture decreased by 1012.2 hectares. The remainder of change within the refuges constituted approximately 200 hectares. These changes were from agriculture to forested wetlands, forest, scrub/shrub, and an occasional emergent wetland. Essentially, 800 hectares of 1012.2 hectares of agricultural change were accounted for in the two wildlife refuges.

Interestingly, the single greatest cause for the decline of palustrine wetlands between 1948 and 1991 was agriculture (1098.8 hectares). Yet, agriculture was attributed as the cause for an increase of 891.2 hectares to palustrine wetlands during

Table VI.8: 1948 Agriculture Which Became Another Habitat/Landcover by 1991, Riverine Tidal Section

New Habitat/Landcover	Sum Hectares
1 (barren land)	18.3
2Ll (lacustrine limnetic)	9.6
2Rt (riverine tidal)	155.1
3 (grassland)	12.0
4Lt (wetland lacustrine littoral)	20.9
4Rt (wetland riverine tidal)	6.6
4P (wetland palustrine)	891.2
5 (scrub/shrub)	107.1
6 (savanna-like)	62.6
7 (forest)	563.2
9 (urban)	1679.1
10 (forested wetland)	218.4

the same period (see Table VI.8). Approximately 600 hectares of the 891.8 hectare increase were located in the refuges. Based upon this trend, it would be reasonable to assume that agricultural land not set aside for wildlife protection experienced minimal change to wetland habitats. This further implies that agricultural land was in use in the riverine tidal section. As a percent of total area, more agricultural land in the estuarine section fell into disuse and experienced change to wetlands, than in the riverine tidal section.

The refuges provide wetland habitat that supports a variety of wildlife, including state and federal listings of threatened and endangered species. In the riverine tidal section, the establishment of the refuge systems mitigated the loss of wetlands. While wetlands generally decreased across the section, concentrated locations of mainly palustrine wetlands in the refuges were largely responsible for increasing wetlands to the extent that the entire section posted a 1% increase.

Forested Wetlands

Forested wetlands steadily increased from 1948 to 1991. The period of most rapid growth occurred between 1973 and 1983 (see Figure VI.4). While other wetland types generally decreased throughout the study period, it was a common phenomenon for forested wetlands to increase along the entire LCR.

Forested wetlands suffered losses between 1948 and 1991 roughly comparable to rates of losses by estuarine and palustrine wetlands. However, unlike other wetlands, the rate of increase experienced by forested wetlands exceeded the rate of decrease. There were 1256.0 hectares of 1948 forested wetlands which changed to other habitats by 1991 (see Table VI.9). Between 1948 and 1983, forested wetlands increased by 2108.5 hectares. From 1983 to 1991, forested wetlands declined.

There were multiple factors which led to the increase in forested wetlands. As previously discussed, the flood of 1948 essentially reset succession for emergent wetlands and for palustrine wetlands within the flood's inundation zone. In the riverine tidal section, much as in the estuarine section, emergent wetlands often changed to palustrine wetlands and then to either forested wetlands or scrub/shrub habitat. By mitigating flood events, Willow, Oregon Ash, Cottonwood, Red Alder, Big Leaf Maple, Vine Maple, and Sitka Spruce grew in locations which were

Table VI.9: 1948 Forested Wetlands Which Became Another Habitat/Landcover by 1991, Riverine Tidal Section

New Habitat/Landcover	Sum Hectares
1 (barren land)	18.7
2Rt (riverine tidal)	42.6
4Lt (wetland lacustrine littoral)	17.8
4Rt (wetland riverine tidal)	14.1
4P (wetland palustrine)	561.3
5 (scrub/shrub)	80.1
7 (forest)	125.3
8 (agriculture)	295.3
9 (urban)	100.8

historically too unstable. Willow populations were the most common species found in forested wetlands. Willows adapt and grow quickly. Between 1948 and 1991, such later succession plant species had ample time to grow.

Sedimentation and subsequent accretion may have also contributed to the growth of wetlands. In 1948, there were 311 hectares of open water riverine tidal habitat which changed to forested wetlands by 1991. Watershed activities, such as timber harvesting, agriculture, and urbanization, contributed large amounts of sediment into the river. The rapid growth of the Portland/Vancouver suburbs and satellite cities upstream were responsible for rampant erosion of soil from construction sites which was washed into drainage ditches and ultimately washed into the river. Soil compaction in the urban environment and subsequent overland flow likewise contributed to the process of erosion and sediment transport. Willow and other forested wetland vegetation species were established over time on several sediment deposition sites.

Slightly more forested wetlands were displaced by agriculture than were replaced. In 1948 there were 295 hectares of forested wetlands which were replaced by agriculture by 1991. Conversely, there were 218 hectares of 1948 agriculture which became forested wetland. Given the opportunity, agricultural land which was historically wetland and left in disuse reverted to wetlands if hydraulic connectivity was restored.

There were multiple locations along the riverine tidal section where forest and scrub/shrub habitats were displaced by forested wetlands. Formerly, upland habitats inundated or exposed to a source of water displayed the ability to adapt. Channelization, dredge spoil deposition, near shore road construction, and shoaling contributed to wetland destruction; however, they were sometimes responsible for inadvertent hydraulic changes which fostered wetland creation. Water tolerant vegetation, such as Willow and Cottonwood, adapted to wetter conditions, thereby increasing forested wetlands. Locations where forested wetlands grew from forest and scrub/shrub habitats were situated near the river.

Finally, forested wetlands in the riverine tidal section increased because of wildlife protection areas. Forested wetlands grew relatively slowly between 1948 and 1973. During this period they increased by 567.8 hectares; yet, between 1973 and 1983, forested wetlands grew rapidly by 1540.7 hectares. There were three reasons for this slower start, followed by rapid growth. First, forested wetlands did not need to recover from the flood of 1948, as did emergent and palustrine wetlands. Forested wetlands were hearty, more stable, and often located further from the destructive forces of the flood. Unlike palustrine wetlands, a rapid increase between 1948 and 1961 did not occur for forested wetlands. Second, the time required to establish a functioning forested wetland was greater than that needed for emergent and palustrine wetlands. In those cases where emergents changed from palustrine wetlands to forested wetlands, a significant span of time was required. By 1973 the impacts of these changing wetlands were apparent in the form of rapidly increasing forested wetlands. Third, forested wetlands increased between 1973 and 1983 because the Lewis and Clark National Wildlife Refuge and the Julia Butler Hansen National Wildlife Refuge were established. Dikes, levees, and jetties were long in disrepair, as agriculture became less productive in these areas. Non-wetland habitats which were historically wetlands held in check by these devices flourished within years of the refuges' openings in 1971 and 1972. By 1983, palustrine wetlands and forested wetlands had reclaimed most of the lowland agriculture. At the onset of recovery, palustrine wetlands tended to dominate the wetland vegetation rather than emergents; therefore, the recovery time to later climax vegetation was likely shortened. The rapid reestablishment of many of the areas in the refuges to wetlands perpetuates the possibilities of passive restoration.

While forested wetlands in the riverine tidal section largely increased, decreases did occur. Table VI.9 illustrates how forested wetlands were displaced. Most forested wetlands were displaced by palustrine wetlands. Logically, palustrine wetlands should change to forested wetlands, not the other way around. The most likely reason for these changes was agriculture. In nearly all cases where forested wetlands were displaced by palustrine wetlands, the location of change was adjacent to agricultural land. Perhaps the proximity of agriculture to forested wetlands perpetuated hydraulic change. Following palustrine wetlands, agriculture had the second largest impact on displacing forested wetlands. Agriculture directly replaced 295 hectares of forested wetlands by 1991. Forest, urban, and scrub/shrub, likewise, displaced significant amounts of forested wetlands by 1991.

Lacustrine Littoral Wetlands

Lacustrine littoral wetlands are shallow wetlands which extend from the shore to the non-persistent emergent deepwaters of the lacustrine limnetic system. Lacustrine littoral wetlands experienced minor changes between 1948 and 1991 (see Figure VI.4). Lacustrine wetlands slowly and consistently decreased. These wetlands were intrinsically tied to changes to lacustrine limnetic habitats. A decline in lacustrine littoral wetlands reflected change in lacustrine limnetic habitats. There were 595.6 hectares of lacustrine littoral wetlands in 1948. By 1991, there were

Table VI.10: 1948 Lacustrine Littoral Wetlands Which Became Another Habitat/Landcover by 1991, Riverine Tidal Section

New Habitat/Landcover	Sum Hectares
2Ll (lacustrine limnetic)	13.9
2Rt (riverine tidal)	24.8
4P (wetland palustrine)	61.6
7 (forest)	6.7
8 (agriculture)	288.5
10 (forested wetland)	66.1

376.3 hectares. Similarly, lacustrine limnetic habitats decreased. In 1948, there were 1006.7 hectares of lacustrine limnetic habitat, which decreased 486 hectares by 1991.

Agriculture was by far the chief cause of lost lacustrine littoral wetlands. In 1948, there were 288 hectares of lacustrine littoral wetlands which were displaced by agriculture by 1991 (see Table VI.10). This amount exceeds the total change measured between 1948 and 1991 by 68 hectares. There were 219.3 hectares of total lacustrine littoral wetland change during this period. The net result in the case of lacustrine littoral wetlands was a decrease. Nearly all of the changes from agriculture to lacustrine wetlands occurred in the southern portion of the section along Sturgeon Lake, northern Vancouver Lake, and numerous other smaller lakes found in the vicinity. Dikes, drainage ditches, and levees were prominent features on the cultural landscape. After accounting for the impacts of agriculture, changes from lacustrine littoral wetlands to other wetland habitats were most common. There were 66.1 and 61.6 hectares respectively of lacustrine littoral wetlands which changed to forested wetlands and palustrine wetlands by 1991.

Table VI.11: 1948 Lacustrine Limnetic Which Became Another Habitat/Landcover by 1991, Riverine Tidal Section

New Habitat/Landcover	Sum Hectares
1 (barren land)	1.1
2Rt (riverine tidal)	8.8
4Lt (wetland lacustrine littoral)	158.2
4P (wetland palustrine)	96.4
7 (forest)	5.1
8 (agriculture)	284.8
9 (urban)	27.3
10 (forested wetland)	19.6

Increases in lacustrine littoral wetlands were negligible and are not visible on the Figure VI.3 area chart. Lacustrine limnetic habitat accounted for 56.2% of all increases in lacustrine littoral wetlands. In 1948, there were 158.2 hectares of lacustrine limnetic habitat which changed to lacustrine littoral wetlands (see Table VI.11). Increased sedimentation into the deeper waters of the lakes and irrigation drawdown were the most likely causes for this change. As lake water became more shallow, emergent vegetation grew.

Nearly 22% of the increase in lacustrine littoral wetlands was accounted for, as 61.7 hectares of 1948 palustrine wetlands became emergent lake vegetation by 1991 (see Table VI.7). Barren land, agriculture, and forested wetlands combined contributed to the remainder of the change. These habitats and landcover consisted of 61.8 hectares in 1948, and, by 1991, were lacustrine littoral wetlands. Perhaps changes in the lakes' water level caused by varying precipitation events, irrigation draw, and dyking provided barren areas which were historically wetlands with a source of water. Thereby, emergent lacustrine littoral wetlands once again grew. Agriculture was responsible for far greater losses to lacustrine wetlands than gain. Only 20.9 hectares of agriculture became lacustrine littoral wetlands by 1991.

Section Three: Riverine Lower Perennial

The riverine lower perennial section is 72 kilometers in length, extending from the upstream boundary of the riverine tidal section to Bonneville Dam. The geomorphology of this section varies greatly from that of the estuarine and riverine tidal section. The riverine lower perennial section is more confined than the other sections. From Bonneville Dam downstream to the Sandy River, the topography adjacent to the river is often rugged and steep. The floodplain in this section is smaller, and the river is naturally more channelized. Downstream from the Sandy River, the Columbia becomes less confined, opening into the lowlands of Portland and Vancouver. The floodplain is wider and more conducive to settlement.

The varied geomorphology of this section impacts the growth and distribution of wetland habitats. There are fewer wetlands in the more confined upstream area than in the broader downstream floodplain. Steep well-drained soils foster less suitable conditions for wetlands to become established and grow. As a percent of total area, there are fewer wetlands in this section than in the other two sections. Likewise, there are fewer islands in this section. In the estuarine and riverine sections, islands proved to harbor significant wetland populations.

There are four wetland types found in the riverine lower perennial section of the LCR. They are: riverine lower perennial, palustrine, forested, and lacustrine littoral. The principal cause for wetland losses was urban development. Unlike the estuarine and riverine sections, the riverine lower perennial section experienced extensive urbanization. This single factor displaced more wetlands than all other causes of change combined.

Riverine Lower Perennial Wetlands

As a percent of total area, there were fewer riparian emergents in the lower perennial section than in the estuarine and riverine tidal sections. In the estuarine and riverine tidal sections, estuarine intertidal and riverine tidal wetlands were more readily established on the expansive, low gradient floodplain adjacent to the river and in those areas where the current generally slowed to allow for colonization. Protected bays, inlets, and islands were ideal locations. These lowland features were less common in the riverine tidal section. Subsequently, so were riverine lower perennial wetlands.

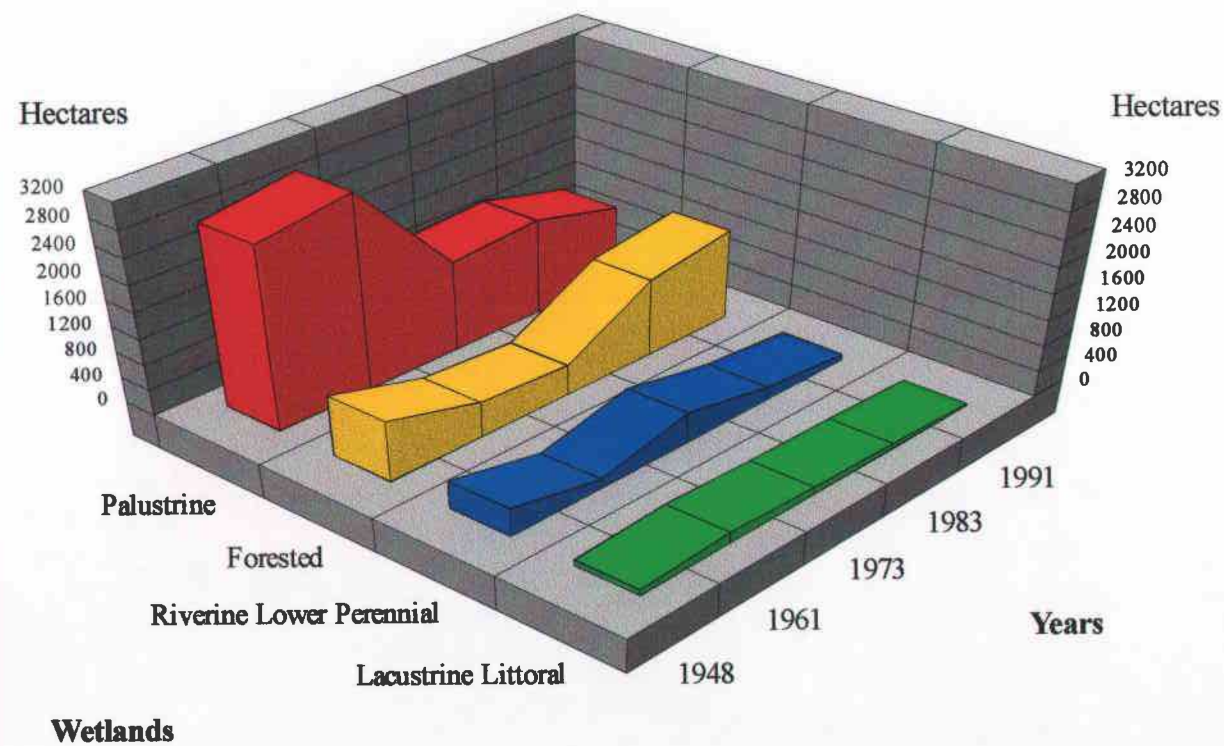
The upstream half of the riverine lower perennial section is largely confined. The hydraulic connectivity of the river to the adjacent terrain was cut off via rapid near-shore elevation gains. The placement of roads on the comparatively smaller floodplain of both sides of the river served to sever hydraulic linkage between aquatic and terrestrial environments more abruptly than the nearby natural elevation gain.

Therefore, there was less suitable space for riverine lower perennial wetlands to colonize.

The downstream half of the riverine lower perennial section begins to become less confined and has a wide floodplain, much like the riverine tidal section. Topographic elevation gain is much more gradual before changing into low foot-hills. This lower portion of the section should support riverine lower perennial wetlands based upon favorable physiographic conditions and its similarities with the adjacent tidal section which maintained such emergent vegetation. By 1948, the land in this region had been so impacted by urbanization and agriculture, that few emergent wetlands remained. The hydraulic connectivity between the river and the adjacent land was severely diminished; therefore, riverine lower perennial wetlands which rely on the river as a primary source of water decreased. Upland palustrine wetlands were the most common wetland found in the region. This wetland type depends less upon the river for a constant source of water. By 1991, there were virtually no riverine lower perennial wetlands in the highly urban region. Of the 86.6 hectares of riverine lower perennial wetlands located in the section in 1991, 96% of these were found in the sparsely populated upstream half.

There were 435.1 hectares of riverine lower perennial wetlands in 1948, which sharply decreased to 136.7 hectares by 1961 (see Figure VI.8). In comparison to the other sections, the 435.1 hectares of riverine emergent wetlands located in this section represented a small amount. Despite incorporating less area than the riverine lower

Figure VI.8: Wetland Change, 1948-1991, Riverine Lower Perennial Section



perennial section, the estuarine section contained far more river-related emergent type wetlands. Between 1961 and 1973, riverine lower perennial wetlands experienced their only significant increase. From 1973 to 1991, these wetlands steadily declined.

All river-related emergent type wetlands experienced major losses between 1948 and 1961, while palustrine wetlands increased during the same period. Even though this pattern remained true for riverine lower perennial wetlands, both the increase and decrease represented comparatively smaller changes. Following the flood of 1948, riverine emergents quickly regenerated. Riverine lower perennial wetlands grew onto the floodplain and inhabited formerly more upland palustrine habitats. Shortly after this period of expansion, these wetlands began to decline and were found mostly within the active channel of the river. Perhaps the smaller decline in riverine lower perennial wetlands and subsequent limited increase in palustrine wetlands between 1948 and 1961 was minimized, due to this section's closer proximity to upstream dams. In the wake of the 1948 flood, fewer riverine emergents were established. Additionally, the changes to these wetlands may have been minimized, because there were fewer riverine lower perennial wetlands in the section. Significant changes were difficult to detect because there were relatively few wetlands of this type in 1948.

There were numerous minor factors affecting the decline of riverine lower perennial wetlands; however, a single overriding factor was primarily responsible. Urban development displaced most of the 1948 wetlands in the section, and riparian emergents were no exception. Between 1948 and 1991, urban growth was constant and rapid (see Figure VI.9). In 1948, there were 3451.0 hectares of urban area, and in 1991, there were 8850.7 hectares. At 5399.7 hectares of growth and subsequent habitat and landcover displacement, a portion of the displaced habitat was riverine lower perennial wetlands. There were 84.5 hectares of 1948 riverine lower perennial wetlands which were displaced by urban development by 1991 (see Table VI.12). Urbanization was not responsible for displacing as much of this wetlands type as it was for displacing palustrine and forested wetlands. Urbanization caused more than 1000 hectares of palustrine wetland decline. By 1948, the riparian emergents in this section were typically located well inside of the active channel. Such sites were not ideal for urbanization; thus, losses of these wetlands were by other causes. However, riparian emergents closer to the banks of the Columbia and its tributaries were displaced.

There were 83 hectares of 1948 riverine lower perennial wetlands which changed to palustrine wetlands by 1991. Figure VI.10 illustrates these changes. The location of greatest change occurred on historically more transitional alluvial deposits adjacent to the river and north of Troutdale. The change from emergents to palustrine wetlands was common in all sections of the study. There were 81 hectares of riverine lower perennial wetlands which changed to forested wetlands by 1991. Riverine lower perennial wetlands generally changed to palustrine wetlands and then to

Figure VI.9: Habitat/Landcover Change, 1948-1991, Riverine Lower Perennial Section

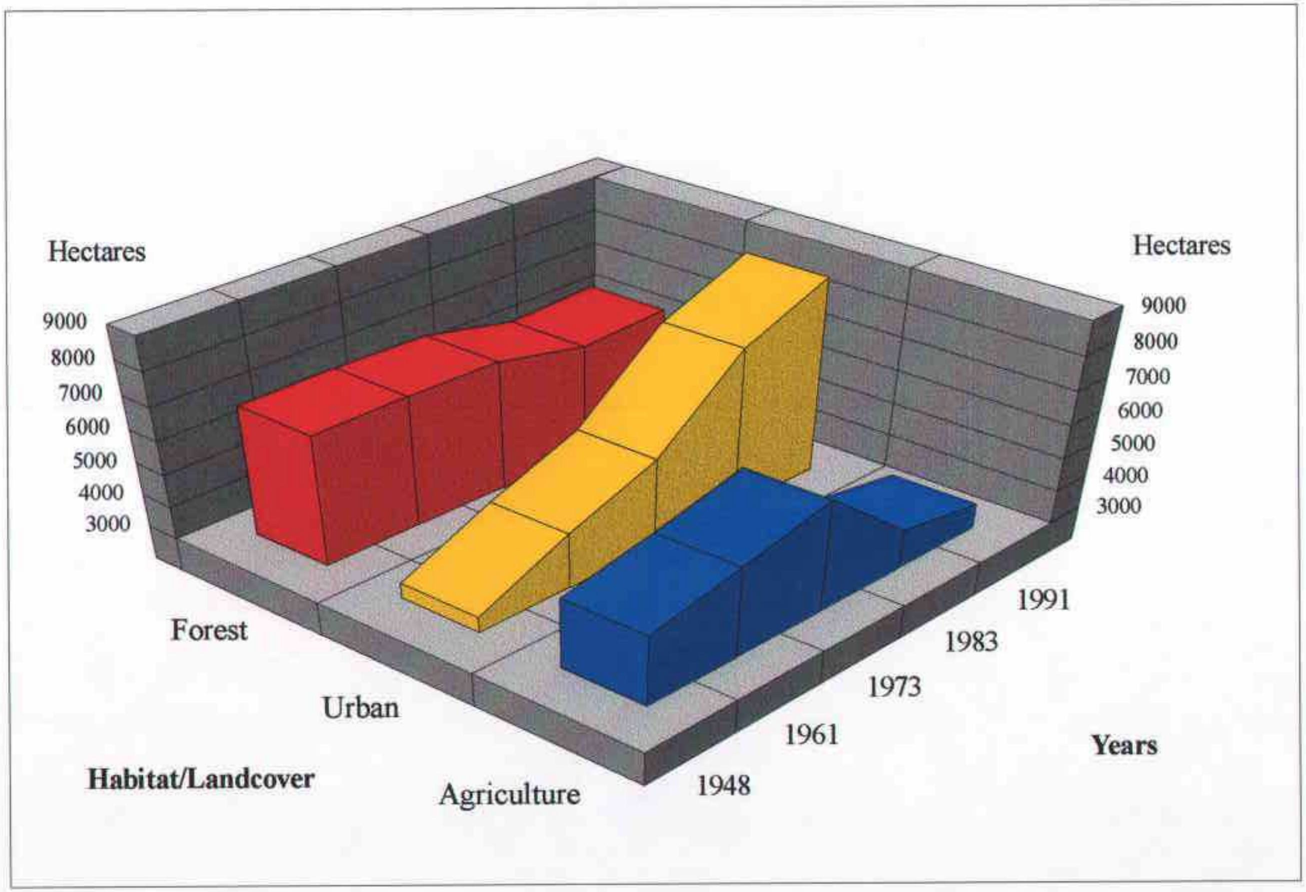


Figure VI.10: Wetland Habitats Which Became Another Habitat/Landcover by 1991, Riverine Lower Perennial Section

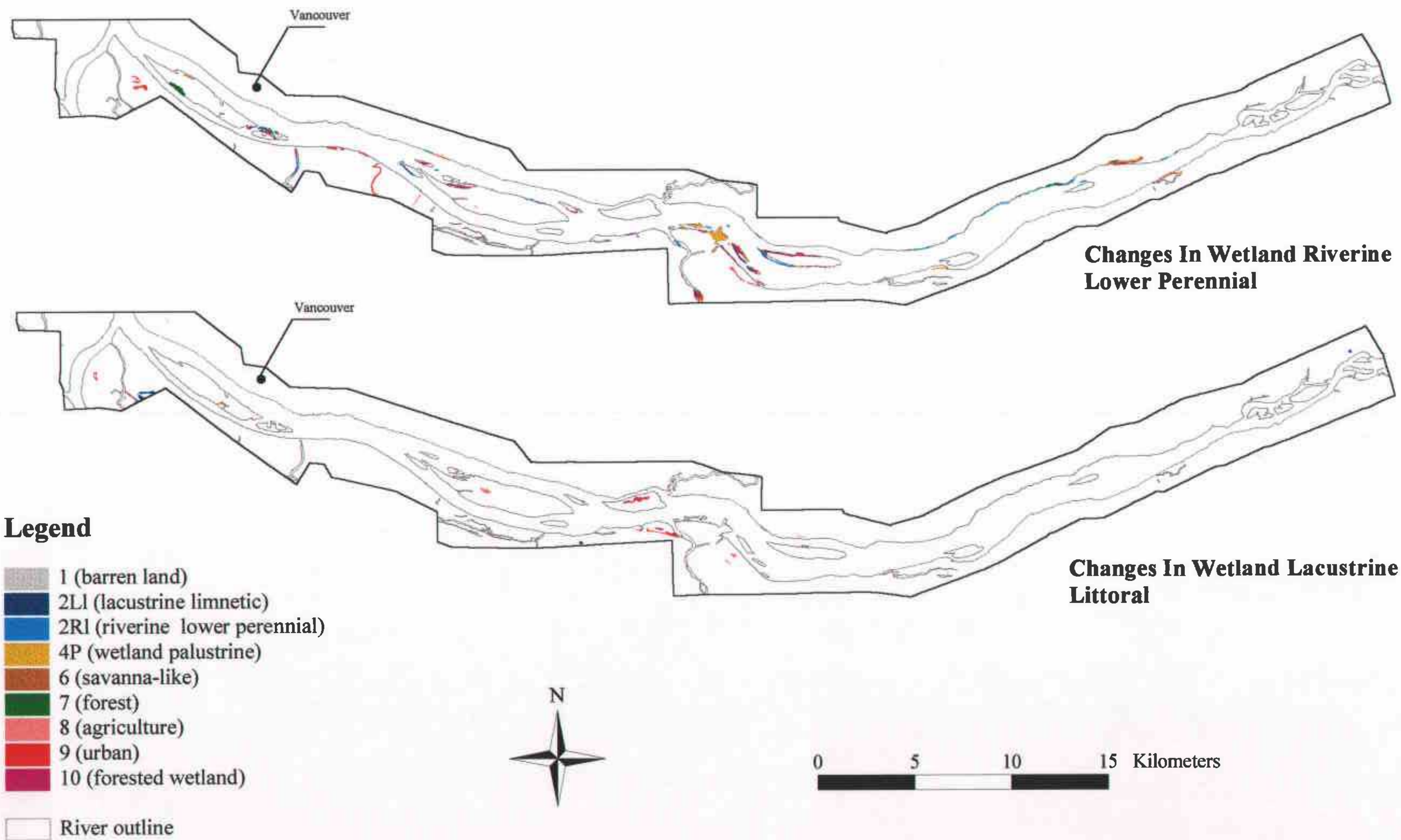


Table VI.12: 1948 Riverine Lower Perennial Wetlands Which Became Another Habitat/Landcover by 1991, Riverine Lower Perennial Section

New Habitat/Landcover	Sum Hectares
1 (barren land)	40.5
2Rl (riverine lower perennial)	79.0
4P (wetland palustrine)	83.0
6 (savanna-like)	3.8
7 (forest)	32.0
8 (agriculture)	15.3
9 (urban)	84.5
10 (forested wetland)	80.0

forested wetlands. The regulatory effects of upstream dams provided ample time without flooding for emergents to change to palustrine wetlands.

While riverine lower perennial wetlands experienced severe losses between 1948 and 1991, smaller increases to other habitat types within these years were observed. Between 1961 and 1973, riparian emergents increased. Barren land and deepwater habitats were the only significant factors associated with causing this growth. There were 49.1 hectares of 1948 riverine lower perennial (deepwater) habitat that changed to riverine lower perennial (emergent) wetlands by 1991. Either the natural change of river dynamics over time or the adjustment to upstream damming was partly responsible for the increase in riparian emergents. Channelization and dredge spoil disposal, while less important between Portland/Vancouver and Bonneville Dam than in the other two sections, remained a factor in altering river dynamics. Regardless of multiple indirect causes, emergent wetlands displaced deepwater habitats by sediment accretion. Conversely, the same

Table VI.13: 1948 Barren Land Which Became Another Habitat/Landcover by 1991, Riverine Lower Perennial Section

New Habitat/Landcover	Sum Hectares
2Rl (riverine lower perennial)	158.7
3 (grassland)	5.2
4Rl (wetland riverine lower perennial)	18.4
4P (wetland palustrine)	71.3
5 (scrub/shrub)	6.5
6 (savanna-like)	12.4
7 (forest)	76.8
8 (agriculture)	26.0
9 (urban)	207.4
10 (forested wetland)	54.2

processes were liable for decreasing 1948 riverine lower perennial wetlands by 79 hectares.

Barren land was responsible for minor changes in riverine lower perennial wetlands. There were 18.4 hectares of barren land which became riverine emergent wetlands by 1991 (see Table VI.13). These changes were similarly linked to river dynamics. Sediment deposited in linear patterns along the shoreline of the river sustained populations of riverine lower perennial wetlands depending upon water level. When these barren areas were slightly submerged, emergent vegetation often grew. Many of the barren areas were found downstream of jetties.

Palustrine Wetlands

Palustrine wetlands were the primary wetland type found in the riverine lower perennial section. Generally, in 1948 there were fewer palustrine wetlands in the more confined upstream region of the section than downstream. Palustrine wetlands in the upstream half of the section were largely located adjacent to the river, while wetlands on the downstream half were more evenly distributed. By 1991, the palustrine wetlands in this half were reduced to less than 20 locations. Both the area of each palustrine wetland and its number of locations were reduced throughout the entire section. Palustrine wetlands were limited to 59 locations in 1991, down from 154 in 1948. In 1948, there were 3007.2 hectares of this wetland, and by 1991, there remained 1153.7 hectares. Palustrine wetlands slightly increased between 1948 and 1961, followed by rapid decline between 1961 and 1973. Between 1973 and 1983, palustrine wetlands increased by a nominal amount of 93.1 hectares and, by 1991, had fallen again by 337.3 hectares.

There was little doubt as to the primary cause for the decline of palustrine wetlands in this section. By 1991, the urban landscape dominated both sides of the river, forming a near continuous cover from Hayden Island to Lady Island (approximately 30 kilometers). The decline of palustrine wetlands between 1961 and 1973 represents one of the most rapid and large losses of wetlands for all wetland types in all sections. During those 12 years, palustrine wetlands diminished by 1609.3 hectares. The cause of this decline can be extrapolated from analyzing the cause of palustrine wetland change between 1948 and 1991. There were 1000.3

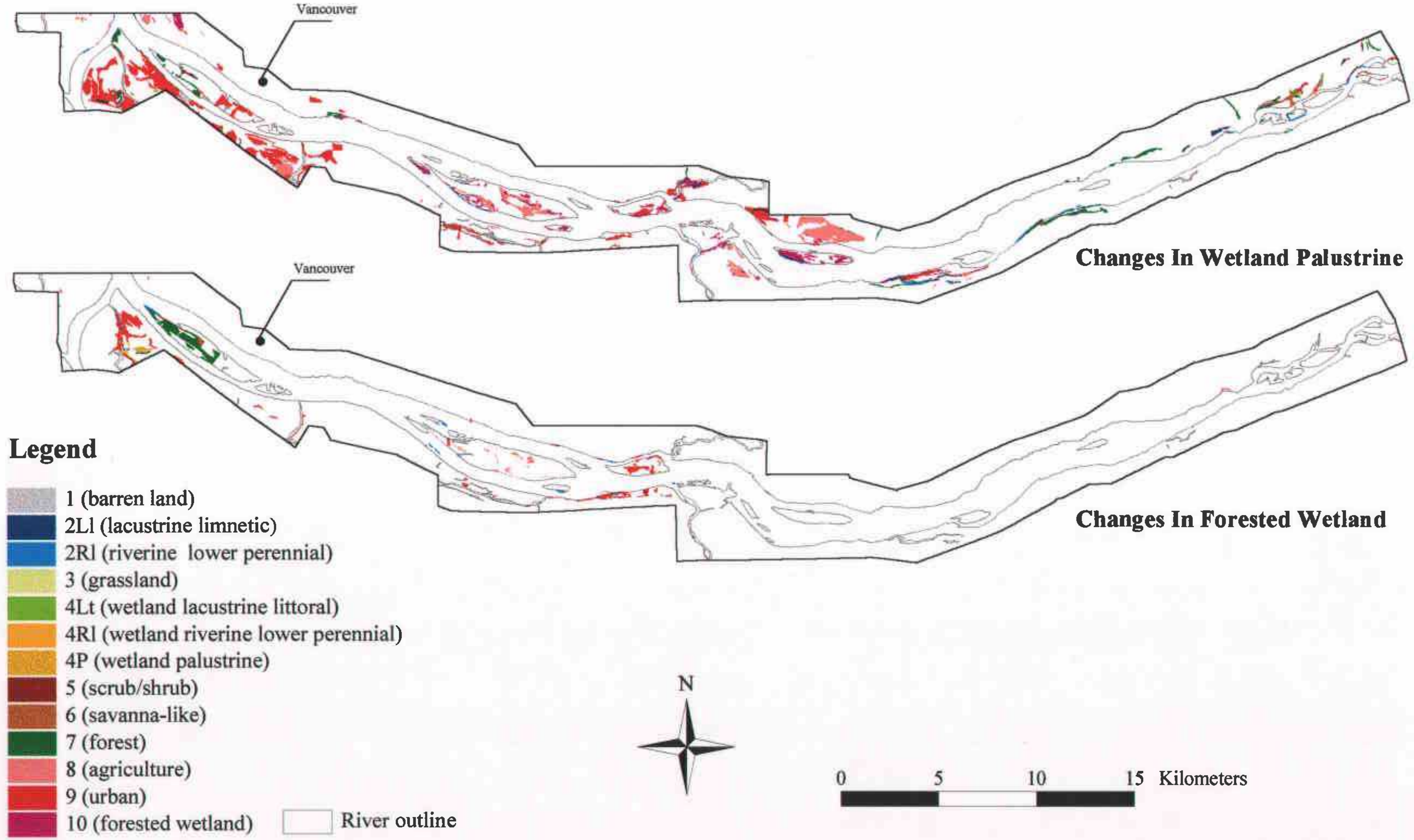
Table VI.14: 1948 Palustrine Wetlands Which Became Another Habitat/Landcover by 1991, Riverine Lower Perennial Section

New Habitat/Landcover	Sum Hectares
1 (barren land)	55.1
2Ll (lacustrine limnetic)	27.9
2Rl (riverine lower perennial)	62.8
3 (grassland)	5.4
4Lt (wetland lacustrine littoral)	10.9
4Rl (wetland riverine lower perennial)	9.4
5 (scrub/shrub)	16.6
6 (savanna-like)	50.1
7 (forest)	197.8
8 (agriculture)	588.0
9 (urban)	1000.3
10 (forested wetland)	297.9

hectares of 1948 palustrine wetlands which were displaced by urban development by 1991(see Table VI.14).

The population of the metropolitan Portland/Vancouver area increased rapidly between 1948 and 1991 and continues to do so today. In 1948, industry which relied upon the river as its chief means for transporting goods dominated the river front, displacing wetlands. While these primary sector type facilities remained important in 1991, expansion had taken place largely because of residential development and to cater to the service sector of the economy. Palustrine wetlands, the dominant wetland type that remained in 1948, represented unused space with potential to become lucrative development areas. By 1973, population pressure exerting control to develop displaced most of the wetlands in the lower half of the riverine lower perennial section. Figure VI.11 illustrates the location of 1948 palustrine wetlands

Figure VI.11: Wetland Habitats Which Became Another Habitat/Landcover by 1991, Riverine Lower Perennial Section



which became other habitats and landcover. Concentrated and extensive changes from palustrine wetlands to urban were located in the vicinity of North Portland Harbor and the Willamette River.

While urbanization was the primary reason for the reduction of palustrine wetlands in the section, additional factors contributed to the decline. Deep rich alluvial soils in the downstream half of the section were ideal for cultivation and produced lush grasses for grazing. By 1948, farm and urban land were the dominant land covers. Agriculture displaced many wetlands. However, by the early 1970's, agricultural land was quickly being displaced. As population pressures mounted and urban development escalated, agricultural land was displaced by urban land. Since agricultural land was much more valuable than developed land, many farmers sold their land. The sharp decline in agriculture beginning in 1973 authenticates this point. Between 1973 and 1991, agriculture decreased by 2611.8 hectares. Clearly, agriculture in the section was being eclipsed by urbanization; yet, concurrently, agriculture was displacing palustrine wetlands. This indicates that agriculture experienced minor increases.

Agriculture displaced 588 hectares of 1948 palustrine wetlands by 1991. Figure VI.11 illustrates the location of these changes. While 588 hectares does not rival the total decrease in agriculture, this amount was a significant increase when considering that the increase took place within a single wetland type. Before agriculture began to diminish in 1973, it was increasing. Between 1948 and 1973, agriculture increased by 1219.9 hectares. Most palustrine wetlands were displaced during this time of relative agricultural growth. However, this conclusion is complicated by the fact that not all palustrine wetland losses occurred between 1948 and 1973. For those palustrine wetlands which were displaced after 1973, urbanization was indirectly the most likely cause. Urban areas displaced both palustrine wetlands and agriculture. As increasing amounts of agriculture were displaced by urbanization, agriculture was forced to expand into more marginal lands. Perhaps, there once was no need to convert certain palustrine wetlands to agriculture. Yet, as the value derived from prime agricultural land could not compete with the value of urban land, farming focused more readily on palustrine wetlands which historically were not profitable to convert.

Another major factor which contributed to the decline of palustrine wetlands was succession. Palustrine wetlands, many of which had been emergent riverine lower perennial wetlands, changed to forested wetlands. While the process of palustrine wetlands changing to forested wetlands occurred naturally, by regulating river flow, riparian wetland succession occurred more frequently and was accelerated in the absence of significant flooding. There were 297.9 hectares of 1948 palustrine wetlands which changed to forested wetlands by 1991. Nearly 30% of this change occurred on Reed Island (see Figure VI.11).

Two periods experienced minor increases in palustrine wetlands: 1948 to 1961 and 1973 to 1983. Between 1948 and 1961 palustrine wetlands were recovering

Table VI.15: 1948 Grassland Which Became Another Habitat/Landcover by 1991, Riverine Lower Perennial Section

New Habitat/Landcover	Sum Hectares
1 (barren land)	4.0
2Rl (riverine lower perennial)	2.8
4P (wetland palustrine)	100.6
5 (scrub/shrub)	33.3
6 (savanna-like)	7.3
7 (forest)	42.4
8 (agriculture)	12.9
9 (urban)	162.9
10 (forested wetland)	18.1

from the 1948 flood and increased by being reestablished on former habitat. Numerous emergent wetlands changed to palustrine wetlands during this period. The factors which influenced increases between 1973 and 1983 were less apparent; however, they could be determined by ascertaining what habitats and landcover most commonly changed to palustrine wetlands between 1948 and 1991. Grassland, riverine lower perennial wetlands, agriculture, and barren land were the only habitats and landcover which contributed significantly to increases in palustrine wetlands. There were 100.6 hectares of 1948 grassland which changed to palustrine wetlands by 1991 (see Table VI.15). The three remaining habitats and landcover attributed less than 85 hectares each to palustrine wetlands by 1991.

Forested Wetlands

Forested wetlands declined between 1948 and 1973, before rebounding between 1973 and 1991. This pattern of rapid increase following 1973 occurred in all sections. The role of flood storage incrementally increased as new upstream dams were built and the storage capacity of existing dams was increased. Water storage capacity greatly increased after 1968 with the construction of John Day Dam. In order for emergent and palustrine wetlands to reach later successional stages following the flood of 1948, time was required. In the absence of large scale flooding after 1964 (two floods of significance occurred, both of which were much smaller than the 1948 flood -- one in 1956 and the other in 1964), forested wetlands had enough time to begin to flourish by 1973. Between 1973 and 1991, forested wetlands increased by 953.7 hectares as a response to greater flood control.

In 1948, forested wetlands were more evenly spread across the section than riverine lower perennial and palustrine wetlands; however, fewer were found in the more confined upstream half. By 1991, more forested wetlands were found in the upstream half, as urbanization had eliminated most of the downstream forested wetlands. The forested wetlands which remained in the downstream half of the section were largely confined to Government Island and surrounding smaller islands. Only one large forested wetland was situated inland from the river. This forested wetland was located south of Vancouver Lake in an area that was historically

Table VI.16: 1948 Forested Wetlands Which Became Another Habitat/Landcover by 1991, Riverine Lower Perennial Section

New Habitat/Landcover	Sum Hectares
1 (barren land)	13.3
2Ll (lacustrine limnetic)	6.8
2Rl (riverine lower perennial)	22.3
4P (wetland palustrine)	35.9
5 (scrub/shrub)	7.0
6 (savanna-like)	12.8
7 (forest)	126.8
8 (agriculture)	56.6
9 (urban)	247.4

lacustrine, but had changed to palustrine, due to reduced water volume in the lake before reaching its 1991 state.

Between 1948 and 1991, forested wetlands experienced a net increase of 478.3 hectares. This amount was somewhat low, because it incorporated the loss of forested wetlands between 1948 and 1973. During this time, forested wetlands declined by 475.4 hectares. Urbanization was the primary cause for decrease in forested wetlands. There were 247.4 hectares of 1948 forested wetlands which were displaced by urbanization by 1991 (see Table VI.16). Forested wetlands near the river's banks and landward were most readily degraded by urbanization. With the exception of Lady Island, urban land displaced few island wetlands, due to their relative inaccessibility. Lady Island had easy road access and experienced extensive development. Considerable forested wetlands were developed along lowland backwaters and canals east of the mouth of the Willamette (see Figure VI.11).

Forest habitat and agriculture displaced the greatest amount of forested wetlands following urbanization. There were 146.8 hectares of 1948 forested wetlands which became forest by 1991. Nearly 95% of this change occurred on the downstream half of Hayden Island. These changes take the form of a straight line along the forest's eastern border. Geometric shapes on the landscape are typically the result of human activity. Changes from forested wetland to forest were likely caused by urbanization. The straight line existing at the abrupt end of forest habitat was formed because of a railroad which spans the Columbia. East of the railroad, developed land dominates the island's cover. A highway bridge also spans the river at this location. Agriculture did not account for as much of a decline in forested wetlands as forest. There were 56.6 hectares of 1948 forested wetlands which were displaced by agriculture by 1991. Because of the relative decline in importance of agriculture in the section, this amount was low.

Much like the other sections of the LCR, one process was largely responsible for the increase in forested wetlands. The rapid increase in forested wetlands between 1973 and 1991 largely occurred because of the process of palustrine wetlands progressing to later successional vegetation. In the absence of significant flooding, frequency of occurrence and rate of change increased. Control of river flow is one of the most notable impacts of upstream dams on wetlands. The river flow of the LCR is less variable than it was before dam construction. Average flood flow is lower (Fox et al. 1982). Floods which once scoured the low-lying land adjacent to the river, clearing it of woody wetland vegetation, occurred less frequently. Historically, such floodplain inundating events occurred every June on the LCR.

The fact that considerable riverine lower perennial wetlands and palustrine wetlands were displaced by forested wetlands supports the conclusion that forested wetlands increased when all other wetlands generally decreased. There were 297.9 hectares of 1991 palustrine wetlands which became forested wetlands by 1991. Further, there were 83 hectares of 1948 riverine lower perennial wetlands which changed to forested wetlands by 1991.

Similar increases in forested wetlands are not uncommon on other impounded large rivers. According to a study on the Mackenzie River in Canada, under conditions of flow constancy, riparian vegetation frequently becomes dominated by riparian tree species (Petts et al. 1992). Similar studies on other impounded large rivers, such as the Peace River (Canada) and the Colorado River (USA), determined that flood pulses no longer checked the growth of forested wetlands on lowlands adjacent to the river (Petts et al. 1992). On the Colorado below Glen Canyon Dam, woody vegetation has invaded lowland formerly cleared by floods. Dams on the Platte River in Nebraska which modify the seasonal pattern of flow volume were responsible for causing the river channel to become more confined and for much of the original channel becoming covered by riparian cottonwoods (Cox 1993).

Table VI.17: 1948 Lacustrine Littoral Wetlands Which Became Another Habitat/Landcover by 1991, Riverine Lower Perennial Section

New Habitat/Landcover	Sum Hectares
2Ll (lacustrine limnetic)	16.2
8 (agriculture)	19.0
9 (urban)	32.7
10 (forested wetland)	9.7

Lacustrine Littoral Wetlands

Lacustrine littoral wetlands generally decreased from 1948 to 1991. In 1948, there were 84.7 hectares of these wetlands, and, by 1991, there were 33.7 hectares. Changes to lacustrine limnetic habitats often reflect similar changes to lacustrine littoral wetlands. There were 350 hectares of lacustrine limnetic habitat in 1948, and, by 1991, there were 131.4 hectares. Lakes in the more confined upstream half of the section were largely located near the river. Most lakes were backwaters cut off from their source of water by sediment deposition. These lakes were often deep and had small or no emergent wetland growth; therefore, the primary loss of lacustrine wetlands occurred in the downstream half of the section. Lakes in the vicinity of Smith Lake and on Government Island dwindled in size, affecting a similar decline in lacustrine littoral wetlands.

There were few habitats and landcover which directly displaced lacustrine littoral wetlands (see Table VI.17). Urbanization was responsible for the greatest losses, followed by agriculture. There were 32 hectares of 1948 lacustrine littoral wetlands which were displaced by urban land by 1991. By the same date, 19 hectares were displaced by agriculture.

The greatest loss of lacustrine littoral wetlands occurred between 1961 and 1973. During this time, these wetlands decreased by 54.7 hectares. Nearly all of these changes were located near Smith Lake. Smith Lake and smaller lakes in the area were reduced in size or completely diminished, due to the effects of urban encroachment. The section most commonly experienced the loss of lacustrine limnetic habitat because of urbanization. There were 146.2 hectares of 1948 lacustrine limnetic habitats which were displaced by urban by 1991.

The only significant increase in lacustrine littoral habitats (88.1 hectares) occurred between 1948 and 1961, as a result of diminishing lacustrine limnetic habitat. Shallow pockets of emergent wetlands were left in the wake of the drying lacustrine limnetic habitats of Smith Lake and surrounding smaller lakes. As deepwater habitats were diminished, lacustrine littoral habitats increased. By 1973, most of the pocket lacustrine littoral wetlands had disappeared. Essentially, these wetlands dried, as shallow surface water and soil moisture content were depleted and not replenished, forcing the watertable to drop. By 1983, the pockets of lacustrine littoral wetlands were almost completely diminished. Between 1961 and 1983, lacustrine littoral wetlands decreased by 91.3 hectares. This reduction approximates the increase in lacustrine littoral wetlands between 1948 and 1961, confirming that the increase and subsequent decrease were linked to the same geographic area. Further, it confirms that these lacustrine littoral wetlands were intermediary, existing for a short while, until the water supply from past lacustrine limnetic habitats was exhausted.

Implications of Wetland Regulatory Programs and Policies

The protection of wetlands can be provided by regulatory programs and policies. It might appear that a host of programs and policies protect wetlands along the LCR. A century ago, it was official federal government policy to fill all wetlands. In the 1970's, scientists and, subsequently, government decision makers began to realize the value of these ecosystems, and, since that time, policy has shifted towards the pursuit of protection. The primary means for wetland protection in the United States is Section 404 of the Federal Water Pollution Control Act of 1972 and subsequent amendments. Section 404 gave the Corps of Engineers the authority to establish a permitting system to regulate dredge and fill materials. By 1975, the Corps revised the regulations for the 404 program and concluded that the destruction of wetlands should be discouraged. In 1977, President Jimmy Carter issued Executive Order 11990, which established the protection of wetlands and riparian systems as the official policy of the government. By the early 1980's, the intent to protect wetlands at the federal level was high; but, in reality, the degradation and destruction of wetlands continued.

Other regulatory programs (such as the National Environmental Protection Act, Coastal Zone Management Act, and Flood Disaster Protection Act) provide some wetlands protection. The "Swampbuster" provision of the Food Securities Act of 1985 was an important event for wetland protection. This provision denied federal subsidies to any farmer who knowingly converted wetlands to agricultural land (Mitsch and Gosselink 1993). Four years later, the "no net loss" policy which became the cornerstone of wetland protection and conservation was established. Mitigation as a policy became an issue of great debate. A Memorandum of Agreement between the Environmental Protection Agency and the Department of the Army concerning the type and level of mitigation necessary to demonstrate compliance with the regulatory guidelines for discharges of dredged or fill material under Section 404(b)(1) of the Clean Water Act was signed on November 14, 1989. Compensatory mitigation is required for unavoidable impacts to wetlands.

The purpose of outlining these important events in establishing wetland regulatory programs and policy is to demonstrate that they had little impact on wetland change on the LCR between 1948 and 1991. Despite numerous programs and policies, actual wetland conservation and protection on the LCR was minimal. There are no specific federal wetlands laws. Wetlands protection results from laws which were intended for other purposes. Between 1948 and 1972, there were no real regulations or policy governing wetland destruction; therefore, federal efforts during this time did not impact wetland management on the LCR. Regulations and policies established between 1972 and 1991 were generally ineffective for combating wetland losses. Losses continued and, in many locations, increased. Policies were voiced, but not enforced. Wetlands lacked an agreed upon definition, and permits to impact wetlands were historically easy to obtain. Mitigation programs were not reasonably effective. A study by the Florida Department of Environmental Regulation revealed that, out of a total number of 119 inspected freshwater and tidal mitigation sites in Florida, only three met full compliance. By the late 1980's, wetland protection moved from its initial stages of limited direction and became more focused. With stronger, more clear federal regulations, wetland losses on the LCR are likely to be moderated. Unfortunately, these changes were not visible by 1991.

At the state level, wetland regulatory programs and policies on the LCR reflect federal protection. However, both Oregon and Washington have implemented protective laws and policies which are more stringent than those of the federal government. For example, the federal Clean Water Act prohibits filling in specific wetlands, but it does not regulate dredging, draining, or land clearing. Washington States's Shoreline Management Act of 1971 restricts most activities in wetlands to 61 meters of coastal shorelines, streams, and large lakes (The 1991 State of the Environment Report, 1992).

Washington further protects some wetlands through programs, such as the Hydraulic Approval process, the State Environmental Policy Act, and the Flood Control Maintenance Act. "However these programs do not protect many wetlands -- especially those wetlands which do not meet restrictive size or other jurisdictional criteria" (Washington State Department of Ecology, 1992). In 1990, the most promising steps to protect Washington's wetlands were established with the passing of the Growth Management Act. This act requires local governments to adopt regulations to plan for protection of sensitive areas, including wetlands.

While Washington's regulations and policies expanded upon federal wetland protection, the Washington State Department of Ecology (1992) concludes that "these programs do not protect many wetlands". Wetland mitigation projects under the section 404 program have been largely unsuccessful. Much like federal regulations, the most promising steps for protecting wetlands were established more recently. Positive impacts on wetlands from the Growth Management Act of 1990 were not yet apparent by 1991, the final coverage date of this study.

Oregon has a state removal/fill law administrated by the Oregon Division of State Lands, which is the primary means protecting wetlands. The law predates the federal section 404 mitigation program, but is quite similar. It requires a permit for fill or removal from a waterway of 45.7 cubic meters or more of material from one location in any calender year (Good and Sawyer 1998). Oregon's statewide landuse planning goals include provisions for wetland conservation and protection. Goal 5 -- Open Spaces, Goal 16 -- Esturine Resources, and Goal 17 -- Coastal Shorelands mandate that significant wetlands should be inventoried and protected.

While these regulations and Goals have been more effective in protecting wetlands than federal efforts, wetlands have continued to decrease. Mitigation associated with both state and federal plans in Oregon has not been as successful as perhaps it should. In Oregon, under section 404, more wetlands have been lost than gained. Mitigation efforts in Oregon are well ahead of most state programs but have been criticized as being overwhelmingly dependent upon wetland creation, as opposed to restoration (Good and Sawyer 1998). Creation projects are more prone to failure than restoration of former wetland sites. To resist continued wetlands losses, the Oregon Legislature passed Senate Bill 3 in 1989, which required a statewide wetland inventory and called for local governments to develop Wetland Conservation plans. The long term impacts on wetlands from this Bill are encouraging, however were not yet apparent by 1991.

While efforts at the state and federal levels to begin to work toward the goal of "no net loss" were promising, their impacts were not yet discernible by 1991. Between 1948 and 1970, wetland regulatory programs and policies had no effect on the riparian wetlands of the LCR, as such protective efforts were not deemed necessary and were not yet formulated. Between 1972 and the late 1980's, when wetland management plans were still in their formative stages, wetland losses were not noticeably curbed (despite innovation at the state level). In fact, most of the greatest losses in wetlands occurred between 1961 and 1983. Generally, wetland losses were not as great between 1983 and 1991 as during previous years. Perhaps wetland regulatory programs had a minor impact during this time; however, it would be purely speculative to arrive at this conclusion. Significant changes in wetlands have largely been explained based upon evidence which best reflects the highest probable cause.

CHAPTER VII. RESULTS OF ANALYSIS ON WETLAND HABITAT RESTORATION POTENTIAL

Preface

Wetland habitat identification and change analysis studies are important for determining why wetlands experience periods of loss and gain. The results should be applied as a necessary guide when examining the restoration potential of degraded or destroyed wetlands. The habitat change analysis portion of this study, which utilized historical data and trends to determine factors which influenced change along the LCR riparian zone, provides the backdrop for selecting sites for restoration potential and wetland resource sustainability.

This chapter justifies the need for restoration and develops regional wetland habitat models which indicate ranked areas most conducive for restoration potential. Accurate site selection is one of the most important steps in wetland restoration. By identifying restoration sites with varying degrees of plausibility, efforts can focus on the most important locations. The final section in this chapter discusses the prospects of applying the techniques used in this study for identifying historical wetlands with restoration potential to future research.

While this research advocates restoration potential, it does not contend that restoration is a surrogate for responsible ecosystem-wide stewardship of riparian systems along the LCR. Restoration will not succeed unless elements which degrade wetlands are mitigated or removed.

Terminology

Use of the term "restoration potential" needs to be fully explained. This study does not describe the means for physically restoring a wetland. Rather, the objective is more geographic in nature -- to locate areas which exemplify the qualities needed for restoration to be successful. Restoration of riparian wetlands, strictly defined as a return to natural or original conditions, is unlikely (Frenkel and Morlan 1991). "Natural" may be interpreted by some as "before or without human occupation". If the term "natural" is translated to mean "before the Euro-American colonization of the past 150 years along the LCR", then to restore wetlands exactly as they once were would be improbable. Fortunately, it is not necessary to restore wetlands to their original conditions in order to gain benefits. A more realistic definition of restoration acknowledges that historical wetlands need to be brought back into existence; but, the degree to which lost values are replaced is variable. Current societal constraints define the extent to which wetland values are replaced at the point where wetland benefits attained through restoration are outstripped by the consequences to society to replace them. The ecological values associated with riparian wetlands of the LCR 44 years ago were more desirable than they are today. It is more feasible to restore displaced wetlands to their 1948 value than to pre-settlement conditions.

Development is necessary, but should be managed, such that riparian wetlands are not continually degraded or lost. Locations which are currently developed or in use and were historically wetlands have little potential for restoration. It is not likely that the roads, buildings, or productive uses of the land, such as agriculture, will be removed, nor is it possible that the river will be dechannelized, in order to ameliorate floodplain isolation. Full-scale restoration of the LCR is improbable, due to population growth and economic development. The scale of restoration, therefore, is ultimately dependent upon societal consensus. Pockets of restoration may be the best that can be achieved.

Justifying Wetland Restoration

Justification for wetland restoration stems from the fact that wetlands are considered important to society. In addition, most wetlands have already been lost as a resource, and depletion of the remainder continues. Further, national policy favors the protection and restoration of wetlands (Mitsch and Gosselink 1993). The widely touted, less frequently applied policy of "no net loss" requires that unavoidable wetland losses be replaced. The primary objective of the policy is:

> To achieve no overall net loss of the nation's remaining wetlands base and to create and restore wetlands, where feasible, to increase the quantity and quality of the nations wetland resource base (National Wetland Policy Forum, 1988, cited from Mitsch and Gosselink 1993).

At one level, there is policy which encourages wetland restoration. At another, there is law which requires restoration. Recent, more rigorous enforcement of Section 404 of the Clean Water Act (1977), requires that wetlands lost due to development be restored or created in another location. It remains difficult for enforcement agencies to track and encourage each isolated mitigation project to comply with regulations; but, the necessary programs to enforce and ensure successful restoration are improving. All adverse impacts to existing wetlands must be avoided to the maximum extent practical, and unavoidable impacts must be minimized, before mitigation permits will be considered. Once guidelines for the avoidance and minimization have been met and adverse impacts are demonstrated to be necessary and unavoidable, compensation and mitigation are required. Compensatory actions are defined as the restoration of existing degraded wetlands or creation of human-made wetlands (Scodari 1997).

At the state level, both Oregon and Washington share similar policies governing the restoration of wetlands. The no-net-loss policy lies at the core of all recent wetland protection programs in the state of Washington. Protection and restoration programs in Washington include the Puget Sound Water Quality Plan, the 2010 Action Agenda, and the Governor's Executive Orders for Wetlands (Washington State Department of Ecology 1992). The U.S. Fish and Wildlife Service and the Washington Department of Wildlife recently formed a partnership and initiated the implementation of the Washington State Ecosystems Conservation

Project. This Project will restore wetlands wildlife habitat on private lands (Washington State Department of Ecology 1992).

Restoration of wetlands in Oregon is an important state-wide objective. The Oregon Removal-Fill law requires mitigation much like the Section 404 program. This law is expanding, as jurisdiction of federal regulatory programs increases. Statewide Planning Goals 16 and 17 of Oregon's land use planning program address wetland restoration. These goals recognize the necessity for restoration and articulate the need to locate sites for regulatory mitigation. The 1989 wetland conservation law addresses restoration (Good and Sawyer 1998). The legislation provides for the development of local conservation plans. In these plans, locating potential wetland restoration sites is required to mitigate for future development that will adversely impact wetlands.

Clearly there is a need to locate potential wetland restoration sites along the LCR. Development and human activities which are destructive to wetlands will continue, despite efforts to moderate the losses. Based upon current trends in wetland degradation along the LCR, it is unlikely that restored wetlands will be as diverse or numerous as wetlands found in the region in 1948. At the very least, restoration increases wetlands within a specific location and partially stems the tide of losses.

Restoration or Creation

Restoration is the preferred solution to compensatory mitigation. An objective of mitigation projects should be the restoration of an ecosystem, rather than creation of artificial wetlands. Between 1948 and 1991, wetlands decreased significantly along the LCR. In many situations, once destroyed wetlands could be restored. With such extensive supplies of "lost" wetlands, mitigation efforts can be focused upon sites where habitat restoration seems the most probable.

Historically degraded wetlands retain some of their former characteristics; thus, restoration increases the likelihood of mitigation success. Pre-existing hydraulic conditions may remain intact for many years. The most notable of these pre-existing characteristics are wetland soil types which maintain their texture for extended periods of time, seedstock which may lie dormant, and fauna which may reestablish themselves from adjacent areas.

Many mitigation sites involve creation exclusively. Created wetlands are not as successful as natural wetlands. They are more costly and require much more engineering of hydrology and soils. They are often built in a location situated far from the original site of the degraded or destroyed wetland. When wetlands are made, pre-existing physical conditions of the land weigh heavily on the type of wetland introduction. It would be difficult to recreate the degraded or destroyed wetland without creating from a similar environment. Many wetland functions are inherent to a specific site. Mitigation for wetlands which were degraded along the

LCR should be restored as close to the original site as possible. When wetlands are destroyed or degraded, it would be challenging to create the former ecosystem in an off-site location.

Passive Restoration

Many of the riparian wetlands along the LCR could be restored through passive restoration. Passive restoration may be defined as restoration of historically degraded or destroyed wetlands by means of limited human intervention. Passive restoration is based upon the process of self-design. Wetlands are phenomenally resilient. In some cases, historical wetlands, given the opportunity, will adapt to imposed changes and begin to recover in the absence of continued perturbations. In other cases, imposed changes, in the form of land use, need only be scaled back or removed, and historical wetlands will recover.

Given the opportunity, historical wetlands may recover with minimal human interference. The National Wildlife Refuges located on the riverine tidal section of the LCR reflect this conclusion. Soon after the Lewis and Clark National Wildlife Refuge and the Julia Butler Hansen National Wildlife Refuge were established in the early 1970's, wetlands began to recover. Dikes, levees, and jetties were in disrepair, as agriculture became less productive in these areas. Once the refuges were established, agriculture was abandoned all together. Drainage ditches became plugged, dikes were worn and floodgates leaked; thereby, wetlands started to emerge.

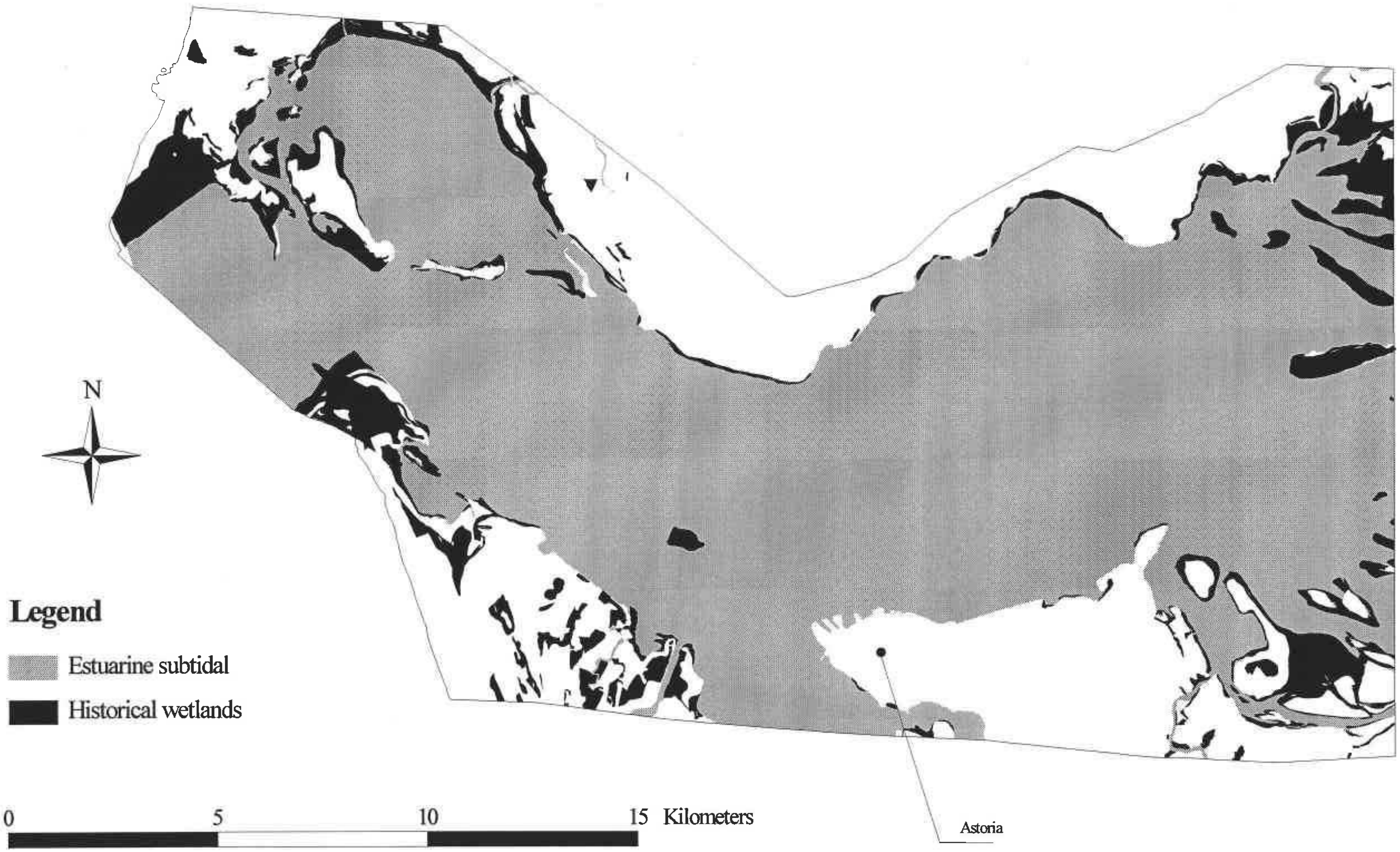
By 1991, palustrine wetlands and forested wetlands had reclaimed most of the lowland agriculture. The rapid reestablishment of wetlands in many of the areas in the refuges demonstrates the possibilities of passive restoration.

Section One: Estuarine

The estuarine section contained more historic wetlands as a total percent of area than the riverine tidal or riverine lower perennial sections. Historical wetlands are all wetlands that were identified in the 1948, 1961, 1973, or 1983 coverages, but not identified as a wetland in 1991. Areas which remained as wetlands in 1991 were not considered historical wetlands. There were 1149 locations consisting of 2660 hectares in the estuarine section that were identified as historical wetlands (see Figure VII.1). Such a large amount of historical wetlands indicates that there was tremendous change in the estuarine section between 1948 and 1991. Many of the historical wetlands were not originally wetlands, but became wetlands and then changed again to a non-wetland state by 1991. See Figure IV.7 (in Chapter IV. Materials and Methods) for methods for identifying historical wetlands.

Greater than 75% of the historical wetlands in the section were located within or adjacent to the active channel. Most historical wetlands were impermanent emergent wetlands, which greatly fluctuated over time in response to in-water activities. Recall that the greatest wetland increases and decreases in this section were attributed to extensive in-water activities, such as channelization, pile dike and jetty

Figure VII.1: Restoration Analysis, All Historical Wetlands, Estuarine Section



building, and dredge spoil disposal. These rapid changes after 1948, largely within estuarine intertidal wetlands (emergent wetlands), explain why there were so many historical wetlands. The fact that most of the historical wetlands in this section were lost because they became submerged is further evidence which explains the large amount of historical wetlands. There were 511 locations consisting of 1872 hectares of historical wetlands which were lost because they became submerged (see Figure VII.2). This amount represents 70 percent of the area of all historical wetlands in the section. The locations of the submerged wetlands were within the active channel, where primarily in-water activities impacted the hydrologic dynamics of the river.

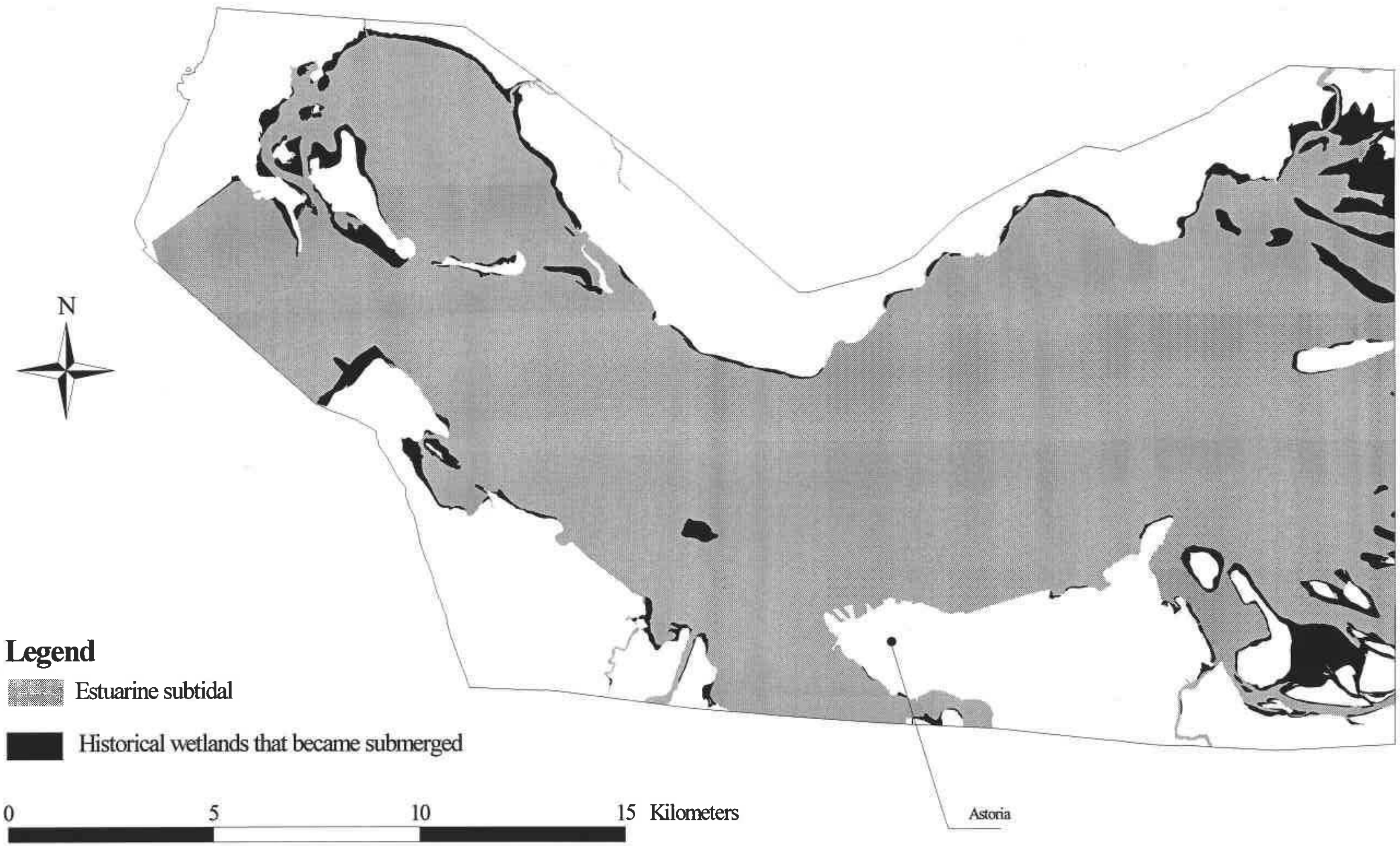
Low Potential

The low potential model for restoration represents the least likely historical wetlands which should be considered for restoration potential. The number of historical wetlands which were considered to be low potential were identified through a series of queries. The query criterion were:

- Historical wetlands which were less than or equal to 1 hectare in 1991 or,
- Historical wetlands which were urban/developed in 1991 or,
- Historical wetlands were submerged in 1991.

There were 341 historical wetlands which were less than one hectare. Historical wetlands less than or equal to 1 hectare in area should receive less attention with regard to restoration than larger areas. The costs in terms of time and labor may

Figure VII.2: Historical Wetlands with Low Potential for Restoration, Estuarine Section

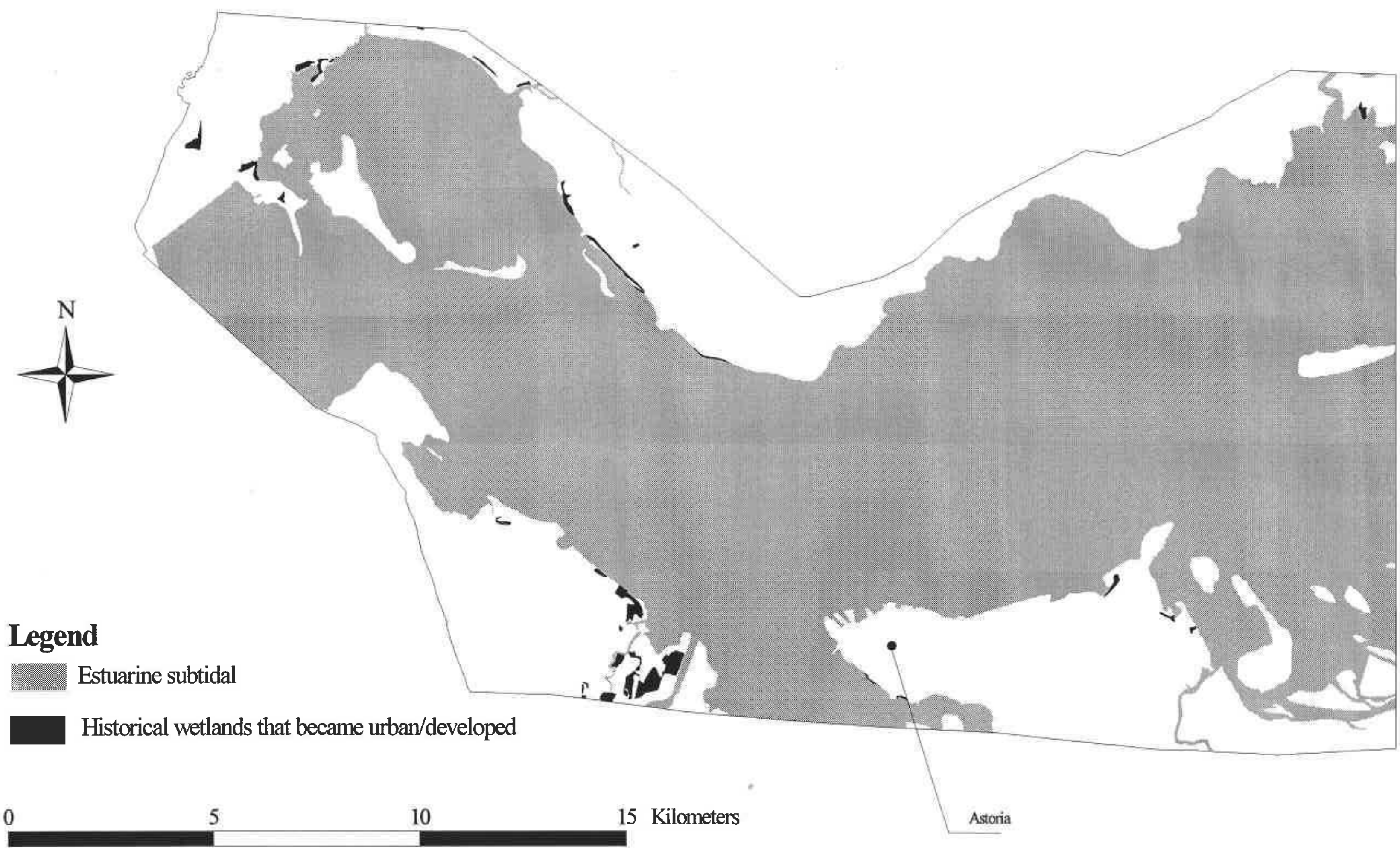


exceed the benefits. The cost for restoring one larger wetland at one time is typically much lower than the cost of restoring many smaller wetlands over a long period of time. It is more cost effective to restore one 10 hectare historical wetland than ten 1 hectare wetlands. With an abundance of larger historical wetlands from which to choose, the focus of restoration was swayed to larger, potentially more productive sites.

Historical wetlands which became urban/developed represent a small percent of the total. There were only 176.3 hectares of historical wetlands which became urban/developed (see Figure VII.3). Most of this change occurred in a small geographic area near Warrenton. Areas which are identified as currently urban/developed have a low potential for restoration. There is little likelihood that a home, business, or road will be dismantled to restore a wetland. Such developed areas retain very little of their historical wetland character and would require an extensive effort to restore. It is unrealistic to consider restoring wetlands that are now developed, particularly when other, more easily restorable, historical wetlands are present.

Approximately 80% of all low potential historical wetland locations were identified as such because they became submerged (see Figure VII.2). This number of submerged historical wetlands reflects tremendous changes to wetlands through human activities after 1948. Submerged areas which became deepwater habitats were assessed to be ecologically necessary, warranting no restoration intervention.

Figure VII.3: Historical Wetlands with Low Potential for Restoration, Estuarine Section



According to Cowardin et al. (1979), deepwater habitats are ecologically related to wetlands. Values associated with wetlands were lost when they became submerged; yet, the interconnectedness between wetland and deepwater habitat remained strong. The highly dynamic nature of the LCR creates and deposes wetlands through accretion and submersion. While this process has been influenced by humans, it is also quite natural. To restore an historical wetland that has become submerged would be largely futile, as it is most likely to change again. Drastic intervention could almost certainly assure that the restored wetland remain a wetland. But the damages of structural engineering on downstream habitats would outweigh the potential benefits of the wetland. Because deepwater habitats were considered ecologically necessary, highly transitional, and cost prohibitive to convert to wetlands, the restoration potential was ranked as low.

Moderate Potential

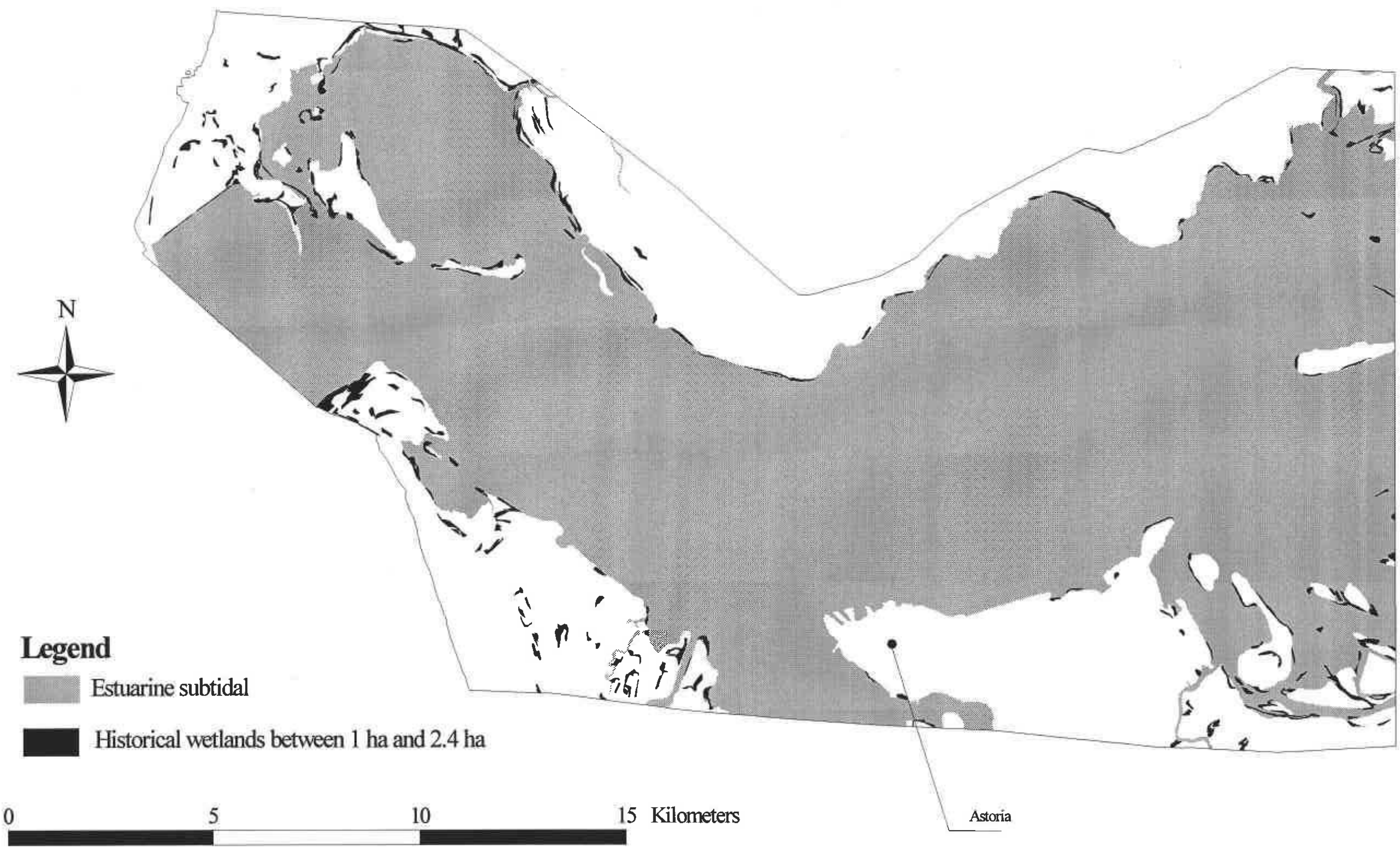
The moderate potential model relied upon a series of hierarchical queries. In this model, historical wetlands were identified as moderate potential for restoration, based upon the condition that each query in sequence was true. As such, the number of historical wetlands with potential for restoration at the beginning of the query sequence was high. By progressing through the sequence, the number of historical wetlands was reduced. The query sequence was: was historically a wetland; was greater than or equal to 1 hectare, but less than 2.5 hectares; was not urban/developed; was not submerged in 1991; and, included agricultural land.

There were 1149 sites consisting of 2660 hectares of historical wetlands in the estuarine section. The query "all areas which were greater than 1 hectare, but less than 2.5 hectares" reduced the total number of historical wetlands from 1149 to 402 (see Figure VII.4). Because there were few locations which were urban/developed in this section, 402 historical wetlands were reduced by merely 36 sites. Of the remaining 366 historical wetlands, more than half became submerged (see Figure VII.5). In the moderate potential model for restoration, there remained 169 locations, consisting of 261.4 hectares.

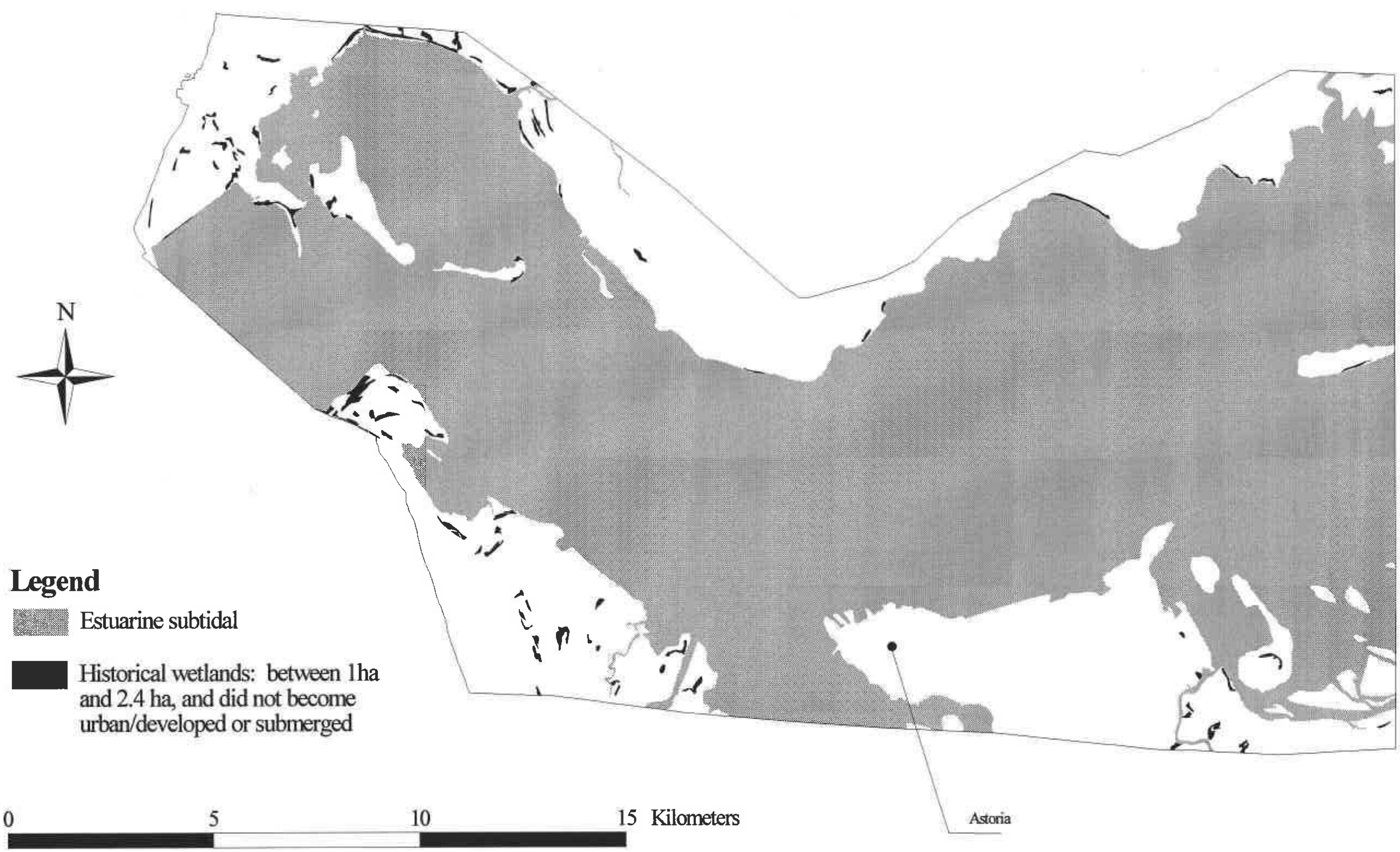
High Potential

The high potential model built upon the moderate potential model. Like the moderate potential model, it was hierarchical, each step relying upon the query that preceded it. Two additional queries were applied. They were "greater than or equal to 2.5 hectares" and "not agricultural land". While the changes appeared to be minor, the results were substantial. The high potential model provided a means to measure the impact of agriculture on wetland habitats. By querying to remove agricultural lands from the areas with potential for restoration, restoration potential focused on far fewer historical wetlands.

Figure VII.4: Historical Wetlands with Moderate Potential for Restoration, Estuarine Section



VII.5: Historical Wetlands with Moderate Potential for Restoration, Estuarine Section



Surprisingly, in the high potential model, there were numerous, very large historical wetlands. Of 1149 historical wetlands, there were 290 which were greater than or equal to 2.5 hectares (see Figure VII.6). Three locations were each greater than 75 hectares. Each of these sites should offer promising restoration potential. There were only 20 historical wetlands which became urban -- most of which were situated near Warrenton. The low potential and the moderate potential models clearly indicated that there were numerous submerged historical wetlands in the section. The high potential model confirmed that there were numerous submerged wetlands and that 189 of these sites were greater than or equal to 2.5 hectares. After removing submerged wetlands from the high potential model, 81 historical wetlands remained.

Agricultural diking, most of which occurred between 1880 and 1930, accounted for most of the extensive losses of wetlands before 1948. By 1948, most dikes were in place. Little change, in terms of wetlands losses due to agriculture, have occurred in the estuarine section since that time. Because most agricultural lands were long established before 1948, their impacts upon wetland degradation were not included in this study. Between 1948 and 1991, the amount of land in service for agriculture steadily declined by 43.7% in the estuarine section. In reality, between those years, more land changed from agriculture to wetlands than did wetlands to agriculture. Therefore, the impacts of agriculture on the high potential model were negligible. Figure VII.7 illustrates all historical wetlands which became agricultural land. There were only 7 historical wetlands which changed to agriculture

Figure VII.6: Historical Wetlands with High Potential for Restoration, Estuarine Section

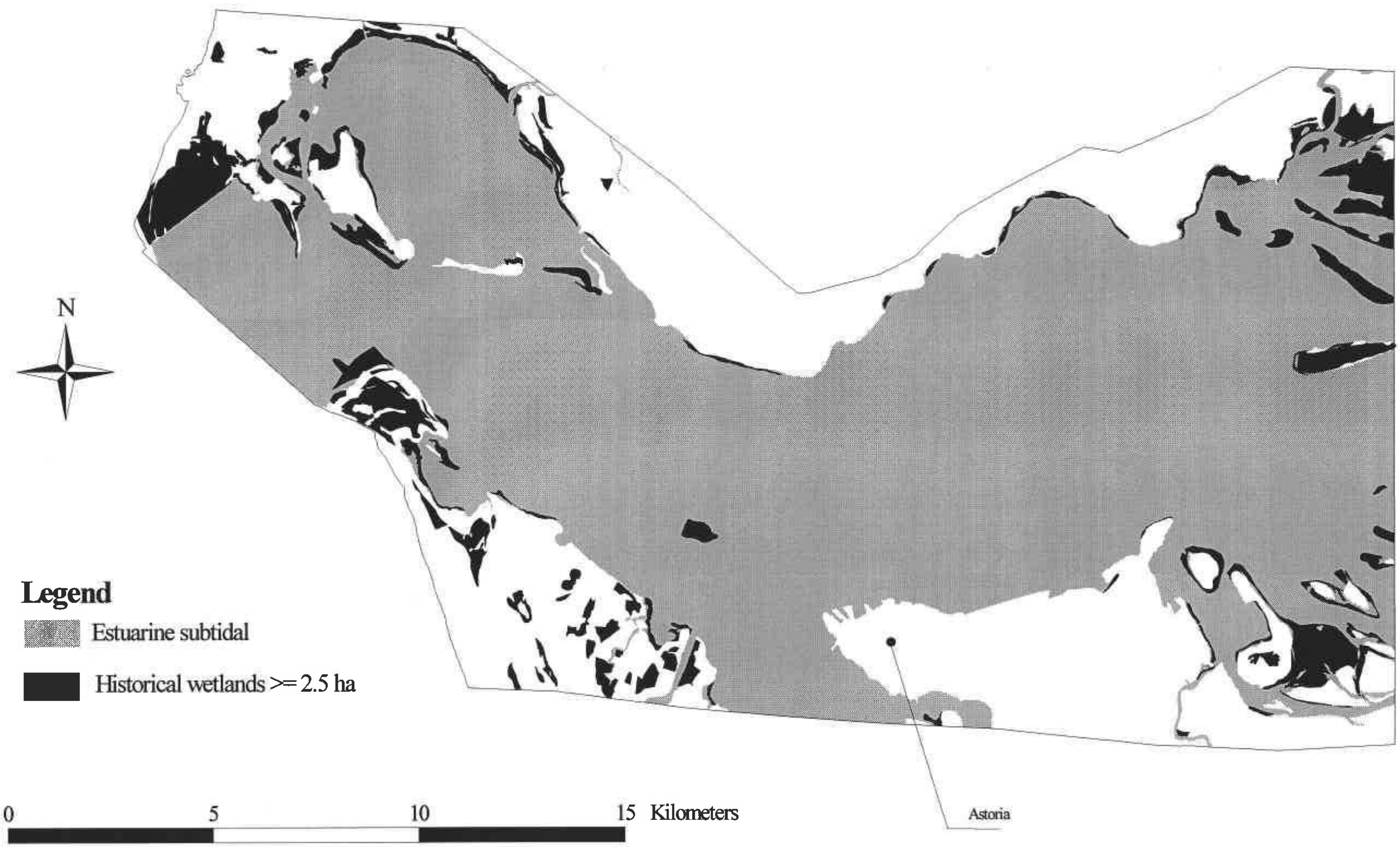
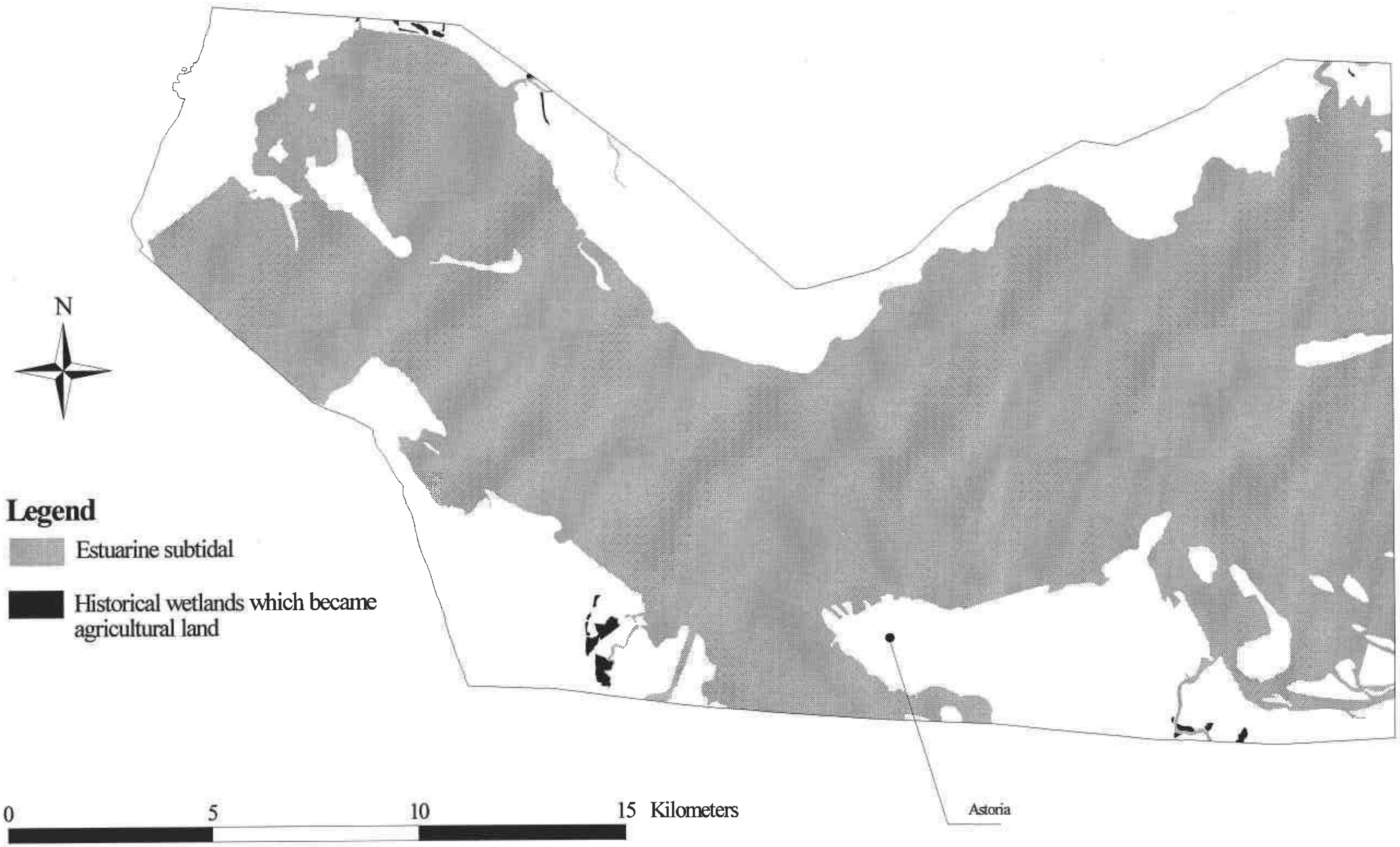


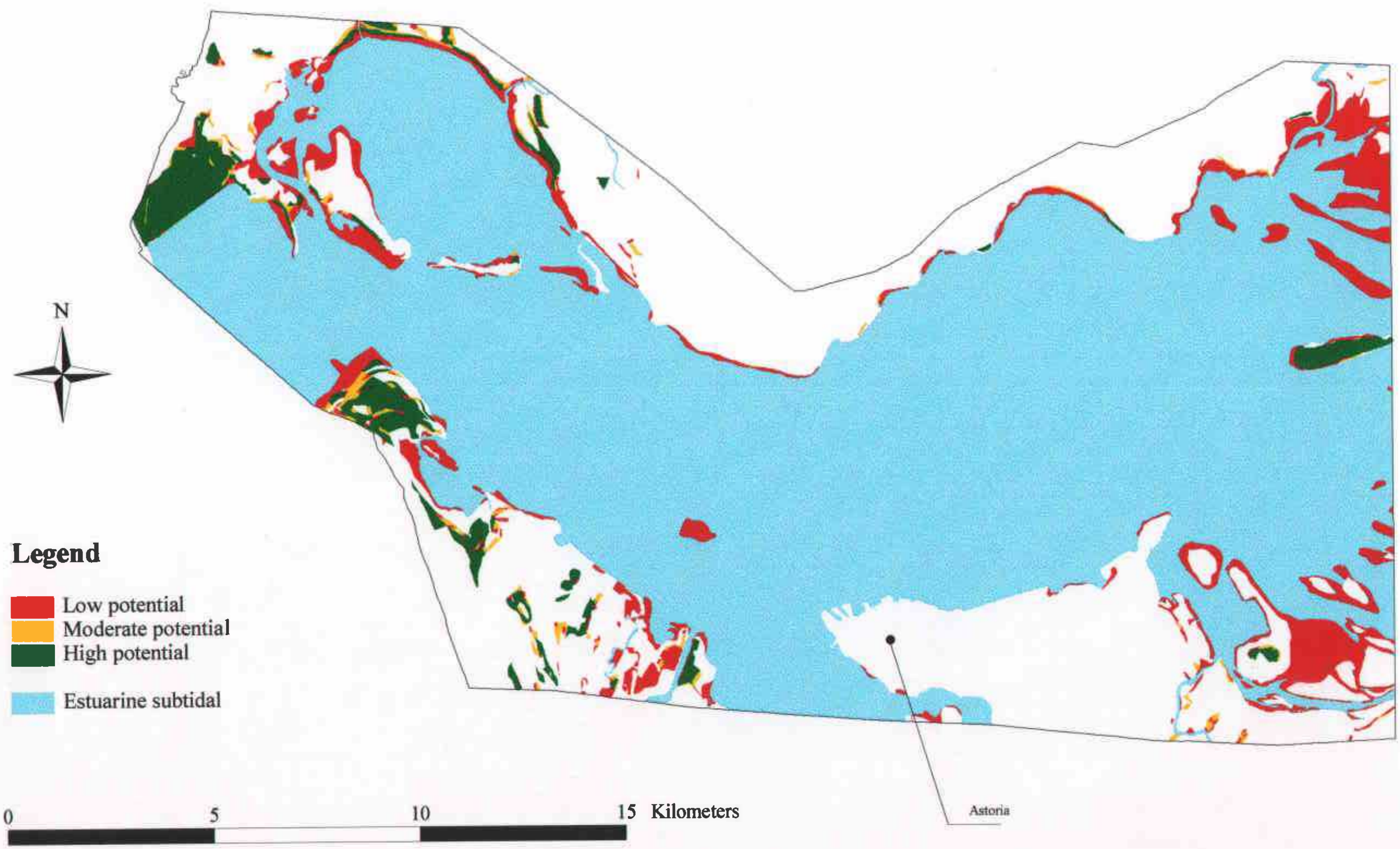
Figure VII.7: Historical Wetlands Which Became Agricultural Land, Estuarine Section



in the high potential model. Most of these changes took place in one region south of Warrenton.

The total number of historical wetlands in the high potential model was reduced from 1149 to 74 (see Figure VII.8). There appear to be even fewer than 74 high potential for restoration sites on Figure VII.8. In all examples throughout the restoration section of this study where the number of historical wetland sites is given, there will appear to be fewer actual sites on the maps. For example, in Figure VII.3, there appear to be only 34 historical wetlands which became urban, despite the fact there are 91. This occurs because all the historical wetland types which composed what appears to be a single polygon retained their values. For instance, the large historical wetland on Clatsop Spit and Trestle Bay appears to be a single polygon representing a single site. In reality, there are 9 historical wetlands in this location composed of estuarine and palustrine wetlands. Rather than lumping the 9 polygons into a single category called historical wetlands, it remains possible to determine exactly what type of historical wetland changed and where the changes occurred. It is critical for restoration efforts to know the exact type and location of historical wetlands if they are to be properly restored. Additionally, if historical wetlands were "lumped", the wetland values which comprise the site would be lost. Future research which may build upon this study could not address changes to specific wetland types. If the objective of a future study were to restore estuarine intertidal wetlands, it would be impossible to identify that value.

Figure VII.8: Wetland Restoration Potential, Estuarine Section



Historical wetlands identified as high, moderate and low potential for restoration were compiled onto Figure VII.8. The number of low potential sites composed most of the historical wetlands. Moderate potential sites were numerous (169), but did not occupy as much space. Size limitations of greater than 1 hectare but less than 2.5 hectares were applied to these sites, which is why they appeared so uniform. Of most importance to restoration efforts was the relative abundance of high restoration potential sites. There were 74 sites consisting of 768.5 hectares which have high potential for restoration. This small number of sites could be field verified in order to determine the likelihood for restoration. Once onsite, it will be far more obvious if the site could be restored. It is feasible that many of the sites identified as high potential for restoration could not readily be restored. The process of identifying high potential sites, however, narrows the total number of possible locations to a manageable field verifiable amount.

Section Two: Riverine Tidal

As a percent of total area there were far fewer historical wetlands in the riverine tidal section than in the estuarine section. There were 2997 historical wetlands consisting of 5716 hectares in the riverine tidal section. Historical wetlands are a measure of all wetland losses. Wetland increases have no bearing on historical wetlands. Considering that wetlands increased in this section by 1%, while suffering significant decreases indicates the dynamic nature of the riparian environment as it responds to human influence. For this section to experience a 1% increase, wetlands grew by approximately 5750 hectares. Certainly this section was marked by growth. Both palustrine wetlands and forested wetlands increased significantly. Likewise, the establishment of wildlife refuges and the return of favorable habitat increased wetlands.

Low Potential

There were 2076 historical wetlands consisting of 3588 hectares identified as low potential for restoration. From a total of 2997 historical wetlands made up of 5716 hectares, the low potential model generated the greatest amount of restoration potential sites (see Figure VII.9). Like low potential wetlands in the estuarine section, submerged historical wetlands composed the majority of locations with low potential for restoration. Urbanization impacted this section more so than in the estuarine section. There were 824 hectares where historical wetlands became urban/developed (see Figure VII.10). Most of the historical wetlands which became developed were located in the Longview area.

Moderate Potential

The moderate potential model identified all historical wetlands which were greater than or equal to 1 hectare and less than 2.5 hectares. There were 1265 historical wetland sites which fell into this category. From this amount, 131 historical

Figure VII.9: Wetland Restoration Potential, Riverine Tidal Section

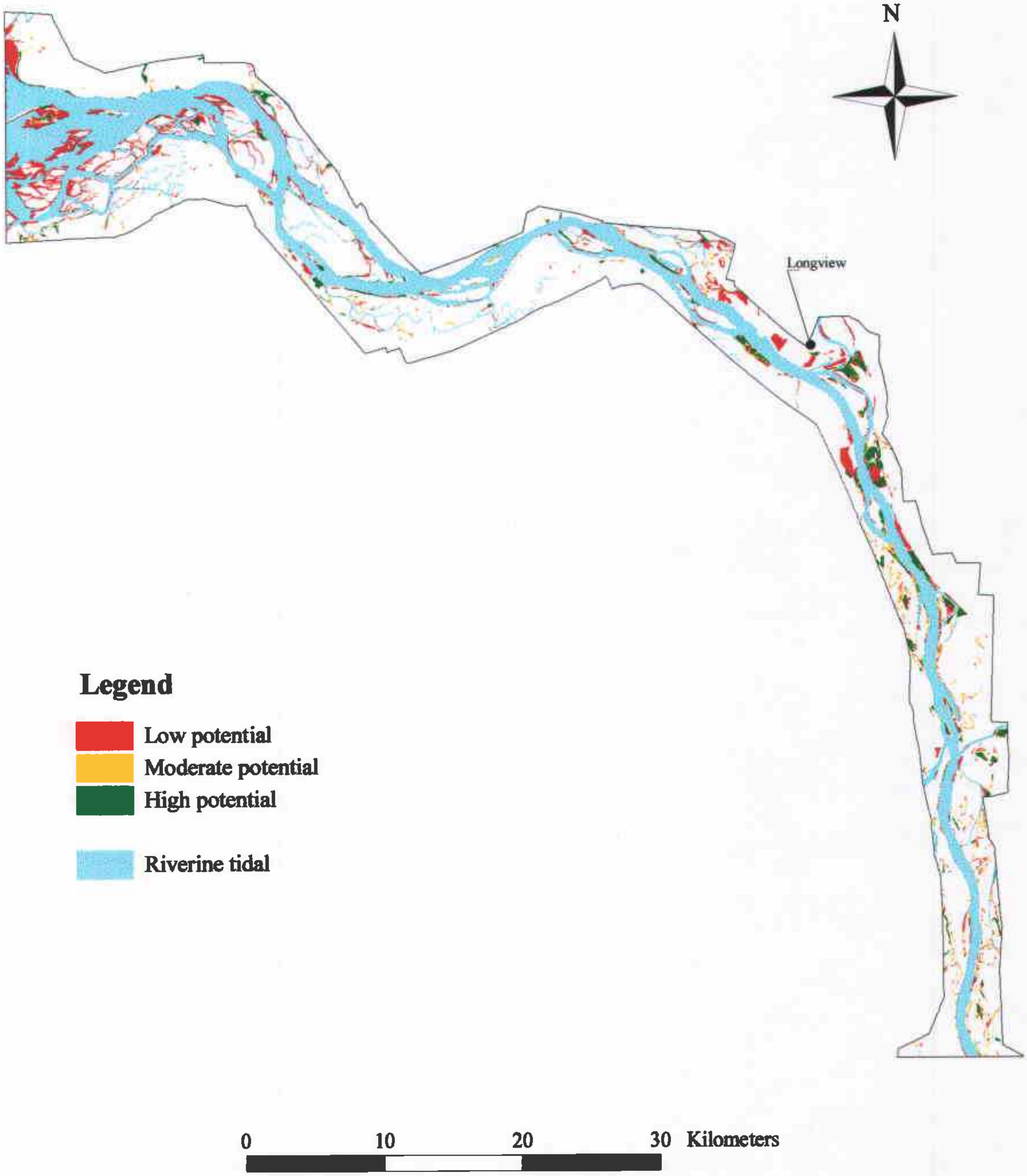
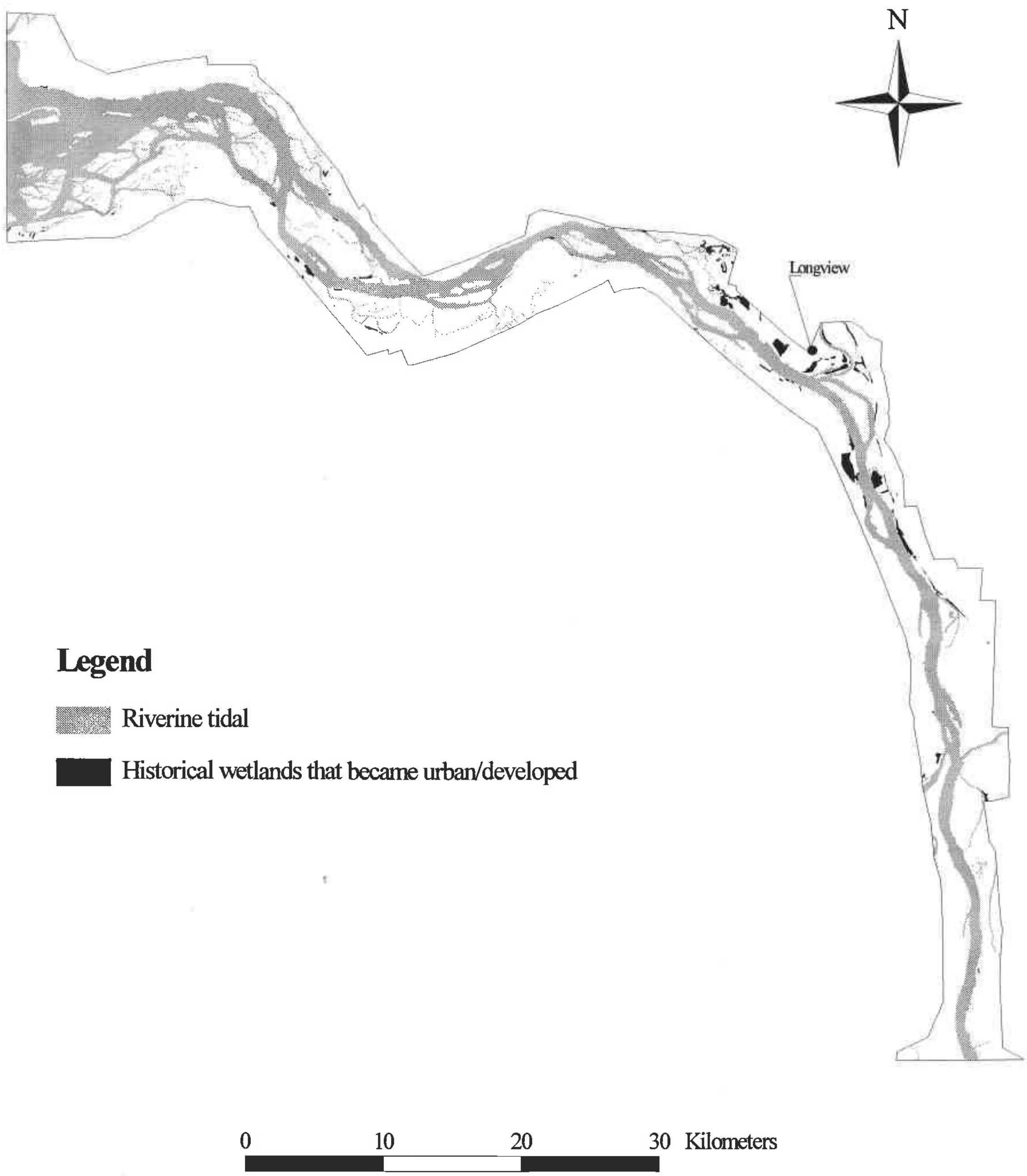


Figure VII.10: Historical Wetlands with Low Potential for Restoration Riverine Tidal Section



wetlands were identified as urban. Urbanization did not impact the moderate potential model heavily, as only 204 hectares were found. Historical wetlands which became urban were removed in the moderate potential model. There were 391 submerged historical wetlands. These sites were reduced from the overall number of moderate potential historical wetlands. Through this process of refining the total number of historical wetlands, 753 historical wetlands consisting of 1146 hectares were identified as moderate potential for restoration (see Figure VII.9). The sites were spread consistently across the section.

High Potential

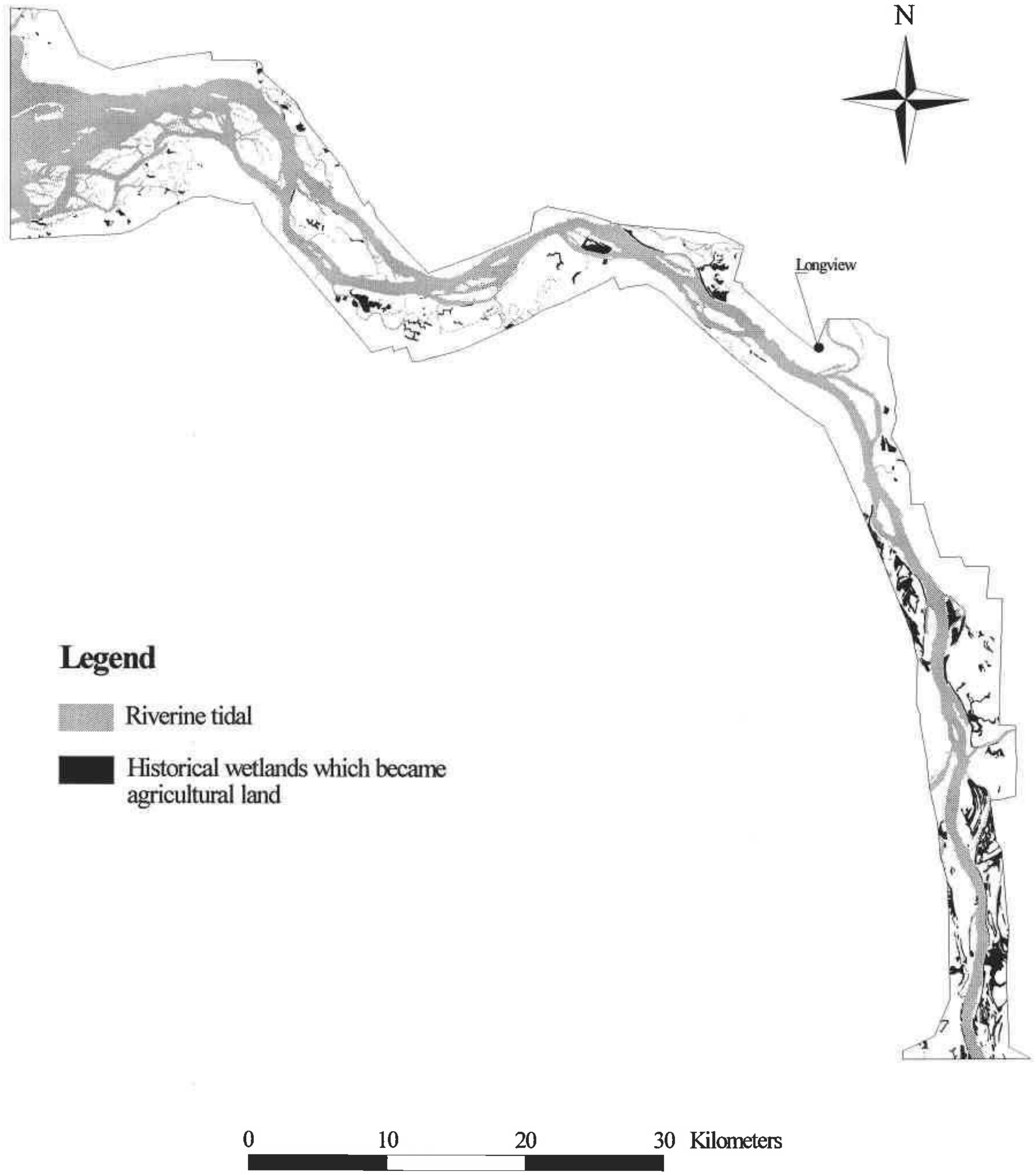
The first query in the high potential model was designed to locate all historical wetlands which were greater than 2.5 hectares. The query identified 753 historical wetlands. Combined, these historical wetlands were 5700 hectares in area. Several of the largest historical wetlands were located at the mouth of the Cowlitz River. The river deposited a thick bed of sediment in these locations, following the eruption of Mount St. Helens in 1980. The next query in the high potential model identified all historical wetlands which were not urban and were greater than 2.5 hectares. There were 73 such sites, consisting of 592 hectares. Upon removing from the model historical wetlands which became urban, 680 sites remained. Of this amount, 214 historical wetlands which became submerged were identified. Most of these large submerged historical wetlands were located in Cathlamet Bay and the Lewis and Clark National Wildlife Refuge.

To meet the criteria of the high potential model, historical wetlands which became agriculture were extracted from those sites with high potential for restoration. Agricultural land was the most common landcover in the riverine tidal section. Agriculture had the greatest impact on the decline of wetlands in this section. Unlike the estuarine section, agriculture in the riverine tidal section was on the increase. Figure VII.11 illustrates the location of all historical wetlands which became agricultural land. Historical wetlands which became agriculture were concentrated in the upstream quarter of the section. There were 1376 hectares of agricultural land which were extracted. In total, there were 178 historical wetlands consisting of 982 hectares identified as areas with high potential for restoration in the riverine tidal section.

Section Three: Riverine Lower Perennial

The riverine lower perennial section experienced extensive change between 1948 and 1991. There were numerous minor causes for these changes; however, a single overriding cause was primarily responsible -- urbanization. Urban development displaced most of the wetlands in the section. Between 1948 and 1991, urban growth was constant and rapid. In 1948, there were 3451.0 hectares of urban area, and in 1991, there were 8850.7 hectares. At 5399.7 hectares of growth and

Figure VII.11: Historical Wetlands Which Became Agricultural Land Riverine Tidal Section



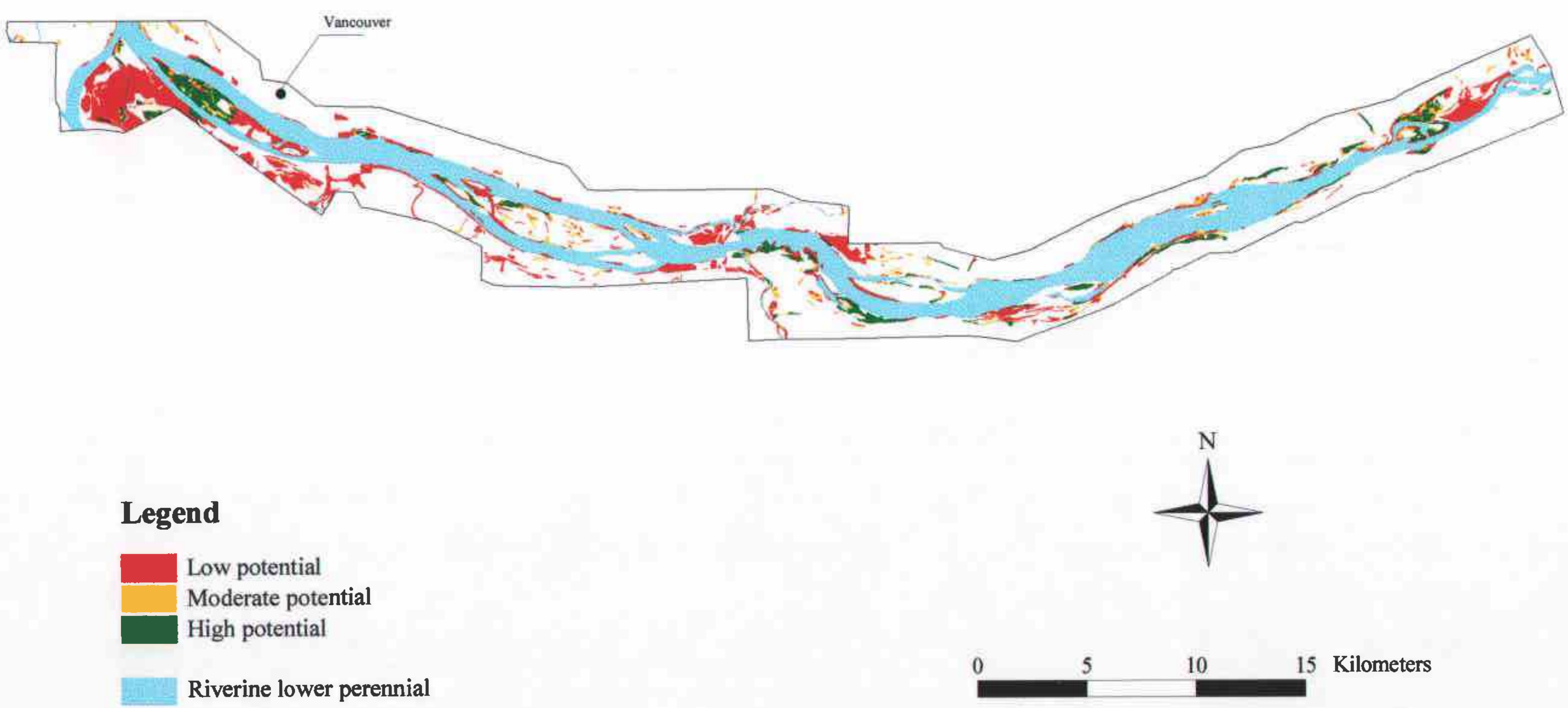
subsequent habitat and landcover displacement, a considerable portion of the displaced habitat was wetland. These displaced wetlands contributed to an inordinately large amount of historical wetlands. There were 1740 historical wetlands consisting of 3541 hectares in the riverine lower perennial section. Urbanization accounted for 57% of all historical wetlands.

Figure VII.12 illustrates wetland restoration potential for this section. Low potential historical wetlands dominate the landscape. These sites were largely situated in the downstream half of the section; however, one region upstream was well represented. This region just below the Bonneville Dam was wetlands, but became urban when the town of North Bonneville was relocated. The town was relocated when the second power house has built. Most of the low restoration potential sites were urban in the downstream half of the section. High potential historical wetlands were less abundant. Most of these sites were located on islands (especially Hayden Island) or were situated adjacent to the river.

Low Potential

Like the estuarine section, the low potential ranking in the riverine lower perennial section was largely comprised of a single component. In the estuarine section, submerged historical wetlands made up most of the low restoration potential sites. In the riverine lower perennial section, urban areas were the primary cause for the formidable amount of historical wetlands which had low potential for restoration.

Figure VII.12: Wetland Restoration Potential, Riverine Lower Perennial Section

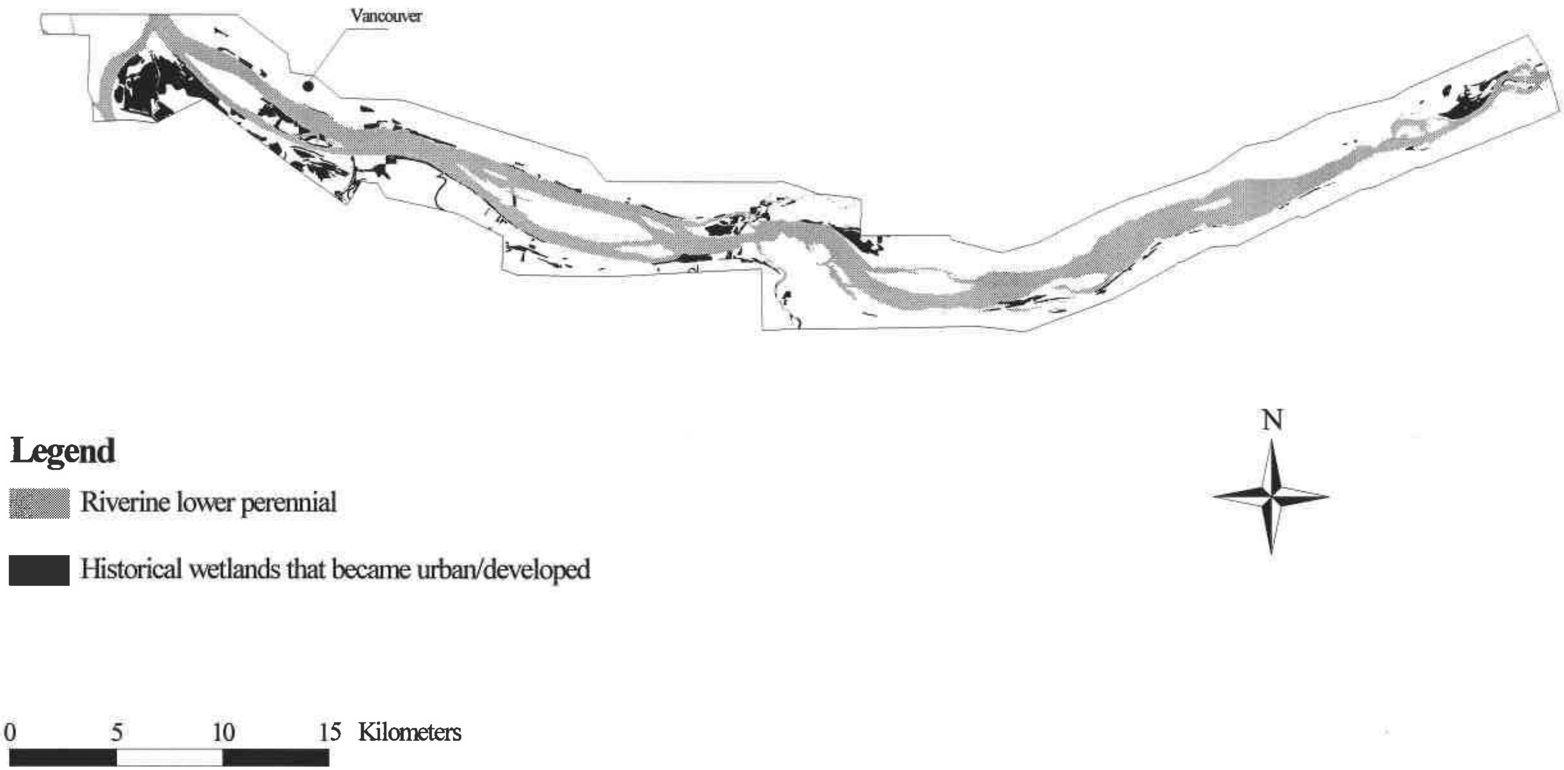


These areas were ranked as such because there was little likelihood that they could be restored. There were 2032 hectares of historical wetlands in the low potential model which were considered as such because of urbanization (see Figure VII.13). Urbanization was the most extensive in the region adjacent to the Willamette and Columbia Rivers. Historical wetlands which where less than 1 hectare and historical wetlands which became submerged were less of a factor than urban/development when considering locations for low restoration potential. Most historical wetlands which became submerged were located on the outside margins of the downstream portion of islands.

Moderate Potential

The first query in the moderate potential model located all historical wetlands which were greater than or equal to 1 hectare and less than 2.5 hectares. This query identified 797 historical wetlands, consisting of 1222 hectares. These historical wetlands were evenly spread across the riverine lower perennial section. Of this amount, 508 remained after all historical wetlands which became urban/developed were extracted. There were only 108 historical wetlands which became submerged. These sites were extracted. Remaining as moderate potential for restoration were 400 sites, consisting of 608 hectares.

Figure VII.13: Historical Wetlands with Low Potential for Restoration
Riverine Lower Perennial Section



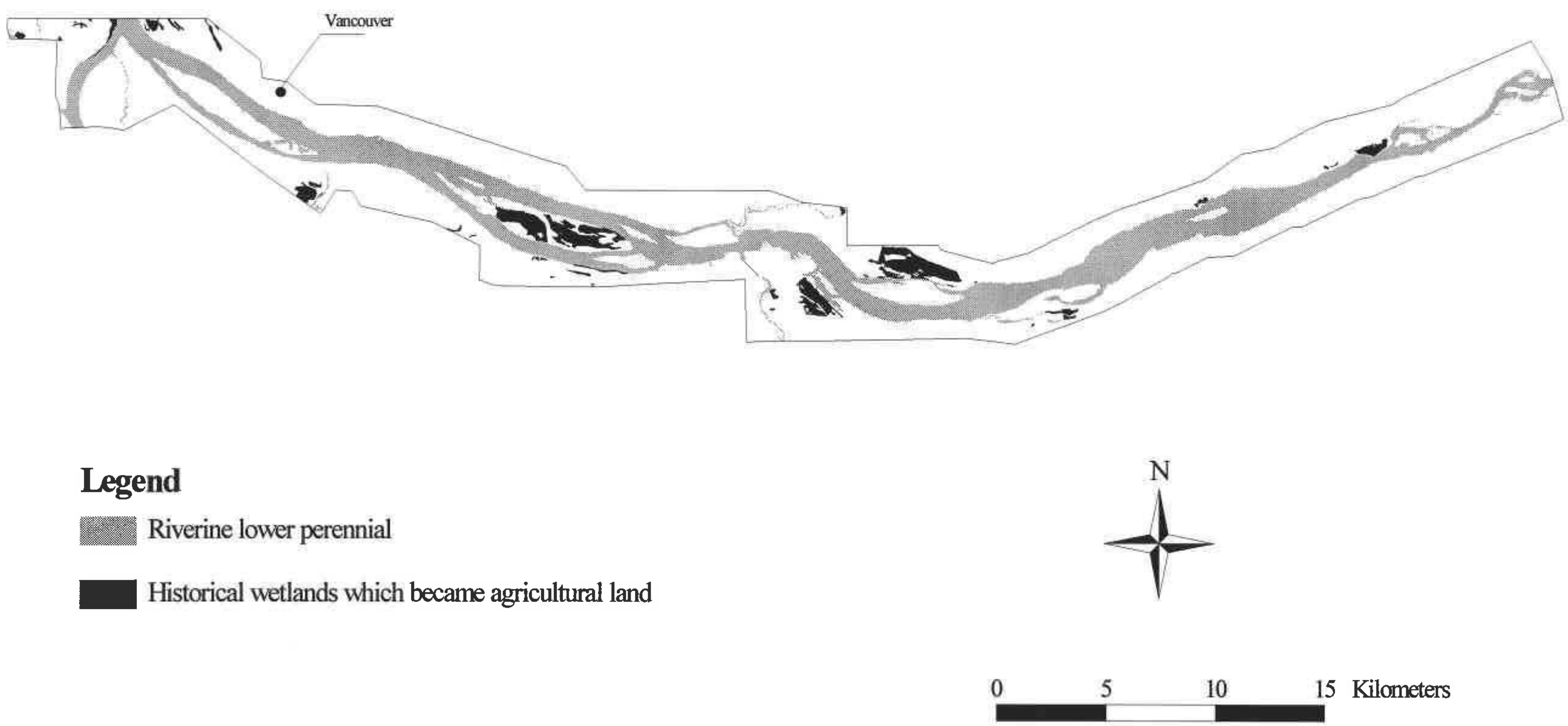
High Potential

Each sequential step in the high potential model narrowed the total number of historical wetland sites to be considered for restoration. As expected, historical wetlands that became urban/developed greatly refined the total number of sites in this model. And, much like the moderate potential model, historical wetlands which became submerged did not significantly refine the total number of areas for restoration potential. Historical wetlands which became agricultural land refined the model by 704 hectares. Figure VII.14 illustrates all historical wetlands which became agricultural land in the riverine lower perennial section. Historical wetlands which became agriculture were largely compressed into three locations. Most of these changes occurred when palustrine wetlands were displaced by agriculture. After refining the high potential model, there were a total of 105 historical wetlands, consisting of 655 hectares identified as areas with high potential for restoration in the riverine tidal section.

Future Research on Restoration

The possibilities of building from the historical wetlands GIS database constructed in this study for future wetlands restoration research are high. The GIS database of the five coverages taken over time may be used as a tool to better manage existing wetlands. Another coverage could be interpreted for the year 2000, providing more information on how habitats and wetlands change or the data from

Figure VII.14: Historical Wetlands Which Became Agricultural Land
Riverine Lower Perennial Section



this study could be used to predict future changes. It would be interesting to determine if the 1996 flood had impacts on wetlands similar to the 1948 flood.

The objectives for restoring historical wetlands may vary depending upon specific application-oriented projects. Using the low, moderate, and high potential models for restoration as a template, the possibilities for further refining the data with application-specific queries are great. A multitude of variables influence how one site may be chosen over another for restoration. Some of the variables may include:

- What influences does the regional geography exert on a potential site?
- What physical or anthropogenic factors act to prohibit or promote restoration?
- What are the organizations responsible for restoration?
- Is the organization public or private?
- What resources are available to the organization?
- What are the goals of restoration?
- Is the purpose for restoration mitigation?

Another important variable for choosing which historical wetlands should be considered for restoration on the LCR is location. The location of an historical wetland, with respect to a current wetland, impacts the size and functionability of a potentially restored area. Based upon this directive concerning location, the basis for a future task-specific research project is established. The following discussion lays the foundation for such a project. The purpose would be to create wetland corridors forming a continuum of linked habitats.

The LCR forms an ecological corridor from the Bonneville Dam to the Pacific Ocean. Over time, wetland habitats which collectively contribute to shaping the corridor have been depleted and dissected. Considering that the corridor is segmented logically, restoration efforts should focus on reestablishing the broken links. While reestablishing a contiguous corridor along either side of the river for the entire study site is not very feasible, at a minimum, such a goal would restore larger, uninterrupted tracts of wetlands. Therefore, the querying process was refined, based upon the application-specific objective of restoring the LCR wetland corridor. Historical wetlands adjacent to current wetlands were selected for their potential to create a corridor and to increase the size of contiguous wetlands. The methods for finding these adjacent polygons were discussed in Chapter IV. Materials and Methods.

Three maps were made to illustrate the possibilities of linking wetlands to form large, uninterrupted tracts of riparian habitat (see Figures VII.15-17). On these three maps (one for each section of the river), all historical wetlands which met the criteria of the high potential model were further refined to form a new category called the highest potential for restoration. This new model reduced the total number of sites to an even more manageable amount to be field verified for restoration potential. The estuarine section contained 43 historical wetlands, comprising 322 hectares identified for highest restoration potential. In the riverine tidal section, 63 sites were selected, making up 490 hectares, and in the riverine lower perennial section, 44 historical wetlands were selected, consisting of merely 263 hectares.

Figure VII.15: Historical Wetlands with Highest Potential for Restoration, Estuarine Section

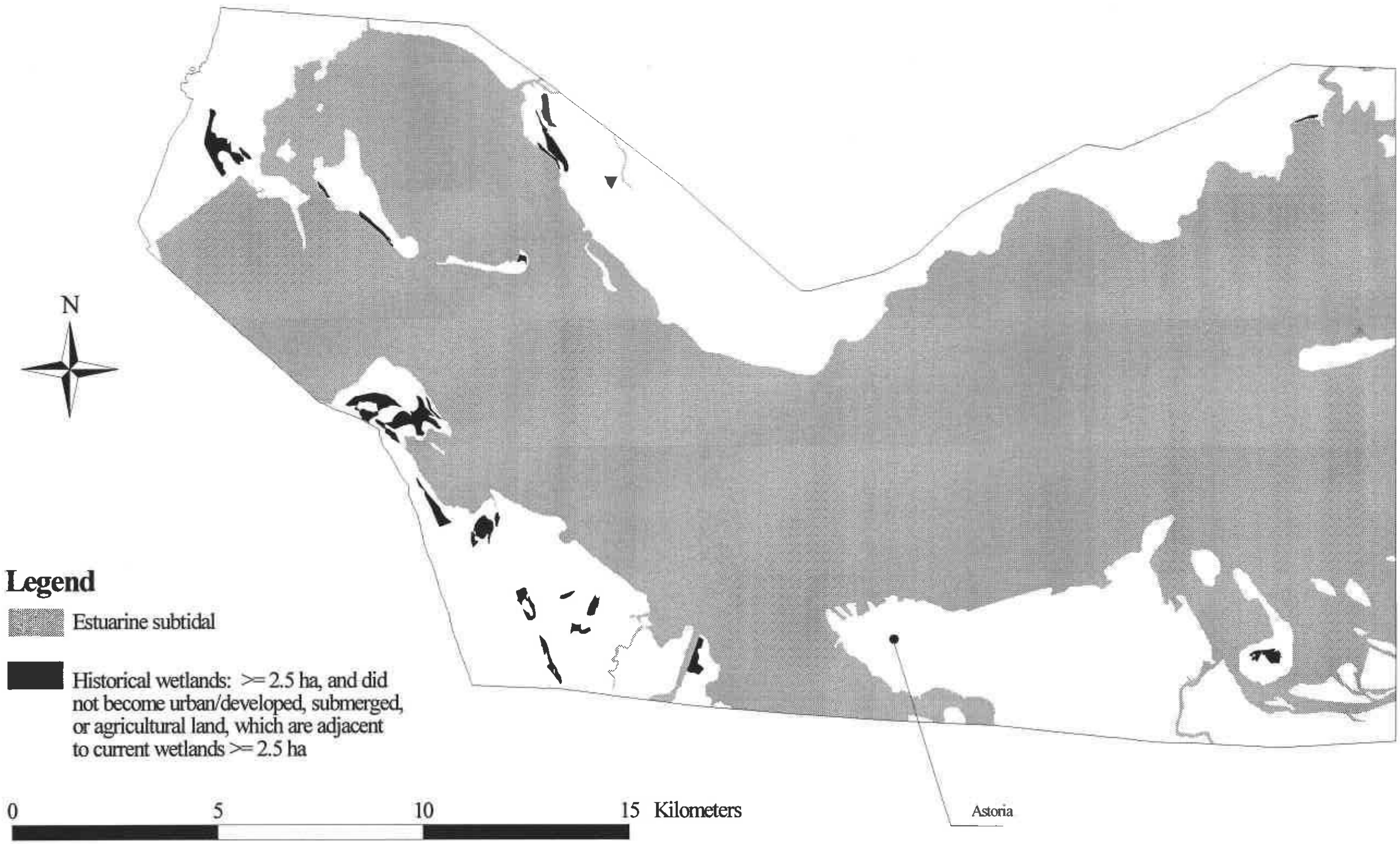


Figure VII.16: Historical Wetlands with Highest Potential for Restoration
Riverine Tidal Section

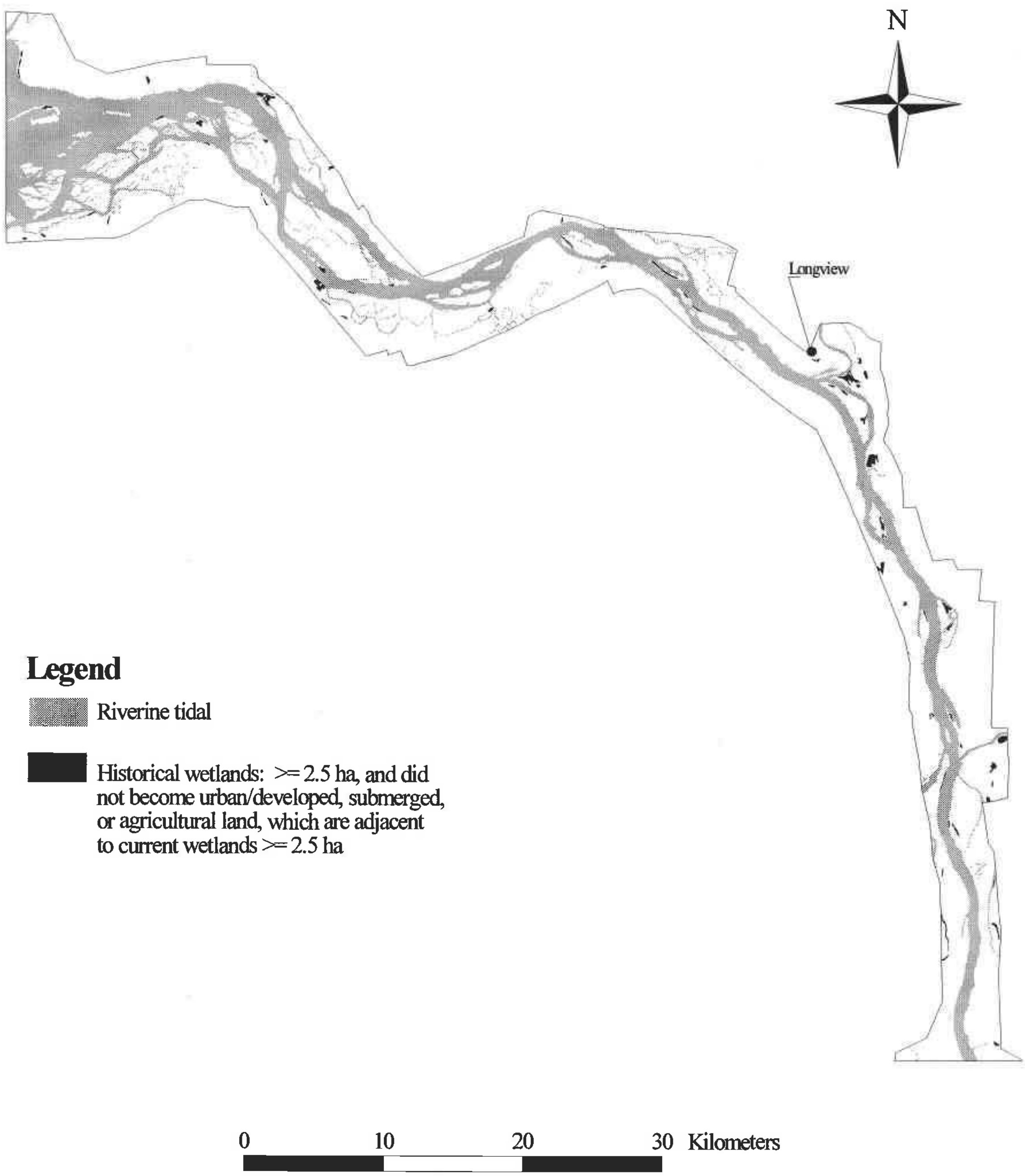
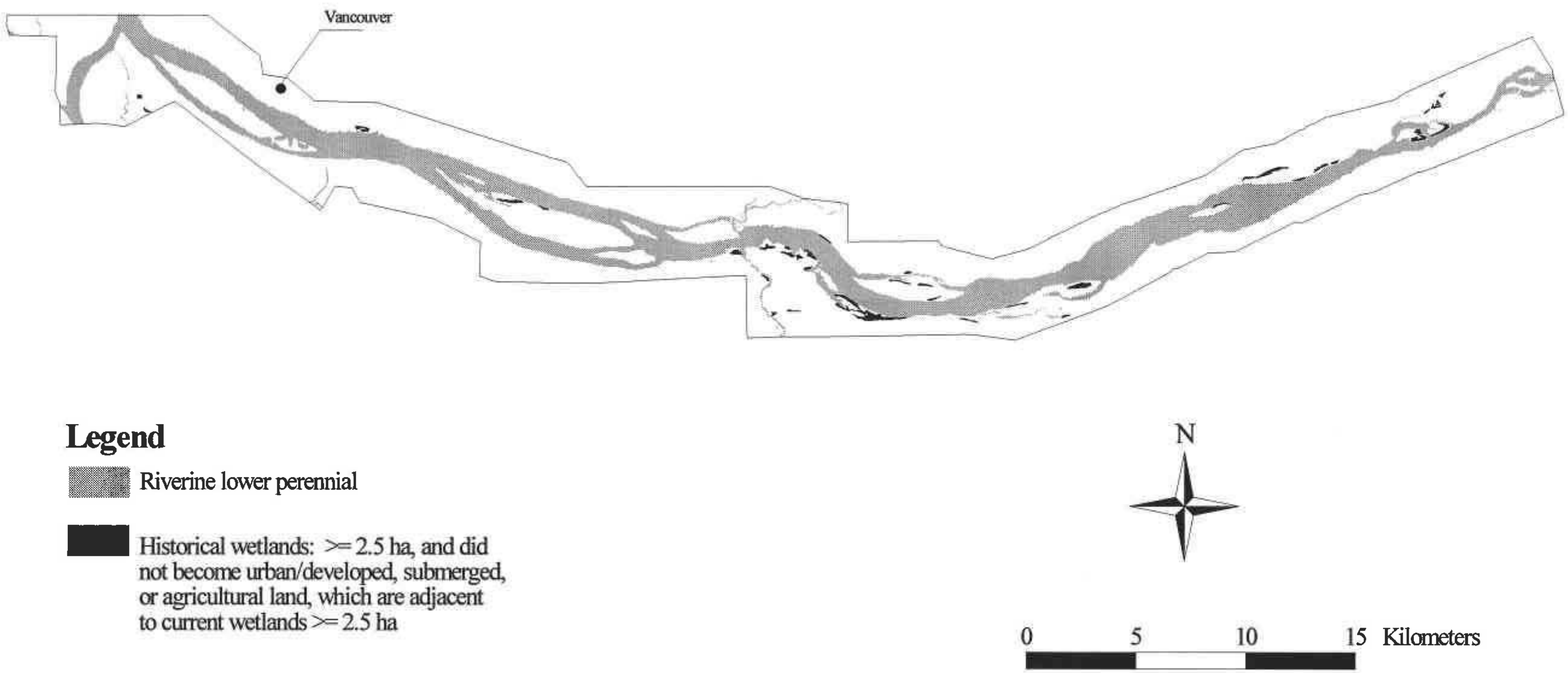


Figure VII.17: Historical Wetlands with Highest Potential for Restoration Riverine Lower Perennial Section



CHAPTER VIII. CONCLUSIONS

Research Basis and Objectives

The LCR riparian zone is a resource which attracts habitation by humans and wildlife alike. Human activities were characterized in this study as encroaching or displacing natural habitats. Wetland habitats, among the most biologically productive areas on earth, have suffered the greatest impacts. Wetlands which were once contiguously draped along the linear features of the river, are decreasing in size and becoming fragmented. Perturbations identified by this research which destroy or degrade wetlands within the riparian zone, such as in-water activities, agriculture, and urban/development, should be managed in order to curb current rates of wetlands losses.

The basis of this research was tied to several concerns: a) wetlands have been deemed important, thereby focusing efforts on conservation and protection; b) wetland losses along the LCR are not well known, and losses need to be documented and data input into a GIS for easy use (Lower Columbia River Bi-State Program 1993); and, c) despite limited information, it is clear that the primary ecological concern along the LCR is habitat loss (Lower Columbia River Estuary Program Survey 1998).

This study addressed these concerns. The objectives were to: a) quantify the extent and location of habitat change along the LCR riparian zone from 1948 to 1991; b) determine the factors and patterns which influenced wetland habitat change; and, c) develop regional wetland habitat models which ranks areas most conducive to restoration efforts. Each of these study objectives was achieved. The locations of wetlands change were identified through the use of aerial photography and quantified via a GIS. Factors and patterns which influence wetlands change were examined through research and comparative area analyses. Potential restoration sites were located by ranking historical wetlands according to specific GIS queries.

Extent of Wetlands Change

Assessment of the extent, distribution, and type of riparian habitats associated with the LCR was necessary in order to understand why wetland habitats changed. As a result, greater awareness of the overall health of the system was achieved. A comparison of the total area of wetland habitats between each of the five coverages provided change data. Between 1948 and 1991, wetlands decreased in the estuarine section by 25%, increased in the riverine tidal section by 1%, and decreased in the riverine lower perennial section by 37%. In total, wetlands within the LCR riparian zone decreased by 12%.

The largest decrease in the estuarine section occurred within estuarine intertidal wetlands. Between 1948 and 1973 these wetlands decreased by 1284.6 hectares. In the riverine tidal section, the single largest decrease of wetlands occurred within riverine tidal wetlands. These wetlands decreased by 1777.6 hectares between 1948 and 1961. In the riverine lower perennial section, the greatest loss of wetlands occurred between 1961 and 1973 within palustrine wetlands. These wetlands decreased during this period by 1609.3 hectares.

The extent of changes in non-wetland habitats and landcover were calculated. It was necessary to determine the extent of changes in non-wetland habitats and landcover, because they provided information related to changes in wetlands distribution. Changes in agriculture, for example, impacted wetlands. Agriculture generally decreased in the estuarine section, but increased in the riverine tidal section. In the riverine lower perennial section, it increased greatly, before decreasing in 1973. Forested habitats marginally increased within the estuarine section; however, they generally declined within the riverine tidal and riverine lower perennial sections. The largest and most consistent increases in landcover were unquestionably attributed to urban development. Within the estuarine section, urban landcover expanded the least. The riverine tidal section witnessed steady urban increases, and the riverine lower perennial section consistently doubled the total amount of urban area between each of the coverage years. In the riverine lower perennial section urban landcover became more uniform, and wetlands subsequently became more fragmented.

Factors Which Influenced Wetland Change: Estuarine Section

The causes for wetland losses in the estuarine section were largely related to in-water activities, such as channelization, dredge disposal, pile dike and jetty construction, and upstream damming. Numerous cases were cited where channelization and subsequent fill disposal degraded, depleted, or precluded growth of estuarine intertidal and palustrine wetlands. Evidence supported the fact that watershed activities such as timber harvesting, agriculture, and urban/development had comparatively minor impacts on wetlands losses. For example, between 1948 and 1991, the amount of land in service for agriculture steadily declined by 43.7%. In reality, between those years, more land changed from agriculture to wetlands than did wetlands to agriculture. A mere 1.6 hectares of 1948 estuarine intertidal wetlands became agriculture by 1991.

The majority of the 25% decrease in wetlands in the estuarine section occurred within estuarine intertidal wetlands. Because these emergent type wetlands were highly dependent upon the river as their major source of water, in-water activities which altered this source had a considerable impact on their decline. Within a pristine river system, such a rapid decrease in wetlands over a short period of time is not likely to occur. Directly or indirectly, human activities were the chief cause for the changes. Following the flood of 1948, in-water activities continued in earnest, and the regulatory effects of river flow via increased flood storage capacity incrementally increased, as dam construction was completed. These actions guaranteed that the river would become increasingly disconnected from the adjacent terrestrial environment over time. By regulating annual flooding, exchanges between the river and emergent vegetation were reduced, and estuarine intertidal wetlands were not replenished. These wetlands were often displaced by upland woody vegetation such as scrub/shrub. Over time, excess water ceased to be the controlling factor in the composition of the vegetation, and scrub/shrub habitats became the dominant cover.

The effects of flooding and flood control on the LCR were complex. Wetlands responded by both increasing and decreasing. Directly after the 1948 flood, emergent wetlands increased. This flood was the second largest flood on record for the LCR. River regulating effects of upstream dams were largely not in place in 1948. Bonneville Dam, which was completed in 1938, was not specifically designed for flood control; however, it does impound water in a reservoir, thereby partially moderating minor annual flood events. Greater control was exerted over large flood events, following the construction of the John Day Dam (1968), which was designed for flood control. Because of increased flood storage capacities, emergent wetlands, such as estuarine intertidal wetlands, significantly declined on all sections of the river.

The flood of 1948 scoured estuarine intertidal wetlands and all other habitats within the river's floodplain. As the flood receded, estuarine intertidal wetlands were the first vegetated habitat to be quickly reestablished. Other habitats/landcover close or adjacent to the river, such as palustrine wetlands, forested wetlands, lowland forest, agriculture, or scrub/shrub, were, in part, initially reestablished as esturine intertidal wetlands. In essence, the 1948 flood partially reset wetland succession. Such flood events are necessary for the colonization and development of emergent wetlands, but may be very infrequent in the future.

Forested wetlands increased slightly in the estuarine intertidal section, due to the increases in flood storage capacity regulated by upstream dams. The most common trend in wetland change in this section involved estuarine wetlands becoming palustrine wetlands, which, in turn, became forested wetlands or scrub/shrub habitat. Later, successional wetland species developed.

Factors Which Influenced Wetland Change: Riverine Tidal Section

The decline of 1777.6 hectares of riverine tidal wetlands accounts for the majority of all wetland losses in the riverine tidal section. While this decline in wetlands can be partially attributed to the direct and indirect impacts of development, diking, draining, channelization, and erosional activities, most of the losses were directly accounted for as riverine tidal wetlands changed to other wetland types. Specifically, palustrine wetlands accounted for most of the change. The total number of palustrine wetlands in 1948 was relatively few, yet increased by 2644.6 hectares by 1961. The decline in riverine tidal wetlands reflects the extensive increase in palustrine wetlands. This provides further evidence of the regulatory effects of upstream damming and the necessity of flooding in order to maintain a balanced mix of a variety of wetland types.

The second greatest decline in wetlands occurred in this section as agriculture displaced palustrine wetlands. There were 1098.8 hectares of palustrine wetlands in 1948 that changed to agriculture by 1991. Interestingly, agriculture was attributed as the cause for an increase of 891.2 hectares to palustrine wetlands during the same period.

Despite significant decreases in wetlands, the riverine tidal section experienced a slight overall increase in wetlands. Wetland increases were generally caused by the proliferation of palustrine and forested wetlands and the establishment of wildlife refuges. Forested wetlands increased, especially after the late 1960s, because of the lack of flood flows. In the riverine tidal section, emergent wetlands often changed to palustrine wetlands and then to either forested wetlands or scrub/shrub habitat.

The Lewis and Clark National Wildlife Refuge was established in 1971, and the Julia Butler Hansen Wildlife Refuge was established in 1972. Historically, portions of both refuges were diked for agricultural purposes. The Lewis and Clark National Wildlife Refuge was extensively diked. Areas which were not often inundated by annual flooding and could be converted to agricultural land were diked and drained. Over 650 hectares of agricultural land converted to wetlands shortly after the refuges were established. The impacts of passive restoration were visible by 1983. Over time, agricultural land left in disuse reverted to wetlands.

Factors Which Influenced Wetland Change: Riverine Lower Perennial Section

As a percent of total area, there were fewer wetlands in the riverine lower perennial section than in the other two sections. The upstream half of the riverine lower perennial section is largely confined. The placement of roads on the comparatively smaller floodplain of both sides of the river serves to sever hydraulic linkage between aquatic and terrestrial environments more abruptly than the nearby natural elevation gain. Therefore, there was less suitable lowland space for wetlands to colonize.

The causes for wetlands degradation and destruction in the riverine lower perennial section were correlated with rapid urbanization. By 1991, the urban landscape dominated both sides of the river, forming a near continuous cover along the downstream half of the section. Between 1948 and 1991, urban growth rapidly increased by 5399.7 hectares. By 1991 merely 86.6 hectares of riverine lower perennial wetlands remained. The greatest losses of wetlands occurred within palustrine wetlands. The decline of this habitat between 1961 and 1973 represents one of the most rapid and large losses of wetlands for all wetland types in all sections. During those 12 years, palustrine wetlands were diminished by 1609.3 hectares. More than 1000 hectares of palustrine wetlands were directly displaced by urbanization. Agriculture displaced most of the remaining amount.

Much of the increase in wetlands in this section was caused by the growth of forested wetlands. Forested wetlands sharply increased between 1973 and 1991. This pattern of rapid increase within forested wetlands following 1973 occurred in all sections. With the marked reduction of flooding, forested wetlands had enough time to begin to flourish. The only wetland habitat that consistently increased within all of the river sections was forested wetlands.

Wetlands Restoration Potential

The restoration analysis in this study located historical wetlands which exemplified the best qualities needed for restoration to be successful. The research provided a template for identifying historical wetlands. Through the use of a GIS, each historical wetland was ranked into low, moderate, or high categories, based upon its potential for restoration. By applying focused sequentially-refined queries, sites were identified for restoration potential. Historical wetlands identified in the high potential model were of most importance to restoration efforts, as these sites were limited in number and could be field verified.

In the estuarine section, most historical wetlands fall into the low potential category, and many of these were considered as such because they became submerged. These submerged historical wetlands were impermanent emergent wetlands, which greatly fluctuated over time in response to in-water activities. In total, there were 1149 historical wetlands identified. Greater than 75% of the historical wetlands in the section were located within or adjacent to the active channel. Such a large amount of historical wetlands indicates that there was tremendous change in the estuarine section between 1948 and 1991. Many of the historical wetlands were originally not wetlands, but became wetlands and then changed again to a non-wetland state by 1991. There were merely 74 historical wetlands ranked as high potential for restoration, consisting of 768.5 hectares.

In the riverine tidal section there were 2997 historical wetlands. The preponderance of historical wetlands were identified as having low potential for restoration. Most historical wetlands considered as low potential became urban or were submerged by 1991. Historical wetlands were converted to agriculture were extracted from those sites with high potential for restoration. Not only was agricultural land the most common landcover in the riverine tidal section, but it had the greatest impact on the decline of wetlands. By removing historical wetlands which became agriculture, the total number of high potential sites was significantly reduced. There were 178 historical wetlands consisting of 982 hectares identified as areas with high potential for restoration.

In the riverine lower perennial section, there were 1740 historical wetlands. Of all historical wetlands 57% became urban. These sites were largely located in the downstream half of the section, especially near the confluence of the Willamette and the Columbia Rivers. Such sites were ranked as low potential for restoration. While wetlands have great value, homes, roads, and places of business are basic to human needs and activities, and are not apt to be dismantled to restore wetlands. Developed areas retain very little of their historical wetland character and would require an extensive effort to restore. It is unrealistic to consider restoring wetlands that are now developed, particularly when other, more easily restorable, historical wetlands are present. In the riverine lower perennial section, there were only 105 historical wetlands, consisting of 655 hectares, identified as having high potential for restoration.

While this study advocates restoration potential, restoration is not a surrogate for responsible ecosystem-wide stewardship of the riparian zone. Restoration will not succeed unless degrading elements are mitigated or removed. Wetlands are resilient, and, given the chance, they often recover with minimal intervention.

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APPENDIX

APPENDIX

The following three sections are examples of the ARC macro language (AML).

<u>Example One: Quantifying Wetland Habitat Change</u>

```
/************ START MAIN *************
&severity &error &ignore

identity %in_cover1% %identity_cov% %out_cover1% poly 1

kill %in_cover1% all

tables
sel %out_cover1%.pat
 /* CHANGE RIVERINE CLASSES IN ESTUARY TO ESTUARY TYPES
 /* 1948
 res %identity_cov%-id = 1 and habcode48 = '2Rt'
 move '2Es' to habcode48
 asel
 res %identity_cov%-id = 1 and habcode48 = '4Rt'
 move '4Ei' to habcode48
 asel
/* 1961

 res %identity_cov%-id = 1 and habcode61 = '2Rt'
 move '2Es' to habcode61
 asel
 res %identity_cov%-id = 1 and habcode61 = '4Rt'
 move '4Ei' to habcode61
 asel

/* 1973
 res %identity_cov%-id = 1 and habcode73 = '2Rt'
 move '2Es' to habcode73
 asel
 res %identity_cov%-id = 1 and habcode73 = '4Rt'
 move '4Ei' to habcode73
 asel

/* 1983
```

```
res %identity_cov%-id = 1 and habcode83 = '2Rt'
move '2Es' to habcode83
asel
res %identity_cov%-id = 1 and habcode83 = '4Rt'
move '4Ei' to habcode83
asel

/* 1991
res %identity_cov%-id = 1 and habcode91 = '2Rt'
move '2Es' to habcode91
asel
res %identity_cov%-id = 1 and habcode91 = '4Rt'
move '4Ei' to habcode91
asel

/* CHANGE CLASSES IN RIVERINE-TIDAL TO RIVERINE-TIDAL TYPES
/* 1948
res %identity_cov%-id = 2 and habcode48 = '2Es'
move '2Rt' to habcode48
asel
res %identity_cov%-id = 2 and habcode48 = '4Ei'
move '4Rt' to habcode48
asel
res %identity_cov%-id = 2 and habcode48 = '2Rl'
move '2Rt' to habcode48
asel
res %identity_cov%-id = 2 and habcode48 = '4Rl'
move '4Rt' to habcode48
asel

/* 1961
res %identity_cov%-id = 2 and habcode61 = '2Es'
move '2Rt' to habcode61
asel
res %identity_cov%-id = 2 and habcode61 = '4Ei'
move '4Rt' to habcode61
asel
res %identity_cov%-id = 2 and habcode61 = '2Rl'
move '2Rt' to habcode61
asel
res %identity_cov%-id = 2 and habcode61 = '4Rl'
move '4Rt' to habcode61
asel

/* 1973
res %identity_cov%-id = 2 and habcode73 = '2Es'
```

```
move '2Rt' to habcode73
asel
res %identity_cov%-id = 2 and habcode73 = '4Ei'
move '4Rt' to habcode73
asel
res %identity_cov%-id = 2 and habcode73 = '2Rl'
move '2Rt' to habcode73
asel
res %identity_cov%-id = 2 and habcode73 = '4Rl'
move '4Rt' to habcode73
asel

/* 1983
res %identity_cov%-id = 2 and habcode83 = '2Es'
move '2Rt' to habcode83
asel
res %identity_cov%-id = 2 and habcode83 = '4Ei'
move '4Rt' to habcode83
asel
res %identity_cov%-id = 2 and habcode83 = '2Rl'
move '2Rt' to habcode83
asel
res %identity_cov%-id = 2 and habcode83 = '4Rl'
move '4Rt' to habcode83
asel

/* 1991
res %identity_cov%-id = 2 and habcode91 = '2Es'
move '2Rt' to habcode91
asel
res %identity_cov%-id = 2 and habcode91 = '4Ei'
move '4Rt' to habcode91
asel
res %identity_cov%-id = 2 and habcode91 = '2Rl'
move '2Rt' to habcode91
asel
res %identity_cov%-id = 2 and habcode48 = '4Rl'
move '4Rt' to habcode91
asel

/* CHANGE CLASSES IN RIVERINE-NONTIDAL TO RIVERINE-NONTIDAL TYPES
/* 1948
res %identity_cov%-id = 3 and habcode48 = '2Rt'
move '2Rl' to habcode48
asel
res %identity_cov%-id = 3 and habcode48 = '4Rt'
```

```
 move '4Rl' to habcode48
 asel
/* 1961
 res %identity_cov%-id = 3 and habcode61 = '2Rt'
 move '2Rl' to habcode61
 asel
 res %identity_cov%-id = 3 and habcode61 = '4Rt'
 move '4Rl' to habcode61
 asel
/* 1973
 res %identity_cov%-id = 3 and habcode73 = '2Rt'
 move '2Rl' to habcode73
 asel
 res %identity_cov%-id = 3 and habcode73 = '4Rt'
 move '4Rl' to habcode73
 asel
/* 1983
 res %identity_cov%-id = 3 and habcode83 = '2Rt'
 move '2Rl' to habcode83
 asel
 res %identity_cov%-id = 3 and habcode83 = '4Rt'
 move '4Rl' to habcode83
 asel
/* 1991
 res %identity_cov%-id = 3 and habcode91 = '2Rt'
 move '2Rl' to habcode91
 asel
 res %identity_cov%-id = 3 and habcode91 = '4Rt'
 move '4Rl' to habcode91
 asel

q /*quit tables

/* MAKE COVERAGES FOR EACH YEAR OF ENTIRE STUDY AREA
/* 1948
dissolve monster6 hab48all habcode48 poly
tables
 additem hab48all.pat hectares 12 12 n 2
 sel hab48all.pat
 cal hectares = area * 0.000009290341
 statistics habcode48 hab48all.stats
 sum hectares
 mean hectares
 ~
 n
 n
```

```
q
infodbase hab48all.stats hab48all.dbf
export cover hab48all hab48all full

/* 1961
dissolve monster6 hab61all habcode61 poly
tables
 additem hab61all.pat hectares 12 12 n 2
 sel hab61all.pat
 cal hectares = area * 0.000009290341
 statistics habcode61 hab61all.stats
 sum hectares
 mean hectares
 ~
 n
 n
 q
infodbase hab61all.stats hab61all.dbf
export cover hab61all hab61all full

/* 1973
dissolve monster6 hab73all habcode73 poly
tables
 additem hab73all.pat hectares 12 12 n 2
 sel hab73all.pat
 cal hectares = area * 0.000009290341
 statistics habcode73 hab73all.stats
 sum hectares
 mean hectares
 ~
 n
 n
 q
infodbase hab73all.stats hab73all.dbf
export cover hab73all hab73all full

/* 1983
dissolve monster6 hab83all habcode83 poly
tables
 additem hab83all.pat hectares 12 12 n 2
 sel hab83all.pat
 cal hectares = area * 0.000009290341
 statistics habcode83 hab83all.stats
 sum hectares
 mean hectares
 ~
```

```
 n
 n
 q
infodbase hab83all.stats hab83all.dbf
export cover hab83all hab83all full

/* 1991
dissolve monster6 hab91all habcode91 poly
tables
 additem hab91all.pat hectares 12 12 n 2
 sel hab91all.pat
 cal hectares = area * 0.000009290341
 statistics habcode91 hab91all.stats
 sum hectares
 mean hectares
 ~
 n
 n
 q
infodbase hab91all.stats hab91all.dbf
export cover hab91all hab91all full

/* WRITE COVERAGES & STATS FOR EACH RIVER SECTION FOR EACH YEAR
/* ESTUARINE
reselect monster6 estall poly
res %identity_cov%-id = 1
 ~
 n
 n

/* 1948
dissolve estall est48 habcode48 poly
tables
 additem est48.pat hectares 12 12 n 2
 sel est48.pat
 cal hectares = area * 0.000009290341
 statistics habcode48 est48.stats
 sum hectares
 mean hectares
 ~
 n
 n
 q
infodbase est48.stats est48.dbf
export cover est48 est48 full
```

```
/* 1961
dissolve estall est61 habcode61 poly
tables
 additem est61.pat hectares 12 12 n 2
 sel est61.pat
 cal hectares = area * 0.000009290341
 statistics habcode61 est61.stats
 sum hectares
 mean hectares
 ~
 n
 n
 q
infodbase est61.stats est61.dbf
export cover est61 est61 full

/* 1973
dissolve estall est73 habcode73 poly
tables
 additem est73.pat hectares 12 12 n 2
 sel est73.pat
 cal hectares = area * 0.000009290341
 statistics habcode73 est73.stats
 sum hectares
 mean hectares
 ~
 n
 n
 q
infodbase est73.stats est73.dbf
export cover est73 est73 full

/* 1983
dissolve estall est83 habcode83 poly
tables
 additem est83.pat hectares 12 12 n 2
 sel est83.pat
 cal hectares = area * 0.000009290341
 statistics habcode83 est83.stats
 sum hectares
 mean hectares
 ~
 n
 n
 q
infodbase est83.stats est83.dbf
```

```
export cover est83 est83 full

/* 1991
dissolve estall est91 habcode91 poly
tables
 additem est91.pat hectares 12 12 n 2
 sel est91.pat
 cal hectares = area * 0.000009290341
 statistics habcode91 est91.stats
 sum hectares
 mean hectares
 ~
 n
 n
 q
infodbase est91.stats est91.dbf
export cover est91 est91 full


/* RIVERINE TIDAL
reselect monster6 r_tidall poly
res %identity_cov%-id = 2
 ~
 n
 n

/* 1948
dissolve r_tidall r_tid48 habcode48 poly
tables
 additem r_tid48.pat hectares 12 12 n 2
 sel r_tid48.pat
 cal hectares = area * 0.000009290341
 statistics habcode48 r_tid48.stats
 sum hectares
 mean hectares
 ~
 n
 n
 q
infodbase r_tid48.stats r_tid48.dbf
export cover r_tid48 r_tid48 full

/* 1961
dissolve r_tidall r_tid61 habcode61 poly
tables
 additem r_tid61.pat hectares 12 12 n 2
```

```
 sel r_tid61.pat
 cal hectares = area * 0.000009290341
 statistics habcode61 r_tid61.stats
 sum hectares
 mean hectares
 ~
 n
 n
 q
infodbase r_tid61.stats r_tid61.dbf
export cover r_tid61 r_tid61 full

/* 1973
dissolve r_tidall r_tid73 habcode73 poly
tables
 additem r_tid73.pat hectares 12 12 n 2
 sel r_tid73.pat
 cal hectares = area * 0.000009290341
 statistics habcode73 r_tid73.stats
 sum hectares
 mean hectares
 ~
 n
 n
 q
infodbase r_tid73.stats r_tid73.dbf
export cover r_tid73 r_tid73 full

/* 1983
dissolve r_tidall r_tid83 habcode83 poly
tables
 additem r_tid83.pat hectares 12 12 n 2
 sel r_tid83.pat
 cal hectares = area * 0.000009290341
 statistics habcode83 r_tid83.stats
 sum hectares
 mean hectares
 ~
 n
 n
 q
infodbase r_tid83.stats r_tid83.dbf
export cover r_tid83 r_tid83 full

/* 1991
dissolve r_tidall r_tid91 habcode91 poly
```

```
tables
 additem r_tid91.pat hectares 12 12 n 2
 sel r_tid91.pat
 cal hectares = area * 0.000009290341
 statistics habcode91 r_tid91.stats
 sum hectares
 mean hectares
 ~
 n
 n
 q
infodbase r_tid91.stats r_tid91.dbf
export cover r_tid91 r_tid91 full


/* RIVERINE NON-TIDAL
reselect monster6 r_ntall poly
res %identity_cov%-id = 3
 ~
 n
 n

/* 1948
dissolve r_ntall r_nt48 habcode48 poly
tables
 additem r_nt48.pat hectares 12 12 n 2
 sel r_nt48.pat
 cal hectares = area * 0.000009290341
 statistics habcode48 r_nt48.stats
 sum hectares
 mean hectares
 ~
 n
 n
 q
infodbase r_nt48.stats r_nt48.dbf
export cover r_nt48 r_nt48 full

/* 1961
dissolve r_ntall r_nt61 habcode61 poly
tables
 additem r_nt61.pat hectares 12 12 n 2
 sel r_nt61.pat
 cal hectares = area * 0.000009290341
 statistics habcode61 r_nt61.stats
 sum hectares
```

```
 mean hectares
 ~
 n
 n
 q
infodbase r_nt61.stats r_nt61.dbf
export cover r_nt61 r_nt61 full

/* 1973
dissolve r_ntall r_nt73 habcode73 poly
tables
 additem r_nt73.pat hectares 12 12 n 2
 sel r_nt73.pat
 cal hectares = area * 0.000009290341
 statistics habcode73 r_nt73.stats
 sum hectares
 mean hectares
 ~
 n
 n
 q
infodbase r_nt73.stats r_nt73.dbf
export cover r_nt73 r_nt73 full

/* 1983
dissolve r_ntall r_nt83 habcode83 poly
tables
 additem r_nt83.pat hectares 12 12 n 2
 sel r_nt83.pat
 cal hectares = area * 0.000009290341
 statistics habcode83 r_nt83.stats
 sum hectares
 mean hectares
 ~
 n
 n
 q
infodbase r_nt83.stats r_nt83.dbf
export cover r_nt83 r_nt83 full

/* 1991
dissolve r_ntall r_nt91 habcode91 poly
tables
 additem r_nt91.pat hectares 12 12 n 2
 sel r_nt91.pat
 cal hectares = area * 0.000009290341
```

```
statistics habcode91 r_nt91.stats
sum hectares
mean hectares
~
n
n
q
infodbase r_nt91.stats r_nt91.dbf
export cover r_nt91 r_nt91 full
```

Example Two: Factors Which Influence Wetland Habitat Change

```
/* CREATE COVERAGE & STATS SHOWING CHANGE 1948 TO 1991
reselect monster6 chng4891 poly
res habcode48 ne habcode91
~
n
n

tables
additem chng4891.pat hectares 12 12 n 2
sel chng4891.pat
cal hectares = area * 0.000009290341
res habcode48 = '1'
statistics habcode91 chng_1.stats
sum hectares
mean hectares
~
n
n
asel
res habcode48 = '2Mi'
statistics habcode91 chng_2mi.stats
y
asel
res habcode48 = '2Es'
statistics habcode91 chng_2es.stats
y
asel
res habcode48 = '2Rt'
statistics habcode91 chng_2rt.stats
y
```

```
asel
res habcode48 = '2Rl'
statistics habcode91 chng_2rl.stats
y
asel
res habcode48 = '2Ll'
statistics habcode91 chng_2ll.stats
y
asel
res habcode48 = '3'
statistics habcode91 chng_3.stats
y
asel
res habcode48 = '4Ei'
statistics habcode91 chng_4ei.stats
y
asel
res habcode48 = '4Rt'
statistics habcode91 chng_4rt.stats
y
asel
res habcode48 = '4Rl'
statistics habcode91 chng_4rl.stats
y
asel
res habcode48 = '4Lt'
statistics habcode91 chng_4lt.stats
y
asel
res habcode48 = '4P'
statistics habcode91 chng_4p.stats
y
asel
res habcode48 = '5'
statistics habcode91 chng_5.stats
y
asel
res habcode48 = '6'
statistics habcode91 chng_6.stats
y
asel
res habcode48 = '7'
statistics habcode91 chng_7.stats
y
asel
res habcode48 = '8'
```

```
statistics habcode91 chng_8.stats
y
asel
res habcode48 = '9'
statistics habcode91 chng_9.stats
y
asel
res habcode48 = '10'
statistics habcode91 chng_10.stats
y
asel

q
infodbase chng_1.stats chng_1.dbf
infodbase chng_2mi.stats chng_2mi.dbf
infodbase chng_2es.stats chng_2es.dbf
infodbase chng_2rt.stats chng_2rt.dbf
infodbase chng_2rl.stats chng_2rl.dbf
infodbase chng_2ll.stats chng_2ll.dbf
infodbase chng_3.stats chng_3.dbf
infodbase chng_4ei.stats chng_4ei.dbf
infodbase chng_4rt.stats chng_4rt.dbf
infodbase chng_4rl.stats chng_4rl.dbf
infodbase chng_4lt.stats chng_4lt.dbf
infodbase chng_4p.stats chng_4p.dbf
infodbase chng_5.stats chng_5.dbf
infodbase chng_6.stats chng_6.dbf
infodbase chng_7.stats chng_7.dbf
infodbase chng_8.stats chng_8.dbf
infodbase chng_9.stats chng_9.dbf
infodbase chng_10.stats chng_10.dbf

export cover chng4891 chng4891 full

/* ESTUARINE CHANGE
reselect chng4891 est4891 poly
res %identity_cov%-id = 1
~
n
n

tables
additem est4891.pat hectares 12 12 n 2
sel est4891.pat
cal hectares = area * 0.000009290341
res habcode48 = '1'
```

```
statistics habcode91 est_1.stats
sum hectares
mean hectares
~
n
n
asel
res habcode48 = '2Mi'
statistics habcode91 est_2mi.stats
y
asel
res habcode48 = '2Es'
statistics habcode91 est_2es.stats
y
asel
res habcode48 = '2Rt'
statistics habcode91 est_2rt.stats
y
asel
res habcode48 = '2Rl'
statistics habcode91 est_2rl.stats
y
asel
res habcode48 = '2Ll'
statistics habcode91 est_2ll.stats
y
asel
res habcode48 = '3'
statistics habcode91 est_3.stats
y
asel
res habcode48 = '4Ei'
statistics habcode91 est_4ei.stats
y
asel
res habcode48 = '4Rt'
statistics habcode91 est_4rt.stats
y
asel
res habcode48 = '4Rl'
statistics habcode91 est_4rl.stats
y
asel
res habcode48 = '4Lt'
statistics habcode91 est_4lt.stats
y
```

```
asel
res habcode48 = '4P'
statistics habcode91 est_4p.stats
y
asel
res habcode48 = '5'
statistics habcode91 est_5.stats
y
asel
res habcode48 = '6'
statistics habcode91 est_6.stats
y
asel
res habcode48 = '7'
statistics habcode91 est_7.stats
y
asel
res habcode48 = '8'
statistics habcode91 est_8.stats
y
asel
res habcode48 = '9'
statistics habcode91 est_9.stats
y
asel
res habcode48 = '10'
statistics habcode91 est_10.stats
y
asel

q
infodbase est_1.stats est_1.dbf
infodbase est_2mi.stats est_2mi.dbf
infodbase est_2es.stats est_2es.dbf
infodbase est_2rt.stats est_2rt.dbf
infodbase est_2rl.stats est_2rl.dbf
infodbase est_2ll.stats est_2ll.dbf
infodbase est_3.stats est_3.dbf
infodbase est_4ei.stats est_4ei.dbf
infodbase est_4rt.stats est_4rt.dbf
infodbase est_4rl.stats est_4rl.dbf
infodbase est_4lt.stats est_4lt.dbf
infodbase est_4p.stats est_4p.dbf
infodbase est_5.stats est_5.dbf
infodbase est_6.stats est_6.dbf
infodbase est_7.stats est_7.dbf
```

```
infodbase est_8.stats est_8.dbf
infodbase est_9.stats est_9.dbf
infodbase est_10.stats est_10.dbf

export cover est4891 est4891 full

/* RIVERINE NON_TIDAL CHANGE
reselect chng4891 rtid4891 poly
res %identity_cov%-id = 2
 ~
 n
 n

tables
 additem rtid4891.pat hectares 12 12 n 2
 sel rtid4891.pat
 cal hectares = area * 0.000009290341
 res habcode48 = '1'
 statistics habcode91 rtid_1.stats
 sum hectares
 mean hectares
 ~
 n
 n
 asel
 res habcode48 = '2Mi'
 statistics habcode91 rtid_2mi.stats
 y
 asel
 res habcode48 = '2Es'
 statistics habcode91 rtid_2es.stats
 y
 asel
 res habcode48 = '2Rt'
 statistics habcode91 rtid_2rt.stats
 y
 asel
 res habcode48 = '2Rl'
 statistics habcode91 rtid_2rl.stats
 y
 asel
 res habcode48 = '2Ll'
 statistics habcode91 rtid_2ll.stats
 y
 asel
 res habcode48 = '3'
```

```
statistics habcode91 rtid_3.stats
y
asel
res habcode48 = '4Ei'
statistics habcode91 rtid_4ei.stats
y
asel
res habcode48 = '4Rt'
statistics habcode91 rtid_4rt.stats
y
asel
res habcode48 = '4Rl'
statistics habcode91 rtid_4rl.stats
y
asel
res habcode48 = '4Lt'
statistics habcode91 rtid_4lt.stats
y
asel
res habcode48 = '4P'
statistics habcode91 rtid_4p.stats
y
asel
res habcode48 = '5'
statistics habcode91 rtid_5.stats
y
asel
res habcode48 = '6'
statistics habcode91 rtid_6.stats
y
asel
res habcode48 = '7'
statistics habcode91 rtid_7.stats
y
asel
res habcode48 = '8'
statistics habcode91 rtid_8.stats
y
asel
res habcode48 = '9'
statistics habcode91 rtid_9.stats
y
asel
res habcode48 = '10'
statistics habcode91 rtid_10.stats
y
```

```
asel

q
infodbase rtid_1.stats rtid_1.dbf
infodbase rtid_2mi.stats rtid_2mi.dbf
infodbase rtid_2es.stats rtid_2es.dbf
infodbase rtid_2rt.stats rtid_2rt.dbf
infodbase rtid_2rl.stats rtid_2rl.dbf
infodbase rtid_2ll.stats rtid_2ll.dbf
infodbase rtid_3.stats rtid_3.dbf
infodbase rtid_4ei.stats rtid_4ei.dbf
infodbase rtid_4rt.stats rtid_4rt.dbf
infodbase rtid_4rl.stats rtid_4rl.dbf
infodbase rtid_4lt.stats rtid_4lt.dbf
infodbase rtid_4p.stats rtid_4p.dbf
infodbase rtid_5.stats rtid_5.dbf
infodbase rtid_6.stats rtid_6.dbf
infodbase rtid_7.stats rtid_7.dbf
infodbase rtid_8.stats rtid_8.dbf
infodbase rtid_9.stats rtid_9.dbf
infodbase rtid_10.stats rtid_10.dbf

export cover rtid4891 rtid4891 full

/* RIVERINE NON-TIDAL CHANGES
reselect chng4891 r_nt4891 poly
res %identity_cov%-id = 3
~
n
n

tables
additem r_nt4891.pat hectares 12 12 n 2
sel r_nt4891.pat
cal hectares = area * 0.000009290341
res habcode48 = '1'
statistics habcode91 r_nt_1.stats
sum hectares
mean hectares
~
n
n
asel
res habcode48 = '2Mi'
statistics habcode91 r_nt_2mi.stats
y
```

```
asel
res habcode48 = '2Es'
statistics habcode91 r_nt_2es.stats
y
asel
res habcode48 = '2Rt'
statistics habcode91 r_nt_2rt.stats
y
asel
res habcode48 = '2Rl'
statistics habcode91 r_nt_2rl.stats
y
asel
res habcode48 = '2Ll'
statistics habcode91 r_nt_2ll.stats
y
asel
res habcode48 = '3'
statistics habcode91 r_nt_3.stats
y
asel
res habcode48 = '4Ei'
statistics habcode91 r_nt_4ei.stats
y
asel
res habcode48 = '4Rt'
statistics habcode91 r_nt_4rt.stats
y
asel
res habcode48 = '4Rl'
statistics habcode91 r_nt_4rl.stats
y
asel
res habcode48 = '4Lt'
statistics habcode91 r_nt_4lt.stats
y
asel
res habcode48 = '4P'
statistics habcode91 r_nt_4p.stats
y
asel
res habcode48 = '5'
statistics habcode91 r_nt_5.stats
y
asel
res habcode48 = '6'
```

```
statistics habcode91 r_nt_6.stats
y
asel
res habcode48 = '7'
statistics habcode91 r_nt_7.stats
y
asel
res habcode48 = '8'
statistics habcode91 r_nt_8.stats
y
asel
res habcode48 = '9'
statistics habcode91 r_nt_9.stats
y
asel
res habcode48 = '10'
statistics habcode91 r_nt_10.stats
y
asel

q
infodbase r_nt_1.stats r_nt_1.dbf
infodbase r_nt_2mi.stats r_nt_2mi.dbf
infodbase r_nt_2es.stats r_nt_2es.dbf
infodbase r_nt_2rt.stats r_nt_2rt.dbf
infodbase r_nt_2rl.stats r_nt_2rl.dbf
infodbase r_nt_2ll.stats r_nt_2ll.dbf
infodbase r_nt_3.stats r_nt_3.dbf
infodbase r_nt_4ei.stats r_nt_4ei.dbf
infodbase r_nt_4rt.stats r_nt_4rt.dbf
infodbase r_nt_4rl.stats r_nt_4rl.dbf
infodbase r_nt_4lt.stats r_nt_4lt.dbf
infodbase r_nt_4p.stats r_nt_4p.dbf
infodbase r_nt_5.stats r_nt_5.dbf
infodbase r_nt_6.stats r_nt_6.dbf
infodbase r_nt_7.stats r_nt_7.dbf
infodbase r_nt_8.stats r_nt_8.dbf
infodbase r_nt_9.stats r_nt_9.dbf
infodbase r_nt_10.stats r_nt_10.dbf

export cover r_nt4891 r_nt4891 full

&watch &off
&echo &off
```

Example Three: Restoration Potential

```
tables

additem monster7.pat hist_wet 4 5 b
additem monster7.pat river 4 5 b

sel monster7.pat

/* TAG HISTORIC WETLANDS
/*1948
res habcode48 = '4Ei'
cal hist_wet = 1
asel
res habcode48 = '4Rt'
cal hist_wet = 1
asel
res habcode48 = '4Rl'
cal hist_wet = 1
asel
res habcode48 = '4Lt'
cal hist_wet = 1
asel
res habcode48 = '4P'
cal hist_wet = 1
asel
res habcode48 = '10'
cal hist_wet = 1
asel

/*1961
res habcode61 = '4Ei'
cal hist_wet = 1
asel
res habcode61 = '4Rt'
cal hist_wet = 1
asel
res habcode61 = '4Rl'
cal hist_wet = 1
asel
res habcode61 = '4Lt'
cal hist_wet = 1
asel
res habcode61 = '4P'
cal hist_wet = 1
```

```
asel
res habcode61 = '10'
cal hist_wet = 1
asel

/*1973
res habcode73 = '4Ei'
cal hist_wet = 1
asel
res habcode73 = '4Rt'
cal hist_wet = 1
asel
res habcode73 = '4Rl'
cal hist_wet = 1
asel
res habcode73 = '4Lt'
cal hist_wet = 1
asel
res habcode73 = '4P'
cal hist_wet = 1
asel
res habcode73 = '10'
cal hist_wet = 1
asel

/*1983
res habcode83 = '4Ei'
cal hist_wet = 1
asel
res habcode83 = '4Rt'
cal hist_wet = 1
asel
res habcode83 = '4Rl'
cal hist_wet = 1
asel
res habcode83 = '4Lt'
cal hist_wet = 1
asel
res habcode83 = '4P'
cal hist_wet = 1
asel
res habcode83 = '10'
cal hist_wet = 1
asel

/*TAG RIVER
```

```
/* 1948
res habcode48 = '2Mi'
cal river = 1
asel
res habcode48 = '2Es'
cal river = 1
asel
res habcode48 = '2Rt'
cal river = 1
asel
res habcode48 = '2Rl'
cal river = 1
asel

/* 1961
res habcode61 = '2Mi'
cal river = 1
asel
res habcode61 = '2Es'
cal river = 1
asel
res habcode61 = '2Rt'
cal river = 1
asel
res habcode61 = '2Rl'
cal river = 1
asel

/* 1973
res habcode73 = '2Mi'
cal river = 1
asel
res habcode73 = '2Es'
cal river = 1
asel
res habcode73 = '2Rt'
cal river = 1
asel
res habcode73 = '2Rl'
cal river = 1
asel

/* 1983
res habcode83 = '2Mi'
cal river = 1
asel
```

```
res habcode83 = '2Es'
cal river = 1
asel
res habcode83 = '2Rt'
cal river = 1
asel
res habcode83 = '2Rl'
cal river = 1
asel

/* 1991
res habcode91 = '2Mi'
cal river = 1
asel
res habcode91 = '2Es'
cal river = 1
asel
res habcode91 = '2Rt'
cal river = 1
asel
res habcode91 = '2Rl'
cal river = 1
asel

q

reselect monster7 hist_wetl poly
res hist_wet = 1
~
n
n

reselect monster7 rivers1 poly
res river = 1
~
n
n

dissolve rivers1 rivers2 river poly


q
```