PNNL-15934

Evaluating Cumulative Ecosystem Response to Restoration Projects in the Columbia River Estuary, Annual Report 2005

FINAL REPORT
December 2006

Prepared for:
U.S. Army Corps of Engineers, Portland District
Under a Related Services Agreement with
The U.S. Department of Energy
Contract DE-AC05-76RLO 1830

Prepared by:
Pacific Northwest National Laboratory, Marine Sciences Laboratory
NOAA Fisheries, Pt. Adams Biological Field Station
Columbia River Estuary Study Taskforce

PACIFIC NORTHWEST NATIONAL LABORATORY
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Cover Photo: View of the Columbia River estuary looking north with Trestle Bay in the foreground.

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Preface

This report is the second annual report of a six-year project to develop a methodology to evaluate the cumulative effects of habitat restoration projects in the Columbia River Estuary (CRE). Future annual reports will be prepared for the remaining study years 2006 through 2010. This report is a deliverable for the 2005 study. As such, it includes all of our work products for the 2005 study year. In this report we summarize the background and objectives of the study (Chapter 1), briefly describe the study area and site selection (Chapter 2), describe the field research methods employed (Chapter 3), summarize and discuss the results (Chapters 4 and 5), and provide conclusions and recommendations (Chapters 6 and 7). Based on the 2005 field research, we have updated the draft monitoring protocols presented in the previous report and the revised version is provided here (Appendix A). We intend to publish the protocols as a stand-alone document at a later date. The previous report, *Evaluating Cumulative Ecosystem Response to Restoration Projects in the Columbia River Estuary, Annual Report 2004,* provided a foundation for subsequent research on the cumulative effects of habitat restoration in the CRE. It included a literature review, summary of CRE habitat use by juvenile salmon, expanded study area description, and conceptual model for the CRE ecosystem.

This research was conducted under the auspices of the U.S. Army Corps of Engineers, Pacific Northwest Division's Anadromous Fish Evaluation Program (study code EST-02-P-04). It is related to and complements other estuary research (study codes EST-02-P-01 and EST-02-P-02). This study was funded by the Portland District, U.S. Army Corps of Engineers (Ref. No. W66QKZ50397907) under an agreement with the U.S. Department of Energy, and was conducted by Pacific Northwest National Laboratory, operated by Battelle. Subcontractors to PNNL included the Columbia River Estuary Study Taskforce (No. 3594) and Mr. Earl Dawley (No. 11324).

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Recommended citation for Protocols Manual in Appendix A:

Roegner, GC, HL Diefenderfer, AH Whiting, AB Borde, RM Thom, and EM Dawley. 2006. *Monitoring Protocols for Salmon Habitat Restoration Projects in the Lower Columbia River and Estuary.* PNNL-15793, Working draft report prepared by the Columbia River Estuary Study Taskforce (CREST), National Marine Fisheries Service (NMFS), and Pacific Northwest National Laboratory (PNNL) for the U.S. Army Corps of Engineers, Portland District, Portland Oregon. (Available at http://www.lcrep.org/lib_other_reports.htm)

Executive Summary

This report is the second annual report of a six-year project to evaluate the cumulative effects of habitat restoration projects in the Columbia River Estuary, conducted by the Pacific Northwest National Laboratory Marine Sciences Laboratory, the National Oceanic and Atmospheric Administration National Marine Fisheries Service Pt. Adams Biological Field Station, and the Columbia River Estuary Study Taskforce for the U.S. Army Corps of Engineers. This project is establishing methods for evaluating the effectiveness of individual projects and a framework for assessing estuary-wide cumulative effects including a protocol manual for monitoring restoration and reference sites.

In 2005, baseline data were collected on two restoration sites and two associated reference sites in the Columbia River estuary. The sites represent two habitat types of the estuary – brackish marsh and freshwater swamp – that have sustained substantial losses in area and that may play important roles for salmonids. Baseline data collected included vegetation and elevation surveys, above- and below-ground biomass, water depth and temperature, nutrient flux, fish species composition, and channel geometry. Following baseline data collection, three kinds of restoration actions for hydrological reconnection were implemented in several locations on the sites: tidegate replacements (2) at Vera Slough near the city of Astoria in Oregon, culvert replacements (2), and dike breaches (3) at Kandoll Farm in the Grays River watershed in Washington. Limited post-restoration data were collected during this study year: photo points, nutrient flux, water depth and temperature, and channel cross-sections. In subsequent work, this and additional post-restoration data will be used in conjunction with data from other sites to develop a methodology to estimate net effects of hydrological reconnection restoration projects throughout the estuary.

Acknowledgments

We gratefully acknowledge contributions to this study by

- The staff of the Lower Columbia River Estuary Partnership, particularly Scott McEwen
- Ian Sinks of the Columbia Land Trust
- The estuary restoration project managers and monitoring specialists who participated in a June 2004 meeting to identify minimum monitoring indicators and develop protocols; these included representatives of the following organizations: Ash Creek Forest Management, Columbia Land Trust, Columbia River Estuary Study Taskforce, Oregon Parks and Recreation Department, Pacific States Marine Fisheries Commission, Scappoose Bay Watershed Council, Sea Resources, and US Geological Survey.
- Kathryn Sobocinski and Dick Ecker of Pacific Northwest National Laboratory
- The Estuary and Ocean Subgroup for Research, Monitoring, and Evaluation
- Those individuals who provided review comments on the draft version of the 2004 annual report: Craig Cornu, South Slough Estuarine Research Reserve; Cliff Pereira, Oregon State University; John Skalski, University of Washington; and Kristiina Vogt, University of Washington.
- Shon Zimmerman of PNNL for operation of the real-time kinematic (RTK) survey system.

Abbreviations and Acronyms

BACI Before After Control Impact

cfs cubic feet per second

CLT Columbia Land Trust

COE U.S. Army Corps of Engineers

CPUE catch per unit effort

CRE Columbia River Estuary (rkm 0-235)

CREDDP Columbia River Estuary Data Development Program

CREST Columbia River Estuary Study Taskforce

CTD Instrument package including sensors to measure conductivity, temperature, and depth

Dbh diameter at breast height

DO **d**issolved oxygen

EPA U.S. Environmental Protection Agency

FCRPS Federal Columbia River Power System

GIS geographic information system

GPS global positioning system

HTCO high temperature catalytic oxidation method

HUC hydrologic unit code

JGOFS Joint Global Ocean Flux Study

LCREP Lower Columbia River Estuary Partnership

LiDAR Light Detection and Ranging

MS-222 tricaine methane sulfonate

NDIR non-dispersive infra-red

NGS National Geodetic Survey

NMFS National Marine Fisheries Service (now called NOAA Fisheries)

NOAA National Oceanic and Atmospheric Administration

NOAA Fisheries - NOAA National Marine Fisheries Service (formerly known as NMFS)

NPCC Northwest Power and Conservation Council (formerly Northwest Power Planning Council)

NRC National Research Council

OBS optical backscatterance

OPUS Online Positioning User Service

PNNL Pacific Northwest National Laboratory

PVC polyvinyl chloride

rkm river kilometer

RPA reasonable and prudent alternative

RTK real-time kinematic

SSE Seal Slough East

SSW Seal Slough West

sd standard deviation

TIN Total Inorganic Nitrogen

TNP total nitrogen and phosphorus

TOC Total Organic Carbon

UNESCO United Nations Education, Scientific and Cultural Organization

USGS US Geological Survey

WDFW Washington State Department of Fish and Wildlife

2D two-dimensional

3D three-dimensional

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1.0 Introduction

This report is the second annual report of a six-year project to evaluate the cumulative effects of habitat restoration projects in the Columbia River Estuary (CRE), conducted by Pacific Northwest National Laboratory (PNNL) Marine Sciences Laboratory, the National Oceanic and Atmospheric Administration National Marine Fisheries Service (NOAA Fisheries) Pt. Adams Biological Field Station, and the Columbia River Estuary Study Taskforce (CREST) for the U.S. Army Corps of Engineers (COE). Measurement of the cumulative effects of ecological restoration projects in the Columbia River estuary is a formidable task because of the size and complexity of the estuarine landscape (Small 1990) and the metapopulations of salmonids in the Columbia River basin (Bottom et al. 2005). Despite the challenges presented by this system, developing and implementing appropriate indicators and methods to measure cumulative effects is the best way to enable estuary managers to track the overall effectiveness of investments in estuarine restoration projects. In 2004, we developed a framework for cumulative effects assessment and a set of measurable parameters that restoration managers can apply at most if not all restoration project sites (Diefenderfer et al. 2005a).[a] In 2005, we tested these indicators, sampling methods, and a sampling design supporting an estuary-wide cumulative effects analysis and adaptive management framework, as described in this second annual report. The assessment methodology was applied at two restoration sites and two reference sites in the Columbia River Estuary in 2005; results are provided in this report.

1.1 Background and Needs

Under Congressional authorities in various Water Resource Development acts, the U.S. Army Corps of Engineers is working with the Bonneville Power Administration, NOAA Fisheries, and others to restore estuarine habitats in the Columbia River estuary (Figure 1.1). Most restoration activities being evaluated and implemented involve the hydrologic reconnection of portions of the estuarine system currently isolated to the flow of water and the movement of salmon by dikes, tide gates, and other barriers. The vision of the action agencies' estuary program is to improve CRE functionality through habitat restoration efforts and thus to aid in rebuilding listed salmon stocks of the Columbia River basin (Johnson et al. 2004).

The restoration of damaged ecosystems is fraught with uncertainty. Relevant uncertainties can be grouped into two types: 1) uncertainty regarding responses of ecosystems to restorative actions, and

---

[a] The selection of minimum metrics for project monitoring relied primarily on four criteria: 1) metrics encompass controlling factors, structural factors, and functional factors (NRC 1992); 2) metrics directly correspond to commonly held goals among the restoration projects; 3) metrics are potentially applicable to all sites, with measurements that result in comparable datasets relevant to both present and future investigations; and 4) measurement methods must be feasible for the wide variety of organizations implementing restoration projects. These criteria will facilitate the development of a consistent database permitting estuary-wide analyses of restoration trajectories.

2) uncertainty associated with random, uncontrollable events affecting restoration outcomes (Diefenderfer et al. 2005b). It is therefore difficult to accurately predict when and whether an ecosystem will meet restoration goals, even using methods developed to assess the trajectory of development after restoration actions (Kentula et al. 1992; Thom 1997). Because of this, and the fact that a restoration program of this size is expensive, information that helps to improve predictability is critically needed.

Our first annual report (Diefenderfer et al. 2005a) developed the following foundation for the 2005 fieldwork:

- literature review of cumulative effects research methods
- synthesis of proposed approach to estuarine cumulative effects research
- analysis of Columbia River estuary habitat use by juvenile salmonids
- enhancement of a Columbia River estuary conceptual model
- development of core monitoring metrics and associated protocols for the Columbia River estuary
- determination of management implications.

Our literature review found no published formal methods to quantify the cumulative effects of multiple restoration projects across one estuary. The review confirmed that our project is unique in three ways: 1) others have monitored the cumulative effects of degradation but not of restoration, 2) others have monitored estuarine restoration at the project level, but not cumulatively across multiple projects, and 3) others have evaluated cumulative effects in forests and wetlands but not for estuaries. Our effort is the first, to our knowledge, that is attempting to quantify whether the restoration of multiple estuarine sites has a measurable cumulative effect on the health and functionality of the estuarine ecosystem (Diefenderfer et al. 2005a).

The application of a consistent protocol throughout a region appears to be an important step toward achieving a cumulative assessment of restoration effects (e.g., Neckles et al. 2002). Regional performance curves can be developed when a protocol is applied consistently across many sites in order to assess restoration efforts. An example of such a protocol is the *Estuarine Habitat Assessment Protocol,* which is in wide use in Puget Sound (Simenstad et al. 1991). The Florida Everglades and Louisiana coastal wetlands studies provide examples of statistical sampling designs and decision-support modeling systems covering large geographic scales (NRC 2003; Steyer et al. 2003). Recently, information on the CRE has become available through a draft geographic information systems (GIS) database developed to aid in the prioritization of projects for restoration (Evans et al. 2006). This database can be utilized for comparing the configuration and condition of proposed restoration sites within HUC (Hydrologic Unit Code) 6 level hydrologic units throughout the estuary.

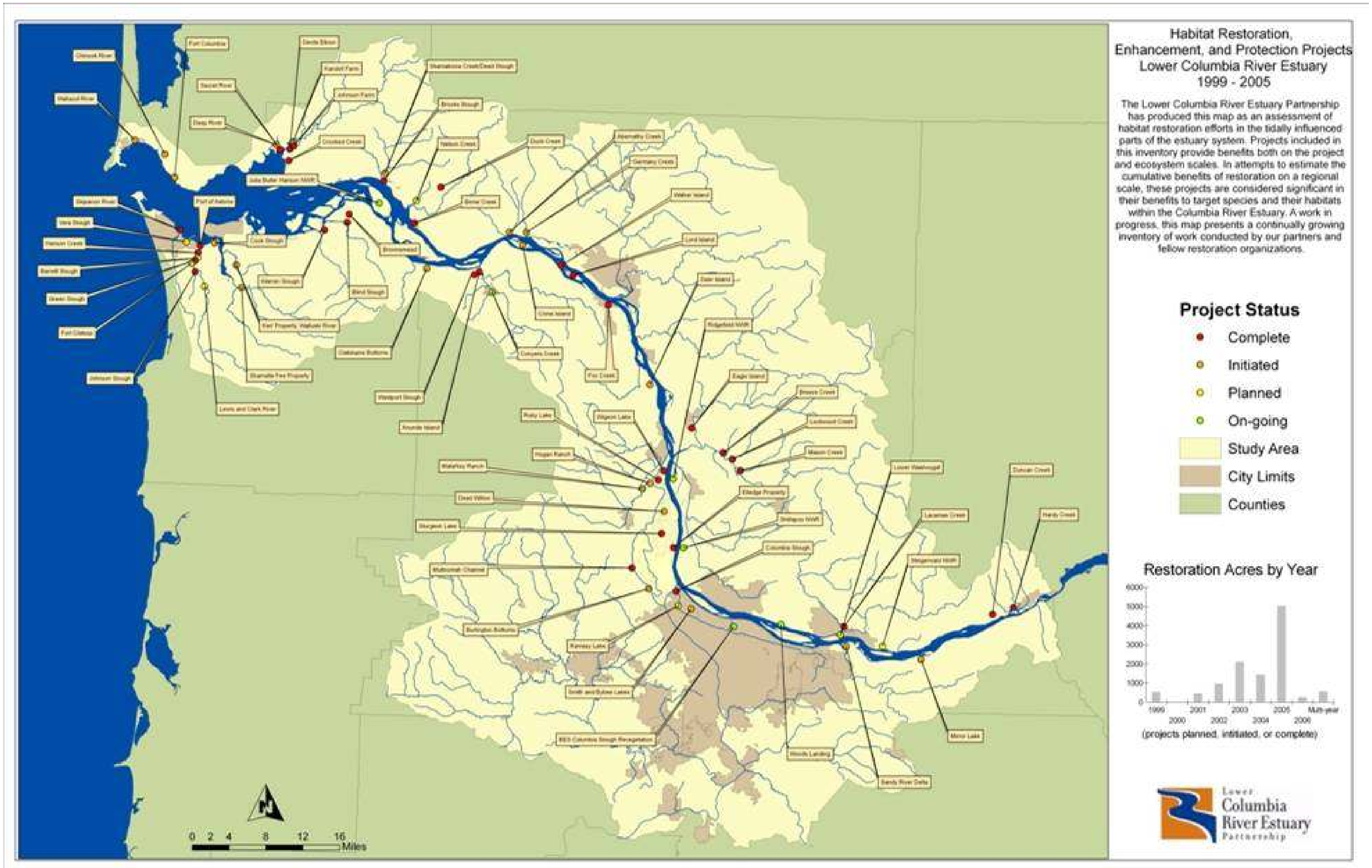

Figure 1.1. Habitat restoration, enhancement, and protection projects: Lower Columbia River Estuary 1999-2005. (Figure courtesy of the Lower Columbia River Estuary Partnership.)

In our first annual report (Diefenderfer et al. 2005a), we adopted definitions of cumulative impacts and cumulative effects from Leibowitz et al. (1992) (paraphrased as follows):

> *Cumulative restoration impacts* are the net sum of all changes in selected habitat metrics of all restoration projects occurring over time and space, including those changes in the foreseeable future of the development of these projects.
>
> *Cumulative restoration effects* are the net change in ecosystem-wide metrics and ecosystem state resulting from cumulative restoration impacts.

We have also introduced the concept of the "net ecosystem improvement" of previously degraded sites, which is defined as "following development [and associated restoration], there is an increase in the size and natural functions of an ecosystem or natural components of the ecosystem" (Thom et al. 2005). We argue that, given the present degraded condition of many coastal sites, combined with pressure for development, net ecosystem improvement is critical to the sustainability of coastal systems as defined by the World Commission on Environment and Development (1987).

1.2 Goals and Objectives

This study is intended to both develop methods for quantifying the effects of restoration projects and lay a foundation for effectiveness[a] evaluation and validation[b] of cumulative restoration activities in the CRE. The primary goal of this multi-year study is to develop a framework and methodology to measure and evaluate the cumulative effects of habitat restoration actions in the CRE aimed at increasing population levels of listed Columbia Basin salmon. This framework and methodology will ensure comparable data sets across multiple restoration monitoring efforts estuary-wide. The management implications of this research are two-fold in that it is expected to provide techniques allowing decision-makers to 1) evaluate the ecological performance of the collective habitat restoration effort in the CRE and its effects on listed salmon, and 2) apply knowledge from comparable datasets for ongoing monitoring to prioritize future habitat restoration projects.

The *overall objectives* of this multi-year study are to

1. Develop standard monitoring protocols and methods to prioritize monitoring activities that can be applied to CRE habitat restoration activities for listed salmon.
2. Develop the empirical basis for a cumulative assessment methodology, together with a set of metrics and a conceptual model depicting the cumulative effects of CRE restoration projects on key major ecosystem functions supporting listed salmon.

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[a] Effectiveness Monitoring = Activities designed and undertaken to assess how well a particular restoration project performs relative to reference site(s).
[b] Validation Monitoring - Monitoring directed at testing cause-and-effect relationsips between management activities and monitoring indicators (Busch and Trexler 2003).

3. Design and implement field evaluations of the cumulative effects methodologies by applying standard methods, a COE GIS database[a] of habitat types and land ownership (private, federal, state, local), and sensors or remotely operated technologies to measure through-ecosystem response of the cumulative effects of multiple habitat restoration projects on listed salmon.
4. Develop an adaptive management system including data management and dissemination to support decisions by the COE and others regarding CRE habitat restoration activities intended to increase population levels of listed salmon.

As the salmon habitat restoration program in the CRE grows, projects being implemented will require monitoring and evaluation of effectiveness, yet it will not be practical to intensively monitor the results of every project. Therefore, methods must be established to prioritize and manage limited monitoring budgets in order to assess whether the restoration actions have a net cumulative benefit to CRE health and functionality. Data from numerous restoration monitoring efforts should be as comparable as possible to aid decision-makers as they learn from the collective project-specific results. Thus, standardized monitoring protocol*s* associated with core monitoring metrics are necessary to compare restoration effectiveness through time at a given project site and through space among multiple projects. Focused, prioritized, and standardized monitoring at the project level will support evaluation estuary-wide that will ultimately help determine the success of the CRE salmon habitat restoration.

Adaptive management can provide the framework for improving the predictability of restoration projects (Thom 1997; 2000). Hence, there is a growing awareness of the need to conduct restoration projects within an adaptive management framework in order to maximize the benefit to the ecosystem from the effort to restore the system. It is our intent in this multi-year study to develop an adaptive management framework for restoration of the CRE. The framework will include the most common components: goal statements, a conceptual model, a monitoring program, evaluation and decision guidance, and an information dissemination system (Diefenderfer et al. 2003; Thom and Wellman 1996). The framework will benefit from components either already developed or under development through this study and other research programs in the CRE. The ultimate aims are to dramatically improve the success of restoration projects in the CRE and to contribute, by example, to the science of ecosystem restoration.

The assumptions guiding our efforts include the following:

- Standardization of monitoring methods will result in comparable data sets.
- Monitoring efforts can be prioritized and designed strategically while maintaining statistical rigor.
- The CRE must be viewed as a landscape to assess cumulative effects of habitat restoration actions designed to benefit salmon.

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[a] The GIS database is a collaborative effort among multiple parties, including the Columbia River Estuary Study Taskforce, the Lower Columbia River Estuary Partnership, the Pacific Northwest National Laboratory, the University of Washington, and the U.S. Geological Survey.

- A conceptual model of the CRE, including the food web, provides organization and focus to the research and assessment.
- Key attributes indicating ecosystem response to restoration can be developed.
- A framework can be designed and applied to assess the cumulative effects for multiple restoration actions.
- An adaptive management system based on project and ecosystem monitoring data will aid decision-makers in implementing salmon habitat restoration in the CRE.

The specific objectives of the 2005 study are listed below with the chapters where they are discussed in this report noted.

1. *Cumulative Effects Methods:* Continue to develop techniques to assess cumulative effects and field test critical elements of these techniques (Chapter 3).
2. *Monitoring Protocols:* Finalize the standard monitoring protocols in a user manual using results from focused field evaluations of particular protocols (Appendix A, Chapters 4-5).
3. *Coordination:* Design, coordinate, and communicate to interested parties a pilot monitoring program to assess cumulative effects based on the results from Objectives 1 and 2 and the GIS work (Chapter 7).
4. *Adaptive Management:* Develop an adaptive management system for COE habitat restoration monitoring that will identify the most important monitoring activities and establish guidelines for data management and dissemination (Chapter 6).

In 2005, field studies were conducted at two restoration sites and two associated reference sites representing two habitat types: brackish marsh and freshwater swamp. The 2005 field studies were based on efforts to develop standardized monitoring protocols and the review and synthesis of approaches to measure cumulative effects (Diefenderfer et al. 2005a). The purpose of the field studies in 2005 was to initiate evaluation of methods for assessing cumulative effects of restoration projects. Thus, the 2005 field studies reported herein had the following objectives: initiate the testing and evaluation of habitat monitoring metrics and protocols, and initiate the evaluation of higher order metrics for cumulative effects.

1.3 Report Organization

The intent of this 2005 annual report is to summarize 2005 field investigations and to release a revised working draft of the CRE Restoration Monitoring Protocols. Therefore, a standard report format was adopted: Study Area, Methods, Results, and Discussion, followed by a section on Coordination in the CRE and Recommendations for field studies in 2006. The revised protocols are presented in Appendix A and are also available on the world-wide web (http://www.lcrep.org/lib_other_reports.htm). Appendix B is a description of cumulative effects in the Grays River watershed and Appendix C lists plant species found in the restoration and reference sites. Presentations of the methods, results, and protocols are organized according to categories of the monitored metrics as follows: water surface elevation, water quality, land/substrate elevation, landscape features, vegetation, fish, and flux.

To meet the objectives of the field sampling described above, "higher-order" metrics for cumulative effects were measured, along with recommended core monitoring metrics. These are reported within corresponding categories of monitored metrics with the exception of "flux," which is a separate category. The core metrics are distinguished from the others within the methods and results sections as necessary.

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2.0 Study Area

2.1 General Study Area

The study area is an open system consisting of the estuary (Figure 2.1), defined in space by the extent of tidal influence on the Columbia River and not including the plume. As a river-dominated estuary characterized by high-volume fluctuating inputs and outputs (e.g., water, sediment, salmon), it is inadvisable to view the CRE as an equilibrium system, even over short timeframes. Estuaries display emergent properties such as the export of organic matter to offshore waters (Odum 1980) and the estuarine turbidity maxima (Simenstad et al. 1994.) Non-linear relationships in the estuary include the exponential relationship between river flow and sediment transport (Sherwood et al. 1990).

A number of publications provide descriptive information about the estuary study area: the *Salmon at River's End* report by Bottom et al. (2005); Fresh et al.'s (2004) *Role of the Estuary in the Recovery of Columbia River Basin Salmon and Steelhead*; the Biological Assessment for the Columbia River Channel Improvements Project by the COE (2001); the Reasonable and Prudent Action (RPA) Action 158 action plan by Berquam et al. (2003); the Ecosystem-Based Approach to Habitat Restoration Projects report by Johnson et al. (2003); and the Northwest Power and Conservation Council (NPCC) subbasin plan for the estuary (Lower Columbia Fish Recovery Board 2004).

Important earlier compendiums include *The Columbia River Estuary and Adjacent Ocean Waters* by Pruter and Alverson (1972); "Columbia River Estuary" in *Changes in Fluxes in Estuaries: Implications from Science to Management* by Dyer and Orth (1994); and "Columbia River: Estuarine System" by Small (1990), which contains reviews of earlier work supported by the Columbia River Estuary Data Development Program (CREDDP) on physical and biological processes (CREDDP 1984a, 1984b). Another comprehensive environmental study of the lower Columbia River was the Bi-State Water Quality Study (TetraTech 1996; Fuhrer et al. 1996), completed as part of the process to include the Columbia River estuary in the U.S. Environmental Protection Agency (EPA)'s National Estuary Program. The brief study site description that follows draws from these major works and other literature to provide context for the CRE cumulative effects study.

The Columbia River, with a drainage basin area of 660,480 km^2 (Simenstad et al. 1990), has the fourth highest average river discharge at the mouth and the sixth largest watershed in the United States (US Geological Survey [USGS] 1990; analysis includes Great Lakes/St. Lawrence and Yukon rivers and separates Mississippi, Missouri, and Ohio rivers). The width of the Columbia River is less than 2 km some 84 rkm from the Pacific Ocean, nearly 15 km at rkm 32, and approximately 3 km at the jetties at the river mouth (Neal 1972). The river bottom is below sea level at Bonneville Dam and the estuary contains scattered deep areas, for example nearly 30 m at Grays Point (Neal 1972). Historically, unregulated flows were estimated to range from a minimum of 2,237 m^3/s (79,000 cfs) in the fall to maximum flood flows of over 28,317 m^3/s (1 million cubic feet per second [cfs]) during spring freshets (Sherwood et al. 1990). Since the 1930s, however, the timing of the Columbia River's discharge has been progressively regulated due to construction and operation of 28 major dams and approximately 100 minor dams on the river's main stem and tributaries that reduce spring freshet flows and increase fall/winter flows. Hydrographic modeling estimated that the spring freshet (May-July) flow reduction attributable to flow regulation is 33.1%, and the total reduction in freshet mean flow when climate and water withdrawal are included is 43% of pre-1900 flows (Jay and Hickey 2001, as cited in Fresh et al. 2004). Alterations in the physical processes of the estuary that are attributable to human intervention include decreased freshwater discharge rates, tidal prism, and mixing; and increased flushing time and fine sediment deposition, resulting in a net accumulation of sediment (Sherwood et al. 1990).

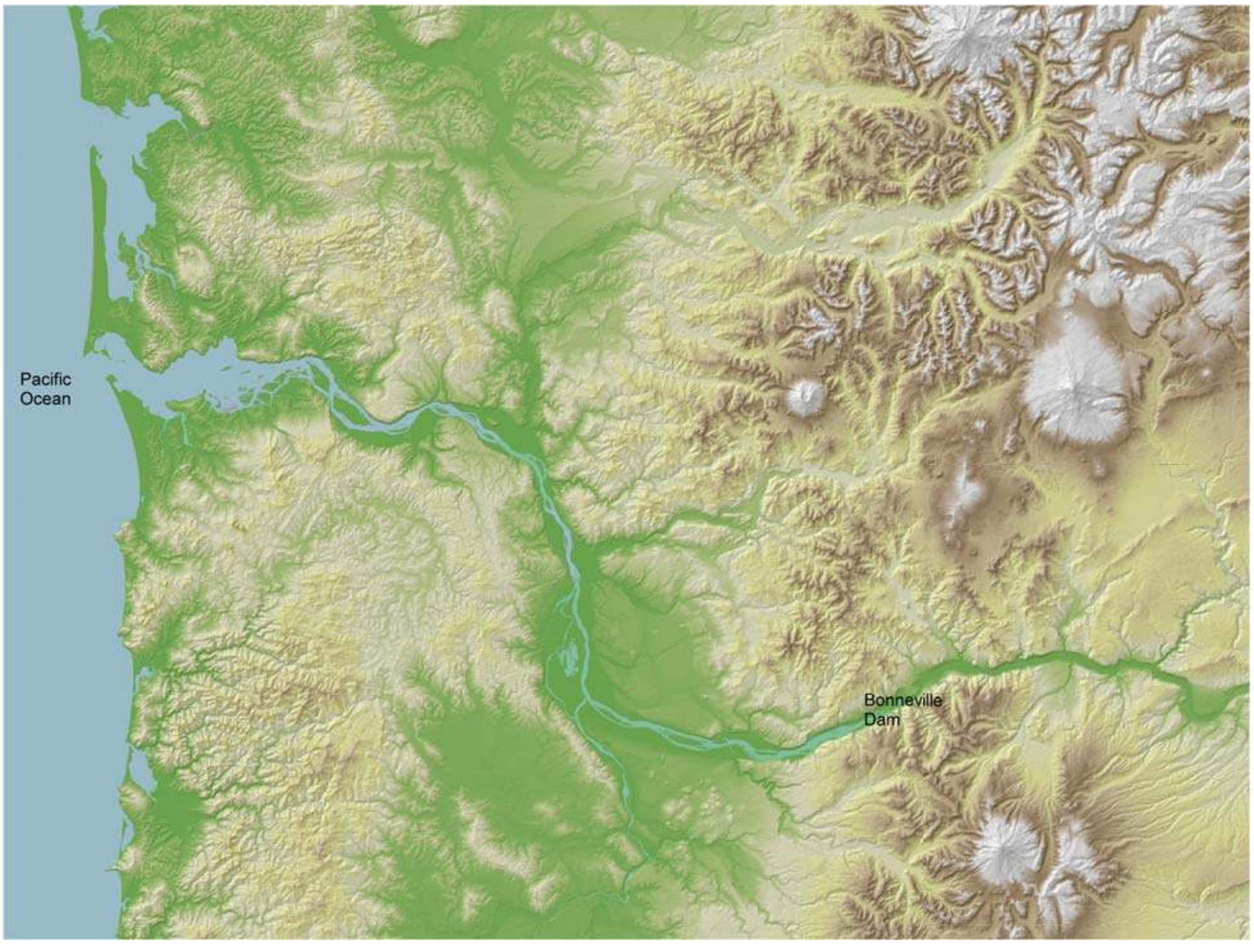

Figure 2.1. The Columbia River Estuary from Bonneville Dam to the Pacific Ocean

Despite alterations to river discharge patterns by the Federal Columbia River Power System (FCRPS) and other factors, the estuary is still river-dominated because of relatively high flow volumes. However, the semi-diurnal tidal range in the estuary is relatively large at 3.6 m and oceanic tides affect water levels throughout the entire lower reach to Bonneville Dam (rkm 235) (Neal 1972; Sherwood and Creager 1990). Maximum seawater intrusion during low river flow is variable but less than 37 km (Neal 1972). Estuary flushing time has been calculated using several methods; calculations using a river flow of 15.5 x 10^7 m^3/tidal cycle (549 x 10^7 cu ft/tidal cycle) and maximum salinity intrusion of 35 km (19 nautical miles), for example, predict total flushing time ranging from 4.97 tidal cycles, using the fraction-of-freshwater method, to 9.0 tidal cycles, using the modified tidal-prism method (Neal 1972). As an extension of the estuary, the Columbia River plume is a dominant factor affecting the hydrography of Pacific Northwest coastal waters (Garcia-Berdeal et al. 2002; Hickey and Banas 2003).

The Columbia River estuary, which occupies a drowned river valley, has been classified as a meso-tidal estuary according to Sherwood and Creager (1990). According to Neal (1972), the Columbia River estuary resists classification by Pritchard's (1955) approach based on mixing characteristics because of temporal and regional variability between three of the classes: vertically stratified, partially mixed, and well mixed. Thus, the study area defined for this study is too broad to allow for a discreet classification.

The landscape context of the estuary may be described by its representative ecoregions, according to the EPA classification (Omernik and Gallant 1986): Coast Range, Puget Lowland, Willamette Valley, and Cascades. The classification on the Oregon side has been refined for the purpose of water quality management to include Coastal Mountains, Coastal Lowlands, Willamette Valley Plains, and Western Cascades (Clarke et al. 1991). The study area, broadly defined for the purposes of terrestrial ecology and plant communities, contains five physiographic provinces: the Southern Washington Cascades, Western Cascades, Puget Trough, Willamette Valley, and Coast Ranges (Franklin and Dyrness 1988).

Estuarine landcover is shown by maps using LandSat and compact airborne spectrographic imaging. Several categories of herbaceous wetlands, shrub-scrub wetlands, and coniferous and deciduous forest wetlands have been identified (Garano and Robinson 2003). For the purpose of a change analysis from 1870 to present, Thomas (1983) found that only five habitat types could be delineated. In order by elevation from highest to lowest, these are tidal swamps, tidal marshes, shallows and flats, medium-depth water, and deep water. He assessed the change in these habitat types in seven subareas: the river mouth, mixing zone, Youngs Bay, Baker Bay, Grays Bay, Cathlamet Bay, and the upper estuary. Habitat loss and habitat conversion are documented in Thomas' maps (1983). Perhaps the most critical findings for salmon are that below Puget Island, the area of tidal swamps has been reduced by 77%, and 65% of the 1870 tidal marshes have been lost while new marshes totaling about 22% of the original area have been formed (a net loss of 43%) (Thomas 1983). The study also showed net losses of medium and deep water habitats (35% and 7%, respectively), and a gain of shallows and flats caused mostly by shoaling in formerly deeper water areas (10%).

Because the metropolitan areas of Vancouver, WA, and Portland, OR, as well as smaller cities such as Longview, WA, and Astoria, OR, span the Columbia River estuary, many pressures from urban development are currently present or have existed in the past. Modifications to riparian areas, tributaries, and the main stem of the river via activities associated with dredging, bridge construction, and port development have dramatically altered the characteristics of the river and estuary. The direct impacts of these physical alterations to juvenile salmon and other biota are largely unknown.

2.2 2005 Field Study Sites

Field studies were conducted within two general regions in the estuary: tidal freshwater and tidal brackish water. The plant communities represent the salmon habitat types that were historically most common in each of these regions and most likely to be restored today were chosen for field studies: tidal freshwater swamps in the tidal freshwater region and tidal brackish marsh in the brackish water region.

Large areas of swamps and marshes have been lost in the estuary and due to the differences between these systems, particularly those associated with plant dominants (e.g., tree species in the swamps versus herbaceous or shrubby plants in marshes), they can be expected to have different responses to restoration treatments. Swamps and marshes also provide different habitat characteristics for salmon, with respect to plant productivity (detritus and associated invertebrate prey) and refugia characteristics (coniferous versus deciduous dominants).

Within each of the salmon habitat types, we conducted studies in one natural reference site and one restoration site. Data from the reference sites were used to help interpret data collected from the restoration sites as per standard procedures for post-restoration monitoring recommended in our first annual report (Diefenderfer et al. 2005).

Site selection was based in part on the *timing of planned restoration,* because the monitoring protocols recommend collecting data before and after implementation of restoration measures. To properly test the protocols, it was necessary to select sites not yet but soon to be restored. Thus candidate restoration sites for field studies included the Johnson property and Kandoll property on Grays River; the Deep River site on Grays Bay; Charnelle Fee site on Youngs River (Youngs Bay); Lewis and Clark site on the Lewis and Clark River (Youngs Bay); Vera Slough (Youngs Bay), and the Ramsey Wetland Complex at the Lower Columbia Slough near the confluence of the Willamette and Columbia rivers.

Another critical factor in site selection was the *type of restoration action.* Our objective was to monitor as many typical hydrological reconnection actions as possible. Dike breaches or removals were among the key restoration measures requiring monitoring. Other restoration measures included tide gate removals or replacements and culvert removals or replacements, channel excavation, vegetation planting and invasive species management.

In summary, perhaps the main driver of the final site selection was timing. In order to maintain the cumulative effects study schedule, it was imperative that field studies begin in 2005 on sites where it was possible to collect baseline data and likely that restoration actions would be implemented by the end of the year. Reference sites corresponding to each site were identified on the basis of a qualitative assessment of geographic proximity, ecological similarity, hydrological similarity, and likelihood that the plant associations at the reference areas would be representative of the endpoint(s) of restoration trajectories at the restored sites.

Vera Slough on Youngs Bay in Oregon, with extremely low salinities, was selected to represent the brackish or freshwater marsh restoration (Figure 2.2). The property, which is near Warrenton, Oregon, is owned by the Port of Astoria and restoration is being planned and managed by the Columbia River Estuary Study Taskforce (CREST). Following baseline data collection in the spring and summer of 2005, in October of 2005 the two tidegates restricting flow into the slough were replaced (Figure 2.3) by two 5-ft x 5-ft square tidegates of different models (one side-hinge and one top-hinge, both with lighter lids and fish-passable doors). Objectives of the project included the following: increase fish access to backwater slough habitat; lower temperatures; improve dissolved oxygen (DO) conditions; increase salinity intrusion; develop estuarine plant communities; and increase food-web productivity.

Figure 2.2. Vera Slough Tidegate Replacement Site (left polygon) and Reference Site (right polygon) Separated by the Astoria Regional Airport on Youngs Bay, Oregon

Figure 2.3. Tidegates at Vera Slough Before (left) and After (right) Replacement (photos courtesy of CREST)

Kandoll Farm on the Grays River in Washington was selected to represent the tidal freshwater swamp restoration (Figure 2.4). The property is owned by the Columbia Land Trust (CLT) and restoration was being planned and managed by CLT with engineering by Ducks Unlimited. Following baseline data collection in the spring and summer of 2005, the two small tidegates restricting flow into the slough were replaced with 13-ft-diameter culverts (Figure 2.5), and the dike along the Grays River was breached in three places in September 2005. Objectives of the project included permanently protecting and restoring 163 acres of diked tideland and approximately 1 mile of shoreline in order to increase access to swamp habitat, lower water temperatures, raise dissolved oxygen levels, and increase food web productivity. Kandoll Farm is part of the Grays River complex, which includes 927 acres of permanently protected habitat lands—spruce forested wetlands (swamps), floodplain channels, and emergent/scrub-shrub wetlands. CLT has restored salmonid access to 400 acres of formerly diked floodplain habitat and enhanced 116 acres within the Seal Slough-Grays River parcel (reference site) through the removal of logging road crossings of tidal channels (Ian Sinks, pers. Comm.).

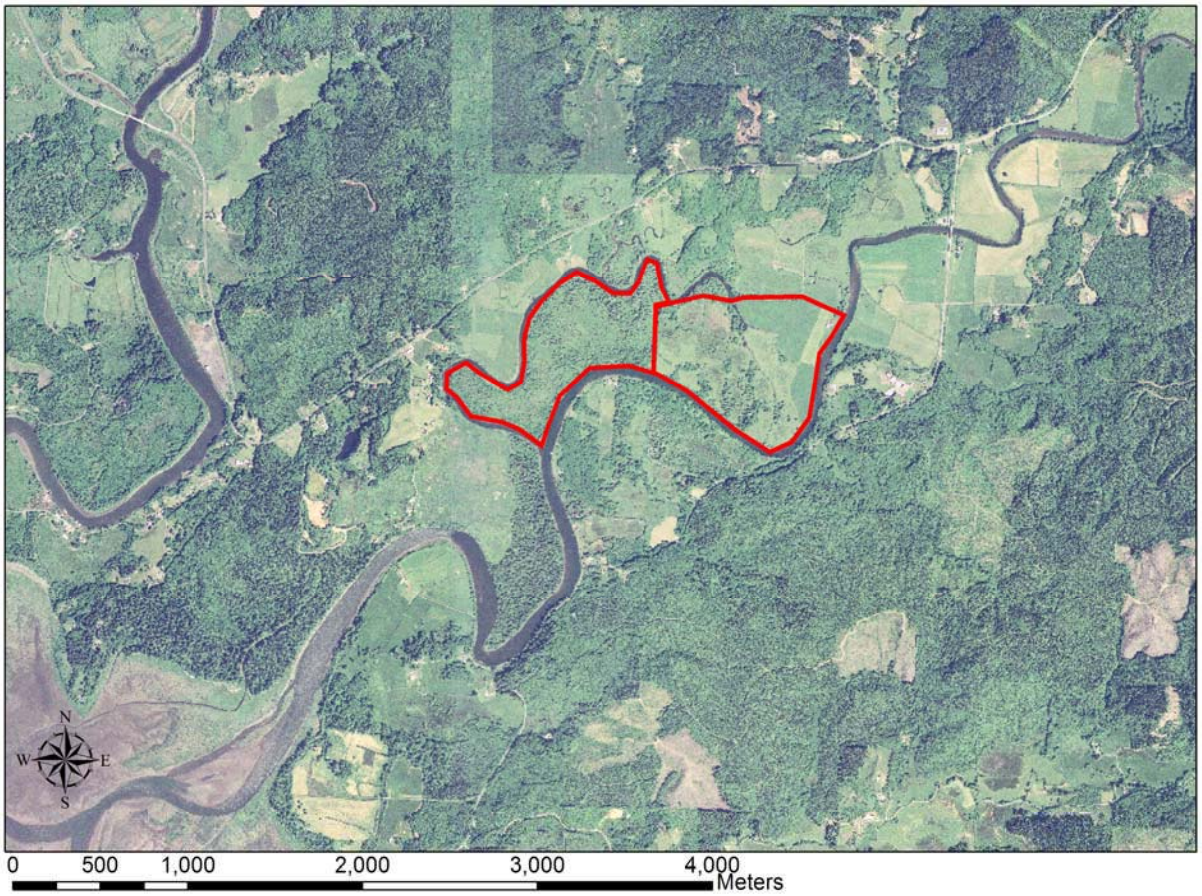

Figure 2.4. Kandoll Farm Dike Breach and Culvert Replacement Site (right side of polygon) and Reference Site (left side of polygon), between Seal Slough and the Grays River in Washington (See Figure 4.1 for details)

Figure 2.5. Tidegate at Kandoll Farm before (left) and Culverts after (right) Replacement

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3.0 Cumulative Effects Study Statistical Approach

Cumulative effects assessment must include by definition multiple restoration locations and activities. While the term "cumulative effects" typically implies that "the whole is greater than the sum of the parts," in fact effects may be additive, synergistic, or countervailing and may occur through interaction of the effects themselves or between effects and the receiving biota. The purpose of cumulative effects analysis in the CRE is to demonstrate whether the effects of a series of restoration activities are synergistic. For example, increased habitat connectivity might be expected to have cumulative effects on salmonid performance measures, biodiversity, nutrient cycling, hydrodynamic processes, etc. Assessment of cumulative effects is therefore equivalent to testing for synergistic effects or additivity of effects.

Consequently, no single site or haphazard collection of restoration sites initiated over time would suffice for cumulative effects assessment. The restoration activities must be structured in such a manner that environmental responses can be related to the scale of restoration. There are several ways to examine this relationship between multiple restoration acts and responses.

3.1 General Design Alternatives

3.1.1 Relating Cumulative Response to Physical Size of Restoration Sites

In the absence of cumulative effects, the magnitude of physical, chemical, or biological responses to restoration should be proportional to the size of the area. Should cumulative effects exist, the size of the response should be disproportionately larger at larger restoration sites (Figure 3.1). A proportional relationship between environmental responses (y_i) and restoration area (A_i) can be written as

$$E\left(y_i\right) = \alpha A_i$$

while an exponential response can be written as

$$E\left(y_i\right) = \alpha A_i^{\beta}$$

In this case, a test of cumulative effects is equivalent to the one-tailed test

$$\mathrm{H_o}:\ \beta \le 1$$
$$\mathrm{H_a}:\ \beta > 1.$$

The study design would consist of multiple restoration sites of different sizes restored at the same time and monitored over time. Log-linear regression of response versus size could then be used to test the significance of the slope term (i.e., β) some years post-restoration.

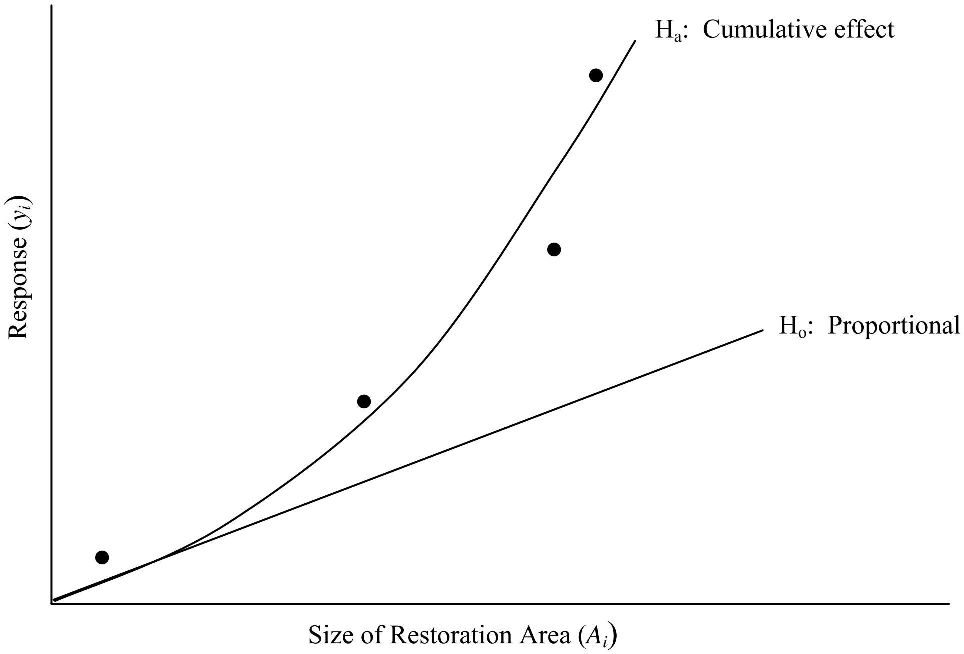

Figure 3.1. Hypothetical Relationships between the Magnitude of Environmental Response and Size of the Restoration Area under the Null (H_o: proportionality) and Alternative (H_a: cumulative effects) Hypotheses

3.1.2 Relating Cumulative Response to Clusters of Restorations

Analogous to project size, cumulative effects may occur as restoration events become more and more spatially clustered together. A single restoration event has little or no opportunity to benefit from interactions with neighboring sites. On the other hand, neighboring restoration activities may benefit from interaction and mutual feedback to produce cumulative effects greater than the sum of the individual projects. If true, the average response per restoration project should increase as the cluster size of the projects increases (Figure 3.2).

In this scenario, the experimental design would consist of restoration clusters of size 1, 2, 3, and more together. Ideally, these different project clusters would be initiated concurrently to eliminate confounding size with duration or time. The clusters of projects of different sizes would be replicated and randomized within the estuary. The test of cumulative effects would be based on the null hypotheses

$$H_o: \ \beta \leq 0$$

versus

$$H_a: \ \beta > 0,$$

where β is the slope of the relationship

$$\overline{y}_i = \alpha + \beta n_i$$

and where

$\overline{y}_i$ = mean response per project within the *i*th cluster,

n_i = number of restoration projects in the *i*th cluster.

A significant positive slope would be evidence of cumulative effects.

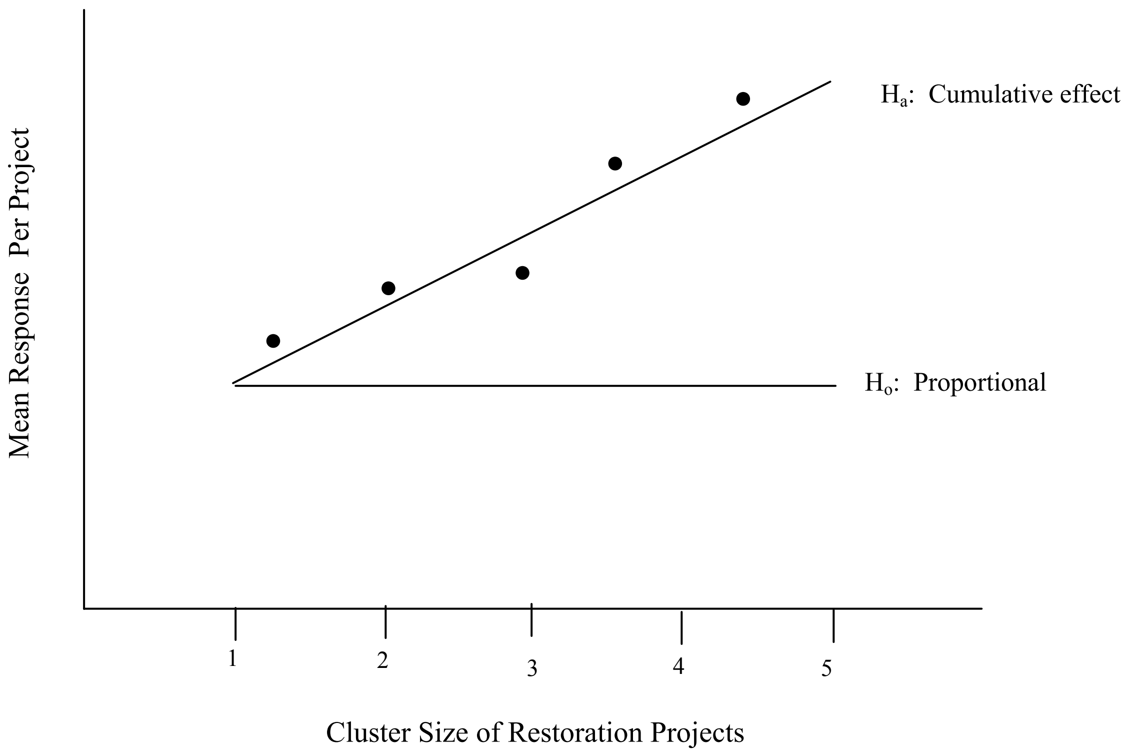

Figure 3.2. Hypothetical Relationship between Numbers of Restoration Projects in a Cluster and Mean Responses per Project under the Null (H_o: no relationship) and Alternative (H_a: cumulative effects) Hypotheses

3.1.3 Relating Cumulative Responses to Temporal Trends in Restoration Events

As time progresses, an isolated restoration site may be joined by new sites in the vicinity that are also restored. The temporal pattern of site response may therefore be altered by these neighboring events. Cumulative effects may be evident if the equilibrium state of a site increases with such subsequent neighboring restoration events (Figure 3.3). The experimental design would consist of a series of replicate restoration events in isolation. Restoration processes would be allowed to reach a new level of equilibrium response before another restoration event in the near vicinity was allowed to occur. A random sample of these sites would then be selected for nearby intervention; the rest would remain in isolation. The working hypothesis is that response output from the sites with a nearby restoration would increase compared to sites in isolation. The statistical test of cumulative effects would be based on a time-by-treatment interaction. The design could be augmented with additional restoration activities over the course of time and the expectations of additive shifts in site productivity (Figure 3.3b).

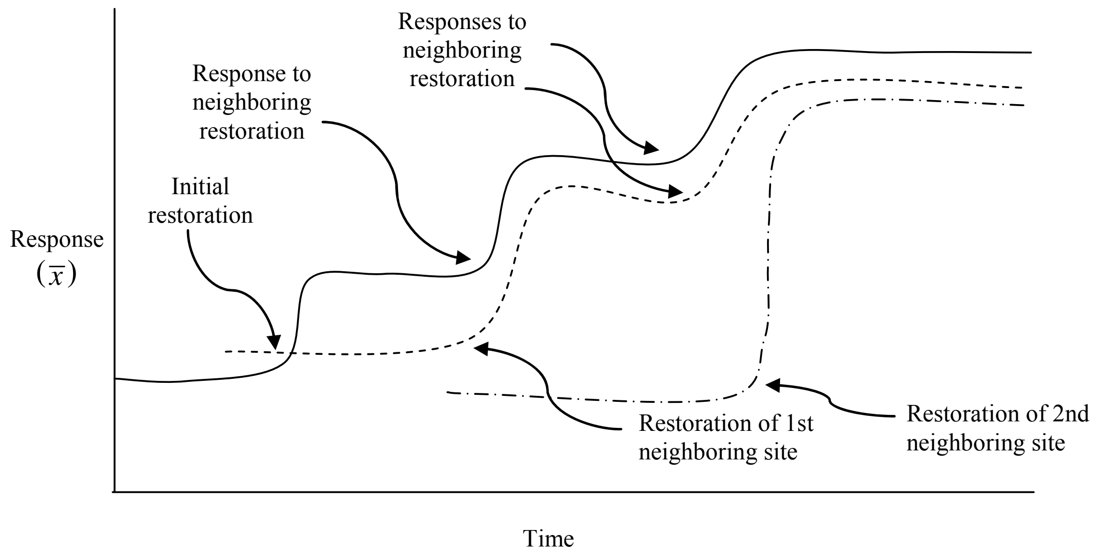

Figure 3.3. Hypothetical Relationship between Temporal Patterns of Site Response to One (A) and More (B) Interventions at Nearby Restoration Sites

3.2 Regional Perspective and Meta-Analysis

In practice, there will be a myriad of restoration projects. Some of these projects may receive formal and structured, site-specific effectiveness evaluations. However, the cost of such studies is relatively high, so the number of such studies may be small. Meta-analysis will therefore be necessary to determine the consistency of effectiveness across studies as a whole. If enough individual assessment studies exist, it may be possible to identify those factors shared by successful restoration and those traits common to failed attempts. Results of the meta-analysis would provide an overall assessment of the effectiveness of restoration projects and provide guidance on which proposed sites and methods have the greatest chance of succeeding.

The replicate restoration-reference design of Section 3.3 is another option for regional assessment of the effectiveness of restoration projects. The replicate approach requires more deliberate action to implement than the meta-analysis of historical restorations but may benefit from less heterogeneity and greater sample sizes. There would be a direct cost in performing an intentional replicated restoration-reference investigation. Neither the opportunistic or planned replicated investigation, however, will provide direct information on synergistic effects such as that provided by the alternatives described in Section 3.1. These meta-analyses will instead determine on average whether restoration activities are beneficial or not. To assess synergistic effects, the study designs in Section 3.1 are needed.

3.3 Replicate Restoration-Reference Design

In many cases, focused effectiveness monitoring at the site level will be cost prohibitive. Therefore, the majority of restoration activities will go largely unmonitored. However, a regional effectiveness monitoring approach may be used substituting extensive sampling for intensive, site-specific sampling. A random sample (or stratified random sample) of restoration sites could be selected according to habitat type and restoration activity (e.g., rechannelization, dike removal, etc.). Each site would be paired with a nearby reference site, similar to match pairs in biometrical studies (Fleiss 1985).

Indicators will be measured prior to restoration and periodically in subsequent years at each site within a pair (Figure 3.4). The replicated investigations would test whether there is a time (i.e., before-after) by treatment interaction (restoration vs. reference site) as well as a convergence of response over time. Site-specific covariates could also be used to determine which conditions are correlated with restoration success. This replicated trial would provide a region-wide assessment of restoration success. By blocking on different habitat or restoration practices, the analysis could also provide insight into which habitats or practices are best suited for restoration.

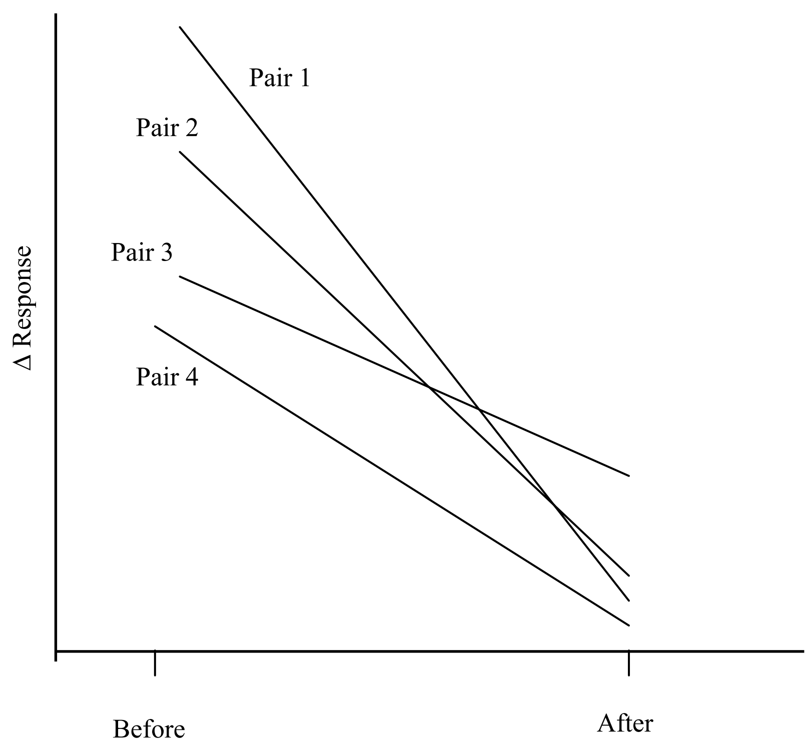

Figure 3.4. Graphical Representation of Before-After Response to Restoration at Replicate Restoration-Reference Sites Used in Regional Assessment. Measured response is the difference (Δ) between reference and restoration sites.

3.4 Conclusion

Assessment of synergistic effects would require the implementation of sets of restoration projects designed to test spatial clusters and temporal sequences. While on-the-ground restoration project design is outside the scope of the present study, if such project sets are implemented on the Columbia River by restoration managers and appropriate monitoring data can be collected then these statistical methods will be applied on an opportunistic basis. The purpose of the dissemination of monitoring protocols by this study is to ensure consistent collection of data at restoration sites, so that meta-analyses can occur to analyze landscape scale or long-term trends. The sampling designs described in Sections 3.1.2 and 3.1.3 will also serve the needs of managers in later years who analyze the effects of restoration projects at the landscape scale. This project will test cumulative responses to the physical size of restoration sites and apply the replicate restoration-reference design at selected sites. To the extent that restoration managers implement the protocols and a regional dataset becomes available in a timely manner, a meta-analysis of paired restoration and reference sites will also be conducted.

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4.0 2005 Field Study Methods

4.1 Overview

The 2005 field studies in Oregon and Washington included restoration sites and corresponding reference sites representing tidal freshwater swamp and emergent marsh. These sites were initially monitored for action effectiveness (Section 4.2), and results are expected to be incorporated into the cumulative effects meta-analysis in the future (Section 3.2). The data-collection locations were Kandoll Farm and Kandoll Reference (Figure 4.1), Vera Slough (Figure 4.2), and Vera Reference (Figure 4.3). Vegetation sampling was concentrated on transects proximal to expected changes – for example, near a culvert replacement or dike breach. This vegetation monitoring was complemented by the collection of digital aerial photos and Light Detection and Ranging (LiDAR). To maximize possibilities for integrating data, channel cross-sections were surveyed along vegetation sampling baselines wherever possible, elevation data were collected at vegetation plots, and datalogging sensors were deployed year-round to acquire water pressure and temperature information. Nutrient and chlorophyll flux samples were gathered near the locations of pressure sensors and fish collection efforts were located in the same channels.

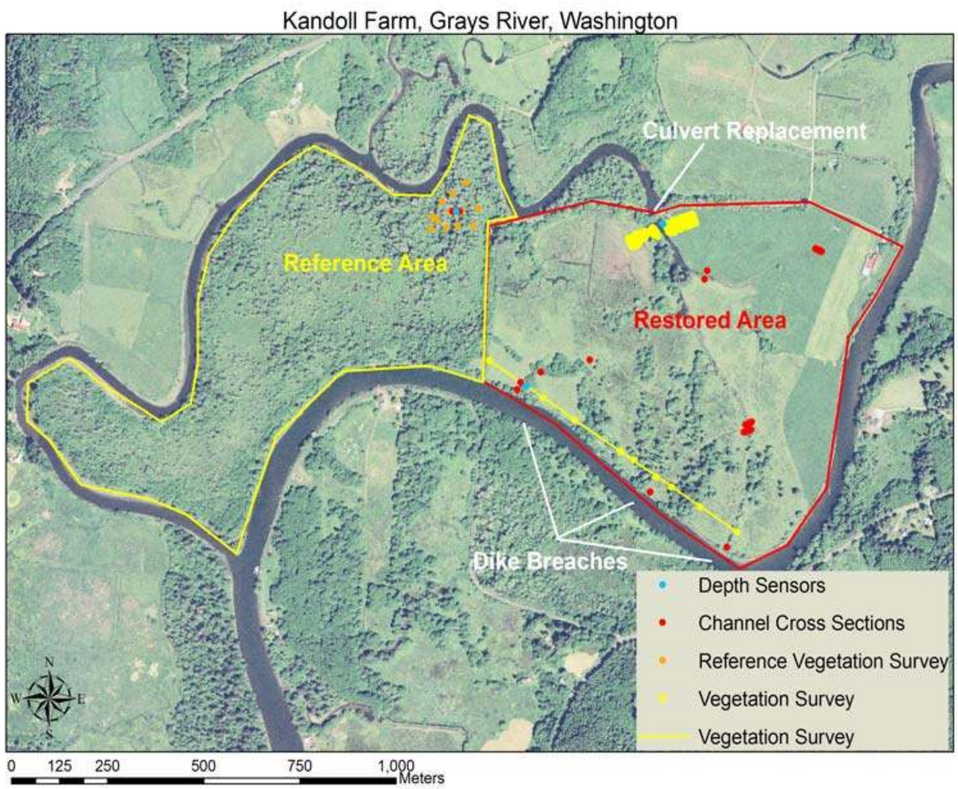

Figure 4.1. Restoration Actions and Sampling at Kandoll Farm Restored and Reference Sites: Water Pressure and Temperature Sensors, Channel Cross Sections, and Vegetation Transects. Farm vegetation plots are on the West and East sides of Seal Slough (SSW and SSE).

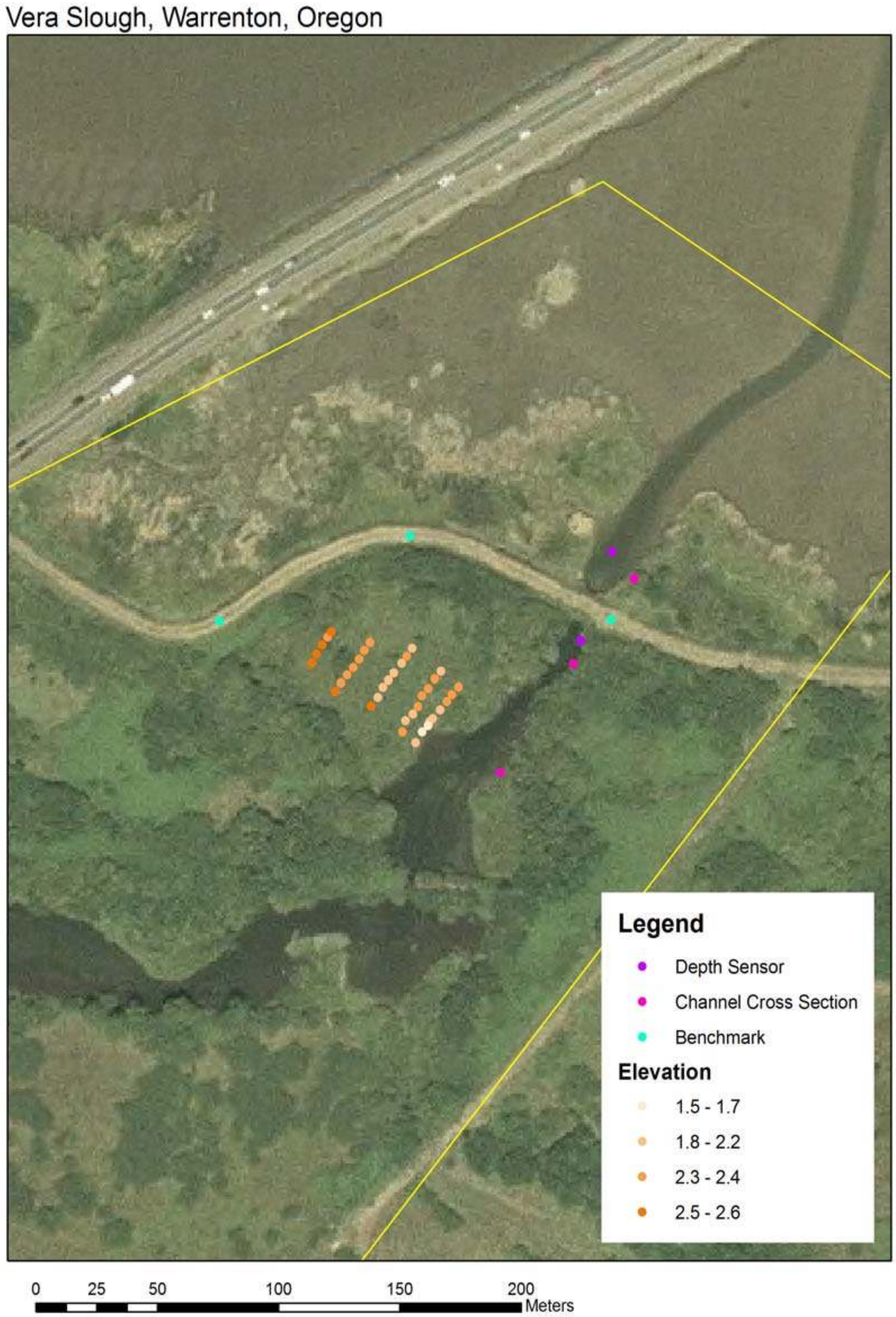

Figure 4.2. Sampling at Vera Slough: Water Pressure and Temperature Sensors, Channel Cross Sections, and Vegetation Transects (with elevations)

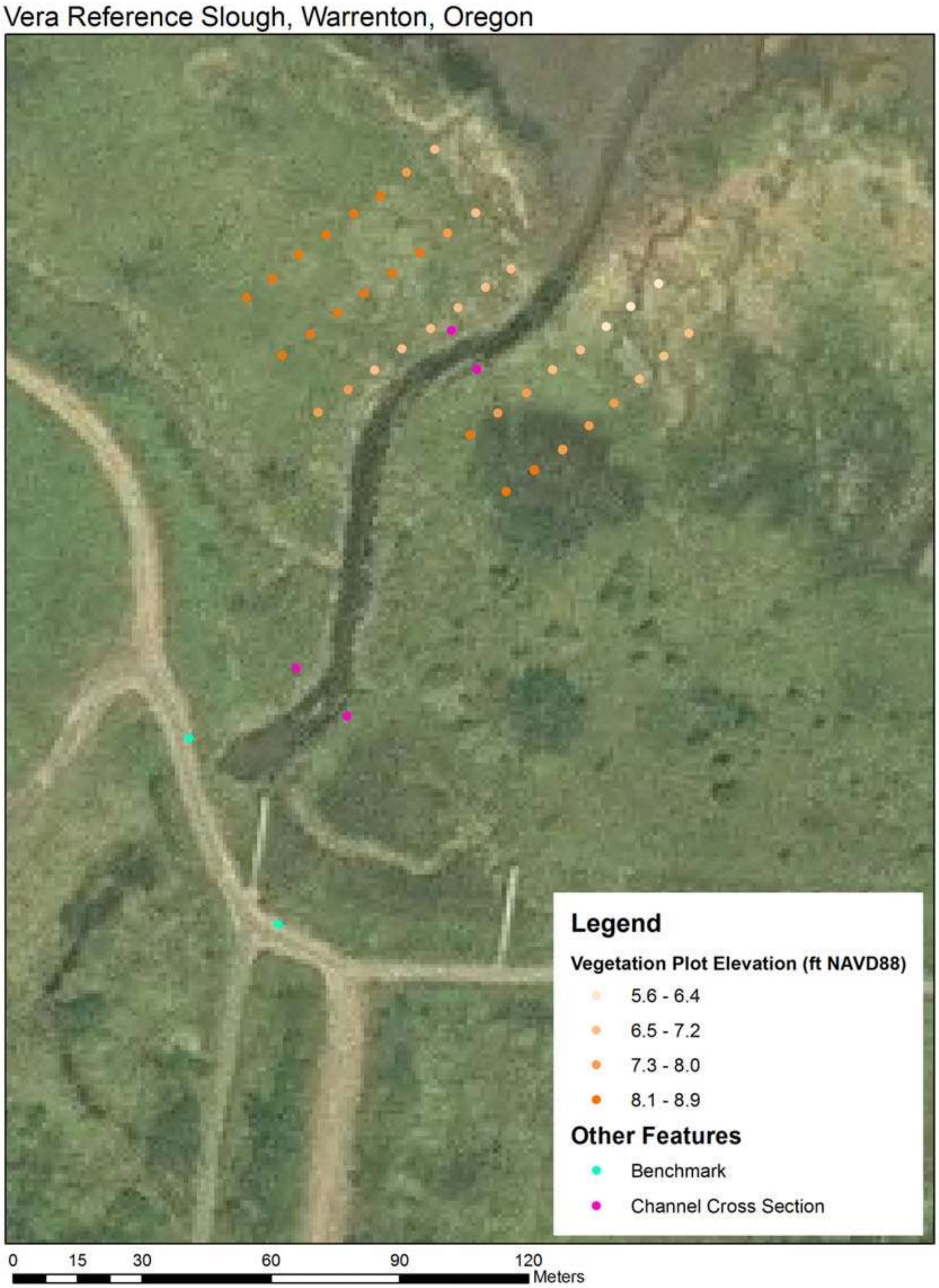

Figure 4.3. Sampling at Vera Reference: Water Pressure and Temperature Sensors, Channel Cross Sections, and Vegetation Transects (with elevations)

4.2 Effectiveness Monitoring Sampling Design

Effectiveness monitoring activities are designed and undertaken to assess how well a particular restoration project performs relative to reference site(s). The 2005 field sampling at Vera Slough, Kandoll Farm, and corresponding reference sites was based on a "reference only design" (Section 4.2.2). This effectiveness monitoring is expected to eventually be incorporated in a cumulative effects meta-analysis (Section 3.2). The purpose of the sampling design for effectiveness monitoring is to assess whether restoration measures achieve project and program goals and objectives. Testing for a simple change in ecosystem structures or processes is unnecessary because a physical change was intentionally performed, although measurement of outcomes may be of ecological interest. Instead, the purpose is to assess whether the restoration activity produced the desired shift from some state A to state B. Auxiliary questions may include how rapidly the shift occurred and the relative costs of alternative restoration activities. The sampling designs described here are appropriate for testing these questions in the complex environment of the CRE.

4.2.1 Control−Reference Designs

The assessment of restoration effectiveness is based on evaluating whether a shift has occurred from a site's current state (A) to a desired state (B) (described as performance standards in project plans), in a natural system subject to spatial and temporal variability (Figure 4.4).

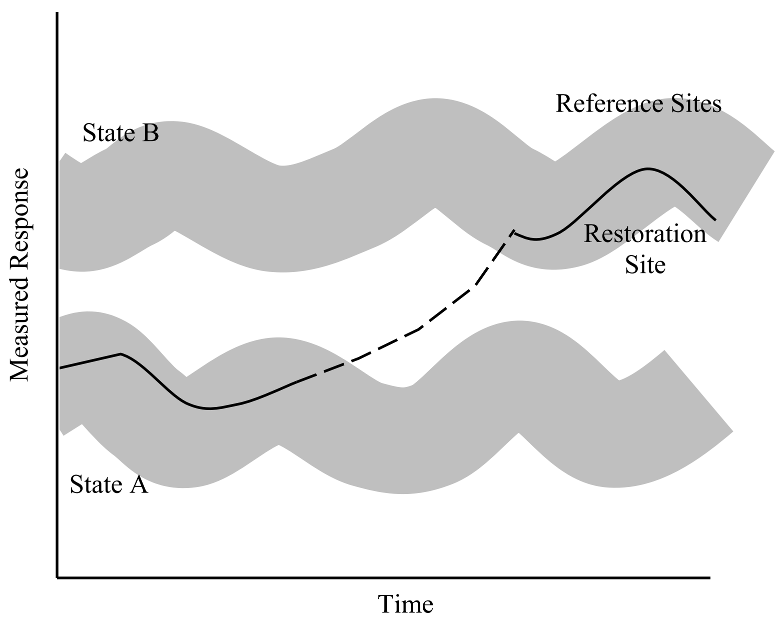

Figure 4.4. Conceptual Framework for Evaluating Restoration Effectiveness. The restoration site should shift from its initial state (A) to a desired state B over time. The successfully restored site should have response values within the range of reference sites and should track their temporal pattern.

Control sites are replicate locations with habitat traits similar to those of the subject site prior to restoration. These sites are sampled over time to monitor any temporal shifts in baseline conditions and to see how the subject area might have responded over time had no restoration action taken place. Reference sites are replicate areas considered representative of the desired outcome of the restoration action. These replicate areas are used to characterize the spatial heterogeneity of the target habitat and any temporal shift in the target over time due to climate shift, maturation, etc. Hence, the habitat goal of the restoration may be best viewed as a range of conditions, itself subject to natural change over time. A fully restored site might therefore be expected to be within this reference range and might mimic any temporal pattern displayed by these reference sites (Figure 4.4).

4.2.2 Reference Only Designs

Control sites might be an unnecessary luxury if the difference between states A and B is great. In other words, if the ranges in the two sites do not overlap, then there should be little or no risk of falsely concluding restoration (i.e., reaching state B, the planned performance standards) when the site is still within the range of the initial state A. In this case, only reference sites are needed to assess the status of recovery (Figure 4.5). Restoration success is still defined as the subject site merging into the range of reference conditions and tracking their responses over time.

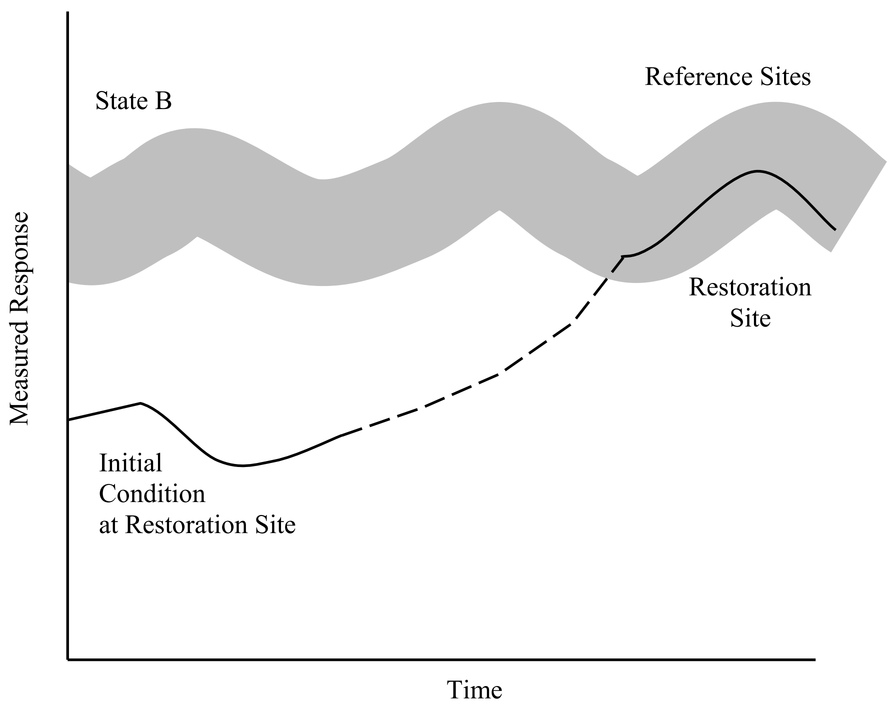

Figure 4.5. Conceptual Framework for Monitoring Restoration Effectiveness Using Only Reference Sites as a Target for Recovery

Using only reference sites as part of an effectiveness monitoring design is analogous in many ways to accident assessment designs (Skalski 1995). Recovery of impacted sites following some environmental accident is defined by the impacted site approaching the range of reference conditions and subsequently sharing their temporal trajectory over time.

4.2.3 Control Chart Method

In accident assessment, typically there are multiple reference sites and multiple potentially impacted sites in the evaluation. Skalski and Robson (1992) suggested using repeated measures analysis in conjunction with a test for parallelism to assess recovery. Recovery is achieved when the reference and impact sites begin tracking each other through time (i.e., parallelism) according to Skalski et al. (2001). However, in monitoring the restoration of a single site, standard tests of parallelism cannot be performed.

There is no between-site, within-treatment variance, only within-site measurement error at the restoration site.

From the repeated sampling at the reference sites, upper and lower control limits for reference responses can be constructed (Figure 4.6). Control limits describe a range of population responses, such that a prescribed proportion of the population falls within their bounds. For example, the limits

$$\mu \pm 3\sigma$$

contain approximately 99.7% of a normally distributed population. Shewhart control charts (Burr 1976, Duncan 1974, Grant and Leavenworth 1972) use this principle to establish control limits to monitor production processes in manufacturing. A variation of this concept could be used to assess whether a restoration site merges into the range of reference conditions (Figure 4.6).

A potentially powerful alternative to control charts is the Cumulative Sum or cusum technique. The cusum technique consists of a sequential test of hypotheses that can be presented graphically. Unlike control chart methodology, which examines the data for the existence of stability, the cusum method sequentially tests whether a target value has been achieved. In restoration activities, a reasonable value for the target is the mean from reference sites. The cusum plot is more difficult to produce than a control chart and "is so homely that only its parent could love it" (Wheeler 1995) but it can be focused on the objectives of restoration sites achieving a new state.

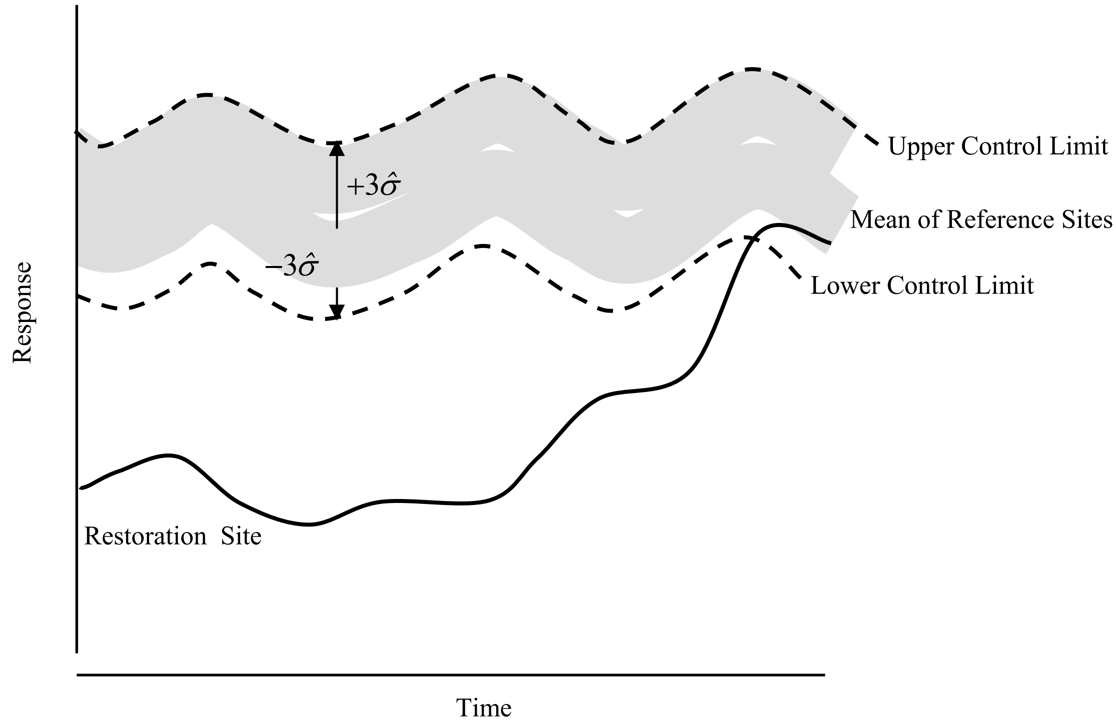

Figure 4.6. Illustration of Using Control Chart Methods to Monitor Recovery Success

4.3 Methods for Core and Cumulative Effects Metrics

The core restoration project monitoring metrics as well as metrics proposed for the estuary-wide cumulative effects study are shown in Table 4.1. During the 2005 field studies, we collected data on the metrics marked with asterisks. The core restoration project monitoring metrics listed in the left column on Table 4.1 provide the organizing principle for much of the remainder of this report: the methods in this section, results (Section 5), and protocols (Appendix A). Data on cumulative effects metrics from the right column are reported in the corresponding category from the left, i.e., hydrology/landscape features, vegetation, and fish. The exception is “flux,” a category added after “fish” for nutrient and chlorophyll flux data, because flux in fact integrates elements of landscape features/hydrology, vegetation, and fish.

Table 4.1. Core Restoration Project Monitoring Metrics and Additional Cumulative Effects Study Metrics (Metrics marked with asterisks were sampled in 2005.)

Core Restoration Project Monitoring Metrics	Candidate Cumulative Effects Metrics
Hydrology (Water surface elevation)*	Hydrological and flood storage modeling
Water Quality (Temperature, Salinity)*	
Elevation (Bathymetry and Topography)*	Correspondence between plant community and elevation*
	Sedimentation and accretion*
Landscape Features*	Hydraulic geometry relationships
Vegetation Changes Resulting from Tidal Reconnection*	Correspondence between plant community and elevation*
	Productivity of swamp and marsh macrophytes*
	Organic matter export and fate*
	Species-area curves*
	Nutrient flux*
Fish Temporal Presence,* Size/Age Structure, and Species Composition*	Salmonid growth and residence time
	Salmonid prey
	Species-area curves

4.3.1 Water Surface Elevation and Water Quality

A total of six water temperature and pressure data loggers were deployed in both restoration and reference sites, near the mouths of major tidal channels (within the constriction), and locations were recorded with a global positioning system (GPS). Additional data loggers were deployed on a short-term basis during flux studies. See Figure 4.1 through 4.3 for the locations of the water temperature and elevation data loggers at restoration and reference sites (denoted as "Depth Sensor"). PVC sleeves were fabricated to encase the instruments to prevent metal-to-metal contact with the metal fence posts used to secure the sensors in the tidal channels. The reference data loggers were situated to record water levels at sites unaffected by restoration activity. Two additional dataloggers were placed upstream and downstream of the restoration site on the Grays River to gauge inputs and outputs. An additional datalogger was placed at the fork of Vera Slough to gauge the extent of tidal effect following tidegate replacement (lags in period and variation in amplitude with distance from the tidegate replacement site). The elevation of the sediment surrounding the post where the sensor is attached is likely to change over time due to accretion or erosion around the post. Therefore the elevation of the post was measured by leveling the stadia rod on top of the post and using a total station or auto-level referenced to nearby benchmarks. Each time the sensors were deployed, the distance from the top of the post to the sensor was measured. The sensors were programmed to record conditions every half hour.

The primary output from the dataloggers is a time series of water levels and temperatures. The relative heights will be converted into height relative to the standard water elevation datum (mean lower water level) or land elevation for comparison between sites and as a reference to site topography. Data are presented to contrast water level fluctuation at reference and impact sites pre- and post-restoration.

4.3.2 Land/Substrate Elevation

Traditional survey methods are not always feasible in the Columbia River's estuarine systems due to limited line of sight and lack of established benchmarks. Site surveys of both study areas were conducted by certified surveyors as part of the restoration project design. However, these surveys were not conducted in combination with vegetation surveys or in other specific areas of interest, such as tidal channels. Therefore, we conducted surveys useful for predicting vegetation colonization or analyzing channel formation and change. We established a series of surveyed benchmarks at the restoration site with a Real-Time Kinematic (RTK) GPS technology, a method which utilizes two GPS receivers linked via a radio connection. These benchmarks have "line-of-site" to the portions of the site where elevation data are critical (e.g., at the location of vegetation transects, channel cross sections, and water depth sensors). An auto level or a total station was then used to survey elevation differences between the established benchmarks and the areas of interest.

For topographic surveys, we used an auto level or a "total station," which is a combination transit and electronic distance measuring device. The total station system consists of an electronic instrument stabilized on a leveled tripod and a reflecting mirror affixed to the end of a graduated stadia rod. The total station uses infrared light to measure the distance and angle from instrument to reflector, then calculates the relative position and elevation. The total station position was always referenced to an established benchmark. Elevation and position data were logged and internally transferred to mapping software for analysis and display. Although simple 2D (distance and elevation) transects across areas of interest can be made, this system can also generate 3D maps from regular or random grids of data points. Such maps were digitized and overlain on aerial photography images to produce digital elevation maps for selected parts of the restoration project sites.

Channel cross sections were measured by determining elevations along a permanent horizontal transect perpendicular to a channel. Endpoints were marked with a permanent marker (PVC pipe) at a distance far enough from the bank to ensure they would not be washed out by erosive forces. The transect endpoint locations were recorded using a GPS with differential correction. If satellite coverage for the GPS was not available due to tree cover, points were established in areas offset from the original location with measurements of distance, azimuth, and elevation difference. With a measuring tape attached to the fixed endpoints, the stadia rod was leveled at each predetermined interval and the interval and horizontal distance were recorded, and the height was measured with the autolevel. The horizontal interval used was greater (e.g., 1-2 m) in areas of low slope and smaller (0.5 m) in areas of steeper slope.

The elevation surveys corresponding to vegetation were conducted in a grid using transects along a baseline. The centerpoint of each quadrat was marked with flagging during the vegetation surveys and the elevation data were recorded at a later time by positioning the stadia rod at the location of the flagging.

Sediment accretion stakes were also installed to track changes in substrate elevation at sites associated with vegetation sampling. The PVC stakes were installed to equal heights in a north-south direction exactly 1 m apart (Figure 4.7). Height to the top of the stakes was measured at 10-cm intervals between the stakes and averaged.

Elevation data were downloaded from the total station and entered into a GIS and a spreadsheet. Elevations and vegetation were plotted in Excel to determine the means and ranges of elevation for species or communities. The channel cross sections listed in Table 4.2 below were also plotted. (Note: "1" denotes the cross section at the depth sensor in each case.) Locations of channel cross section measurements are also shown on Figures 4.1 through 4.3.

Figure 4.7. Sediment Accretion Stakes

Table 4.2. Channel Cross Section Measurements

Site Code	Site Description	Date Surveyed
KF1	Seal Slough Depth Sensor Inside	7/14/05
KF2	Seal Slough Above Fork	7/14/05
KF3	chx-1 (total station)	6/18/05
KF4	chx-3 (total station)	6/18/05
KF5	chx 4 (total station)	6/18/05
KR1	Kandoll Reference Center Transect	9/17/05
KR2	Kandoll Reference Upper	9/20/05
GRD1	Grays River Dike Lower Channel 1	7/14/05
GRD2	Grays River Dike Upper Channel 1	7/14/05
GRD3	Grays River Dike Upper Channel 1 & 2	7/14/05
VS1	Vera Slough Dike Inside	7/13/05
VS2	Vera Slough Dike Outside	7/13/05
VS3	Vera Slough Vegetation Transect	7/12/05
VR1	Vera Reference At Depth Sensor	7/13/05
VR2	Vera Reference Near Light Platform	7/13/05

4.3.3 Vegetation and Landscape Features

The sites at Kandoll Farm (West of Seal Slough), Kandoll Farm (East of Seal Slough), Vera Slough, and Vera Reference were sampled for percent cover with 1-m^2 quadrats on systematically spaced plots with a random start along transects. Due to the presence of trees, Kandoll Farm Reference samples were instead collected using 1-m^2 quadrats for herbaceous vegetation centered on 3-m-diameter circles for shrubs and 10-m-diameter circles for trees (Figure 4.8). An example of the vegetation sampling grid at Seal Slough on Kandoll Farm is shown in Figure 4.9. Vegetation sampling was concentrated on transects proximal to expected changes – in this case, near the culvert replacement on Seal Slough and the tide gate replacement at Vera Slough. A randomly selected subset of the vegetation plots was also sampled for above-ground and below-ground organic matter. The height and age of a subset of the trees on the Kandoll Reference site were measured using a clinometer and increment borer; if present, one Sitka spruce and one red alder from each of the twelve Reference plots was measured.

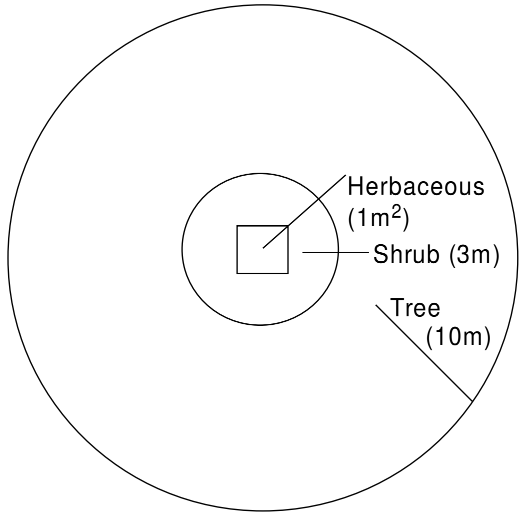

Figure 4.8. Vegetation Plot Design for Forested Wetlands

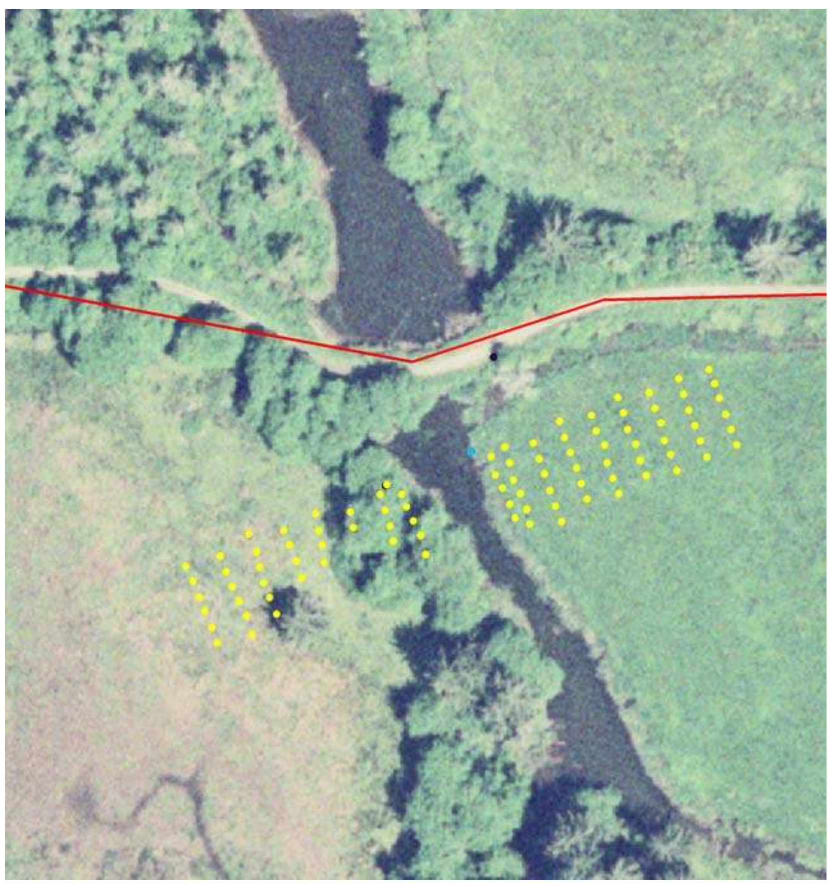

Figure 4.9. Vegetation Sampling Grid at Seal Slough in the Kandoll Farm Restoration Site

4.3.3.1 Vegetation Laboratory Analyses

Below- and above-ground organic matter was iced and shipped to the Battelle Marine Sciences Laboratory in Sequim, Washington, and processed as follows:

Method for Above-Ground Samples

1. Remove from bag and rinse entire sample over a 1- or 2-mm mesh in freshwater to remove sediment. Clean the sample of anything other than macrovegetation.
2. Place the dead (brown and flaccid) plant matter into a pre-weighed piece of aluminum foil (labeled with the sample id), dry the sample in an oven at ~80-90 deg C for 24-48 hours until dry. Record the dry weight to 0.00 g.
3. Repeat 2 with the live green material.
4. Discard the material once the weights are recorded.

Method for Below-Ground Samples

1. Remove from bag into a large bowl and mix to homogenize the sample.
2. Remove a small subsample that would be suitable for placement in a muffle furnace.
3. Place the subsample in a pre-weighed crucible, dry at ~80-90 deg C and record the dry weight to 0.0000 g.
4. Place the sample in the muffle furnace and ash at 500 deg C for 1 hour and record the weight after cooling.
5. Record the ash free dry weight.
6. Calculate the percent loss from ignition.

4.3.3.2 Vegetation Calculations

General statistics were calculated for the *percent cover* of each plant species or category in each site. The mean, standard deviation, maximum, and minimum were calculated for each site using all quadrats. Where there was zero percent cover this was included in the calculations. Calculations were performed on abiotic categories like “open water” and “bare ground/mud” since these are descriptors of the sites. The *species richness,* or number of species, was calculated for each quadrat and summarized by the statistics described above. Abiotic categories were excluded from this and subsequent calculations.

Species-Area curves were calculated for each site using the species richness for each quadrat. The quadrats in a site were assigned a random value and sorted. The number of species present was then determined for the quadrat and all preceeding it (running sum). This was replicated 10 times to get multiple, random assignments of the quadrats, and then the species per quadrat was averaged for all ten replicates for an average species-quadrat curve. Since each sample quadrat was 1 m^2 this could be directly translated into a species-area curve. Species-area curves were not calculated for Kandoll Reference because sampling areas of three different sizes were assigned to measure the herbs, shrubs, and trees.

The *Shannon-Wiener Diversity index* (H') was also calculated for each quadrat and averaged for the site. The formula:

$$\text{Species } H' = | p_i \ln(p_i) |$$

was applied to each species, where p_i is the proportion of the vegetation in the quadrat (i.e., species % cover divided by the total % cover). All the individual species values were then added together to obtain the H' for the quadrat, and all these totals were averaged for the site to obtain the site H'.

Evenness (J') was calculated for each quadrat and summarized at each site using the following equation.

$$J' = H' / H'_{\text{max}}$$

where H' is the Shannon-Weiner Diversity Index for the particular quadrat, and H'_{max} is the maximum Shannon-Weiner Diversity Index for the site.

Similarity indices between all sites were calculated in two ways. First, an unweighted similarity was calculated between two sites with the equation

$$\text{Similarity} = (2a / [2a + b + c]) * 100$$

where a is the number of species in common between the two sites, b is the number of species exclusive to the first site, and c is the number of species exclusive to the second site. A weighted similarity was also calculated using the same equation, but % cover was substituted for number such that a is the % cover of the common species between the two sites (only the overlapping value), b is the total % cover of species exclusive to the first site, and c is the total % cover of species exclusive to the second site.

4.3.3.3 Landscape Features

Prior to restoration, aerial photos for restoration and reference sites were acquired from the property owners and analyzed to identify hydrological barriers, qualitatively assess baseline vegetation conditions, and preliminarily identify locations for vegetation transects, datalogging instruments, and reference sites. In addition, USACE photos documenting historical conditions (i.e., prior to land use changes) were acquired for the Grays River sites and reviewed to acquire a general understanding of changes in plant communities and geomorphology. For the purpose of developing methods for delineation of plant associations in Columbia River estuary marshes and swamps, 0.25-m resolution digital aerial photos were also acquired for both restoration and reference sites. We coupled this digital imagery with ground truthing using a camera and GPS, collecting GPS data with corresponding photos of the vegetation and geomorphological features at each point, line, or polygon. We are currently analyzing this data using GIS; algorithms are being developed to identify pixel values in the images. Those pixel values will then be applied to the whole image to get a classified representation of the site. This kind of image classification provides a spatially accurate method of determining broad vegetation categories and the location of tidal channels that is not subjective and is repeatable in subsequent years. In addition to aerial photography, we established photo points marked with PVC pipe and recorded these locations using a GPS.

4.3.4 Fish

In April, potential sampling sites were evaluated to determine the types of gear necessary for effective evaluation of fish community structure. Channels and substrates were found to be conducive for sampling for fish community structure with beach and pole seines. Seines were then constructed to sample areas with low water velocity and shallow water depths. Three nets were used corresponding to different channel sizes: one pole seine 5 m x 1.5 m and two beach seines 5 m x 2 m and 7 m x 2 m, all with 6.5-mm stretch mesh webbing. During sampling, seines were deployed parallel to shorelines out 3 to 5 m, depending on channel morphology, then pulled into shore where fish were bagged in the net center and dip netted into holding containers. Salmonids were anesthetized with a 50 mg/l solution of tricaine methane sulfonate (MS-222) before measurement. Fish were identified to species, counted, and the standard length of up to 30 individuals per species was determined. Fish were allowed to recover before being released back to the local area. In conjunction with fish catch, conductivity, temperature, and depth (CTD) casts were made to ascertain vertical profiles of water temperature, salinity, chlorophyll fluorescence, and optical backscatterance (OBS). Sampling to evaluate fish communities in the Vera and Kandoll Slough areas was conducted in May and June, before tide gate modification and culvert replacement. We sampled inside and outside of the pre-restoration tide gates as well as at reference sites separate from the impact sites. Because of the late dates of tide gate modification in 2005, post restoration sampling was conducted in 2006.

4.3.5 Nutrient Flux

4.3.5.1 Flux Field Sampling

The flux study involved sampling periodically throughout a tidal cycle at each restoration and reference site, with corresponding restoration and reference sites sampled on the same tides on the same days. Grab samples were collected from the water for nutrient, total organic carbon, and chlorophyll flux analyses; currents were recorded at each time of sampling with a Marsh-McBirney FlowMate™. Water elevation and temperature in the vicinity of the sampling sites were continuously monitored with datalogging HOBO sensors, while YSIs were used for continuous monitoring over approximately 2-week intervals near the flux sampling dates. In addition, water property profiles were collected during the flux sampling by deploying a CTD along the slough from a boat. Samples were stored in coolers on ice in the field and frozen prior to shipping. Nutrient and TOC samples were analyzed by the University of Washington. Chlorophyll samples are being processed.

4.3.5.2 Flux Analytical Laboratory Methods for TOC and Nutrients

4.3.5.2.1 Total Organic Carbon (TOC) Method

General references for the TOC method include Sugimura and Suzuki (1988), UNESCO (United Nations Education, Scientific, and Cultural Organization 1994), and Van Hall et al. (1963). Samples are analyzed on a Shimadzu TOC-Vcsh using the high-temperature catalytic oxidation method (HTCO) and measured on a non-dispersive infra-red (NDIR) detector. Samples for organic carbon analysis are acidified (w/6N HCl), sparged, and injected into the system.

4.3.5.2.2 Nutrients Method

Nutrients methods follow UNESCO (1994) *Protocols for the Joint Global Ocean Flux Study (JGOFS) Core Measurements IOC Manual and Guides 29.*

Ammonium

A modification of the Slawyk and MacIsaac (1972) procedure is used for the analysis of ammonium. A water sample is treated with phenol and alkaline hypochlorite in the presence of NH3 to form idophenol blue (Berthelot reaction). Sodium nitroferricyanide is used as a catalyst in the reaction. Precipitation of Ca and Mg hydroxides is eliminated by the addition of sodium citrate complexing reagent. The sample stream is passed through a 55°C heating bath, then through a 50-mm flowcell and absorbance is measured at 640 nm.

Nitrate/Nitrite

A modification of the Armstrong et al. (1967) procedure is used for the analysis of nitrate and nitrite. For NO3 + NO2 analysis, a water sample is passed through a Cd column where the NO3 is reduced to NO2. This nitrite is then diazotized with sulfanilamide and coupled with N-(1-naphthyl)-ethylenediamine to form an azo dye. The sample is then passed through a 15-mm flowcell and absorbance is measured at 540 nm. A 50-mm flowcell is required for the nitrite. The procedure is the same for the NO2 analysis less the Cd column. Nitrate concentration equals the (NO3 + NO2) concentration minus the NO2 concentration.

PO4

O-Phosphate is analyzed using a modification of the Bernhardt and Wilhelms (1967) method. Ammonium molybdate is added to a water sample to produce phosphomolybdic acid, which is then reduced to phosphomolybdous acid (a blue compound) following the addition of dihydrazine (or hydrazine) sulfate. The sample is passed through a 50-mm flowcell and absorbance is measured at 820 nm.

Silicate

Silicate is analyzed using the basic method of Armstrong et al. (1967). Ammonium molybdate is added to a water sample to produce silicomolybdic acid which is then reduced to silicomolybdous acid (a blue compound) following the addition of stannous chloride. The sample is passed through a 15-mm flowcell and absorbance is measured at 820 nm.

Total Nitrogen and Phosphates (TNP)

TNP is analyzed following the procedure of Valderrama (1981).

4.3.5.3 Flux Calculations

Data entered for each sample included date, time, maximum depth for the flow speed samples (cm), all the flow estimates (either ft s^{-1} or m s^{-1}), TOC (mg L^{-1}), and nutrients (µM).

The area of the waterway cross-section was calculated in two ways depending on the morphology. The Kandoll Farm sampling site is a culvert, while the other three sites are sloughs with an irregular shape. The Vera Slough site has flood gates, but since the samples were collected in the inside of the gate after the water was through the constraint, we felt that estimates based on the cross section were more appropriate than the gate dimensions. This cross-sectional area was calculated for each sample collected since the depth of the water in the waterway would change each time with the tide. All results were converted from cm^2 to m^2.

Culvert Calculations

The calculations were based on the area of a partially filled circle. The area of the filled segment can be determined by the equation:

$$\text{Segment Area} = \tfrac{1}{2} R^2 (\theta - \sin\theta)$$

where R is the radius of the culvert, and θ is the angle formed at the center of the circle where the water surface intersects the sides of the circle (culvert) (see Figure 4.10).

θ is determined as $\theta = 2 \cos^{-1}(b/R)$

where b is the distance from the center of the circle to the water level and is determined by the data as $b = |R\text{-water depth}|$.

Calculations were converted from cm^2 to m^2.

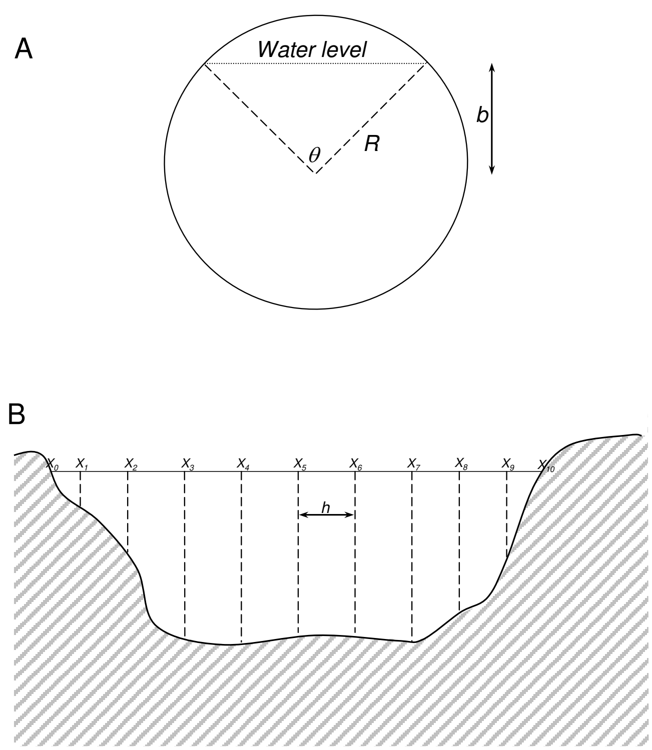

Figure 4.10. Diagram of Components Needed to Calculate the Cross-Section Area for the Different Waterways. A) Cross-Section of a Culvert Pipe. B) Cross-Section of a Natural Slough.

Slough Calculations

Prior to sampling, the depth of the slough was determined along a perpendicular transect line. Measurements were usually made every 1 m in addition to areas where a steep angle was encountered (i.e., edge of channel).

A correction factor was calculated from this profile and calibrated to the deepest reading. Therefore the deepest area was zero, and the other steps in the profile were a negative number equal to the difference in depth (cm).

For each sample period, the slough profile was reconstructed by taking the depth recorded with the sample and assigning that number to the deepest part of the profile. The other depths across the channel were then calculated by modifying the sample depth by the correction factor. This yielded a new depth profile for the slough cross-section specific for that sampling collection.

Area was calculated for the slough cross-section using a modified Trapezoidal Rule:

$$\text{Area} = h\,(½X_1 + X_2 + X_3 \ldots + X_{n-1} + ½\,X_n)$$

where h is the distance between depth measurements (1-m) and X is the depth along the profile. For the few measurements that were not done on the 1-m interval, the depth was multiplied by its proportion of the lateral transect. For example, if a sample had a measurement at 1, 2, 3, 3.5, 4, 5, and 6 m, then the equation would be:

$$\text{Area} = h\,(½X_1 + X_2 + 0.75X_3 + 0.5X_{3.5} + 0.75X_4 + X_5 + ½\,X_6)$$

The average flow speed for the sample period was calculated from all the observed speeds to better estimate flow across the whole depth gradient. When necessary, speeds were converted from ft s^{-1} to m s^{-1}.

Water flux was calculated by multiplying the area by the average flow speed, yielding a flux estimate in m^3 s^{-1}.

The concentration of each of the nutrients was calculated by multiplying the µM value entered by the molecular weight of the compound, yielding a value with the units mg m^{-3}. TOC was already in mg l^{-1}, and only had to be multiplied by 1000 to get the appropriate units.

Chemical flux was calculated by multiplying the water flux and chemical concentration for each sample, yielding a flux measurement of mg s^{-1}.

Total flux for water and each of the nutrients over a tidal phase (e.g., flood, ebb) was calculated for each site. Since there was no data set that spanned the whole of these phases, the two days in each site were combined and overlaid on an average hypothetical tide using the steps outlined below. While not perfect, this is the best way to estimate and compare total flux in and out of the system with the data available.

The times of the low and high tides were estimated from a tide chart for Tongue Point – Astoria (Tides & Currents Software for Windows, Nautical Software Inc.) and by using data provided by YSI depth sensors (YSI Inc.) at the sites.

Each sample time was converted to "time into tide phase". This was in turn converted into "percent% time into phase" by dividing by the total time between the slack times.

A representative tide was constructed for each site by averaging the times for each slack period for both days. All the sample times for a particular phase (e.g., ebb tide, Seal Ref, both days) were superimposed on this constructed tide and ordered according to their percent time into the phase. (This was converted to seconds into the phase based on the duration of the particular phase of the constructed tide.)

The different flux characteristics (water and nutrients) were then integrated over the duration of the constructed tidal phase. First, each sample was assigned a time block. This block started half way between the time of the previous sample and the time of the current sample, while the end time was calculated the same way as half way to the next sample. The first and last samples were integrated all the way to the time of the slack tide. The flux measurement (in m^3 s^{-1} for water flux and mg s^{-1} for nutrients) was then multiplied by the total number of seconds assigned to that sample to yield a total flux estimate for that time period in m^3 or mg. The totals for each section of the phase were then summed to obtain the total flux for the tide phase at each of the sites.

Lastly, differences were calculated for each site by subtracting the total flux on the ebb from the total flux on the flood. This yielded positive numbers for a net flux into the site and a negative flux for a net loss from the site (in relation to the tide).

4.4 Sampling Schedule

All sampling activities in 2005 are summarized in Table 4.3. Specific locations of these sampling activities are shown in Figures 4.1-4.3, above. Methods specific to each metric are further detailed in Section 4.4 and Appendix A.

Table 4.3. Vera Slough and Kandoll Farm Restoration and Reference Site 2005 Sampling Schedule. Sampling activities at each site included the installation of water level and temperature sensors (WQ), elevation surveys (Elevation), surveys of the percent cover of vegetation (Veg Transects), collection of above- and below-ground organic matter samples (Biomass), survey of channel cross sections (Channel XS), and deployment of sediment accretion stakes (Sed Accretion).

Deployment Site	2005											
	J	F	M	A	M	J	J	A	S	O	N	D
Vera												
VR WQ				Y	>	>	H	>	>	>	>	>
VS Inside WQ			HY	>	><	Y	><	H	>	><	H	>
VS Outside WQ				H	>	>	>	>	>	>	>	>
VS Fork WQ						H	>	>	>	>	>	>
VS Elevation								X				
VR Elevation					X		X					X
VS Veg Transects						X						
VR Veg Transects						X						
Photo Points								X				X
Aerial Photos						X						
Aerial Groundtruthing								X				
VS Biomass						X						
VR Biomass						X						
VS Channel XS							X					
VR Channel XS							X					
VS Sed Accretion							X					
VR Sed Accretion							X					
Fish Seines					X	X						
Flux						X						
Kandoll												
Kandoll Ref WQ						Y	H	>	>	>	>	>
Kandoll Farm In WQ					H	>	><	H	>	>	>	>
Kandoll Farm Out WQ	D	D	D			Y	D	L	L	D	D	D
KF Channel 1 WQ					H							
Grays R Upper WQ				H	>	>	>	>	>	>	>	>
Grays R Lower WQ					H	>	>	>	>	>	>	>
Elevation						X		X	X			
KF Veg Transects						X						
KR Veg Transects								X				
Grays Dike Transect						X						
KF Photo Points						X		X				
Aerial Photos						X						
Aerial Groundtruthing								X				
KF Biomass						X						
KR Biomass								X				
SS XS							X					
KF Field XS						X						
KR XS									X			
GRD XS							X					
GRD Sed Accretion							X					
KF Sed Accretion							X					
KR Sed Accretion												
Fish Seines					X	X						
Flux							X		X			

4.5 Literature Cited

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5.0 Results

This section presents results and calculations for three physical parameters: water surface elevation, water temperature, and land elevation. Results presented for vegetation include percent cover, elevation, species/area curves, diversity and similarity indices, tree diameters and heights, and organic matter. Fish catch per unit effort is summarized, and nutrient flux is analyzed.

5.1 Water Surface Elevation and Water Temperature

The water surface elevation and temperature sensors deployed prior to tidegate replacement at Vera Slough and culvert replacement and dike breaching at Kandoll Farm recorded the low tidal influence prior to these restoration actions (Figure 5.1 and 5.2). Temperatures inside Kandoll Farm, initially lower than references, began to climb later in the summer season. Vera Slough was warmer than the reference site and showed less tidal influence (Figure 5.2). These are baseline, pre-restoration data that will be compared with post-restoration data to describe effects.

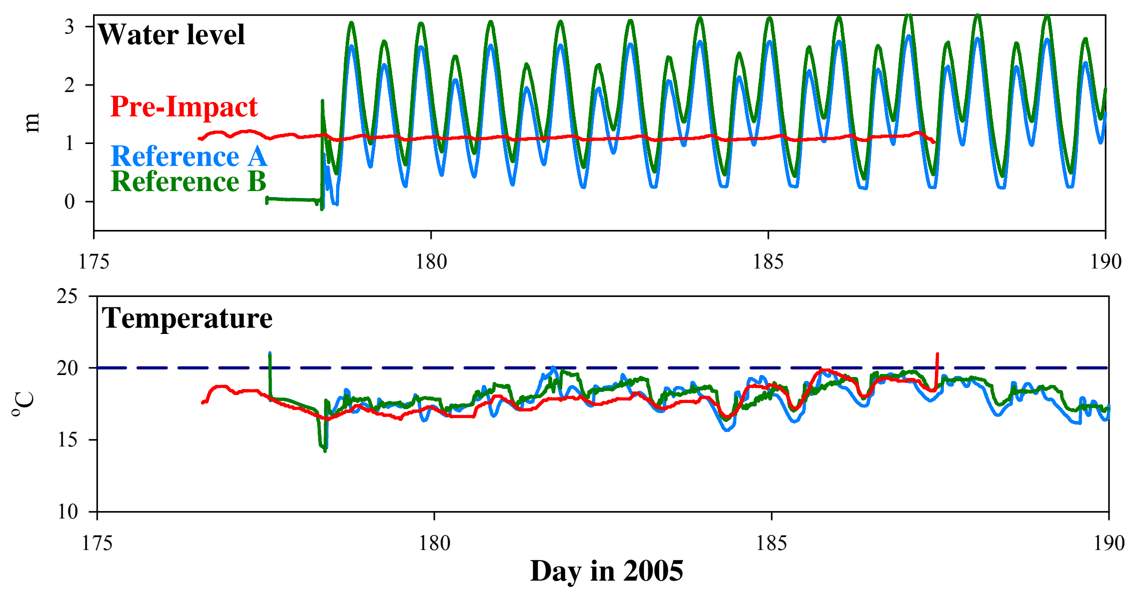

Figure 5.1. Tidal Signal and Temperatures Inside the Passage Barrier at Kandoll Farm prior to Restoration (red line) and at Corresponding Reference Locations Outside (blue and green lines) for 2005

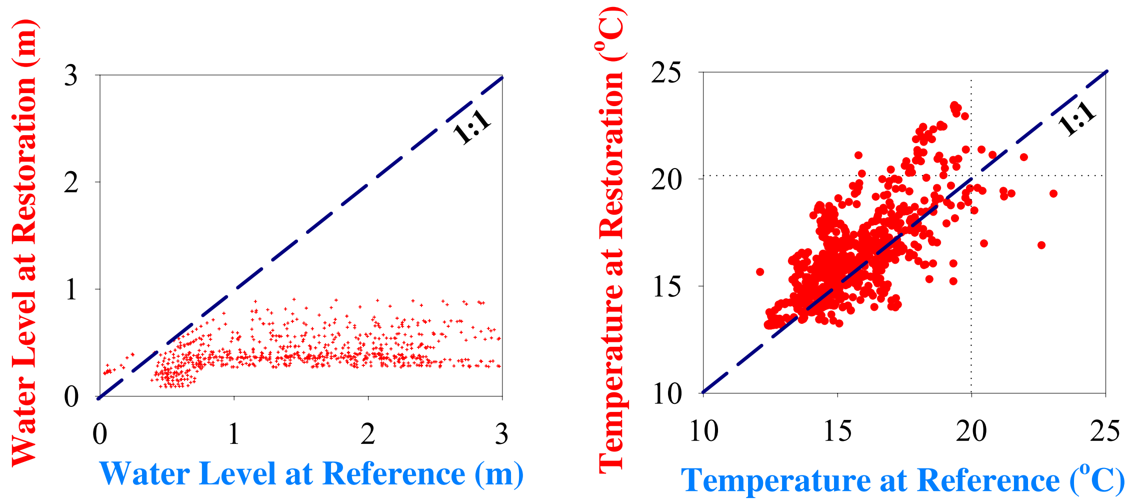

Figure 5.2. Water Levels and Temperatures behind the Tidegate at Vera Slough (Impact) Prior to Restoration, Versus Those at the Reference Site

5.2 Land/Substrate Elevation

The data show that tidally influenced wetland vegetation communities in the CRE are confined to a narrow elevation range. Figure 5.3 shows the ground surface profiles at the sediment accretion stakes at the restoration sites at Kandoll Farm and the restoration and reference sites at Vera Slough in 2005 before restoration activities took place. As described in Section 4, these will be measured periodically to track sediment accretion or erosion relative to this baseline and they are not corrected to an established datum.

The elevation of the vegetation in the Kandoll Farm plots ranged between 2.88 and 7.21 ft relative to NAVD88 (Table 5.1 and Figure 5.4). In general, plants at lower elevations (e.g., *Carex obnupta*, *Juncus effusus*) were either obligate or facultative wetland species. Those species at higher elevations were primarily upland species. The wetland species generally occurred at elevations lower than 6 ft. The vegetation communities at the Vera reference and Vera restored sites were dominated by wetland species. Many of these species had a very narrow elevation range, with most less than 2 ft (Table 5.2 and Figure 5.5).

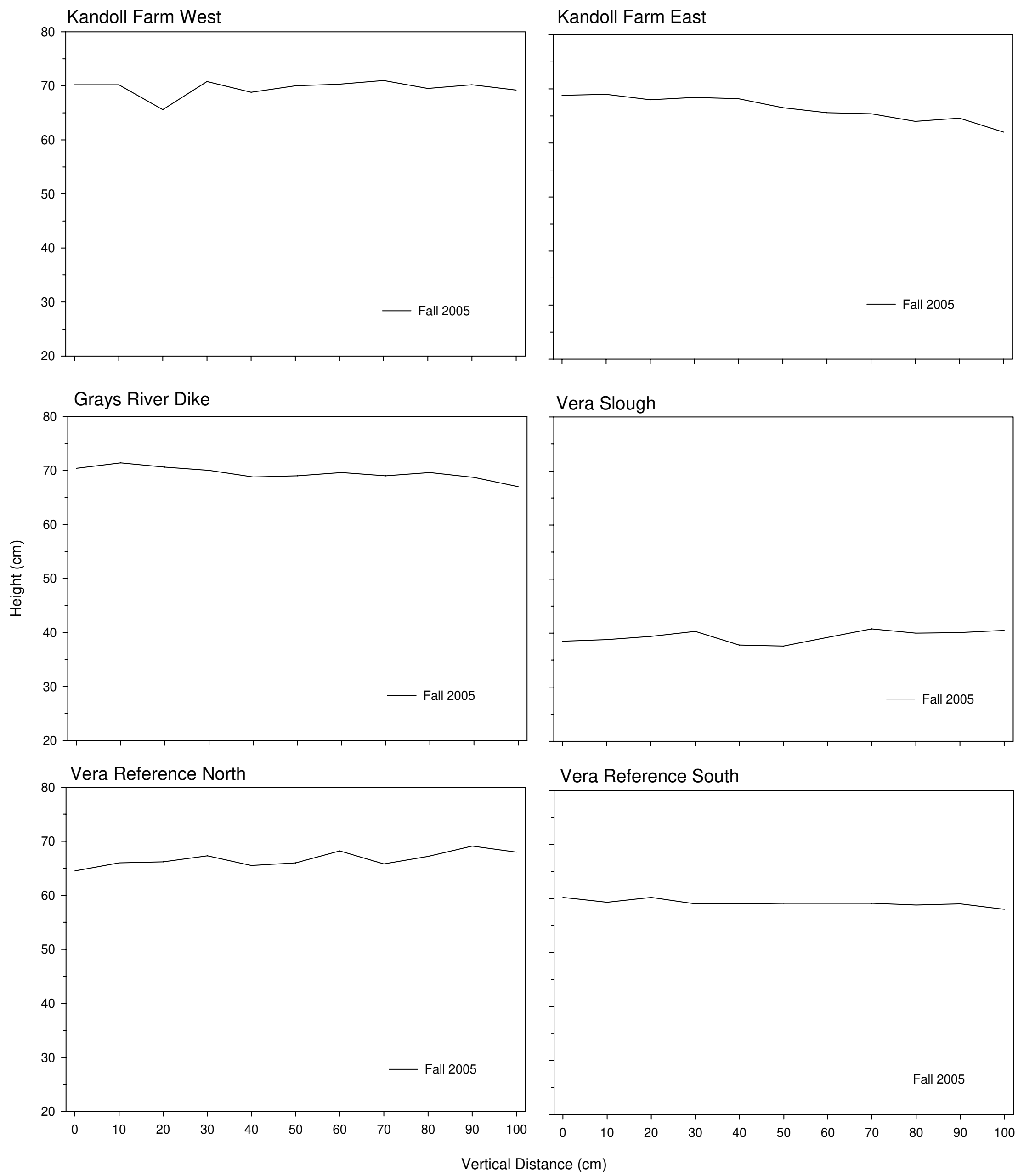

Figure 5.3. Ground Surface Profiles at Sediment Accretion Stakes at Kandoll Farm and Vera Slough

Table 5.1. Elevation Ranges and Averages for Plant Species Sampled at Kandoll Farm Restoration Site. Four-letter codes are the first two letters of the genus and species in the Latin name.

			Elevation (feet above NAVD88)		
Species	**Common Name**	**Code**	**MIN**	**MAX**	**Average**
Carex obnupta	Slough sedge	CAOB	2.88	5.99	4.94
Phalaris arundinacea	Reed canary grass	PHAR	2.88	7.21	5.52
Juncus effusus	Soft rush	JUEF	3.88	5.67	4.81
Galium trifidum var. *pacificum*	Pacific bedstraw	GATR	4.08	5.74	4.77
Lysimachia nummularia L.	Moneywort	LYNU	4.08	6.95	5.49
Ranunculus repens	Creeping buttercup	RARE	4.08	7.21	5.88
Impatiens noli-tangere	Common touch-me-not	IMNO	4.19	6.74	5.84
Mixed Grass	Mixed grass	MG	4.19	6.95	5.98
Lysichiton americanum	Skunk cabbage	LYAM	4.26	5.96	4.97
Polygonum hydropiper	Waterpepper	POHY	4.32	5.08	4.70
Plantago lanceolata var. *lanceolata*	Rib plantain	PLLA	4.35	6.95	6.19
Carex stipata	Sawbeak sedge	CAST	4.36	5.13	4.74
Lotus corniculatus	Birdsfoot trefoil	LOCO	4.36	6.23	5.24
Glecoma hederacea	Creeping Charlie	GLHE	5.08	7.21	6.01
Alnus rubra	Red alder	ALRU	5.11	7.21	6.45
Trifolium repens	White clover	TRRE	5.43	6.95	6.30
Trifolium dubium	Small hop-clover	TRDU	5.51	6.95	6.34
Cirsium arvense var. *horridum*	Canada thistle	CIAR	5.58	6.76	6.10
Trifolium pratense	Red clover	TRPR	5.73	6.95	6.35
Hypochaeris radicata	Spotted cat's ear	HYRA	5.80	6.90	6.46
Prunella vulgaris	Self heal	PRVU	5.90	6.81	6.42
Rubus discolor	Himalayan blackberry	RUDI	6.20	6.74	6.54
Polystichum munitum	Sword fern	POMU	6.37	6.37	6.37
Sambucus racemosa	Red elderberry	SARA	6.48	6.74	6.61
Parentucellia viscosa	Yellow parentucellia	PAVI	6.51	6.65	6.60
Rubus laciniatus	Evergreen blackberry	RULA	6.69	6.69	6.69
Heracleum lanatum	Cow-parsnip	HELA	6.74	6.74	6.74
Tellima grandiflora	Fringe cup	TEGR	6.74	6.74	6.74
Rubus ursinus	Trailing blackberry	RUUR	7.21	7.21	7.21

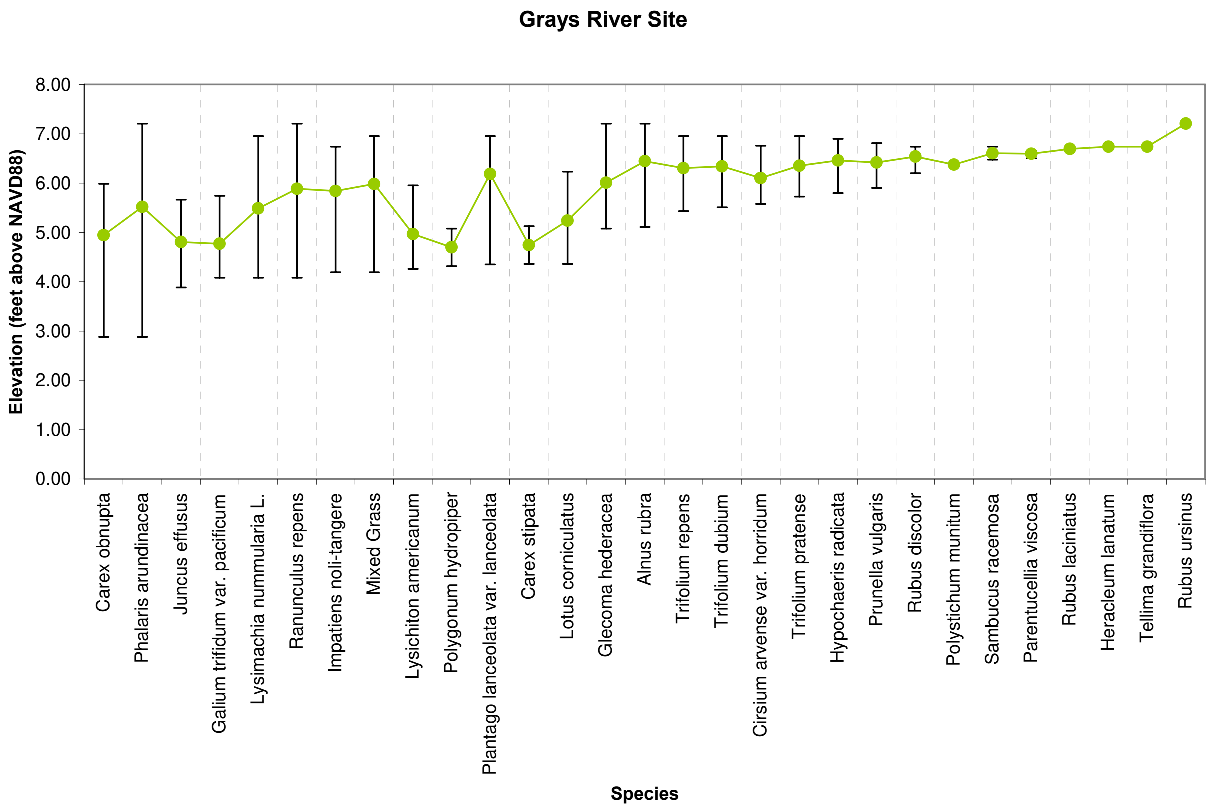

Figure 5.4. Elevation Ranges for Plants Occurring on Kandoll Farm Restoration Site near Grays River, WA, Prior to Restoration

Table 5.2. Elevation Ranges and Averages for Plant Species Sampled at Vera Slough Restoration and Vera Reference Sites. Four-letter codes are the first two letters of the genus and species in the Latin name.

			Vera Slough			Vera Ref		
Species	**Common Name**	**Code**	**Min**	**Max**	**Average**	**Min**	**Max**	**Average**
Callitriche heterophylla	Different leaved water-starwort	CAHE	2.08	2.32	2.18			
Carex lyngbyei	Lyngby sedge	CALY				5.58	8.75	7.33
Carex obnupta	Slough sedge	CAOB	1.93	2.60	2.25			
Convolvulus arvensis	Morning glory	COAR				8.29	8.80	8.51
Eleocharis spp.	Spike-rush	ELSP	1.55	2.21	1.91			
Epilobium angustifolium	Fireweed	EPAN				8.47	8.47	8.47
Galium trifidum var. pacificum	Pacific bedstraw	GATR	2.40	2.47	2.43			
Impatiens noli-tangere	Common touch-me-not	IMNO	2.32	2.32	2.32			
Iris pseudacorus	Yellow iris	IRPS				8.31	8.31	8.31
Juncus balticus	Baltic rush	JUBA	2.03	2.25	2.14			
Lilaeopsis occidentalis	Western lilaeopsis	LIOC	2.32	2.32	2.32	5.75	6.50	6.12
Lotus corniculatus	Birdsfoot trefoil	LOCO	1.93	2.37	2.14			

Mixed Grass	Mixed Grass	MG	2.21	2.31	2.26	6.80	8.75	7.49
Myriophyllum spicatum	Eurasian water-milfoil	MYSP				5.75	5.75	5.75
Oenanthe sarmentosa	Water parsley	OESA	1.93	2.60	2.27	7.48	8.80	8.47
Phalaris arundinacea	Reed canary grass	PHAR	2.26	2.39	2.33	8.07	8.80	8.41
Polygonum hydropiperoides	mild waterpepper	POHY				8.47	8.78	8.62
Potentilla anserina ssp. Pacifica	Pacific silverweed	POAN	1.93	2.39	2.19	8.47	8.75	8.64
Prunus emarginata	Bitter cherry	PREM	2.25	2.25	2.25			
Pteridium aquilinum	Bracken fern	PTAQ	1.67	2.03	1.85			
Rumex crispus	Curly dock	RUCR				8.47	8.47	8.47
Salix spp.	Willow	SASP	2.02	2.31	2.14	6.80	8.80	7.80
Scirpus acutus	Hardstem bulrush	SCAC	2.16	2.56	2.35	6.14	7.23	6.62
Scirpus maritimus	Seacoast bulrush	SCMA	1.55	1.55	1.55			
Solanum dulcamara	Bittersweet nightshade	SODU	2.56	2.56	2.56			
Typha angustifolia	Narrowleaf cattail	TYAN				7.34	7.34	7.34
Typha latifolia	Common cattail	TYLA	1.67	2.60	2.24	7.23	8.80	8.22
Veratrum calilfornicum	California false hellebore	VECA				8.47	8.47	8.47
Vicia americana	American vetch	VIAM	1.93	2.21	2.04	8.47	8.47	8.47

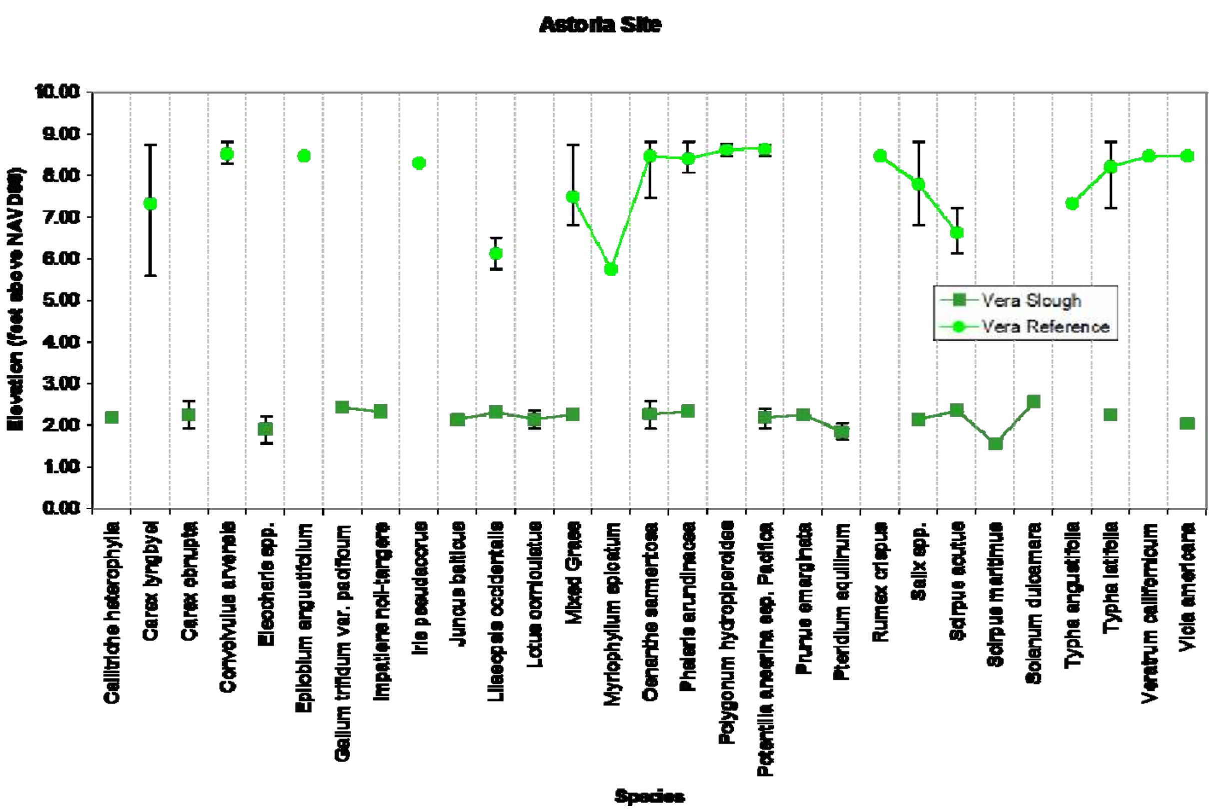

Figure 5.5. Elevation Ranges for Plants Occurring at the Vera Slough Restoration and Reference Sites Near Astoria, OR Prior to Restoration

5.3 Vegetation

5.3.1 Percent Cover

The sites differed considerably in species composition and species cover (Table 5.3). The restoration plots contained herbaceous species and some shrubs. In the restoration site, mixed grass, reed canary grass and creeping buttercup dominated the East side of Seal Slough (SSE), whereas slough sedge, reed canary grass and Himalayan blackberry dominated the West side (SSW). The Kandoll reference site was unique from the marsh and pasture systems and was dominated by *Gaultheria shallon, Picea sitchensis,* and *Cornus stolonifera*. The key to the species codes used in Table 5.3 is provided in Appendix C.

Table 5.3. Average Percent Cover by Species for Plot (top 5 per site in bold). KR-F and KR-R=Kandoll Reference, not proximal versus proximal to channel, SSE and SSW=Kandoll Restoration, East versus West of Seal Slough, VR=Vera Reference, VS=Vera Slough).

	Site										KR sites separated			
	SSE		SSW		VR		VS		KR total		KR-F		KR-R	
Species	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
ACCI	--	--	--	--	--	--	--	--	6.67	14.82	0.83	2.04	12.50	19.94
ALRU	--	--	0.29	0.46	--	--	--	--	**12.17**	14.92	7.50	9.87	**16.83**	18.44
ATFI	--	--	--	--	--	--	--	--	5.00	12.43	--	--	10.00	16.73
BG/MUD	--	--	0.83	5.77	2.50	6.98	2.88	6.69	7.08	14.84	0.83	2.04	13.33	19.66
CAHE	--	--	--	--	--	--	0.80	3.50	--	--	--	--	--	--
CALY	--	--	--	--	**61.25**	41.41	--	--	--	--	--	--	--	--
CAOB	1.02	6.83	**5.83**	15.69	--	--	**45.38**	30.83	0.50	1.45	--	--	1.00	2.00
CASA tree	--	--	--	--	--	--	--	--	4.67	5.76	4.17	5.85	5.17	6.18
CAST	0.02	0.14	0.23	1.02	--	--	--	--	--	--	--	--	--	--
CIAR	0.30	1.51	1.15	5.18	--	--	--	--	--	--	--	--	--	--
CISP	--	--	--	--	--	--	--	--	3.75	9.32	7.50	12.55	--	--
COAR	--	--	--	--	1.96	5.35	--	--	--	--	--	--	--	--
COST	--	--	--	--	--	--	--	--	**20.00**	16.65	**20.00**	13.04	**20.00**	20.98
DET	--	--	--	--	--	--	--	--	7.50	15.45	6.67	16.33	8.33	16.02
DW	--	--	--	--	**9.00**	19.02	2.63	7.59	--	--	--	--	--	--
ELPA	--	--	--	--	--	--	3.75	10.36	--	--	--	--	--	--
EPAN	--	--	--	--	0.06	0.40	--	--	--	--	--	--	--	--
Vicea spp.	--	--	--	--	--	--	0.21	0.88	--	--	--	--	--	--
FRLA	--	--	--	--	--	--	--	--	2.50	8.66	5.00	12.25	--	--
GASH	--	--	--	--	--	--	--	--	**23.33**	17.62	**22.50**	16.66	**24.17**	20.10
GATR	1.29	4.71	0.75	3.26	--	--	0.09	0.42	--	--	--	--	--	--
GLHE	--	--	1.34	4.26	--	--	--	--	--	--	--	--	--	--
HELA	--	--	0.42	2.89	--	--	--	--	--	--	--	--	--	--
HYRA	2.82	6.38	--	--	--	--	--	--	--	--	--	--	--	--
IMNO	0.04	0.19	2.92	14.17	--	--	0.03	0.16	1.50	2.20	1.83	2.48	1.17	2.04
IRPS	--	--	--	--	0.03	0.16	--	--	--	--	--	--	--	--
JUBA	--	--	--	--	--	--	0.63	2.82	--	--	--	--	--	--
JUEF	0.88	5.48	14.17	21.59	--	--	--	--	--	--	--	--	--	--
LIOC	--	--	--	--	0.05	0.22	0.50	3.16	--	--	--	--	--	--
LOCO	1.13	4.19	0.17	0.75	--	--	3.06	7.30	--	--	--	--	--	--
LOIN	--	--	--	--	--	--	--	--	1.08	2.35	2.00	3.16	0.17	0.41
LYAM	0.51	2.25	4.27	10.00	--	--	--	--	7.50	10.11	**10.00**	10.49	5.00	10.00
LYNU	2.15	3.74	1.65	3.88	--	--	--	--	--	--	--	--	--	--
LW	--	--	--	--	0.56	3.18	0.38	2.37	3.33	11.55	--	--	6.67	16.33

MAFU	--	--	--	--	--	--	1.06	6.33	8.75	17.21	0.83	2.04	**16.67**	22.29
MG	**49.69**	32.92	4.19	13.96	1.15	3.39	--	--	1.67	3.89	1.67	4.08	1.67	4.08
MYSP	--	--	--	--	0.13	0.79	--	--	--	--	--	--	--	--
OECE	--	--	--	--	--	--	--	--	1.58	4.27	3.00	5.93	0.17	0.41
OESA	--	--	--	--	**4.83**	9.30	**18.19**	12.56	0.42	1.44	0.83	2.04	--	--
OW	1.67	6.14	1.67	5.86	--	--	4.50	12.18	--	--	--	--	--	--
PAVI	0.07	0.26	--	--	--	--	--	--	--	--	--	--	--	--
Lichen	--	--	--	--	--	--	1.40	4.23	5.83	20.21	--	--	11.67	28.58
PHAR	**27.10**	34.11	**33.13**	34.99	**12.75**	31.56	--	--	5.00	11.68	6.67	16.33	3.33	5.16
PHCA	--	--	--	--	--	--	--	--	5.83	6.34	7.50	7.58	4.17	4.92
PISI	--	--	--	--	--	--	--	--	**21.92**	12.59	**20.00**	13.04	**23.83**	13.04
PLLA	8.43	9.09	0.21	1.44	--	--	--	--	--	--	--	--	--	--
POAN	--	--	--	--	2.03	8.53	**5.50**	9.73	--	--	--	--	--	--
POHY	0.02	0.14	0.02	0.14	0.78	4.74	--	--	--	--	--	--	--	--
POMU	--	--	1.04	7.22	--	--	--	--	--	--	--	--	--	--
PREM	--	--	--	--	--	--	0.13	0.79	0.42	1.44	0.83	2.04	--	--
PRVU	0.18	0.47	--	--	--	--	--	--	--	--	--	--	--	--
PTAQ	--	--	--	--	--	--	0.13	0.55	0.33	0.78	0.33	0.82	0.33	0.82
PTGL	--	--	--	--	--	--	--	--	0.08	0.29	0.17	0.41	--	--
RARE	**21.51**	17.62	**6.78**	14.81	--	--	--	--	--	--	--	--	--	--
RIBE	--	--	--	--	--	--	--	--	0.25	0.62	0.50	0.84	--	--
Rosa spp.	--	--	--	--	--	--	--	--	0.33	0.65	0.67	0.82	--	--
RUCR	--	--	--	--	0.03	0.16	--	--	--	--	--	--	--	--
RUDI	--	--	**16.77**	33.29	--	--	--	--	0.08	0.29	0.17	0.41	--	--
RULA	--	--	3.02	9.66	--	--	--	--	--	--	--	--	--	--
RUPA	--	--	--	--	--	--	--	--	3.08	3.87	1.67	2.58	4.50	4.64
RUSP	--	--	1.04	7.22	--	--	--	--	**10.25**	12.04	4.67	3.14	15.83	15.30
RUUR	--	--	0.42	2.89	--	--	--	--	--	--	--	--	--	--
Salix spp.	--	--	--	--	0.38	1.75	**8.03**	14.47	6.67	14.97	**13.33**	19.66	0.83	2.04
SARA	--	--	5.10	19.00	--	--	--	--	--	--	--	--	--	--
SCAC	--	--	--	--	1.80	2.82	--	--	--	--	--	--	--	--
SCMA	--	--	--	--	--	--	0.38	2.37	--	--	--	--	--	--
SODU	--	--	--	--	--	--	0.13	0.79	--	--	--	--	--	--
SPDO	--	--	--	--	--	--	--	--	4.67	9.76	9.17	12.69	0.17	0.41
TEGR	--	--	0.63	4.33	--	--	--	--	--	--	--	--	--	--
THPL	--	--	--	--	--	--	--	--	3.92	9.98	1.67	2.58	6.17	14.15
THSE	--	--	--	--	--	--	--	--	1.83	3.86	1.67	4.08	2.00	4.00
TRDU	**8.49**	12.01	--	--	--	--	--	--	--	--	--	--	--	--
TRPR	1.69	3.29	--	--	--	--	--	--	--	--	--	--	--	--
TRRE	**9.25**	9.95	--	--	--	--	--	--	--	--	--	--	--	--
TYAN	--	--	--	--	2.50	15.81	--	--	--	--	--	--	--	--
TYLA	--	--	--	--	**7.25**	17.64	**18.63**	10.48	--	--	--	--	--	--
VAPA	--	--	--	--	--	--	--	--	2.17	4.47	0.83	2.04	3.50	5.96
VECA	--	--	--	--	0.13	0.79	--	--	--	--	--	--	--	--
VIAM	--	--	--	--	0.03	0.16	0.03	0.16	--	--	--	--	--	--

5.3.2 Species/Area Curves

The species-area curves for Kandoll plots indicate that the majority of species were found by sampling approximately thirty 1-m^2 plots. Approximately 50% of the species were found within three replicate samples at SSE and within seven replicate samples at SSW (Figure 5.6). However, the curves have not leveled off and additional species might be found with more sampling. (The area under the curve represents the cumulative area from successive 1-m^2 quadrat samples.) Kandoll reference plots in the forested wetland contained the greatest number of species (32), followed by SSE (Table 5.3).

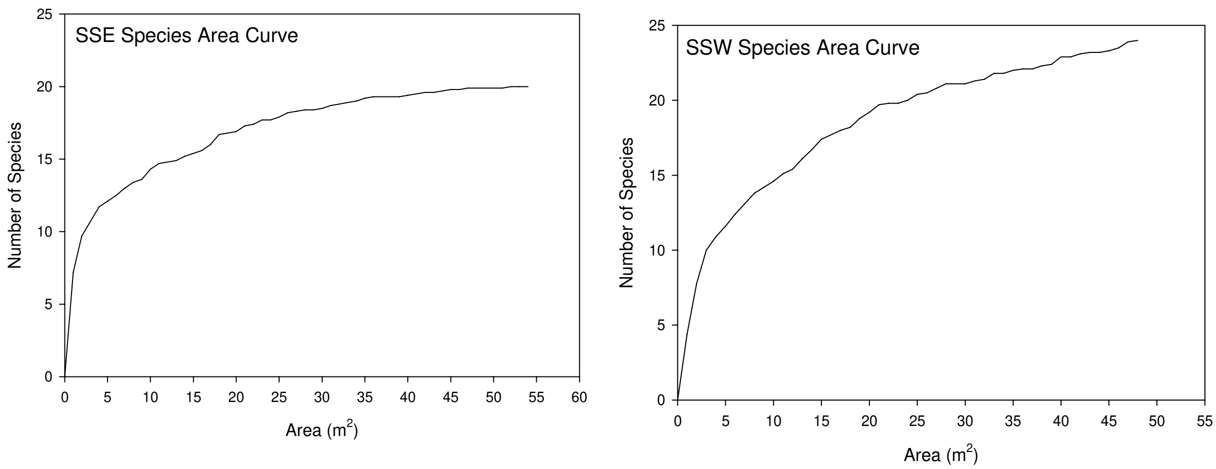

Figure 5.6. Species Area Curves for Kandoll Farm: Seal Slough East (SSE) and Seal Slough West (SSW)

Vera Slough contained four more species than Vera reference (20 vs. 16, respectively). The species-area curves for both indicated that over 50% of the species were encountered within the first 10 random quadrat samples at Vera Slough Restoration Site; in fact, over 80% were encountered in the first 30 random samples at Vera reference site (Figure 5.7). Again, while the curves are beginning to level off, they indicate that additional species might be found with additional sampling.

The species-area curves for all four sites are compared in Figure 5.8.

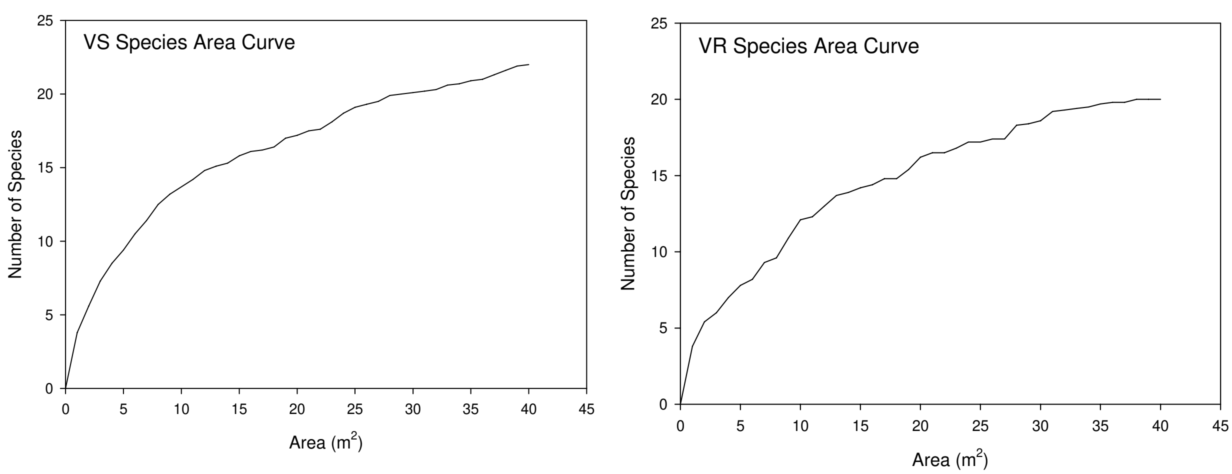

Figure 5.7. Species Area Curves for (left) Vera Slough Restoration Site and (right) Vera Slough Reference Site

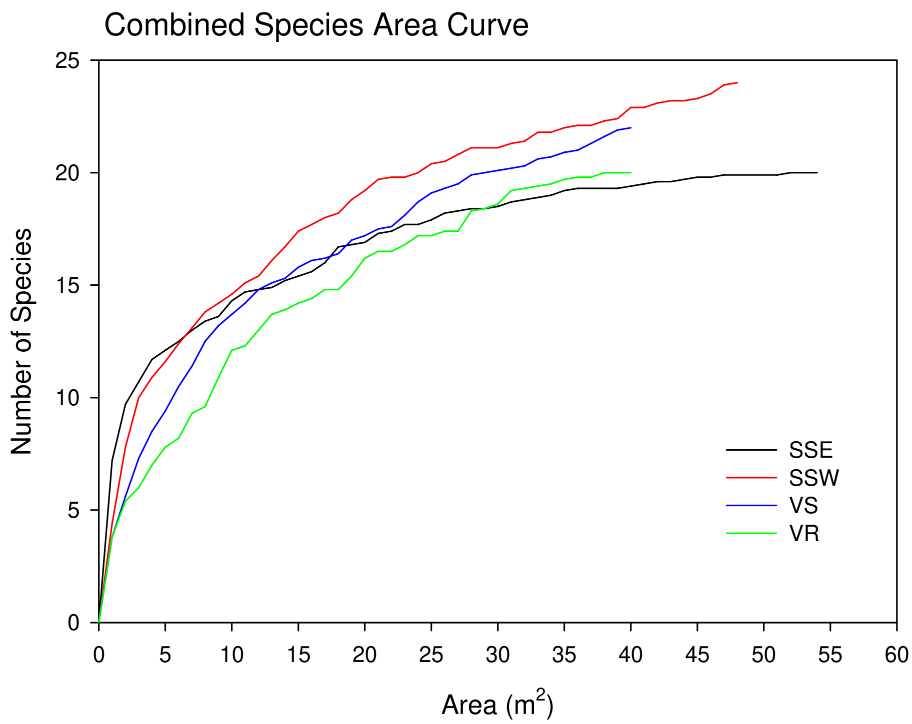

Figure 5.8. Comparison of Species Area Curves for Kandoll Restored (SSE and SSW), Vera Slough Restored (VS) and Vera Slough Reference (VR).

5.3.3 Diversity and Similarity Indices

The assemblage of plants at SSE was only 62.4% similar to the assemblage at SSW, although these plots represent the East and West sides of Seal Slough, both in the Kandoll Farm restoration area. The very low similarities between these restoration plots and the Kandoll reference site (KR-F and KR-R) reflect the major differences between these areas. Shannon-Weiner diversity and evenness indices are shown in Table 5.4. Vera slough was dominated by *Carex obnupta* and *Oenanthe sarmentosa*, whereas Vera reference was dominated by *Carex lyngbyei* with *Phalaris arundinacea* as a subdominant. The Vera Slough and Vera reference assemblages were only 24.5% similar using a weighted similarity coefficient, and 47.6% similar using the unweighted similarity coefficient (Table 5.5). This indicates a major difference, both in species composition and in species abundances.

Table 5.4. Shannon-Weiner Diversity (H') and Evenness (J') Indices

Site	Number of species	Ave # sp	H'	J'
SSE	20	6.25	1.19	0.63
SSW	24	4	0.84	0.5
VR	20	2.9	0.48	0.22
VS	22	4.6	1.18	0.65
KR	37	12.8	2.17	0.89
KR-F	33	13.5	2.19	0.92
KR-R	28	12	2.15	0.88

H' = Shannon-Weiner Diversity Index
J' = Evenness

Table 5.5. Weighted and Unweighted Similarity Indices

Similarity (weighted)							
	SSE	SSW	VR	VS	KR	KR-F	KR-R
SSE		62.4	15.4	7.5	9.8	13.5	7
SSW			14.7	12.6	16.3	20.5	11.7
VR				24.5	10.4	13.4	6.7
VS					10.3	6.7	8.2
KR						93.7	97.8
KR-F							81.8
Similarity (unweighted)							
	SSE	SSW	VR	VS	KR	KR-F	KR-R
SSE		63.6	10	28.6	20.9	19.4	25
SSW			9.1	26.1	28.6	27.7	30.5
VR				47.6	23	25	20
VS					32.9	25.9	39.3
KR						93.5	84.5
KR-F							75.8

5.3.4 Trees: Diameters and Heights

A subset of the trees on the twelve Kandoll Reference site 10-m vegetation plots were measured for height, diameter at breast height (dbh), and age (Figure 5.9), including Sitka spruce (Figure 5.10) and red alder (Figure 5.11). Other trees sampled in 2005 were alder (Figure 5.10) and hemlock and cedar (Figure 5.12).

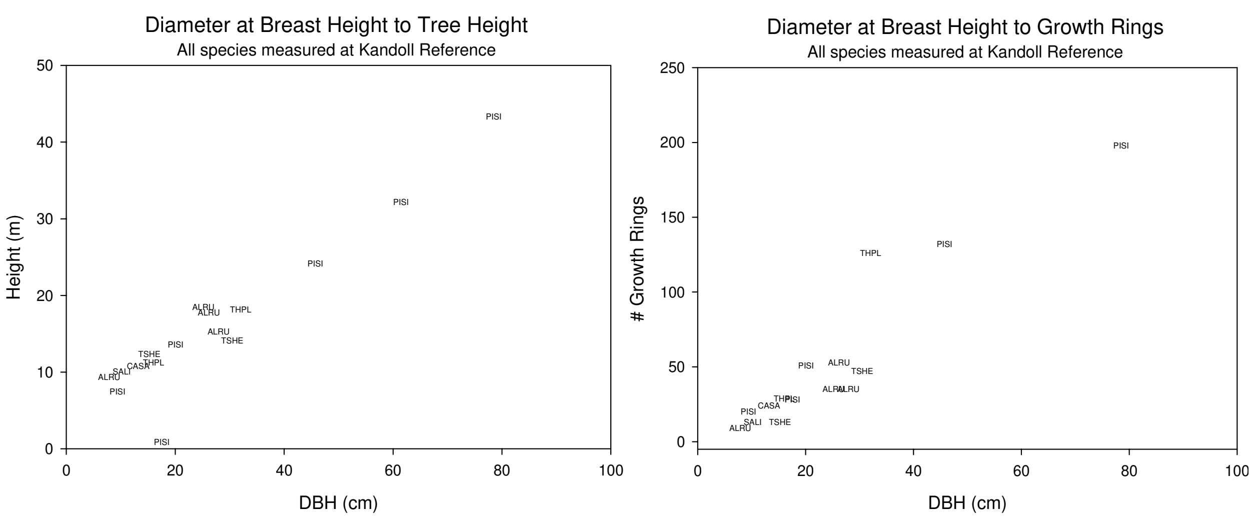

Figure 5.9. Diameter at Breast Height (dbh) Compared to Height and Age (growth rings) for all Species Measured at Kandoll Reference Site. See Appendix C for Species Codes.

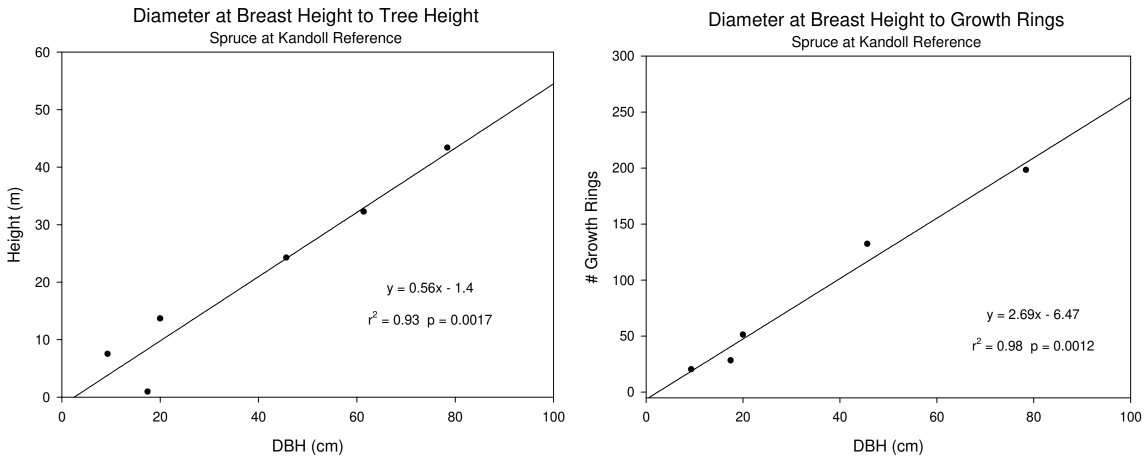

Figure 5.10. Diameter at Breast Height (dbh) Compared to Height and Age (growth rings) for Spruce Measured at Kandoll Reference Site

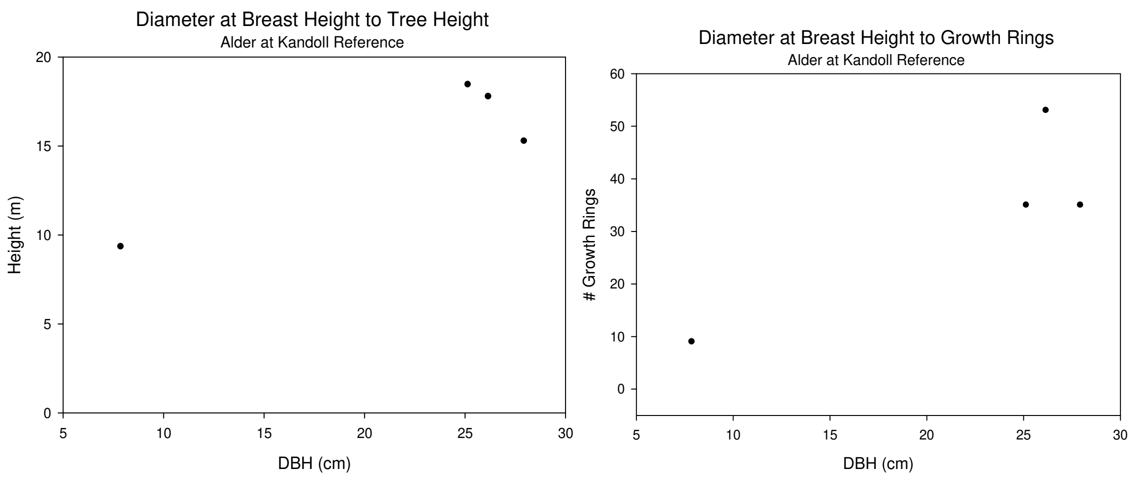

Figure 5.11. Diameter at breast height (dbh) Compared to Height and Age (growth rings) for Alder Measured at Kandoll Reference Site

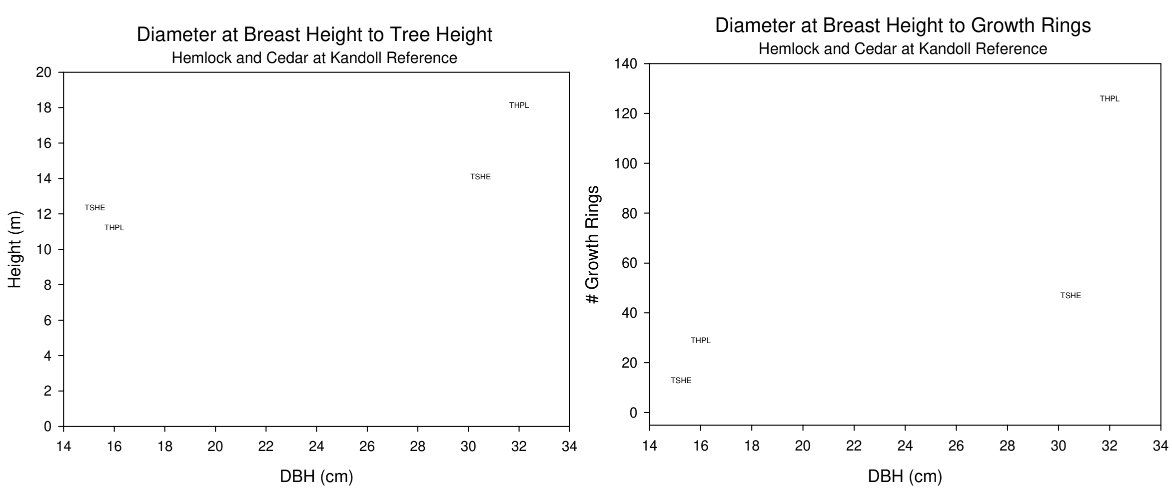

Figure 5.12. Diameter at Breast Height (dbh) Height and Age (growth rings) for Hemlock and Cedar Measured at Kandoll Reference Site

5.3.5 Organic Matter

Above-ground standing live and dead macrophytic vegetation biomass was sampled along with below-ground organic matter. Above-ground biomass averaged nearly 500 g/m^2 at all sites except Kandoll reference (Figure 5.13). This site had a very low standing biomass of herbaceous plant species. Above-ground biomass showed high variance at all sites. Kandoll reference site had the highest ratio of dead to live biomass (Figure 5.14). Below-ground organic matter at Kandoll reference site was between 5% and 35% of soils (Figure 5.15). There appears to be no correspondence between below-ground organic matter and above-ground biomass. Vera Slough and Reference sites had similar AGOM levels, whereas BGOM was much greater in Vera Slough. This may reflect the restricted flushing of this site.

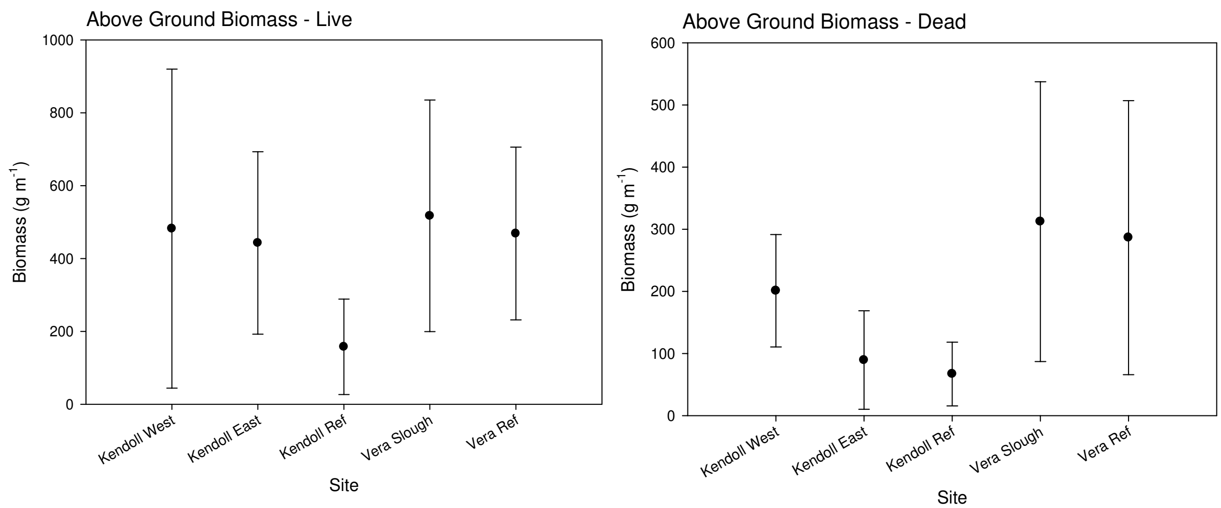

Figure 5.13. Amounts of Above-Ground Biomass, Live and Dead, Measured at Each Site

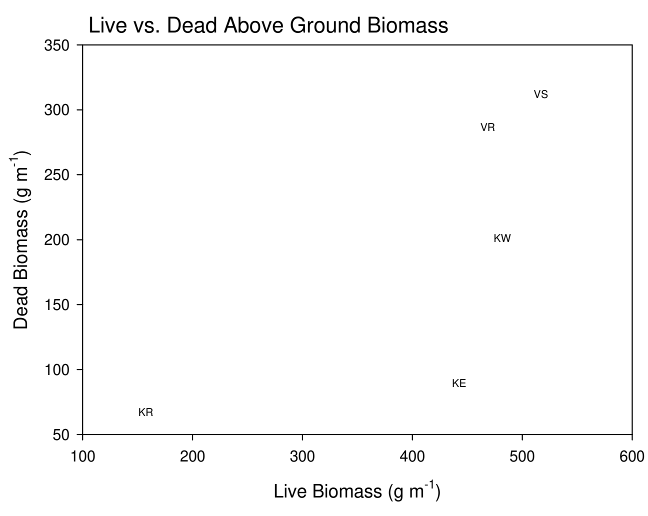

Figure 5.14. Comparison of Live to Dead Biomass at Each Site

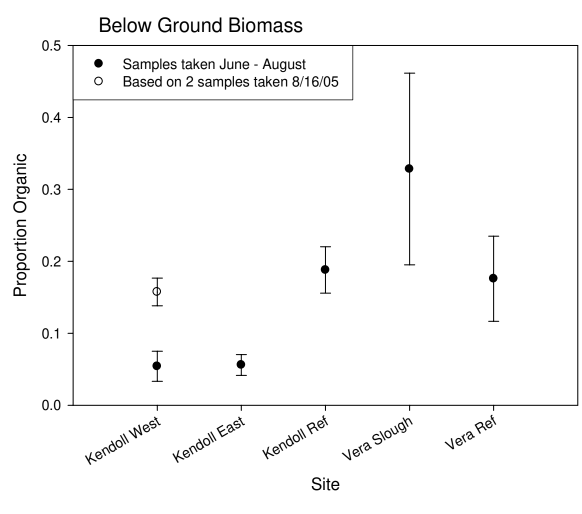

Figure 5.15. Amounts of Below-Ground Biomass Measured at Each Site

5.4 Landscape Features

Channel cross sections measured at three points along the Gray's River dike in the Kandoll Farm restoration site and at two points in the Kandoll Farm reference site are shown in Figures 5.17 and 5.18. Channel cross sections were also measured at three spots at the Vera Slough restoration site and two locations at the Vera Slough reference site; these cross section measurements are shown in Figures 5.19 and 5.20. Figures 4.1-4.3 show the locations of these channel cross-sections relative to channel networks at all sites, and Table 4.2 provides the key to cross-section codes. In all cases, cross sections were surveyed to include the top of the bank at each end, and the thalweg or deepest channel.

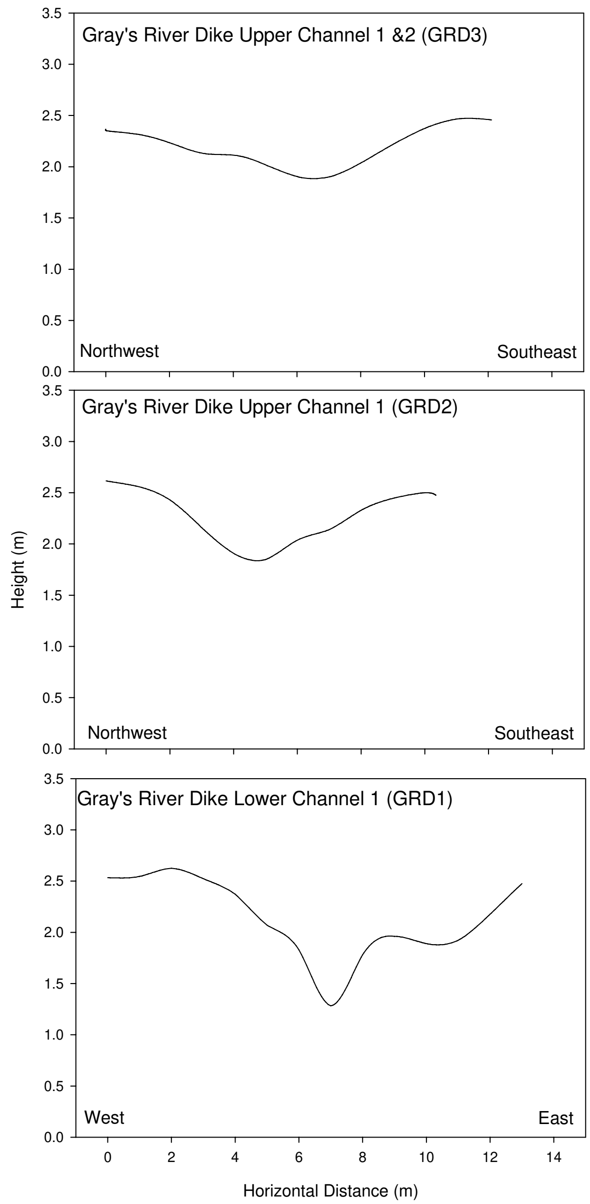

Figure 5.17. Channel Cross Sections at the Gray's River/Kandoll Farms Dike Restoration Site. Cross section elevations are in NAVD 88.

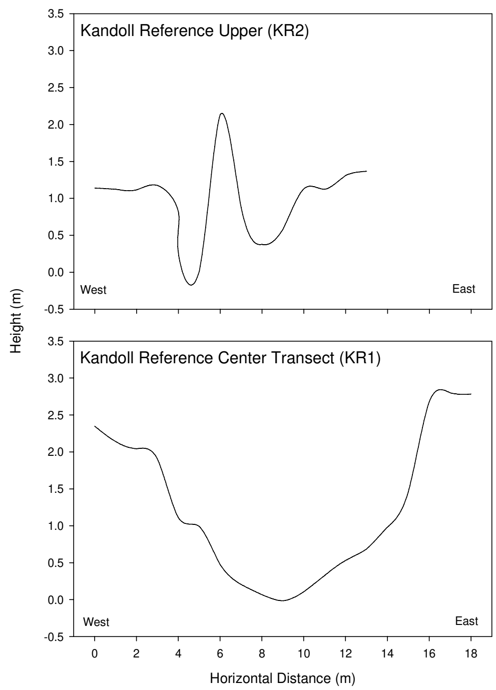

Figure 5.18. Channel Cross Sections for the Kandoll Reference Site (note forked channel above beaver dam in reference site in above plot). Cross section elevations are in NAVD 88.

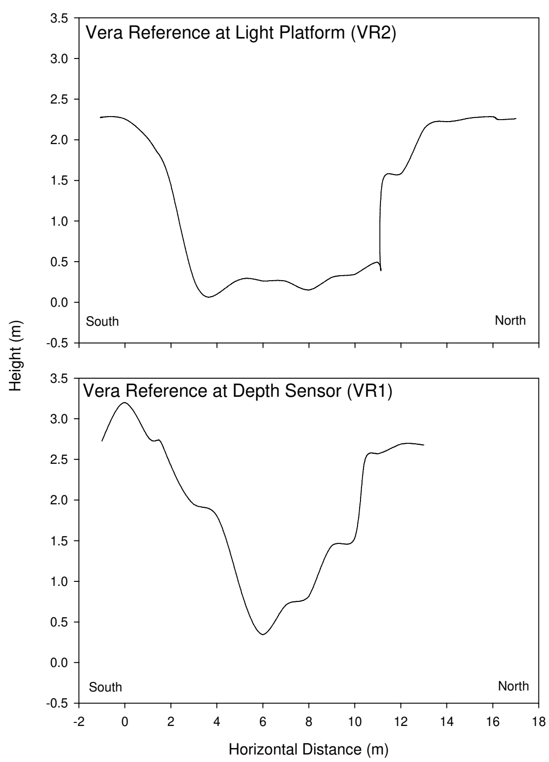

Figure 5.19. Channel Cross Sections for the Vera Slough Reference Site. Cross section elevations are in NAVD 88.

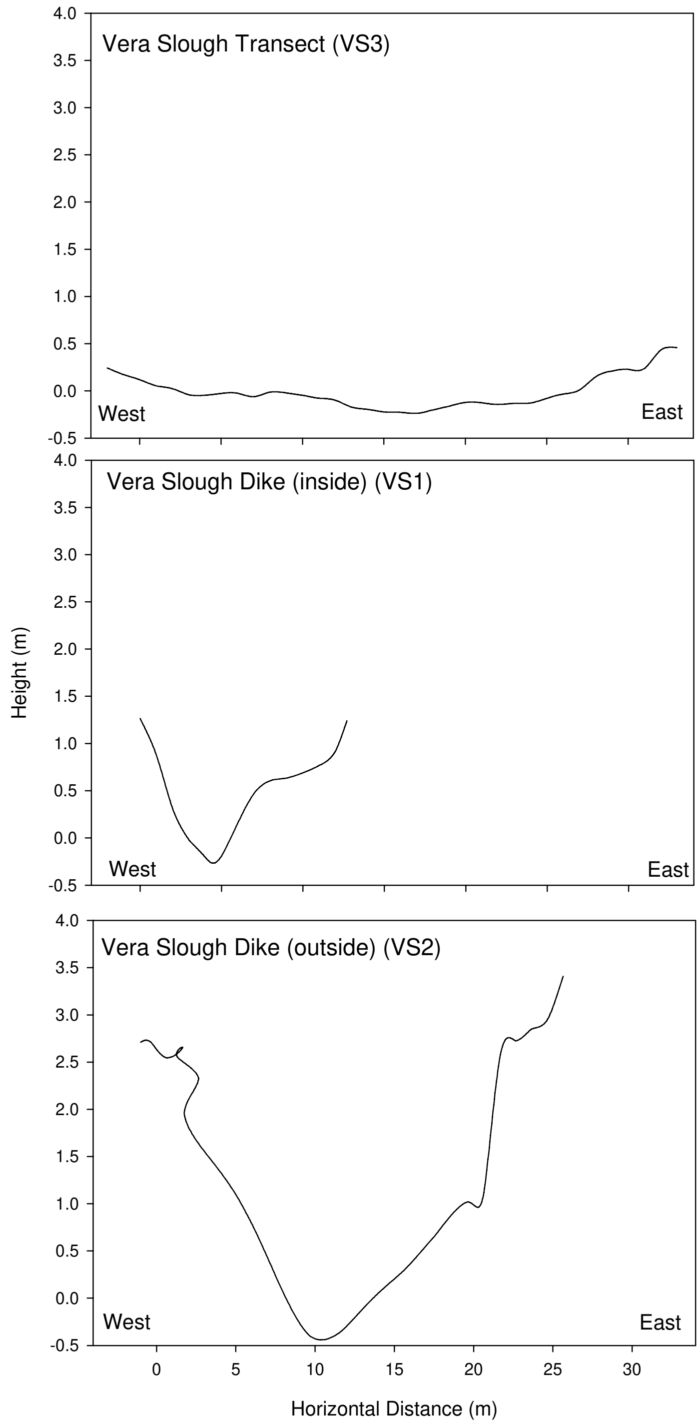

Figure 5.20. Channel Cross Sections for the Vera Slough Restoration Site, including surveys both outside and inside the tidegate prior to replacement. Cross section elevations are in NAVD 88.

5.5 Fish

Catch per unit effort (CPUE) and mean length of fish caught at Vera Slough and Kandoll Reference and Impact sites are presented in Tables 5.6 through 5.9. At Vera Slough, three coho salmon *(Oncorhynchus kisutch)*, one Chinook salmon *(Oncorhynchus tshawytscha)*, and one chum salmon *(Oncorhynchus keta)* were captured in May and none in June; all were less than 45 mm fork length (Table 5.8). All salmon were captured outside of the tide gate or in the reference area; none were captured inside the area eventually to be affected by restoration. At Kandoll Slough, one coho salmon was captured in May (46 mm) and four were captured in June (80-81 mm); all these fish were also captured outside the tide gate (Table 5.9).

Species composition was dominated by threespine stickleback, which comprised 80% and 81% of the catch in Vera and Kandoll sites, respectively. Other abundant resident fish were sculpin, peamouth, and killifish. Staghorn sculpin and killifish were the next most common fish at Vera, and Peamouth and prickly sculpin were the next most common fish at Kandoll. Sculpins were not found inside either tide gate controlled areas. No fish other than stickleback were found at Kandoll inside the culvert controlled area. Species richness was higher at Vera (12 species) than at Kandoll (7 species).

Table 5.6. Catch Per Unit Effort of Fish Caught by Seine at Vera Slough Reference and Impact Sites, 2005. (In = Inside Impact, Out = Outside Impact, Ref = Reference. Gear type: 1 = Pole seine 5m x 1.5 m with 0.25-in. stretch mesh; 2 = Beach seine 5 m x 2.2 m, with 0.25-in stretch mesh; 3 = Beach seine 7 m x 2.2 m, with 0.25-in. stretch mesh.)

Date	Station	Gear	Chin. sal.	Coho sal.	Chum sal.	Stickle-back	Killi-fish	Staghorn sculpin	Prickly sculpin	Pumpkin seed	Centracid spp.	English sole	Pea-mouth	Shiner perch
5/13	In 2.1	1				75						1		
5/13	In 2.2	1				70	2							
5/13	In 2.3	1				118	4							
5/13	In 3	1				100	9				4			
5/13	In 5	1				184								
5/13	In 6	1				162								
5/13	Out 2.1	1		1	1	56		20				2		
5/13	Out 2.2	1		1		716	60	73						
5/18	Ref. 1	1		1		150		9						
5/18	Ref. 2	1				150		23						
5/18	Ref.3.1	1				95		26	2					
5/18	Ref 3.2	1	1			35		62					1	
5/18	Ref.4.1	1				8		10						
5/18	Ref 4.2	1				2		4						
6/14	In 2	2				73	3							
6/14	In 3	2				144	7							
6/14	In 5	2				124				2				
6/14	Out 1	2				201	91	40						
6/14	Out 2	2				1238		4						
6/14	Ref. 1	2				54								
6/14	Ref. 2	2				224	4	12						
6/14	Ref. 3	2				29		21						1

Table 5.7. Mean Fork Length of Fish Caught by Seine at Vera Slough Reference and Impact sites, 2005. (In = Inside Impact, Out = Outside Impact, Ref = Reference.)

Date	Station	Chin. sal.	Coho sal.	Chum sal.	Stickle-back	Killi-fish	Staghorn sculpin	Prickly sculpin	Pumpkin seed	Centracid spp.	English sole	Pea-mouth	Shiner perch
5/13	In 2				34	35							
5/13	In 2				34						30		
5/13	In 2				40	35							
5/13	In 3				38	59				31			
5/13	In 5				46								
5/13	In 6				49								
5/13	Out 2		43	40	39		45				36		
5/13	Out 2		38										
5/18	Ref. 1		40		51		62						
5/18	Ref. 2				56		61						
5/18	Ref. 3				3		59	57					
5/18	Ref. 3	39			52		58					81	
5/18	Ref. 4				44		43						
5/18	Ref. 4				34		34						
6/14	In 2				46	53							
6/14	In 3				45	49							
6/14	In 5				51								
6/14	Out 1				44	58	68						
6/14	Out 2				46		45						
6/14	Ref. 1												
6/14	Ref. 2				52	66	74						
6/14	Ref. 3				48		66						

Table 5.8. Catch per Unit Effort of Fish Caught by Seine at Kandoll Reference and Impact Sites, 2005. (In = Inside Impact, Out = Outside Impact, Ref = Reference. Gear type: 1 = Pole seine 5m x 1.5 m with 0.25-in. stretch mesh; 2 = Beach seine 5 m x 2.2 m, with 0.25-in stretch mesh; 3 = Beach seine 7 m x 2.2 m, with 0.25-in. stretch mesh.)

Date	Station	Gear	Chin. sal.	Coho sal.	Chum sal.	Stickle-back	Killi-fish	Prickly sculpin	Centracid spp.	Pea-mouth	Starry flounder
5/14	Out 01	1		1		6		1			
5/14	Out 01	1									
5/14	Out 01	1				41	5		3	31	
5/14	Out 04	1				18					
5/14	Out 11	1				4		1			1
6/13	In 1	3				15					
6/13	In 2	3				27					
6/13	In 3	3				51					
6/13	Out 01	3				26		1	1	3	
6/13	Out 11	3		2		2					1
6/13	Out 11	3		2		2					1
6/13	Out 11	3				7					
6/13	Out 11	3				80					
6/28	Out 1.1	3				18		1		3	
6/28	Out 1.2	3				22		24			
6/28	Out 1.3	3				61				10	

Table 5.9. Mean Fork Length of Fish Caught by Seine at Kandoll Reference and Impact Sites, 2005. (In: In = Inside Impact, Out = Outside Impact, Ref = Reference).

Date	Station	Chin. sal.	Coho sal.	Chum sal.	Stickle-back	Killi-fish	Prickly sculpin	Centracid spp.	Pea-mouth	Starry flounder
5/14	Out 1		46		36		54			
5/14	Out01									
5/14	Out01				35	43		35	33	
5/14	Out04				43					
5/14	Out11				38		40			31
6/13	In 1				40					
6/13	In 2				41					
6/13	In 3				42					
6/13	Out01				34		35	44	31	
6/13	Out11		80		40					39
6/13	Out11		81		54					42
6/13	Out11									
6/13	Out11				47					
6/28	Out01				51		31		63	
6/28	Out01				23		22			
6/28	Out01				18				17	

5.6 Nutrient Flux

The results from the two nutrient flux experiments, one at the Vera Slough and Reference and one at the Seal Slough sites (outside the culvert at Kandoll Farm and at the mouth of the reference channel) are presented together to capture the wide variation in nutrient concentrations among habitat types and between reference sites and the sites to be restored. Flux data were collected in June 2005 at Vera and in July and September 2005 at Kandoll (Table 4.3). The primary factors affecting the results are (1) concentrations of the properties and (2) the water volume flux rate. The average concentrations from all samples are shown in Table 5.10. Overall, concentrations at the Seal Slough restoration and reference sites were similar, whereas Vera restoration and reference sites differed substantially in several (i.e., total organic carbon (TOC), silicate, all of the nitrogen compounds). Ammonium concentrations were relatively high at all sites on average, with a low among-sample variance. Ambient ammonium is often less than 1 μM in marine and estuarine systems. Overall there was a negative correlation between TOC and total inorganic nitrogen (TIN) over all sites and samples (Figure 5.21).

Table 5.10. Mean Concentrations (1 standard deviation) of Nutrients at Each Site for Each Sampling Date. Seal sites were sampled on June 27-28 and Vera sites were sampled July 12-13.

	Kandoll Reference (Seal Slough Side Channel)	Kandoll Farm (Seal Slough)	Vera Slough	Vera Reference
TOC (mg L^{-1})	4.93 *(4.71)*	5.04 *(1.55)*	15.12 *(2.59)*	3.59 *(1.48)*
	n = 6	n = 7	n = 13	n = 13
PO_4 (µM)	0.47 *(0.16)*	0.49 *(0.15)*	0.42 *(0.13)*	0.67 *(0.26)*
	n = 13	n = 12	n = 13	n = 13
SiO_4 (µM)	64.54 *(36.7)*	74.73 *(26.32)*	17.15 *(12.96)*	158.35 *(38.41)*
	n = 13	n = 12	n = 13	n = 13
NO_3 (µM)	4.72 *(1.13)*	2.29 *(0.99)*	0.10 *(0.29)*	4.71 *(0.71)*
	n = 13	n = 12	n = 13	n = 13
NO_2 (µM)	0.23 *(0.02)*	0.20 *(0.05)*	0.13 *(0.07)*	0.44 *(0.27)*
	n = 13	n = 12	n = 13	n = 13
NH_4 (µM)	4.65 *(1.09)*	5.75 *(1.81)*	2.66 *(1.86)*	6.58 *(3.07)*
	n = 13	n = 12	n = 13	n = 13
TIN (µM)	9.60 *(1.18)*	8.24 *(1.41)*	2.89 *(2.18)*	11.74 *(3.18)*
	n = 13	n = 12	n = 13	n = 13

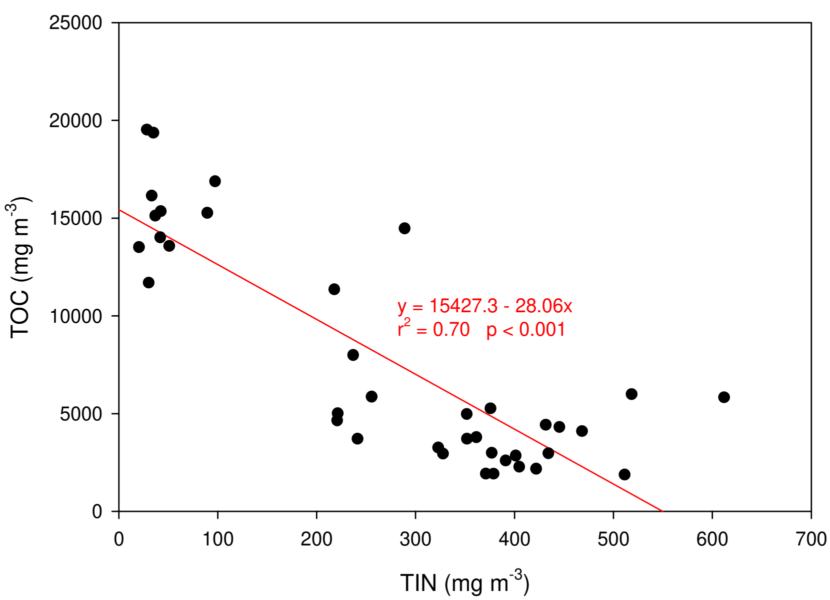

Figure 5.21. Relationship of Total Organic Carbon to Total Inorganic Nitrogen Water Concentrations in all the Sites Sampled

Flux is dependent on water volume flux, which is illustrated in Figure 5.22. The net flux is near zero for the Kandoll/Seal Slough sites, whereas there is a net export of water from both Vera sites.

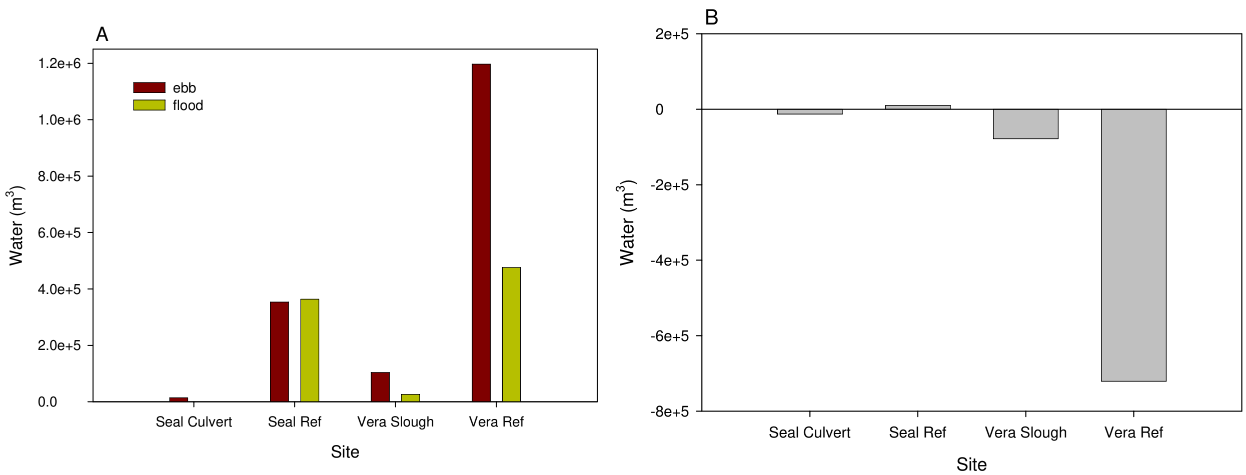

Figure 5.22. A. Calculated total volume of water transported during the ebb and flood tides for each site. B. Net water volume per site over half a tidal cycle (i.e., one ebb and flood). Negative numbers indicate net seaward flow and positive numbers indicate net landward flow.

Vera Reference was the largest source of phosphate, silicate, nitrate, nitrite, ammonium, and total inorganic nitrogen to the ecosystem among all sites sampled (Figures 5.23 to 5.28). In contrast, the Kandoll/Seal Reference Site was the largest sink for all parameters among all sites. It appeared that import of silicate, nitrate, and nitrite was disproportionately high relative to total water flux for that site. TOC is not plotted since too few samples were analyzed (because of sample container breakage) during some sampling periods to make reliable estimations of net flux.

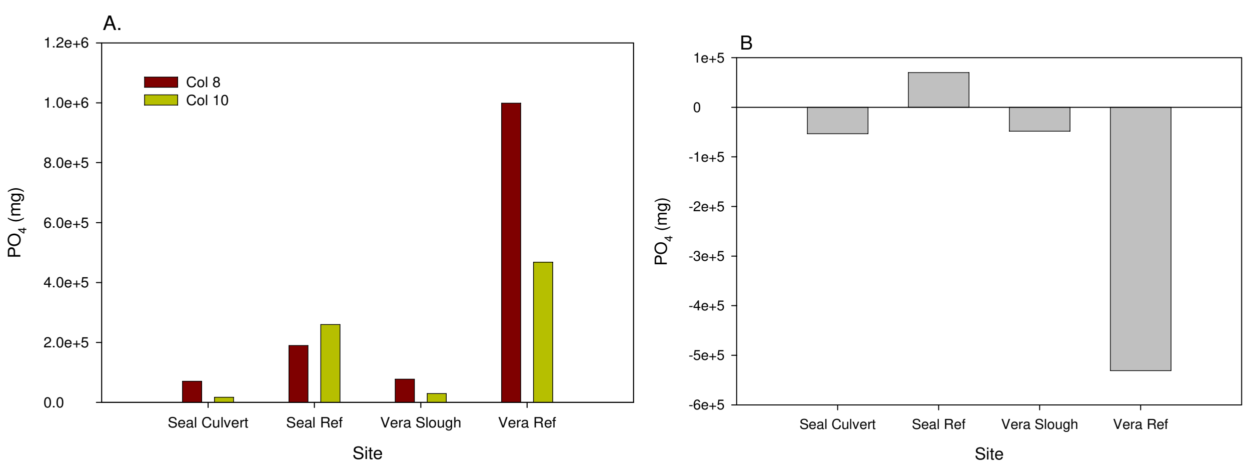

Figure 5.23. A. Total flux of phosphate in each site for each phase of the tide sampled. B. Net flux of phosphate at each site over half the tidal cycle. Negative numbers indicate net seaward flow.

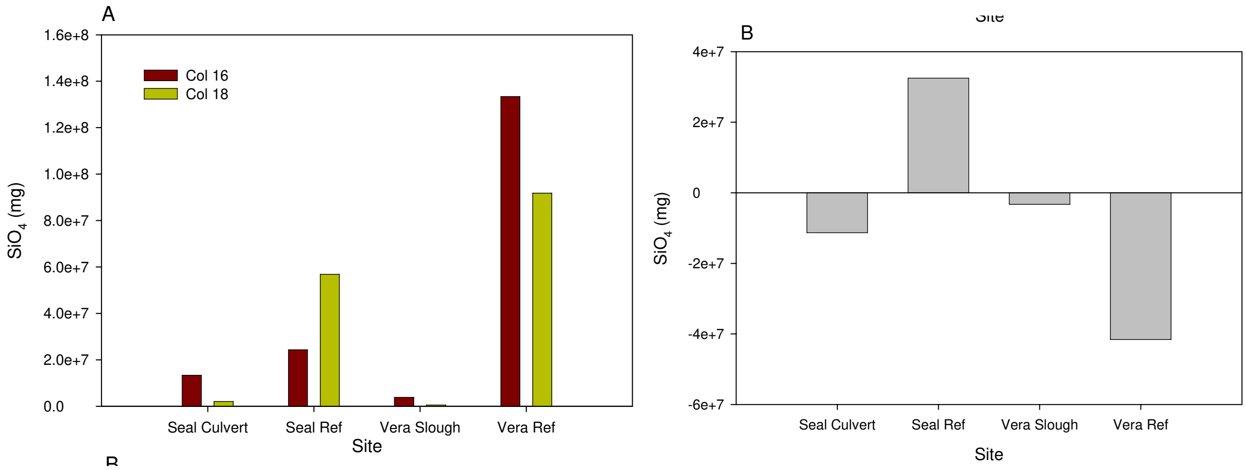

Figure 5.24. A. Total flux of silicate in each site for each phase of the tide sampled. B. Net flux of silicate at each site over half the tidal cycle. Negative numbers indicate net seaward flow.

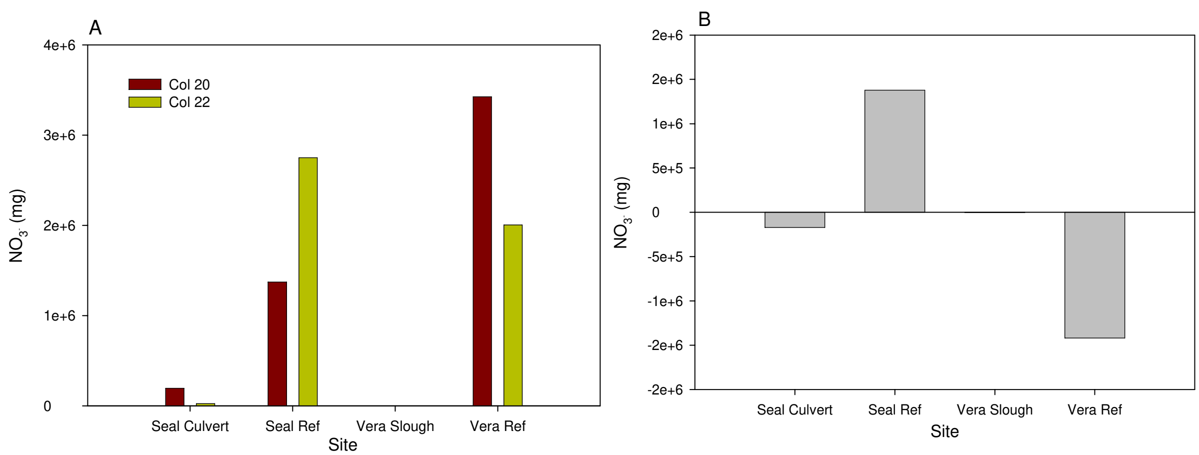

Figure 5.25. A. Total flux of nitrate in each site for each phase of the tide sampled. B. Net flux of nitrate at each site over half the tidal cycle. Negative numbers indicate net seaward flow.

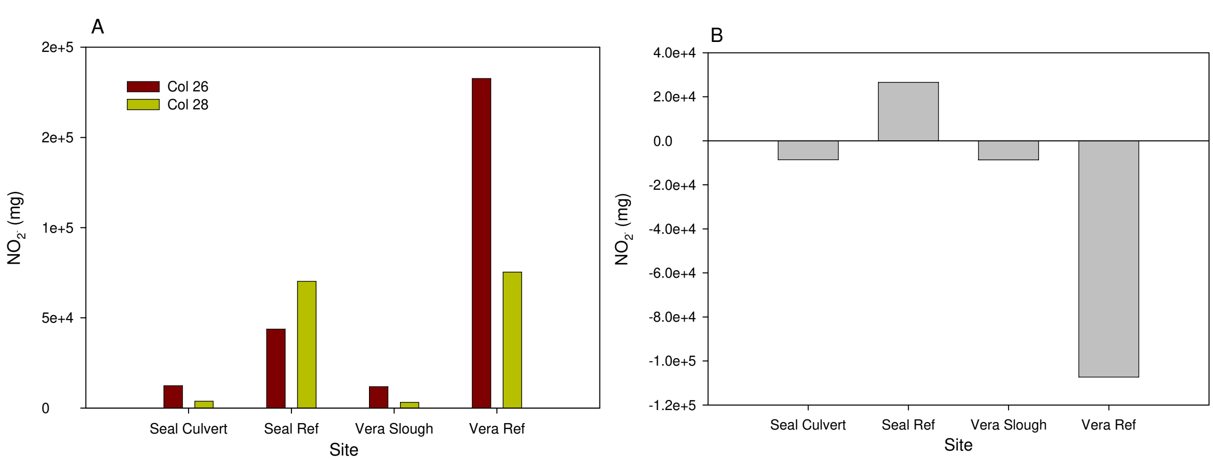

Figure 5.26. A. Total flux of nitrite in each site for each phase of the tide sampled. B. Net flux of nitrite at each site over half the tidal cycle. Negative numbers indicate net seaward flow.

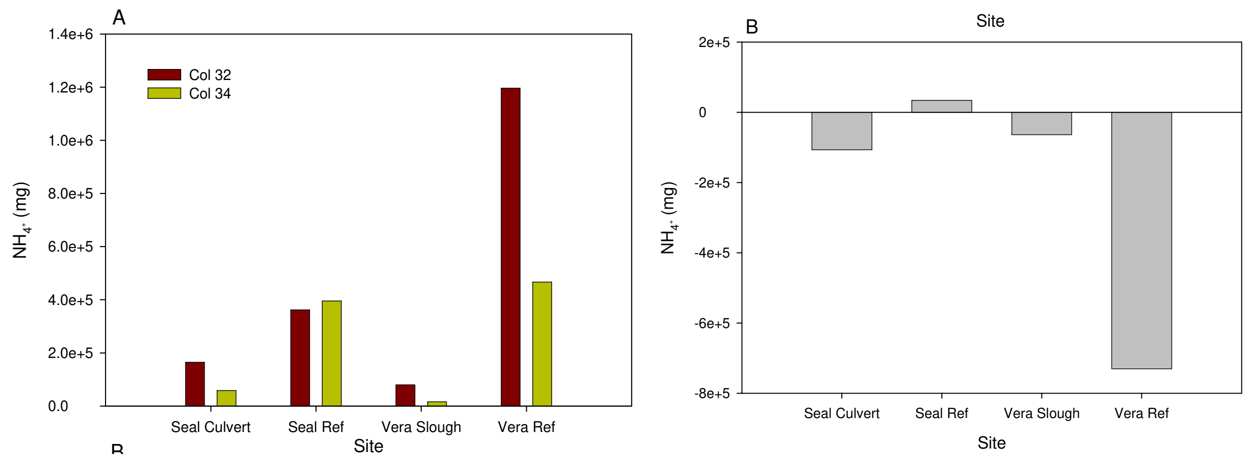

Figure 5.27. A. Total flux of ammonium in each site for each phase of the tide sampled. B. Net flux of ammonium at each site over half the tidal cycle. Negative numbers indicate net seaward flow.

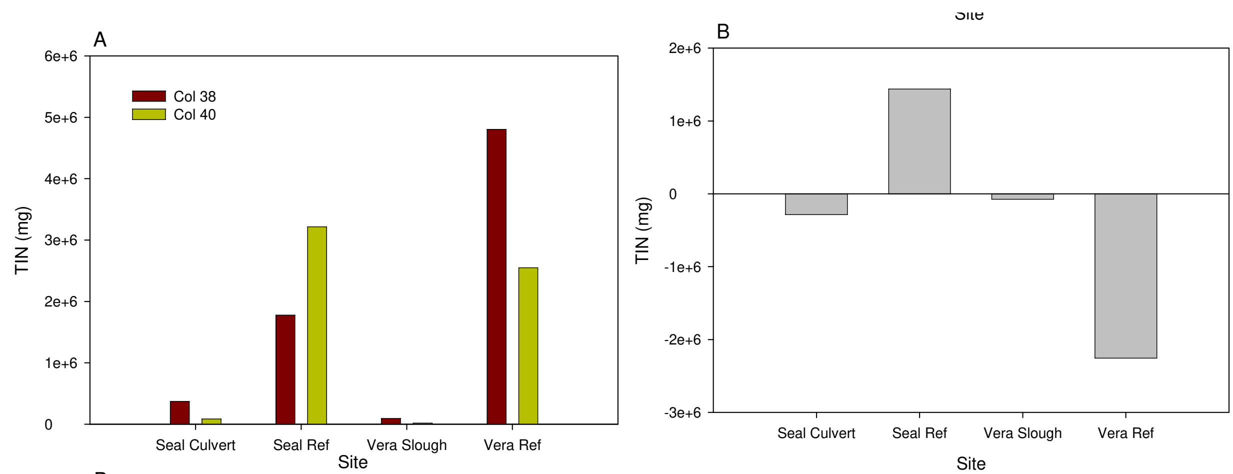

Figure 5.28. A. Total flux of total inorganic nitrogen (TIN) in each site for each phase of the tide sampled. B. Net flux of TIN at each site over half the tidal cycle. Negative numbers indicate net seaward flow.

6.0 Discussion and Recommendations

The analyses and interpretations regarding pre-restoration site status made based on baseline, pre-restoration data in this 2005 Annual Report are necessarily limited by the short time frame of research to date. The baseline, pre-restoration data collected in 2005 at the Kandoll Farm and Vera Slough study sites will be compared to post-restoration data collected at these areas in 2006, in the 2006 Annual Report. However, the process of baseline data collection, and associated revision of the monitoring protocols, also has implications for coordination and cumulative effects assessment methods in the estuary, which are discussed below.

6.1 Baseline Monitored Indicators

Water Surface Elevation and Water Quality

The baseline, pre-restoration water quality data demonstrated the substantial restriction of tidal influence relative to reference sites inside the culverts at Kandoll Farm and inside the tide gates at Vera Slough. While Vera Slough exceeded salmonids temperature maximums in Columbia River marshes of 20°C (Bottom et al. 2005) prior to tide gate replacement, Kandoll Farm did not prior to culvert replacement. The dataloggers deployed at these restoration and reference sites are expected to record for at minimum the next year. Thus, summer temperatures and tidal influence in 2006 will be compared to the pre-restoration conditions in the next project annual report.

Land/Substrate Elevation

Ground-truthed elevation data, such as that presented here, also may be useful in combination with LiDAR (elevation) data and remotely sensed imagery to classify tidal vegetation communities on an estuary-wide scale. Difficulties in obtaining point measurements stem primarily from overhead vegetation and surface area of the nearby water causing signal multi-path error where the signal reflects off vegetation or water surfaces. Errors can also be caused by soft sediments resulting in sinking of the survey pole. Error in measurements could be decreased by including traditional sampling techniques to perform station and offset measurements in areas where overhead vegetation interferes with satellite signals. Errors caused by soft sediments could be reduced by increasing the surface area of the downward end of the GPS survey pole. Estimates of the errors associated with all elevation survey methods (i.e., RTK, Total Station, autolevel) can be conducted using secondary checks on a subset of points. While this estimation was not conducted in 2005, efforts will be made to initiate an error analysis in 2006.

Vegetation

The narrow elevation ranges of plant species in the estuary indicate that small differences in elevation result in large changes in vegetation community. Further, hydrology controlled by river flows, tides, and topography is affecting vegetation distribution on a site-specific basis. Based on the large elevation differences between restored and reference sites, lengthy restoration trajectories are expected. We expect that re-establishment of tidal inundation will result in major changes in this assemblage, with a shift toward obligate wetland species in the vicinity of Seal Slough on Kandoll Farm. The most change will likely occur for upland species that only occur within a narrow elevation range (Figure 5.2). Baseline profiles from the sediment accretion stakes installed prior to restoration in 2005 will be compared with profiles taken annually to evaluate accretion/erosion rates.

The forested swamp at Kandoll Reference represents the remnants of what was likely a much more widely distributed assemblage in the area prior to settlement, forestry, and agriculture. While the subset of trees measured for dbh, age, and height is as yet insufficient to develop relationships that might serve as a guide to height and age based on dbh, linear correlations are beginning to develop between spruce dbh and height, and spruce dbh and age (Figure 5.8). Additional trees will be sampled in 2006 at this site and others, if possible, to further develop these relationships. The above-ground organic matter sampled at this site was also insufficient to characterize a forested wetland ecosystem; larger samples will be collected in 2006.

Fish

Few salmon were captured at either site, partially due to the late beginning date for sampling (most fish would have migrated through the system by then), and perhaps due to relatively high temperatures. Sampling was not sufficient to characterize the fish community structure. For 2006, sampling is planned to begin in February and to include diet.

Nutrient Flux

The very low concentrations of the nitrogen compounds and the high concentration of TOC in Vera Slough suggest that much of the nitrogen is locked up in organic matter. Nitrogen may be limiting production in Vera Slough judging by the low TIN:PO_4 ratio of 6.9. Vera Reference showed a ratio of 17.5 indicating no limitation. Nitrogen to phosphate ratios in Seal Slough sites were both greater than the Redfield Ratio for freshwater systems (Valiela 1995) of 16:1, indicating no nitrogen limitation. Phosphorus can be limiting in freshwater systems, but this was not greatly apparent at the Seal Slough sites.

As mentioned above, the balance between TOC and TIN concentrations indicates the state of nitrogen metabolism in a system. On average, the ratio of TOC to TIN in Vera Slough samples was at least 10 times the ratio in the other sites. This result suggests that photosynthesis, along with dissolved organic matter produced from other sources, was relatively greater during sampling periods in Vera Slough as compared to other sites. Greater TOC would reflect higher overall productivity of the ecosystem.

The net outward flux of water at Vera Slough is likely due to the fact that there are upland sources of fresh water flowing into each site. The watershed of Vera Reference is likely larger and probably discharges more water than that of Vera Slough. In addition, the flow restriction caused by the tide gate may reduce net outward flow at Vera Slough. Seal Slough sites probably had some upland sources of water flux from local precipitation and water storage, but these were minor compared to those at Vera during the period of the measurements.

The net flux of all parameters shows a strong correlation with water flux. In general, where flux rates are negative (indicating export, the site can be considered a source of this parameter to the broader ecosystem. Where flux rates are positive (indicating import), the site can be considered a sink of the parameter and requires input from the broader ecosystem. Because these preliminary studies were based on only two days of sampling, broad overall conclusions regarding source and sink over a larger period of time cannot be made.

We expect that TOC flux was proportional to water flux. In addition, we expect that flux of TOC from Vera Slough was disproportionately much greater than would be predicted by water flux alone because of the greater TOC concentrations at that site compared to the other sites.

Overall, the preliminary study on water properties flux showed that sites differed in flux rates of various compounds, and that reference and impacted sites were different in flux. The processing of nutrients and organic matter production are fundamental to the ecosystem. Understanding the rates and mass of import and export of these compounds from various natural and restored habitats in the estuary will eventually allow predictions regarding the ecological significance and ultimate results of multiple restoration projects on the broader ecosystem.

6.2 Implications for Monitoring Protocols

The draft monitoring protocols that were implemented in the 2005 field studies reported here were substantially revised based on lessons learned. The revised protocols (Roegner et al. 2006) were released in the spring of 2006 at the Columbia Estuary Research Conference (cerc2006.pnl.gov) in Astoria, Oregon, as well as at the joint conference of the Society of Ecological Restoration and Society of Wetland Scientists' Pacific Northwest chapters in Vancouver, Washington. The revised protocols are also included in this 2005 Annual Report (Appendix A).

6.3 Coordination

Coordination is ongoing between multiple parties conducting restoration planning and design in the Columbia River estuary. Currently, groups like Sea Resources, CREST, watershed councils, and the Columbia Land Trust are compiling effectiveness monitoring data as an important component of their restoration planning and adaptive management activities. These ongoing monitoring efforts can also help to determine the overall effects of restoration on the Columbia River estuary. To help facilitate this, the protocols are intended as tools needed to achieve a standard of repeatability and communication among restoration managers over time.

To better understand how ecological changes are manifested at a larger scale, coordination mechanisms need to continue among these groups to share data and "tell the story" of the ecological consequences of their projects. This is also essential to correct for unplanned contingencies such as flooding and/or infrastructure failure of a dike or tide gate. As groups adopt these methods and apply them within their existing capacity, new data is developed about the current changes resulting from the restoration treatments. Over time, as the "sample size" of restored sites grows, a newly restored landscape begins to emerge through increased comparability of data. This data can be very informative for modeling future restoration and/or management schemes in the system. To that end, the following recommendations are made to increase the coordination and capacity of restoration and monitoring efforts:

- Disseminate and present protocols to restoration managers throughout the Columbia River estuary.

- Conduct site visits/trainings with restoration managers to increase local capacity to utilize protocols and standardized collection of monitoring data.
- Continue to work with regional entities such as the Estuary Partnership and the Lower Columbia Fish Recovery Board to adopt protocols as part of their respective restoration programs.
- Formalize coordination mechanisms in the context of a broader adaptive management program for the Columbia River estuary.
- Provide datasets to help inform ongoing system-wide modeling efforts such as CORIE and the NOAA Research program.

6.4 Implications for Cumulative Effects Assessment Methodology and Adaptive Management

The 2005 field studies examined two salmon habitat types that have been greatly reduced in the estuary, marshes and swamps, on sites where three typical hydrologic restoration actions are planned: dike breach, culvert replacement, and tide gate replacement. In addition, the studies compared one pair of pre-restoration and reference sites in each of the two habitat types, documenting, for example, current differences between water properties and vegetation that will be important for analyzing restoration trajectories. A concerted effort was made to document characteristics of the system about which a high degree of uncertainty exists and that are particularly important for developing predictive capacity regarding the future of restoration sites, for example, the elevation ranges of plant species in marshes and swamps. While this effort remains limited in scale relative to any estuary wide statistical sampling design, it strategically obtained representative samples of key habitats and restoration actions.

Inherent in the development and dissemination of protocols (Appendix A) is providing a foundation for comparing ecological changes resulting from diverse restoration efforts in the system. Data sets compiled from the two sites described in this report provide examples of the kinds of changes taking place due to restoration treatments. However, because of the enormity of the Columbia River estuary relative to any individual restoration project, any system-wide ecological “lift” is not likely to be pronounced enough to reach detectable levels. In particular, it will be a challenge to separate the effects of multiple restoration actions in the floodplain from continuing degradation of the ecological system due to anthropogenic activities at the watershed scale (e.g., logging, roads, and sedimentation). These are documented for the Grays River watershed, the site of the Kandoll Farm restoration and reference sites, in a case study for this report (Appendix B). Nevertheless if restoration treatments are repeated and monitored over time, datasets such as the ones initiated in this study can be extrapolated to build scenarios useful for adaptive management of the system. As described in 6.3, adaptive management is occurring at project scales based on immediate feedback from effectiveness monitoring on early hydrologic restoration sites. At the program scale, while several agencies including the Bonneville Power Administration, U.S. Army Corps of Engineers, Environmental Protection Agency, and NOAA Restoration Center are funding restoration on the estuary, very few groups are carrying it out on the ground (e.g., Columbia Land Trust and Columbia River Estuary Study Task Force). To date, one effect of this structure has been a virtually immediate communication of lessons learned on the ground to program managers and into later proposed project designs. However, the development of a structure for synthesizing data across the agencies' programs estuary-wide remains a priority.

6.5 Recommendations for 2006 Field Studies

The recommended field studies are based on our efforts, initiated in 2005, to develop standardized monitoring protocols and on our review and synthesis of approaches to measure cumulative effects. The purpose of the field studies is to continue the evaluation of methods for assessing cumulative effects of restoration projects begun with baseline (pre-restoration) data collection in 2005. Thus, the field studies described in this plan have the following objectives:

- Continue the testing and evaluation of habitat monitoring metrics and protocols.
- Continue the evaluation of higher order metrics for cumulative effects.

Specifically, the 2006 field effort will collect post-restoration data on the following five categories of assessment metrics, which are described briefly with 2006 objectives below:

1) Water surface elevation, Water Quality (Temperature, Salinity): Download all depth sensors installed in 2005 and re-launch, ensure that a complete dataset of pressure sensor elevations is maintained following redeployments, and establish a regular download/redeployment schedule.

2) Land Elevation, Landscape Features (Channel Cross-Sections): Use sediment accretion measurements to determine whether a significant change has occurred. Repeat channel cross sections, check and if necessary reestablish benchmarks and hub at Kandoll after restoration effects, elevation microtopography, track elevation change proximal to restoration measures, and replicate photo points.

3) Vegetation: Repeat vegetation transect sampling (post-restoration year 1), complete groundtruthing digital aerial photos for plant communities, collect winter and summer above-ground biomass and summer below-ground biomass, elevations of swamp species, and above-ground productivity measure for swamps.

4) Fish: Conduct a pulsed, intensive focused study of fish when they are in the system (February-June based on data at Johnson Property (CREST unpubl.). Add higher order metrics including fish diet (stomach analysis) and prey availability (insect traps) during Flux Study periods.

5) Flux: To replicate 2005 baseline flux sampling and conduct a flux study coordinated with fish collection and fish prey analyses.

Kandoll Farm and Vera Slough and their associated reference sites will be revisited. Additional field sites are also being sought, to represent 1) a greater number of projects, and 2) a greater variety of forested wetlands and other geomorphological characteristics (e.g., mainstem islands), in order to increase the power of analysis and predictability of cumulative restoration effects estuary wide. Sampling methods will continue to follow the protocols (Appendix A) and cumulative effects methods used in 2005 field studies if new sites are brought online in 2006.

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Appendix A

Monitoring Protocols Manual

(also available at http://www.lcrep.org/lib_other_reports.htm)

PNNL--15793

Monitoring Protocols for Salmon Habitat Restoration Projects in the Lower Columbia River and Estuary






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Working Draft Report
April 17, 2006 (title page revised June 6, 2006)

Prepared for the U.S. Army Corps of Engineers
Portland District, Portland, Oregon
Under a Related Services Agreement
with the U.S. Department of Energy
Contract DE-AC05-76RL01830

[1] National Marine Fisheries Service
[2] Pacific Northwest National Laboratory
[3] Columbia River Estuary Study Taskforce
[4] Consultant

DRAFT REPORT

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Abstract

This document describes a set of protocols developed by the Pacific Northwest National Laboratory, the National Marine Fisheries Service, and the Columbia River Estuary Study Taskforce with the support of the US Army Corps of Engineers. The protocols will be used to assess habitat restoration projects as part of the Cumulative Ecosystem Response Evaluation effort begun in 2004 and to conclude in 2010 (Diefenderfer et al. 2005).

The goal of these restoration activities in the lower Columbia River and estuary (CRE) is to repair the connectivity and function of wetland habitats, and thereby to allow juvenile salmon to regain benefit from these important rearing and refuge areas. To do this effectively, researchers and managers require the means to 1) evaluate the results of individual restoration activities, 2) compare results among projects, and 3) determine the long-term and cumulative effects of habitat restoration on the overall estuary ecosystem. To achieve this, we are developing a standardized set of research and monitoring protocols. We limited the number of metrics to a proposed "core" set and selected measurement methods that are straightforward and economical to use. By "core," we mean the smallest suite of metrics that can adequately detail the results of restoration given the financial and logistical limitations of comprehensively monitoring ecological change over extended temporal and spatial scales. We selected core metrics based on the following criteria: 1) metrics correspond to commonly held restoration project goals; 2) are applicable to all sites; 3) represent controlling factors, ecosystem structure, and ecosystem function; 4) are relevant to both present and future investigations; and 5) are practical in terms of available level of effort.

Monitoring protocols are provided for hydrology (water surface elevation); water quality (temperature, salinity, dissolved oxygen); elevation (bathymetry, topography); landscape features; plant community (composition and cover); vegetation plantings (success); and fish (temporal presence, size/age structure, species).

Preface

This research is being conducted under the auspices of the U.S. Army Corps of Engineers (COE)'s Anadromous Fish Evaluation Program (AFEP), study code EST–P-04-04. The study is funded by the Corps' Portland District; Blaine Ebberts is the Corps' Biological Technical Lead for this project. The protocols benefited from feedback and discussions by scientists at a workshop on Columbia River estuary restoration project monitoring convened by the Corps and the Lower Columbia River Estuary Partnership in June 2004. The study is conducted jointly by the Pacific Northwest National Laboratory (operated by Battelle for the U.S. Department of Energy), National Oceanic and Atmospheric Administration National Marine Fisheries Service (NOAA Fisheries), and the Columbia River Estuary Study Taskforce. We invite comments on this working draft of the restoration project monitoring protocols manual. Our intent is to achieve a widely adopted standard set of monitoring metrics and protocols in the Columbia River estuary. Please send comments or questions to Gary Johnson (gary.johnson@pnl.gov; 503-417-7567).

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1.0 Introduction

This document describes a set of protocols developed by the Pacific Northwest National Laboratory (PNNL), the National Marine Fisheries Service, and the Columbia River Estuary Study Taskforce with the support of the US Army Corps of Engineers. The protocols will be used to assess habitat restoration projects as part of the Cumulative Ecosystem Response Evaluation effort begun in 2004 and to conclude in 2010 (Diefenderfer et al. 2005).

1.1 Objectives

The recovery of salmonid stocks requires supporting the diversity of life history patterns that historically mitigated for environmental variability (NOAA 2004; Bottom et al. 2006). Research on salmon distribution patterns in the lower Columbia River and estuary (CRE) as well as other West Coast estuarine systems indicates protracted use of tidal freshwater and estuarine habitats by diverse stocks of subyearling and yearling salmonids (e.g. Reimers and Loeffel 1967; Healey 1980; Levy and Northrote 1982; Shreffler et al. 1990, 1992; Levings et al. 1991; Levings 1994; Sommer et al. 2001; Tanner et al. 2002),. Much of this historically abundant habitat has been isolated, degraded, or destroyed (Thomas 1983; Burke 2004). The goal of restoration activities is to repair connectivity and function of these habitats, and thereby allow fish to regain benefit from these important rearing areas. However, researchers and managers require the means to 1) evaluate the effectiveness of individual restoration activities (Roni et al. 2002), 2) allow comparison between projects (Neckles et al. 2002; Williams and Orr 2002), and 3) determine the long-term and cumulative effects of habitat restoration on the overall ecosystem (Steyer et al. 2002). This can best be achieved with a standardized set of research and monitoring metrics.

We limited the number of metrics to a proposed "core" set and selected measurement methods that are straightforward and economical to use. By "core," we mean the smallest suite of metrics that can adequately detail the results of restoration given the financial and logistical limitations of comprehensively monitoring ecological change over extended temporal and spatial scales. Many studies will use additional metrics to characterize changes of site-specific interest or to develop fundamental knowledge of estuarine structures and processes, and some studies will not require all core metrics. The selection of core metrics developed from interrelated criteria: 1) metrics correspond to commonly held restoration project goals; 2) are applicable to all sites; 3) represent controlling factors, ecosystem structure, and ecosystem function; 4) are relevant to both present and future investigations; and 5) are practical in terms of available level of effort. We strove to keep the protocols accessible not only to scientists but to all staff and volunteers who potentially will be involved in restoration monitoring. Thus, the format and level of detail in the protocols reflect the larger purpose of standardizing data collection on restoration projects in the CRE, that is, the development of a regional database consistent enough to permit estuary-wide analyses.

A review of the literature uncovered many excellent examples of restoration monitoring theory and design (e.g., Simenstad et al. 1991; Callaway et al. 2001; Hillman 2004; Rice et al. 2005), yet none concisely outlined procedures particular to the CRE. The intent of this document, therefore, is to provide the rationale and procedures for standardized metrics specific to the tidal waters of the Columbia River estuary. The ultimate goal for applying these methods, to be fully realized perhaps decades from now, is to compile a compatible time series database of physical and biological metrics collected from many individual restoration projects. This dataset will enable evaluation of the effectiveness of individual restoration projects, as well as the cumulative effects of many restoration projects, on improving salmon habitat in the CRE. Protocols for sampling the monitored attributes are provided below.

1.2 Background

The lower Columbia River and estuary have been highly modified by human activities that converted tidal wetlands into agricultural and commercial uses. Construction of dikes, docks, roads, and tide gates and alterations such as dredging and filling have destroyed habitat and disconnected large areas of emergent and forested wetlands from tidal inundation. The result is the loss of 70% to 90% of the productive wetlands in both estuarine and tidal freshwater regions of the lower Columbia River, including important spawning and rearing habitat for several Evolutionarily Significant Units (ESUs) of salmonids (Thomas 1983; Simenstad et al. 1992; Weitkamp 1994; Kukulka and Jay 2003a,b).

Today there is growing momentum to reverse these land use patterns and specifically to reconnect historical wetland areas to the influence of tidal inundation. The challenge we face is how to evaluate the effects of various restoration projects on wetland function, given that the goals, scales, resources, and managing partnerships of projects vary greatly. To this end, there has been a regional movement in the Pacific Northwest and elsewhere to standardize measurement metrics and techniques that will facilitate comparison between restoration studies over time (Callaway et al. 2001; Neckles et al. 2002; Action Agencies 2003; Hillman 2004; Rice et al. 2005). Standardized metrics are required to provide the best possible input to managers making decisions regarding habitat restoration.

The incentive for many restoration activities in the CRE involves increasing habitat for rearing and migrating juvenile salmonids listed as threatened or endangered under the Endangered Species Act (ESA). Salmon stocks that will most directly benefit from restoration activities in the CRE are the wild and hatchery-reared ocean type Chinook salmon, chum salmon, and stream-type coho salmon from lower river tributaries. However, migrants from tributaries throughout the Snake, and Upper- and Mid-Columbia River systems are thought to have utilized estuarine habitat in the early 1900s, prior to extensive dam construction and loss of shallow water and wetland habitat (Rich 1920; Weitkamp 1994; Lichatowich and Mobrand 1995; Burke 2004). While most individuals from the surviving ESUs of upriver stocks currently migrate rapidly through the estuary to the ocean, some individuals of those groups (usually the smallest and latest migrants) display a protracted migration to and through the estuary and presumably gain enhanced growth and survival prior to ocean entry (Dawley et al. 1986). Thus, while the greatest use of estuarine habitats is expected from fish originating in lower river tributaries, threatened and endangered salmon from upriver tributaries are also expected to benefit from increased habitat opportunity.

In the following section, we summarize the types of restoration strategies being planned and implemented in the CRE. We then propose a minimum set of metrics and sampling design for restoration monitoring activities based on commonly shared ecological goals for restoration projects. Finally, we provide specific protocols for this set of estuary monitoring metrics.

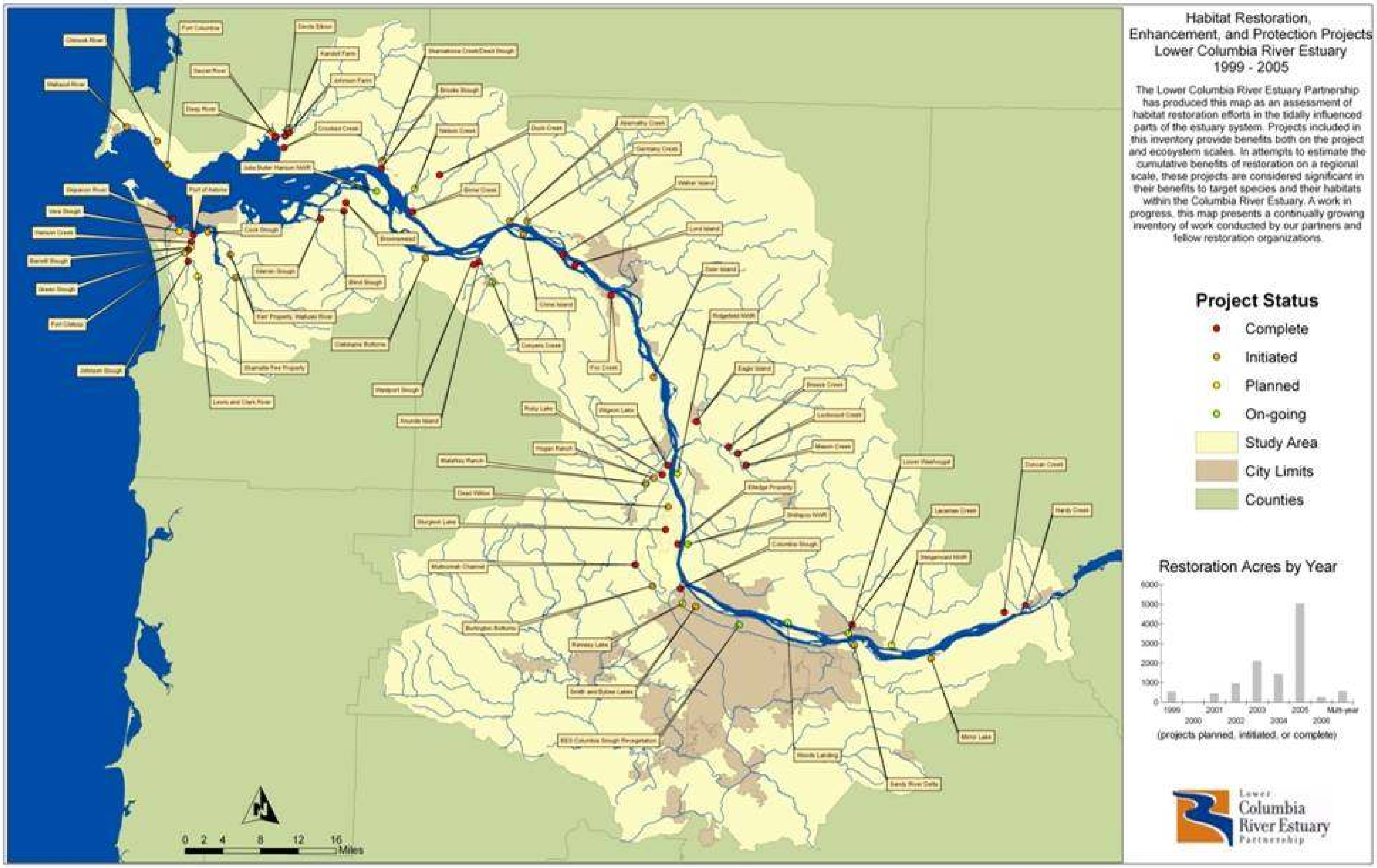
2.0 Types of Restoration Strategies in the CRE

Various types of restoration activities are occurring throughout the CRE region in an effort to recover lost habitat types (Figure 2.1). These activities fall under five broad strategies as described below and summarized in Table 2.1 (Johnson et al. 2004). The protocols we provide deal specifically with creation, enhancement, and restoration activities. Unless stated otherwise, the term “restoration” includes the various strategies described below.

2.1 Conservation

Conservation strategies are perhaps the broadest, encompassing many applications ranging from large-scale sustainable ecosystem initiatives down to small-scale, reach-specific conservation easements. These practices are geared toward increasing the potential for natural processes to work for the benefit of multiple species and include direct payments or other financial incentives to the landowner intended to offset any economic loss resulting from managing the land for conservation. Examples include financial support for the implementation of riparian setbacks and improved agricultural practices such as manure management, the addition of riparian buffer strips, integrated pest management, and off-stream livestock watering techniques.

Figure 2.1. Habitat restoration, enhancement, and protection projects: Lower Columbia River Estuary 1999-2005. (Figure courtesy of the Lower Columbia River Estuary Partnership.)



2.2 Creation

Habitat creation involves constructing or placing habitat features where they did not previously exist in order to foster development of a functioning ecosystem. Habitat creation represents the most experimental approach and, therefore, is likely to have a lower degree of success, particularly when landscape ecological processes are not sufficient to support the created habitat type. Examples include tidal channel excavation and the placement of dredge material intended to create marsh or other habitat.

2.3 Enhancement

Habitat enhancement is the improvement of a targeted ecological attribute and/or process. Enhancement projects in the CRE include tide gate or culvert replacement, riparian plantings and fencing, invasive species removal, and streambank stabilization.

2.4 Restoration

Restoration activities are designed to return degraded habitat to a state closer to the historical ecological condition. This can involve more intense modification and manipulation of site conditions than occurs with enhancement projects. The most common restoration approach in the CRE is tidal reconnection through dike breeching and/or dike removal. The selected monitoring metrics of this manual are specifically chosen to track ecosystem changes resulting from this type of restoration treatment.

2.5 Protection

Habitat protection projects can involve a variety of approaches, but the most common is land acquisition. Another option is to invoke land use regulations in the form of zoning designation and/or protection ordinances, such as defined riparian setbacks and designation of critical areas. Several organizations in the study area (for example the Columbia Land Trust and the Nature Conservancy) are applying these techniques to acquire ownership or development rights to intact patches of habitat or critical areas in need of further restoration treatments. Land use regulations are included in comprehensive plans, shoreline management master programs, floodplain management plans, and coastal zone management plans.

Table 2.1. Restoration Strategies, Examples of Project Types, and Targeted Ecosystem Benefits for the CRE (from Johnson et al. 2003)

Strategy	Project Type	Targeted Ecosystem Benefit
Conservation	Land conservation	Limits land use impacts harmful to salmon habitat such as sediment, contaminants, nutrient loading.
	Easements	Benefits ecological features through legal protection of critical areas, potentially allowing for complimentary restoration strategies to take place.
	Riparian fencing	Deters livestock from degrading stream-side areas.
	Manure management	Minimizes the inputs of nutrients and bacteria into stream corridor.
Creation	Material placement	Mimics habitat function and complexity through the placement of material at a given elevation.
	Tidal channel modification	Restores more natural flows and mimics tidal channel structure.
Enhancement	Riparian plantings	Promotes water temperature reduction, contaminant removal, connection of terrestrial habitat corridors, sediment reduction, and water storage; future source of large woody debris input.
	Tide gate/culvert replacement	Promotes water temperature reduction, dissolved oxygen availability, increased habitat access.
	Invasive species removal	Increases opportunities for native species propagation.
	Bioengineered streambank stabilization	Reduces sediment load, diffuses hydrologic energy.
	Riparian fencing	Protects riparian zones from disturbances.
Restoration	Tide gate removal	Restores partial or full hydrologic connection to slough habitat improving water quality, access to lost habitat types and processes, and potential removal of invasive plant species.
	Dike breaching	Provides similar benefits as tide gate removal, this application requires significant earth moving activities to allow tidal energy to influence historic slough signatures and can involve tidal channel excavation
	Culvert upgrades/culvert installation	Provides similar benefits to above restoration activities through the improvement of water quality, access to lost habitat types and processes, and potential removal of invasive species.
	Elevation adjustment	Restores elevation of site to level that will support appropriate wetland vegetation.
Protection	Land acquisition	Preserves existing intact ecological features, functions, and processes at site scale and/or enables the application of additional strategies without human land use constraints.
	Land use regulations	Limits or prohibits potentially harmful land use activities on or adjacent to the land surrounding the site, thereby protecting habitat-forming processes and features.

3.0 Core Monitored Metrics in the CRE

The CRE comprises a unique continuum of wetland ecosystems strongly influenced by river flow, salinity, and tidal amplitude. Unlike streams in nontidal upland regions and above Bonneville Dam, in the CRE semidiurnal and spring-neap tidal variation in water level imposes a dominant structuring force on both geophysical parameters and biota (Rice et al. 2005). Water elevation fluctuations, keyed to site topography, directly determine periods of inundation and salinity intrusion (Kukulka and Jay 2003a, b) and this in turn structures plant communities and fish habitat use (Cornu and Sadro 2002). The tidal cycle controls the magnitude and duration of bidirectional current velocities that cause sedimentation/erosion and the evolution of geomorphological features like tidal channels and levees (Hume and Bell 1993). Tidal currents additionally affect the spatio-temporal distribution of water quality parameters such as salinity and temperature, and the transport of organic and inorganic materials that affect organism abundance and growth (Roegner 1998). Many restoration projects in the CRE will be tidal reconnections; our metrics reflect this and were specifically chosen to measure changes in hydrology due to restoration activities as well as the physical and biological response in the wetland.

3.1 Metric Selection Criteria

The decision-making process culminating in the suggested core monitoring metrics was based on several interrelated criteria. First, metrics need to be diagnostic of some relevant ecosystem function and directly need to correspond to commonly held goals among the restoration projects in the CRE (Thom and Wellman 1996). Second, we followed NRC (1992) guidelines that at least three classes of monitoring attributes be tracked: one for controlling factors (e.g., tidal regimes), one for structural factors (e.g., fish community structure), and one for functional factors (e.g., vegetation growth). Third, metrics should be potentially applicable to all sites with measurements that result in comparable datasets relevant to both present and future investigations (Tegler et al. 2001). Finally, measurements and data analysis must be practical in terms of funding, manpower, and processing requirements (Callaway et al. 2001). This last factor necessitates limiting the number of metrics to a "core" set and selecting measurement methods that are straightforward and economical to use. *By "core," we mean the smallest suite of metrics that can adequately detail the status and trends of restoration while acknowledging the financial and logistical limitations of comprehensively monitoring ecological change over an extended temporal and spatial scale.* Ideally, all projects in the region would perform the core physical measurements, which we view as encompassing the fundamental forces on, and responses to, changes in the affected systems. Project goals for the biological variables (fish use or vegetation cover) may vary between studies. We encourage researchers to make additional measurements, especially process-related derivations of the core monitored metrics (e.g., fish growth rate, consumption rate, and residence time). Higher order protocols such as those are under development at the time of this draft are described in more detail in Diefenderfer et al. (2006).

The selection of relevant metrics developed from 1) a review of pertinent literature; 2) a meeting with local restoration managers, and 3) iterations of this draft document. We strove to keep the protocols accessible not only to scientists but to all staff and volunteers who potentially will be involved in restoration monitoring. Thus, the format and level of detail in the protocols reflect the larger purpose of standardizing data collection on restoration projects in the CRE, that is, the development of a regional database consistent enough to permit estuary-wide analyses. As discussed above, we are concentrating on projectsfor implementing tidal reconnection, a key ecological driver for a whole array of structural and functional attributes in the CRE. We found many relevant frameworks describing metrics important for monitoring restoration activities of potential salmonid habitat (although none were tailored specifically for the CRE), and we relied extensively on papers by Simenstad et al. (1991), Simenstad and Cordell (2000), Zedler (2001), Johnson et al. (2004), Hillman (2004), and Rice et al. (2005) to derive an initial set of potential metrics. These were augmented and expanded during a meeting with regional restoration managers (Diefenderfer et al. 2005; Appendix A). The process now continues with this working draft document, which we submit for review and refinement of specific metrics and protocols.

3.2 Metrics

Table 3.1 outlines the proposed set of core monitored metrics, their collection methods, sampling frequencies, effectiveness determination, and parameter types, as well as their contributions to each of the three categories in an estuarine monitoring framework developed by Simenstad and Cordell (2000). We are advocating a combination of data logging instruments, on-site survey methods, and remote sensing techniques.

3.2.1 Hydrology (Water Elevation)

Hydrology is a main controlling factor of wetland evolution in the CRE, and it influences habitat structure, processes, and ecological functions (Sanderson et al. 2000; Rice et al. 2005). Measuring water level variation is especially crucial for tidal reconnection restoration projects. Tidal forcing determines such processes as sedimentation/erosion, tidal channel development, inundation periods, and salinity intrusion. We advocate the use of automated data logging pressure sensors set to hourly frequency, which will record tidal, event-scale, and seasonal water elevation data. This method of data collection generates a time-series of measurements that can be compared between habitats and across seasons. Sensors can be “stand alone” or, more commonly, be integrated into a water quality instrumentation package (below).

3.2.2 Water Quality (Temperature, Salinity, Dissolved Oxygen)

Water quality parameters such as temperature, salinity, and dissolved oxygen play a determining role in species abundance and distribution in the CRE (Oregon Watershed Enhancement Board [OWEB] 1999, Johnson et al. 2003). Most organisms have specific tolerances for water parameter ranges or rates of change (fluctuations). For example, temperature is a good predictor of juvenile salmon abundance and condition (OWEB 1999) and salinity is a main determinant of vegetation patterns (Thom et al. 2002). Oxygen concentration can control the distribution of many organisms. We advocate the use of automated data logging multiprobe instruments for measuring time series of water quality parameters. Additional transect surveys with CTD probes provide vertical and horizontal spatial scale data useful to augment the spatially fixed time series data (Callaway et al. 2001).

3.2.3 Elevation (Bathymetry and Topography)

Hydrologic reconnection usually results in substantial alteration of geomorphic features such as location and sinuosity of tidal creeks, changes in the extent and slope of intertidal regions, and substrate characteristics (Cornu and Sadro 2002; Williams and Orr 2002). These landscape changes in turn affect (and are affected by) the composition, distribution, and abundance of biota, which often have distinct habitat requirements in wetland areas (Sanderson et al. 2000). Establishing the time course of bathymetric and topographic change at a restoration site is crucial for evaluating the progress of the restoration effort. We recommend detailed topographic and bathymetric surveys be made using differential GPS or Total Station survey techniques. Transect and survey designs are applicable. These techniques have well-established methodologies and should be coordinated with biological surveys described below.

3.2.4 Landscape Features

Large-scale alterations of landforms and vegetation patterns often accompany wetland restoration activities (Tanner et al. 2002; Williams and Orr 2002). The measurement of spatial changes in biogeophysical features, such as the evolution of tidal channel complexity, alteration in intertidal area, and succession of vegetation communities, is best accomplished by remote sensing using aerial imagery (e.g., Wright et al. 2000). Many technologies are available, including real color and near infrared aerial photography, hyperspectral imagery, digital aerial photography, high-resolution satellite imagery, and LiDAR (Light Detection And Ranging). Ground truthing during topographic/bathymetric surveys (below) is also required. Repeated measures over time are best analyzed using geographic information systems (GIS) to quantify the progress of restoration.

3.2.5 Vegetation Changes Resulting from Tidal Reconnection

Plant community composition can change rapidly following reconnection to a tidal hydrologic regime (Cornu and Sadro 2002; Roman et al. 2002) especially if the reconnection fosters salinity intrusion (Thom et al. 2002). Vegetation patterns confer both structural elements and ecological processes to wetland ecosystems, and may increase ecosystem capacity for foraging salmonids (Sommer et al. 2001; Tanner et al. 2002). We recommend that measurement of changes in vegetation community structure be accomplished at both landscape-scale (described above) and through transect or ground survey techniques. Where projects include revegetation, the effectiveness of plantings can be determined by assessing subsequent survival and the growth of transplants.

3.2.6 Success Rate of Vegetation Plantings

Vegetation plantings are the primary objectives of some restoration projects, for example, in riparian areas intended to provide shade over water bodies. Plantings are also made in tandem with other restoration actions, for example, to forestall the invasion of exotic species or to accelerate the development of desired native plant communities and their associated functions for salmonid prey production. The success rate of vegetation plantings is typically assessed by counting a subset of the plantings and calculating the survival rate; rate of growth and health are also desirable observations.

3.2.7 Fish Temporal Presence, Size/Age-Structure, and Species Composition

The incentive for many restoration activities in the CRE involves increasing habitat for rearing and migrating juvenile salmonid evolutionarily significant unit (ESU)s listed as threatened or endangered under the Endangered Species Act of 1973 (ESA) (Thom et al. 2005). It is generally acknowledged that documenting “realized function” (Simenstad and Cordell 2000) is difficult because of the migratory nature of salmonids, while determining habitat capacity and opportunity are less problematic (Tanner et al. 2002). For minimum effectiveness monitoring, fish sampling should permit the evaluation of changes in community structure in restored locations compared with before treatment and control areas. We advocate conducting the most intense sampling effort logistically possible across sites, habitat types, and time. Additionally, it is highly desirable to determine "realized function" attributes, such as residence time, growth, and survival, which necessitate measuring metrics such as prey availability, prey consumption, age assessment, genetic stock identification, parasite load, and mark-recovery data (e.g., Roegner et al. 2004).

Table 3.1. Summary of Proposed Core Monitored Attributes for Lower Columbia River and Estuary Restoration Projects. (OPP = Habitat Opportunity Metric, CAP = Habitat Capacity Metric, FCT = Realized Function Metric as defined by Simenstad and Cordell 2000.)

Indicator Category	Monitored Metric	Collection Method	Sampling Frequency	Effectiveness Determination	Parameter Type	OPP	CAP	FCT
Physical Attributes								
Physical Condition	Water Elevation	Datalogging Instrument	Hourly	Recovery Time series	Controlling/ Functional	**X**	**X**	
Water quality	Temperature Salinity DO	Datalogging Instrument/ Transect	Hourly/ Seasonal	Recovery Time series	Structural/ Functional		**X**	
Habitat Inventory	Landscape features	Aerial Photo/GIS	Annual	Recovery Survey	Structural/ Functional	**X**	**X**	
	Elevation	Ground Survey	Annual	Recovery Survey	Structural/ Functional	**X**	**X**	
Biological Attributes								
Vegetation Habitat Characteristics	Vegetation cover	Ground Survey	Seasonal - Annual	Recovery Survey	Structural/ Functional	**X**	**X**	
	Planting Success rate				Functional			**X**
Fish Community Structure	Species composition	Ground Survey	Seasonal	Recovery Survey	Functional			**X**
	Size structure							**X**
	Temporal presence							**X**

DO = dissolved oxygen

3.3 Sampling Design

The ability to detect ecological change due to restoration in a naturally varying environmental system is problematic (Osenberg et al. 1994). We considered two basic sampling designs for habitat restoration monitoring, the Before After Control Impact and the Accident-Response. Both have advantages and disadvantages for use in the CRE. The choice of sampling design will depend on site-specific circumstances, and the availability of funding before and after project implementation. Therefore, the design may be a combination of these two approaches, or something less statistically rigorous.

The Before After Control Impact (BACI) sampling scheme integrates both temporal and spatial elements into the effectiveness monitoring experimental design (Underwood 1991; 1992; 1994; Stewart-

Owen and Bence 2001). This effectiveness monitoring approach (Hillman 2004) relies on comparisons between measured values from sites separated both temporally (before versus after) and spatially (control versus impact). The BACI design was therefore reviewed and considered for these protocols. The sequence of sampling events in BACI design is listed in Table 3.2. Monitored parameters are sampled simultaneously at two (or more) locations (control versus impact) before and after the restoration action (before versus after).

Table 3.2. The Sequence of Sampling Events in BACI Design.

A. Before Impact 1. Acquire digital aerial photograph of site (Protocol 4: Landscape) a. Locate elevation and tidal benchmarks from website. b. Choose control and impact study areas. c. Choose survey transect locations. 2. Ground survey (at control and impact sites) a. Conduct topographic/bathymetric survey (Protocol 3: Elevation) b. Deploy water quality and water elevation data loggers at surveyed locations (Protocol 1-2: Hydrology and Water Quality) c. Conduct vegetation/fish community survey (Protocol 5-6: Vegetation Cover and Success rate).
B. Interim 1. Maintain data loggers. 2. Repeat vegetation/fish community surveys.
C. After Impact 1. Repeat Steps A2b-c to acquire After data set. 2. conduct lab analysis using GIS to create: a. Layer digital (hyperspectral) photograph with topography/bathymetry to create a digital elevation map (DEM). b. Layer vegetation (if available) to create vegetation map. c. Use Before and After data sets to quantify physical and biological changes to site. 3. Compute fish community structure analysis (Protocol 7: Fish). 4. Repeat C 1-3 at designated frequency.

The purpose of the BACI design is to test the hypothesis that there is no change between a control and a treatment site before and after impact. In contrast, the purpose of sampling restoration projects is to evaluate recovery, which requires testing the hypothesis that a treatment site recovers, without the ability to measure historical, pre-disturbance conditions at the restoration site. Therefore, recovery represents a change that is best measured by comparison to a relatively undisturbed reference site, as opposed to comparison to "before" conditions (cf. Miller and Simenstad 1997; Skalski et al. 2001; Hood 2002a; Thom et al. 2002). It is recognized that difficulties can arise when choosing the reference site in areas that have been highly modified, whereas at other sites there may be no opportunity to conduct adequate Before sampling (Steyer et al. 2003). One solution is that, within the various ecological zones of the CRE, regional reference sites be identified and monitored. These areas can then provide a range of "target" conditions for restoration activities.

We considered another sampling design called the Accident Response model. This approach tests the "parallelism hypothesis" (Skalski et al. 2001). One selects a reference site that ideally represents a natural, minimally modified, or target condition. This site should be located in a nearby reference area subjected to similar large-scale climatic and environmental conditions, but be independent of activities affecting the restoration site. The restored monitoring site would be within the restoration system and would be chosen to monitor target habitats or processes, such as tidal channels or marsh communities. All sampling techniques and sampling periods should be identical between reference and restoration sites. These paired measurements are to be made before and after the restoration activity: the spatial and temporal replication of the measurements is dependent on the monitoring metric, the size of the restoration area, and logistics (Table 3.2). In contrast to the BACI design, however, this "accident response" model does not require multiple data collection times before implementation of restoration actions, which in BACI are used to assess the variability between control and impact sites (Skalski et al. 2001). One measure of restoration "success" or performance is for values of post-restoration impact parameters (the monitored attributes) to converge with those of the reference site (Kentula et al. 1992;Raposa 2002). It should be emphasized that the ecological processes associated with a given restoration activity, such as breaching a dike, evolve for many years post-implementation. A long-term monitoring commitment (5 to 10 years) is thus necessary for selected projects to adequately document the ecosystem response in relation to natural variation (Zedler 1988, Larsen et al. 2003, NOAA 2004). In forested wetlands, conditions may not converge for decades. See Hillman (2004) for further discussion of these types of statistical comparisons.

Within either the BACI or the accident-response sampling design, two primary data collection categories are likely to be employed in the CRE, depending on the parameter of interest: survey type measurements and time series type measurements. Survey type measurements are "snap shots" in the temporal frame and can include aerial photos, topographic surveys, vegetation surveys, and fish community sampling. Repeated measures over time are made for survey type measurements, while time series measurements, in contrast, consist of regularly timed recordings, usually from fixed spatial stations, for example, data logging instrumentation used to monitor water quality parameters. Time series analysis techniques such as spectral analysis most effectively capture trends in the data.

In conclusion, the BACI and Accident-Response are two possible sampling designs for habitat restoration projects in the CRE. We offer these two designs knowing there will be project- and site-specific considerations that will influence the choice of sampling design. Some projects will have few resources available for monitoring, others will be able to monitor only after the fact, some will not have acceptable control or reference sites, etc. A useful sampling design may be simply to collect basic descriptive data at the site, such as repeated photographs at fixed photo points (Protocol 4). Whatever the sampling design, it should be determined early in the monitoring planning process.

3.4 Sample Site Selection

Where possible, selection of locations for placement of datalogging instrumentation, elevation, and vegetation transects, and fish surveys should be spatially linked (i.e., made in close proximity), so that changes in multiple metrics can be evaluated for a single site. This is especially important for documenting how changes in physical parameters such a tidal elevation and channel morphology affect biological metrics such as vegetation and fish communities. Information derived from measuring Landscape Features (Protocol 4) can complement this monitoring proximal to expected changes by mapping changes in plant communities and tidal channels at the site scale.

4.0 Detailed Monitoring Protocols for Columbia River Estuary Habitat Restoration Projects

The seven monitoring protocols we have developed are provided below. These include protocols for hydrology (water surface elevation); water quality (temperature, salinity, dissolved oxygen); elevation (bathymetry, topography); landscape features; plant community (composition and cover); vegetation plantings (success); and fish (temporal presence, size/age structure, species). For each protocol information is listed on the following: purpose, goal, design, equipment needed, site selection, sampling periodicity, sampling protocol, calculations and analysis, site-specific contingency considerations if any, and references or additional information sources.

4.1 Protocol for Assessing Hydrology (Surface Water Elevation)

PURPOSE

Water-level variation in wetlands is a function of river stage and tidal fluctuations. This variation largely drives wetland evolution in the CRE, with tidal fluctuations probably being the most deterministic for wetland restoration (Cornu and Sadro 2002). A key measure is change in tidal elevation within a restoration project due to tidal reconnection. The extent, period, and duration of tidal forcing will cause changes in aerial exposure, circulation patterns in tidal creeks (including the distribution of water quality parameters such as salinity, temperature, and DO), sedimentation/erosion patterns and tidal creek evolution, and the distribution of vegetation and fishes. Water level data should be properly geo-referenced (Protocol 3; Elevation), related to topography data collected from a terrestrial datum (i.e., NAVD 88), and linked to tidal gauge datum (i.e., MLLW). Water-level information and topographic information combined can be used to determine inundation periods and vegetation response (Protocols 3 and 5; Elevation and Vegetation Cover). This is thus a priority metric best measured with automated data logging pressure sensors. Current technology now offers multiple parameter probes that combine measurements like depth with others such as temperature, dissolved oxygen, and salinity (see protocol 2).

GOAL

Measure the pattern of hydrology with respect to a known reference point to record the timing, frequency, and duration of tidal inundation on reference and impact restored sites.

DESIGN

A recovery time series design should be used to evaluate changes in water quality parameters caused by the restoration activity. At a minimum, two instruments would be deployed, one at the reference and the other at the impact site. The latter would be positioned in a reach near the site of the proposed hydrological reconnection and would ideally be situated where other monitoring activities take place (i.e., fish abundance). If additional instruments are available, water elevation both inside and outside the proposed hydrological reconnection (i.e., culvert replacement) provide useful comparisons. An instrument may also be placed upstream of the reconnection to evaluate the extent of the effect on water elevation. Before-impact (baseline) measurements are desirable to evaluate natural variation in the system. Comparing ranges and fluctuations of the reference and impact time series gives a measure of the effectiveness of the restoration project.

Recording GPS position of depth sensor.

EQUIPMENT

Field: Continuous water level recorders (pressure transducer) or multiple parameter probe (see Protocol 2), monumenting equipment (t-post, surveying equipment).

Lab: Laptop computer, calibration and maintenance manual.

Surveying channel cross section.

SITE SELECTION

Primary site for data loggers in both impact and reference sites is near the mouth of the tidal reconnection site (but within the constriction). The reference datalogger should be situated to record water levels at a site unaffected by restoration activity. Additional dataloggers, if available, can be placed further in the system to gauge for lags in period and variation in amplitude with distance from the impact site.

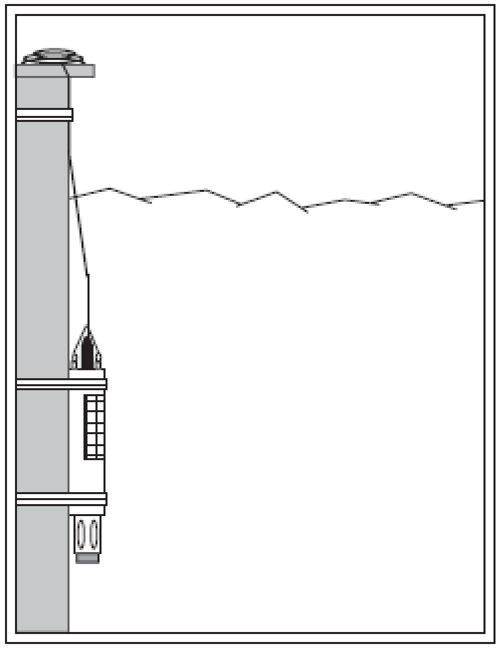
SAMPLING PERIODICITY

A. Minimum sample frequency of 0.5 hr.

B. Note that while tidal parameters may be predicted after a 2-3 month period of field data, water level sensors record river flow events as well as tide; combined effects of extreme events (storms) may not be easily predictable yet can have strong impacts on wetland development.

SAMPLING PROTOCOL

Automated instruments require proper placement to ensure comparable monitoring. Dataloggers should be secured subtidally with sensors positioned 50 to 75 cm below the anticipated lowest tide level but at least 10-20 cm above the substrate. Remember that hydrologic reconnections that increase tidal amplitudes may convert subtidal areas to intertidal zones. The instruments can be attached to existing structures (see figure) such as pilings or fence posts with a protective sleeve. The height of the sensors relative to known elevation point needs to be determined to relate water level fluctuations to topography. The vertical elevation of the sensor needs to be translated accurately from surveyed point (usually the top of post structure) derived from registered benchmarks established during the topographic survey (Protocol 3). Record location of data logger with GPS and periodically visit data loggers as required by factory user’s manual to check for fouling or damage. When removing or redeploying data logger, record position relative to the top of the piling or post so that it can be replaced at the same position over time. Where required, be sure to calibrate sensors before each deployment.



Water Elevation Sensor.

CALCULATIONS & ANALYSIS

A. Primary output from dataloggers is time series of water levels. These relative heights should be converted into height relative to the standard water elevation datum (mean lower water level) or land elevation for comparison between sites and as a reference to site topography. Data should be presented to contrast water level fluctuation at reference and impact sites pre- and post-restoration.

B. Inundation period (% of time inundated) can be calculated for any elevation n within the site, and made into GIS layers or as input into circulation models. Be aware that calculated inundation periods vary according to seasonal changes in tidal amplitude and river flow, and results are affected by the time period used for the calculations.

SITE-SPECIFIC CONTIGENCY CONSIDERATIONS:

- Observe bank conditions of the water body where equipment is deployed; assess its potential for slope failure that can place risk to equipment and affect data quality.
- Ensure probes' metallic characteristics are not in close proximity to any metallic structure as this can cause electrolysis and instrument malfunction.
- Forecast tidal fluctuations and set up maintenance schedule accordingly so that equipment can be extracted safely.
- Review first sets of data carefully and use this to make inferences of site-specific conditions not expected.

4.2 Protocol for Assessing Water Quality (Temperature, Salinity and Dissolved Oxygen)

PURPOSE

Organisms have varying tolerances to water quality parameters such as temperature, salinity, and dissolved oxygen. Measuring variations in pre- and post-restoration water quality conditions are a direct measure of changes in habitat opportunity (Callaway et al. 2001) and are important for explaining floral and faunal changes. Increased circulation due to tidal reconnection may reduce excessive temperature and help maintain suitable DO levels. Increased salinity intrusion on a restored site can also determine vegetation community structure. This protocol relates directly with hydrology measurements from Protocol 1 and topographic data from Protocol 3. As with water elevation (Protocol 1), we advocate the use of autonomous data logging equipment to measure water quality parameters. Many instruments are multiple parameter probes that allow elevation measurements to be concurrent with other parameters such as temperature, salinity, and dissolved oxygen. Deployment of such equipment should follow the guidelines set forth in Protocol 1 for elevation to ensure they are referenced to known benchmarks. Paired deployments provide comparative time series between habitats and over time.

GOAL

Continuously measure temperature, salinity, and dissolved oxygen at reference and impact site and relate to biotic changes.

DESIGN

A Recovery time series design should be used to evaluate changes in water quality parameters caused by the restoration activity. At a minimum, two instruments would be deployed, one at the reference and the other at the impact site. The latter would be positioned in a reach near the site of the proposed hydrological reconnection and would ideally be situated where other monitoring activities take place (i.e., fish abundance). Additional instruments, if available, should be placed upstream of the reconnection to evaluate the extent of the effect (i.e., salinity intrusion). Before-impact (baseline) measurements are desirable to evaluate natural variation in the system. Comparing ranges and fluctuations of the reference and impact time series gives a measure of the effectiveness of the restoration project.


Deploying data logging water quality instrument

EQUIPMENT

A. *Field*: data loggers, laptop computer, and data logger launching/downloading software, data logger attaching/anchoring equipment (stakes, cable ties), hammer, global positioning system (GPS), camera, or field notebook for documenting data logger location, extra batteries, and data loggers.

B. *Lab*: data logger calibration and maintenance manual, data logger output software.

SITE SELECTION

A. Install data loggers in both reference and restoration sites. If possible, install both loggers at the same position relative to a known surveyed elevation (Protocol 1: Hydrology). This will ensure comparable data sets at same position in the water column.

B. Choose a location that is representative of the overall characteristics of the reach and with some assurance of repeatability under changing conditions from the restoration treatment (see CONTIGENCIES below).

SAMPLING PERIODICITY

Continuous deployment with data logging recording frequency set at 1/2-hour intervals. Note time of battery life.

SAMPLING PROTOCOL

Attach monitoring probe on secure structure 10-20 cm from channel bottom. Record elevation distance from surveyed point on structure to ensure consistency in elevation and water column conditions over time. Clean and maintain monitoring probe following factory recommendations usually every 2-4 weeks for power and to prevent biological fouling. See Protocol 1 (Hydrology).

CALCULATIONS & ANALYSIS

A. Primary output from dataloggers is time series of parameters. Data, especially DO, should be inspected for data outliers. Time series from reference and impact site should be temporally aligned and graphed together.

B. Comparisons between sites can be emphasized with difference time series plots (Reference value-Impact value). Mean daily maximum values may be used to examine for periods where values exceed organism tolerances (OWEB 1999).

C. Spectral (Fortier) analysis can be used to establish the dominant periods of parameter variability (i.e., tidal).

SITE-SPECIFIC CONTIGENCY CONSIDERATIONS:

- Observe bank conditions of the water body where equipment is deployed; assess its potential for slope failure that can place risk to equipment and affect data quality.
- Forecast in advance tidal fluctuations and set up maintenance schedule accordingly so that equipment can be extracted safely.
- Review first sets of data carefully and use it to be make inferences of site-specific conditions not expected (i.e. DO data and relation to land use inputs such as nutrients, etc.).

- Multiple parameter probes should be from the same vendor when possible to facilitate data downloads and consistency with inherent variability of readings.

REFERENCES

Callaway et al. (2001)

Schuett-Hames et al. (1999)

4.3 Protocol for Assessing Elevation (Bathymetry and Topography)

PURPOSE

Wetland elevation is a factor in geomorphological evolution, vegetation succession, and fish habitat use (Rice et al. 2005). Dynamic alterations of channel morphology and vegetation patterns usually accompany hydrologic reconnection of sloughs and backwaters with tidal forcing (Zedler 2001; Coats et al. 1995). Establishing the extent and rate of change at a restoration site is important for evaluating the progress of the restoration effort.

GOAL

Quantify changes in elevation before and after restoration actions on portions of the site within the area influenced by tidal inundation.

DESIGN

Accurately monitoring elevation changes in an intertidal area requires a precise elevation survey tied to a benchmark and linked to an established vertical datum (e.g., NAVD88 or mean lower low water). The locations of survey benchmarks and the local tidal datum for sites in the CRE can be found at the National Ocean Service site (http://co-ops.nos.noaa.gov/bench.html). However, established survey benchmarks may not be in close proximity to restoration sites and therefore may be of limited utility for determining elevations at a site. Often a site survey is conducted by a certified surveyor as part of the restoration project design. However, these surveys are not conducted in combination with vegetation surveys or in other specific areas of interest, such as tidal channels, and therefore may not be useful for predicting vegetation colonization or analyzing channel formation and change. At a minimum, surveys should establish a series of surveyed benchmarks at the restoration site with "line-of-site" to the portions of the site where elevation data is critical (e.g., at the location of vegetation transects, channel cross sections, and water depth sensors). An autolevel or a total station can then be used to survey elevation differences between the established benchmarks and the areas of interest.

EQUIPMENT

Field: Auto level, Tripod, Stadia rod, Meter tape, Walkie-talkies, GPS, PVC/rebar and mallet/sledge hammer.

SITE SELECTION

Sampling station locations may be generated from aerial photography. Elevation measurements should include the following locations:

1) channel cross-sections
   a) at the locations of water pressure sensors
   b) near the expected boundary of post-

RTK instrumentation set up at a restoration site restoration inundation

2) fixed points

    a) along vegetation transects

    b) boundaries between vegetation communities

    c) water pressure sensors

SAMPLING PERIODICITY

Sampling should be conducted annually while the system is changing rapidly in the years immediately following restoration.

SAMPLING PROTOCOL

Elevations should be measured at a minimum at the location of vegetation transects (Protocol 5; Vegetation Cover), at selected channel cross sections, and at the location of water level sensors.

Channel Cross Sections

A channel cross section is measured by determining elevations along a permanent horizontal transect perpendicular to a channel.

A. The endpoints should be marked with a permanent marker (e.g., rebar or PVC) at a distance far enough from the bank to ensure they will not be washed out by erosive forces. The transect endpoint locations should also be recorded using a GPS preferably with differential correction. If satellite coverage for the GPS is not available due to tree cover then points can be established in areas offset from the original location with measurements of distance, azimuth, and elevation difference.

B. Attach measuring tape to fixed endpoints. Level stadia rod at each predetermined interval and record the interval on the tape and the height measured with the autolevel. The interval can be greater (e.g., 1 to 2 meter) in areas or low slope and smaller (0.5 meters) in areas of steeper slope. Walkie-talkies are useful when distances make communication difficult.

Repeat at each measurement interval. This procedure is useful for determining two-imensional (2D) change across an intertidal/tidal creek profile.

Vegetation Transects

The vegetation surveys are best conducted in a grid using transects along a baseline as outlined in Protocol 5 (Vegetation Cover). If resources are limited, fewer points may be surveyed, for example: a) the endpoints of the transects, b) borders between plant communities, or c) points representative of certain plant communities. To map elevations in the area of the vegetation transects, the elevations could be measured at three alternative times as follows:

Alternative 1: the elevation survey could be conducted at the same time as the vegetation survey by placing the stadia rod at the center of the quadrat before or after vegetation percent cover is determined (see Protocol 5; Vegetation Cover) and measuring the elevation difference from the established benchmark with the autolevel.

Leveling sediment accretion stakes

Alternative 2: the location of each quadrat location could be marked with flagging in the center of the quadrat and the elevation data can be recorded at a later time by positioning the stadia rod at the location of the flagging. The latter situation carries the risk of the flagging moving or getting lost between the time of the vegetation survey and the elevation survey.

Alternative 3: the meter tapes could be repositioned and the original locations of the quadrats remeasured. This alternative has the highest amount of potential error because it is highly unlikely that the exact position of the quadrats would be located.

It is advantageous to use GPS to determine location and PVC or rebar to permanently mark the endpoints of the transects as defined in Protocol 5 (Vegetation Cover) and the endpoints of the channel cross sections.

Sediment Accretion Stakes

Sediment accretion stakes are an economical means for measuring the erosion or deposition of sediment, a typical result of hydrological reconnection projects.

1. Sediment accretion stakes may be made from 1" schedule 40 sunlight resistant PVC conduit (gray). If possible, the stakes should be driven into the ground at least 1.5 m deep to ensure their stability against hydrological forces following restoration. Stakes are placed one meter apart. The tops of the stakes must be leveled. This is accomplished by laying a construction level between them.

2. To measure sediment accretion, one meter stick is set across the top of the sediment accretion stakes. A second meter stick is held vertically with the zero end touching the sediment surface and is read to the lower edge of the resting meter stick. This is done at 10-cm intervals between the stakes. Measurements should be made to the nearest millimeter.

3. Sediment accretion stakes should be set prior to restoration in an area likely to be inundated and measured once before hydrological reconnection. Pre-restoration measurements may be averaged or plotted for comparison to post-restoration measurements.

Water Level Sensors

The elevation of the water-level sensors is critical to linking the relative water level changes to a known elevation datum. This data can be used to predict inundation over areas of known elevations. The elevation of the sediment surrounding the post where the sensor is attached is likely to change over time due to accretion or erosion around the post. Therefore the elevation of the post should be measured by leveling the stadia rod on top of the post. Each time the sensor is deployed, the distance from the top of the post to the sensor must be measured. If the post is ever moved, the elevation must be re-established.

CALCULATIONS AND ANALYSIS

Data should be entered into a GIS and in a spreadsheet.

A. Difference plots compare changes of elevation over time.

B. Elevations and vegetation can be plotted in Excel showing the means and ranges of elevation for species or communities. This information can be used prior to restoration to predict vegetation colonization post-restoration.

C. Channel condition metrics calculated from above

1. Change in stream gradient (elevation change per unit horizontal distance (zd/x)).

2. Change in cross-sectional area of tidal channel at selected transects.

3. Wetted width: width of water surface perpendicular to flow (modeled from water elevation data).

4. Water elevation analysis as described in Protocol 1.

ADDITIONAL ANALYSIS TOOLS

For topographic surveys, we advocate use of a "total station," which is a combination transit and electronic distance measuring device. Elevation and position data are logged internally and can easily be transferred to mapping software for analysis and display. Although simple 2D (distance and elevation) transects across areas of interest can be made, this system can also generate 3D maps from regular or random grids of data points. Such maps can be digitized and overlain on aerial photography images to produce digital elevation maps and change analysis can be used to measure changes to landforms over time.

The total station system consists of an electronic instrument stabilized on a leveled tripod and a reflecting mirror affixed to the end of a graduated stadia. The total station uses infrared light to measure the distance and angle from instrument to reflector, then calculates the relative position and elevation. The total station position needs to be referenced to an established benchmark. The users manual should be consulted for calibration and other procedures specific to the instrument employed.

In addition, newer real-time kinematic (RTK) GPS technology is a useful means of establishing benchmarks. The method two GPS receivers are linked via a radio connection. The base unit is stationary and the mobile unit is used to make position and elevation measurements. This technique is advantageous in that measurements are made rapidly and only one individual is required. One drawback is that there may be reception problems in many areas; especially areas with heavy tree or shrub cover.

For bathymetry, surveys can be conducted in shallow water (<1 m) using the techniques described for topographic surveys. For deeper water areas, a GPS-referenced sonar will be required.

ADDITIONAL INFORMATION:

Total Station: http://www.usace.army.mil/usace-docs/eng-manuals/em1110-1-1005/toc.htm

Real Time Kinematic (RTK) GPS: http://www.usace.army.mil/usace-docs/eng-manuals/em1110-1-1003/toc.htm

LiDAR: http://www.ghcc.msfc.nasa.gov/sparcle/sparcle_tutorial.html

4.4 Protocol for Assessing Landscape Features

PURPOSE

Aerial photography and photo points are key tools for conducting quantitative measurements and qualitative assessments of landscape features at monitored sites. It is important to document the spatial changes in geomorphological features (such as tidal channel evolution or intertidal area) and vegetation communities (for example agricultural meadow versus emergent marsh) at a site scale to complement less extensive statistical sampling. Full color or near infrared aerial photographs are often publicly available through governmental agencies, and provide a low-cost alternative for evaluating environmental change without image-analysis software and remote sensing expertise. If funds and expertise are available, hyperspectral or multispectral satellite imagery or digital aerial photography can provide additional information at a higher resolution.

GOAL

To quantify project-wide changes in landform and vegetation patterns accompanying restoration.

DESIGN

Prior to restoration, aerial photos should be analyzed to identify hydrological barriers, to establish baseline vegetation conditions, and to make preliminary selections of sampling transects, locations for datalogging instruments (Protocols 1 and 2: Hydrology and Water Quality), and reference sites. Photos documenting historical conditions (i.e., prior to land use changes) are also useful for project design. After restoration actions are implemented, new aerial photographs must be acquired in order to assess changes in geomorphological features and vegetation communities.

Imagery Specifications

Aerial imagery needs to show sufficient detail to identify features of interest (e.g., 1 meter resolution) and should be full color and/or near infrared. Tidal stage, time of day, and seasonality are also important factors to consider. These conditions should be as similar as possible in all imagery, yet this may be difficult due to weather conditions and other factors. Recommendations depend on the main purpose of analyses. For example, low water at spring tide can expose landforms and vegetation, while high water can document the extent of tidal inundation or channel development. Morning or afternoon increases contrast. Late summer season maximizes vegetation growth and has a better chance of favorable weather in the Pacific Northwest.

Using aerial photos to plan monitoring sites

Interpretation

Interpretation of the acquired imagery can be conducted "manually" by digitizing polygons using a GIS platform. This method requires ground-truth data to evaluate the photos and determine where polygons should be drawn. Key elements of ground-truthing imagery include collection of GPS data with corresponding photos of the vegetation and geomorphological features at each point, line, or polygon.

Change Analysis

GIS techniques may also be employed to quantify changes in areas of landform and vegetation type. Polygons of vegetation classes and tidal channel locations are developed from interpretation of the imagery. These vegetation polygons can be evaluated to determine the area of each classification and the change in area over time. For example, tidal channel polygons can be evaluated to assess the amount of marsh area that is accessible via the channels, channel order, and channel sinuosity.

Photo Point Monitoring

The essence of photo point monitoring is consistency. Photo point monitoring requires little more than a camera, measuring and marking tools, and a map. Some important considerations include exact replication of the center point of the photograph, angle, and degree of zoom. Photo points are best permanently marked with PVC or rebar. Using the same camera also increases consistency. Periodicity depends on sampling objectives, i.e. comparing seasonal differences or annual variability.

EQUIPMENT

1. If publicly available aerials are insufficient, overflights of target sites may be arranged through commercial venders. Ideally, large areas of the CRE can be acquired during one flight, thus maximizing coverage and providing cost efficiencies.
2. Desktop analysis requires GIS.

SITE SELECTION

Reference and impact sites need to be imaged concurrently.

SAMPLING PERIODICITY

The frequency of acquisition is often a balance between sampling objectives and costs. For example, publicly available imagery is often flown at long intervals relative to restoration project development (e.g., once every 5 years). More frequent acquisition may be necessary to document periods with high rates of change such as the period immediately following implementation of restoration actions.

SAMPLING PROTOCOL

Step 1. *Before*

A. Obtain aerial photos of reference and impact sites.

B. Examine photos for barrier locations.

C. Assess vegetation patterns.

D. Plan location of random or stratified sampling grid.

Groundtruthing digital aerial imagery in a Columbia Estuary wetland

E. Collect GPS coordinates and corresponding photographs to ground truth landform and vegetation patterns.

Step 2. *After*

A. Obtain aerial photographs of reference and impact sites.

B. Examine photos for barrier locations.

C. Assess vegetation patterns.

D. Plan location of random or stratified sampling grid.

E. Collect GPS coordinates and corresponding photographs to ground truth landform and vegetation patterns.

F. Compare before and after images of reference and impact sites for changes in landforms and vegetation using GIS.

CALCULATIONS & ANALYSIS

GIS-based measurements:

A. Total restoration project area

B. Width, sinuosity, density, and total edge of tidal channels

C. Area and configuration of landforms and vegetation.

ADDITIONAL ANALYSIS TOOLS

Digital imagery coupled with ground truthing may be analyzed using GIS to quantify the progress of restoration. With multispectral imagery and ground-truth data, algorithms can be developed to identify pixel values in an image. Those pixel values are then applied to the whole image to get a classified representation of the site. This kind of image classification provides a spatially accurate method of determining broad vegetation categories and location of tidal channels that is not subjective and is repeatable in subsequent years.

In addition, LiDAR information available for selected areas of the Estuary can identify landscape features at a very high resolution. Examples of such features include topography, drainage signatures, and large woody debris. These data sets are important to correlate with monitoring attributes related to water elevation, passage barriers, and tidal channel edge.

ADDIONAL INFORMATION:

http://www.microimages.com/getstart/pdf/hyprspec.pdf for hyperspectral imagery.

4.5 Protocol for Assessing Vegetation Changes Resulting from Tidal Reconnection

PURPOSE

Tidal reconnections usually result in substantial changes in the species abundance and distribution of vegetation (Cornu and Sadro 2002; Roman et al. 2002; Thom et al. 2002). Vegetation is recognized as a key indicator of ecological conditions in a restored environment (Zedler et al. 2001; Rice et al. 2005), and floristic measurements can be used to document plant succession following the implementation of restoration actions. Native estuarine plant communities have both structural and functional effects on estuarine ecosystems, although we concentrate here only on structural elements. We encourage measurements of functional benefits (i.e., primary productivity); while equally important, these are often more labor intensive to measure. To measure vegetation changes, we advocate georeferenced surveys that can be integrated with water level (Protocol 1), elevation (Protocol 3), and landscape-scale (Protocol 4) GIS data.

GOAL

Measure changes in vegetation species composition and distribution to assess successional trajectories toward reference estuarine plant communities following reconnection to tidal influence.

DESIGN

Vegetation monitoring at restoration sites in Pacific Northwest estuaries typically quantifies changes in species percent cover (e.g., Frenkel and Morlan 1990; Thom et al. 2002). We recommend that vegetation sampling be concentrated on transects proximal to expected changes – for example, near a culvert replacement or dike breach – in order to conserve resources. Information derived from measuring Landscape Features (Protocol 4) can complement this vegetation monitoring by mapping plant communities at the site scale. Sampling designs such as "systematic sampling from a random start" permit appropriate data analysis; transects are established at set intervals along an established 'baseline' with plots spaced equally on each transect with a randomly selected starting point (see image below). A subset of plots may be fixed (i.e., sampled repeatedly), to track *trends*, while others are

Vegetation sampling Baseline tape in Columbia River estuary marsh randomized anew for each sampling event to assess *status*. The location of the baseline is determined in part by site conditions, with the aim of stratifying major vegetation assemblages by elevation. Elevation gradients affect vegetation distribution at various distances from both the main channels and the riverine shore. If a considerable elevation gradient is present at the site, multiple baselines may be required to encompass the variability of communities present at different elevations. Plot size varies depending on dominant vegetation at the site (e.g., forested wetland versus marsh).

EQUIPMENT

- **A.** *Field*: 1m^2 quadrat, plant identification book, bags for unidentified plant collection, 100m-meter tapes, site map, rebar or PVC stakes, mallet or hammer.
- **B.** *Lab* Digital Orthophoto Quads (DOQs), ArcView (if available)

SITE SELECTION

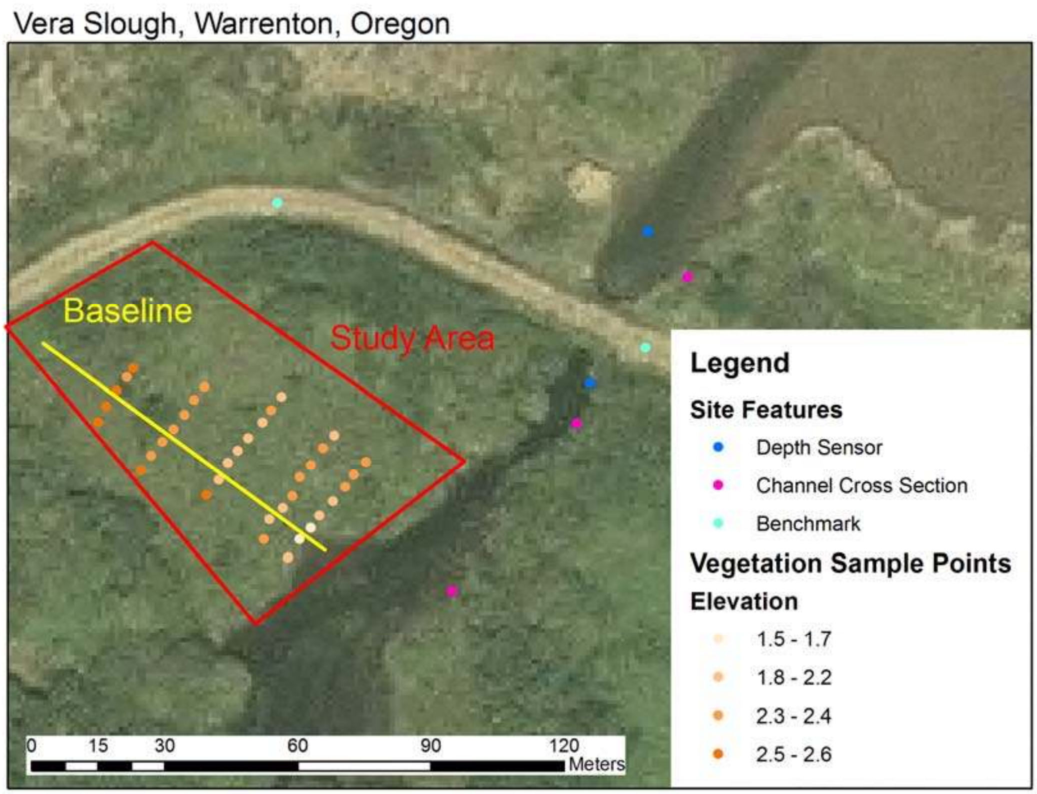
- **A.** A site is selected proximal to the proposed restoration action (e.g., dike breach), and the site is defined by the extent of inundation expected or by the focal area where the primary change in vegetation is expected to occur.
- **B.** A linear baseline is established that is oriented perpendicular to the elevation gradient and that runs through the entire site. The baseline should by representative of the vegetation community within an elevation gradient at the site and proximal to the proposed restoration action (e.g., dike breach). Multiple baselines can be chosen to systematically represent different vegetation communities.
- **C.** Several transects are established at intervals perpendicular to baseline. The position of the first transect is chosen at random from all possible points along the baseline. The additional transects are equally spaced relative to the first transect (e.g., 5 transects at 20-m intervals along a 100-m baseline).
- **D.** For each transect, monitoring plots (1 m^2) are established at equally spaced intervals depending on size of site. As with the positioning of the transects along the baseline, the plots are spaced relative to the first plot, which is positioned at random along the transect. Typically 5 to 10 plots per transect are sufficient to adequately sample the cover of the vegetation.

SAMPLING PERIODICITY

If possible, sampling should occur at least once before restoration treatments and the year following restoration. Subsequent sampling can be conducted at 1 to 3 year intervals for 5 to 10 years to capture the major transition in vegetaion communities. With limited resources, it is best to sample vegetation in mid-summer to capture the period of greatest biomass and cover, although sampling in both spring and late summer generally increases the number of species found on the site.

SAMPLING PROTOCOL

The protocols for sampling are necessarily different for herbaceous, shrub-scrub, and forested wetland communities, because of the horizontal and vertical scales appropriate for capturing variation within and between them.



Example of Vegetation Sampling Design on Diked Wetland

Herbaceous Vegetation Communities

Step 1.

Define Study Area boundaries (see example above) based on extent of expected inundation and proximal to the proposed restoration action.

Step 2.

Use aerial photos to broadly characterize existing plant communities (e.g., herbaceous, shrub/scrub, forested).

Step 3.

Establish baseline(s) based on broad plant communities and elevation strata. Mark baseline endpoints with permanent stakes (e.g., rebar or PVC) and record GPS positions.

Step 4.

Establish transects at intervals according to table below relative to length of baseline.

Baseline Length (meters)	***Number of Cross Transects***
>50	3
50-100	5
100-200	10
200-300	15
>300	20+

Step 5. Select plots along each transect (5-10 plots per transect are often sufficient). The total number of plots is dependant on the size and homogeneity of the area.

Step 6. Measure species cover for each plot using the following techniques:

- **A.** 1m^2 quadrat for percent cover of herbaceous layer.
- **B.** Visually estimate percent cover in 5% increments, using a "trace" category for species that cover less then 5% of the area within the quadrat (e.g., 25% *Carex lyngbyei*, 50% *Phalaris arundinacea*, 25% *Typha latifolia*).

Step 7. Using a random number generator, establish a subset of approximately one-third of the total number of plots to be permanent plots. These plots will be resampled each year. Mark the four corners of each permanent plot with 4-6 foot, 3/4-inch PVC pipe driven to at least a depth of 3 feet. Flag the pipe, so that it can be easily identified from a distance, and record GPS positions.

Step 8. Repeat sampling protocol design at reference site.

Shrub/Scrub and Forested Vegetation Communities

The sampling methods for these community types are much less defined in the literature and are still under development by many organizations in the Pacific Northwest at this time. For these reasons we are recommending some parameters that are important to measure, but are not outlining a specific step-by-step protocol. Conditions in these systems are challenging at best, making many measurements difficult and time consuming. Each situation needs to be considered individually for hazards and feasibility.

Shrub/Scrub Wetland Measurements

Plot size: 3-m radius from a center point

Measurements: Identify species.

Count number of individual stems of each species.

Measure height of each plant of each species found.

Forested Wetland Measurements

Plot size: 10-m radius from a center point

Measurements: Identify species

Count number of trees of each species.

Measure diameter at breast height (DBH) of each tree.

Measure height of each tree.

Measure canopy cover using a densitometer.

Core trees to determine age.

CALCULATIONS & ANALYSIS

Data gathered from these protocols can then be used for the following:

A. A table with a species list containing the 1) mean cover of each species over the entire site along with the standard deviation (SD), 2) mean cover for each species along each transect plus the SD; and 3) mean total vegetation cover for the entire site plus the SD.

B. An x-y plot showing the mean cover of 1 to 3 selected species versus sampling period at the restored site.

C. A bar graph showing the mean cover with SD or 80% confidence limit bars of the selected species at both the restored and reference sites.

D. Calculation of the similarity of the species composition at the restored site versus the species composition at the reference site using the formula presented in Thom et al. (2002).

E. Correlation of dominant plant community with elevations, if elevation data are collected (Sobocinski et al. 2006)

Estimating percent cover in one meter squared quadrats in a Columbia River Estuary Marsh

REFERENCES

Cornu and Sadro 2002

Frenkel and Morlan 1990

Thom et al. 2002

4.6 Protocol for Assessing Success Rate of Vegetation Plantings

PURPOSE

The effectiveness of habitat vegetation plantings can be determined by assessing survival, overall health, and growth of the plantings through time. It is important to determine a criterion for success when monitoring vegetation plantings to ensure that the project goals are being achieved and if not, mid-course corrections should be enacted by the project manager.

GOAL

Measure percent cover of vegetation pre and post restoration.

Criterion for success: 60% tree and shrub survival of initial planting stock by year 5.

DESIGN

Monitoring design is set up to capture the range of plantings that may occur in the Columbia River Estuary from herbaceous to woody strata. To achieve statistically valid results, a random design is recommended with the understanding that it is not always achievable for a given site. Photo point recommendations are also listed to capture qualitative changes on the site over time.

Replanting at a restoration site. Credit: North Coast Watershed Council, Clatsop County, Oregon

EQUIPMENT

Field: field notebook, measuring tape, densio-meter (for percent canopy measurements), rebar stakes, GPS, camera, one-meter square plots.

SITE SELECTION

Determine overall acres of vegetation plantings in reference and site to be restored.

SAMPLING PERIODICITY: study dependent

A. Formal woody plant monitoring in years 1 and 5

B. On projects sites age 5+ monitoring occurs in summer/early fall

C. Informal woody plant monitoring is conducted on project sites, one to four years in age, not after original planting.

D. Upland herbaceous monitoring is conduc-ted in year 1 and 5 from June to July.

Step 1. Establish overall acreage of riparian plantings and mark boundaries with GPS (all four corners of site).

Step 2. Select 10 random points throughout the site, record each with GPS, and construct a 18.7-m^2 circular plot using an 2.4-m pole around each point.

Step 3. Pivot around the point with the 2.4-m pole and count all plantings under the pole (see calculations section).

Step 4. Within each plot identify species, count woody plants, and assess plant vigor.

Plant Vigor Categories

High:	Plants exhibiting remarkable growth and vigor
Medium:	Plants exhibiting moderate growth and vigor and expected to live beyond the immediate growing season
Low:	Plants expected to die within the year

Step 3. Measure height for woody species plantings.

Step 4. Estimate herbaceous cover by percentage of plot occupied for dominant and sub-dominant species.

Step 5. Establish permanent photo points of area planted and log date, location, and orientation of photo.

On Project Sites Age 5+

A. Repeat steps 2-4 above, additional measurements: diameter at breast height and percent cover using a densiometer.

B. Take four densiometer measurements at 1.4 meters above the plot center facing N, E, S, and W.

C. Record average measurement.

Informal Woody Plant Monitoring

A. Calculate average number of trees and shrubs per acre.

B. Calculate percentage of non-native weedy species by cover.

C. Identify and list weed species.

Upland Herbaceous Vegetation Monitoring: Sites Age 1 to 5

A. Use one-meter square plots and sample herbaceous vegetation at 5 plots per acre.

B. Record percent cover of vegetation within each plot.

CALCULATIONS & ANALYSIS

A. Calculate average number of plantings per plot and multiply that number by 216.65 to give the average number of plantings per acre.

Density (acres) = Average s x 216.65 = trees/acre

B. Assess success rate: 60% tree and shrub survival of initial planting stock by year 5.

4.7 Protocol for Assessing Fish Temporal Presence, Size/Age-Structure, and Species Composition

PURPOSE

The incentive for many restoration activities in the CRE involves increasing habitat for rearing and migrating juvenile salmonid ESUs listed as threatened or endangered under ESA. One measure of success in effectiveness evaluations is an increase in salmonid habitat use at restored locations approaching the reference or parallelism. Evaluating changes in community structure is the minimum parameter for effectiveness monitoring. However, we advocate conducting more intense effort and greater sampling diversity over sites, habitat types, and times. This will increase the sensitivity of collected data for each metric and provide better identification of benefits for fish resulting from restoration. Higher orders of assessment intended to evaluate enhancement for listed salmon stocks and life strategies, such as residence time, growth, and survival, necessitate broader ranges of metrics, such as food availability, food consumption, age assessment, genetic stock identification, parasite load, chemical load assessments, and mark recovery data. Ultimately, relation of fish habitat use to physical conditions such as water quality, tidal conditions, hour of day, and diurnal period will be important.

GOAL

Evaluate species composition (lowest practical taxon), fish size (fork length or total length), and temporal abundance patterns (catch/m^2 by date) in each habitat type of the area intended for restoration, in habitats of a reference area similar to that designated for restoration, and in the post-restoration area habitats.

DESIGN

The Recovery survey design should be utilized. Increased numbers of sample sites and higher frequency of sample dates will provide greater sensitivity in data analysis of fish use of restored sites. However, limitations of personnel and resources are the primary determinates for core sampling protocols. Primary data (fish/m^2) provide direct assessment of change through time and differences among reference sites. These metrics for fish sampled post-restoration can then be correlated with metrics for other physical and biological features of each habitat to determine features that provide the greatest enhancement of fish use.

Beach seining near a culvert replacement at a forested wetland

EQUIPMENT

There are a variety of acceptable gear types for sampling juvenile salmon and other fish in the CRE. Particular gear choices depend largely on the physical constraints at the sites: terrain, bottom contour, hydrography, and debris load will affect sampling gear selection and location of sampling sites. It is highly advisable to utilize the same gear at similar sites, although more than one gear type can be used at all sites (such as seines and traps). Appropriate sampling gear types include seines, fyke nets, barrier nets, and traps, as described below.

Permits-- Annually, a state fish sampling permit must be obtained from the Oregon Department of Fish and Wildlife or Washington Department of Fish and Wildlife to conduct sampling in the Columbia River and its tributaries. An Endangered Species Act permit from NOAA Fisheries must also be obtained because of the likelihood that threatened or endangered Chinook salmon and chum salmon will be captured.; additionally, naturally spawned coho salmon may soon be listed.

Ancillary Hardware & Materials—Dark-colored 20-gallon plastic garbage cans for holding containers (with 3/16 holes drilled in side for water overflow), dark colored plastic dish pan for anesthetic bath, dip net, measuring board, standardized waterproof data forms, fin clipper, plastic tissue storage vile, 70% ethanol solution, and anesthetic solution (MS 222 solution at about 50mg/l).

SITE SELECTION

Sampling site selection depends on the physical conditions necessary for the available sampling gear. Sites should be selected in each habitat type of the restoration area. Sites in the different habitat types of the reference area should be as similar as possible to those of the restoration area. It is beneficial to employ several gear types to overcome inherent biases of each sampling gear, but this may not be possible in small restoration projects. Additionally, it is best to systematically sample at established sites with the same gear type through time; in a limited sampling regime, randomizing sites and gear types will increase variability unassociated with changes from restoration.

SAMPLING PERIODICITY

The minimum frequency is 1 day/month, March thru October. Increased sampling is desirable, but this time period will encompass most salmonids residing in or passing through the estuary. As much as possible, standardize the tide cycle and time of day for all samples. Where repetitive depletion sampling in a cordoned off area (providing fish/m^2 data) cannot be accomplished, more than one site should be sampled to provide several fish/sample data points at each period and at each area of different habitat type.

SAMPLING PROTOCOL

Seines and nets of various shapes, sizes, and methods of deployment provide the simplest technology and provide a reasonably degree of reproducibility. Seine size is dependent on the width, breadth, and depth of the water body. Seines can provide estimates of fish/m^2 when combined with barrier nets or screened panels to block a channel or channel section and repetitive depletion sampling, However, seine sites must have relative uniform bottom contours and be clear of debris and boulders. Additionally, high currents diminish catch efficiency. Because of these restrictions, and depending on site characteristics, utilization of other gear types may be necessary, as described below.

Beach seines require a shoreline area with sloping beach for ease of collection. Length of the seine depends on the area to be sampled. General dimensions are: 10 to 30 m long x 2 m deep using 1- to 2-cm (stretch measure) webbing and 0.6 cm mesh bunt in the middle. Two methods can be used to fish a beach seine; pull-to-shore and semicircular hauls.

Pull-to shore haul:

Step 1. Deploy the seine parallel to and a measured distance from the shore.

Step 2. Retrieve net by pulling the two wings simultaneously to shore and crowd fish into the center bunt for capture. Area sampled is thus net length x distance from shore.

Step 3. Use a dip net to transfer fish to holding containers.

Semicircular haul:

Step 1. Anchor one end of seine at the beach, and deploy net either in a pile or stretched along shore.

Step 2. Using skiff, tow net in semicircular pattern back to shore. Haul net in from free end to anchor end, forcing fish into the bunt for capture. Area sampled is thus a half circle with radius = net length.

Step 3. Use a dip net to transfer fish to holding containers.

<u>Pole seines</u> are easily adjustable for size of area and can be utilized in many locations because of the smaller size. However, numbers of fish captured may be small. General dimensions are: up to 10 m in length and 1.5 m depth (1- 2-cm stretch measure with 0.6 cm mesh bunt in the middle). Procedure is similar to seine nets.

<u>Fyke Trap Nets</u> provide a method for sampling shallow, low-velocity tidal channels. This gear is dependent on volitional entry and water current for entrapment. Sufficient depth for sanctuary of captive fish during low water periods is necessary.

Trap netting after culvert replacement in a restoration site

Step 1. Set web tunnels (2 x 2 x 2 m long, 0.6-cm nylon mesh, with an attached fyke tunnel) at high tide in the highest order channel at a point above which the marsh channel system completely dewaters on a sampling tide.

Step 2. Attach upstream facing wings of any length with 0.6-cm mesh to act as a barrier net to deflect fish into the fyke tunnel during ebb current.

Step 3. After tidal channels drain, continue sampling in the remaining upstream pools with pole seines and dip nets. Measure the surface area of upstream channel at high tide to allow an estimate of fish/m^2.

Barrier Nets or Screened Panels are used in conjunction with traps and nets to close off all or portions of a sampling area to control entry and exit of fish (for greater precision of fish/m^2 calculation). Nets and panels are constructed of 1- to 2-cm webbing (of sufficient length and depth for the site) bordered with corkline and leadline or solid framework of any desired construction materials. Use in conjunction with seines and fyke trap nets for sampling short reaches.

Step 1. Deploy to completely enclose one section of the channel. Measure area of channel enclosed.

Step 2. Collect fish with each seine sweep through the channel until the catch approaches zero (depletion sampling). Catches should show an exponential decay pattern with increasing sweep number, allowing estimation of fish densities (fish/m^2 in the cordoned off reach).

Center Pit Traps and Dipnets can be employed in marsh areas not accessible by boats and too shallow for seines where small fish inhabit shallow water (marsh areas) and cannot be otherwise captured. Brown plastic dish pans make an appropriate pit trap.

Step 1. Bury traps flush with marsh surface at low water.

Step 2. Allow tide to rise and fall. Fish are passively collected during ebb tides from either pit traps or natural impoundments using dip nets.

SAMPLE PROCESSING

After collection of fish by each of the gear types used at each site sampled, transfer (dipnet) the catch into a darkened and covered holding container—ensure that the water quality (especially dissolved oxygen) of the holding container is maintained near river conditions throughout the duration of processing. If the numbers of fish are too large and must be subsampled, crowd the fish into an area sufficiently small to limit stratification of different sizes and species. Using a dipnet, catch a subsample of fish collected from bottom to top from the center of the holding area. Place the fish into anesthetic solution (MS 222) until fish become lethargic and loose equilibrium. Identify species and individually measure fork-length of salmonids (tip of snout to center of fork in caudal fin) and total length (tip of snout to end of caudal fin) of other fish. Place the measured fish into a holding container for recovery from anesthetic, maintaining water quality, prior to re-introducing the fish back to the river. Continue the subsample/processing procedure until 100 of the most prevalent fish have been processed then count and release remaining fish back to the river. If depletion sampling is conducted to obtain fish/m^2 estimates, sample two times, hold each sample separately and do not release fish until sampling is complete or release recovered fish outside the cordoned off area.

Fish identification to species if practical may be assisted with guides and keys available for this region: McConnell and Snyder 1972; Scott and Crossman 1973; Carl et al. 1977.

Field assessment of salmon stock identification is impractical because few fish will be marked. Marks encountered will generally be Coded Wire Tags (requiring an expensive detector and sacrifice of fish for identification), and Passive Integrated Transponder tags (requiring an expensive detector). However, tissue samples (1/2 of one pectoral fin) can be collected from up to 30 Chinook salmon each sampling period and placed in plastic vials with 70% ETOH and labeled with date, time, location, species, and size.

CALCULATIONS & ANALYSIS

1. Catch: Absence/presence is minimum metric. If possible calculate fish /m^2 by species.

2. Size frequency and length weight relationships. Compute mean and standard deviations by species for each date sampled.

3. Measures of fish community structure (diversity, evenness, dominance).

For restoration projects with extensive resources, increased sampling efforts and assessment protocols will provide estimates of enhanced fish production such as growth, residence time, feeding rate, and food resources.

See Seber and LeCren (1967) for statistics on two-sweep depletion method.

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Appendix B

Grays River Watershed Cumulative Effects

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Grays River Watershed Cumulative Effects

By Chris May, Ph.D.

Introduction

As part of a BPA-sponsored watershed assessment of the upper Grays River watershed, Battelle contracted Herrera and Associates to complete a geomorphic assessment of the watershed. This appendix summarizes the results of that assessment. Although this discussion applies specifically to the Grays River, there are several common "lessons-learned" that may be applicable to other Lower Columbia River sub-basins.

Since non-native people began settling the lower Columbia River (LCR) region approximately 150 years ago, modifications of river channels, floodplains, and riparian corridors has been a common feature of the landscape. Anthropogenic alterations include dredging, construction of dikes and levees, drainage ditch construction, stream channelization, wetland draining and filling, beaver dam/pond removal, floodplain agriculture and development, riparian forest removal, and dam building/operations. In addition to these direct impacts, upland land uses such as timber harvest, agriculture, and development have resulted in indirect impacts to the environment. As a whole, these human land-use activities have resulted in significant cumulative impacts on aquatic ecosystems and the natural processes that create and maintain these systems. In riverine ecosystems, these cumulative impacts are mainly associated with agricultural activities and other land uses (e.g. roads, residential development, and commercial-industrial activities) that displace floodplains, off-channel wetland habitat, riparian areas, and estuarine habitat. Forestry activities are typically concentrated in the upper watersheds of LCR tributary rivers and streams. Timber harvest and forest road construction in the upper watershed areas can contribute to the degradation of downstream habitat through the alteration of natural processes. An altered hydrologic regime, elevated sediment loads, and reduced large woody debris (LWD) abundance are the main downstream impacts of upland forest-management land-use activities.

Background

In natural forested watersheds of the LCR region, the hydrologic regime is driven by precipitation patterns, vegetation, and soils. Sediment production is a result of hillslope mass-wasting events (e.g. landslides and debris flows) and instream processes including streambank erosion, flooding events, avulsions, and channel migration. Recruitment of LWD and other organic material also results from these same hillslope and instream processes, as well as from windthrow and blowdown events. Woody debris deposited in streams by debris flows or other hillslope processes typically forms jams or dams within the upper watershed channel network. These natural features can create persistent, long-term instream sediment storage "nodes" within the river channel-floodplain system. Debris jams and dams also provide significant instream habitat complexity. In addition, debris jams and LWD dams tend to inhibit downstream propagation of sediment pulses. Furthermore, instream LWD and debris jams typically result in the creation of steps in the channel profile and terraces on the floodplain or valley floor. These features can persist in place even if the LWD is lost due to washout or after long-term decay. The role of LWD and debris jams also changes over time as the river channel evolves and the active channel locations shift (Montgomery et al. 2003).

Channel islands are common riverine features that are created by LWD deposited within the active channel. Instream LWD and debris jams also play a significant role in the creation of side channels and other habitat features located on channel margins. Finally, debris jams are one of the primary causes of channel avulsions and the anastomosing pattern found in many river systems (Montgomery 1999; Abbe and Montgomery 1996; Collins et al. 2002; Montgomery et al. 2003).

In large part, upstream processes control the hydrology and sediment loading of downstream reaches of a river system. Instream LWD and debris jams naturally control sediment output to downstream reaches. In natural systems, sediment output tends to be relatively steady and generally shows little evidence of large, episodic inputs (Leopold et al. 1964). Abundant instream LWD plays a key role in moderating sediment flux from upstream sub-basins when natural hillslope mass-wasting and debris-flow events do occur. On the other hand, landslides and debris flows that occur in areas with a lack of abundant LWD, such as is the case in watersheds impacted by long-term timber harvest activities, often result in more frequent and larger episodic sediment flux to downstream channels and habitat features (Abbe and Montgomery 1996).

Debris jams and instream LWD deposited on the floodplain and in the lower reaches of river systems also contributes structure and function to the river ecosystem. LWD jams are frequently instrumental in creating the braided, multi-channel morphology common to many rivers. LWD jams also promote and regulate channel avulsions and floodplain sloughs. Sediment storage also continues to be a functional attribute of debris jams in the lower reaches of rivers, including estuarine areas. Very large, “key” pieces of LWD are especially important in larger rivers. These key pieces of LWD trap smaller debris and form jams, eventually creating forested islands within the river channel complex. It is generally accepted that these reforested floodplains can develop from naturally recruited LWD jams within 50-100 years (Collins and Montgomery 2002). LWD and debris jams are also ecologically important in rivers that are characterized by a single, meandering channel. In these systems, debris jams provide habitat complexity, create and maintain off-channel habitat, and provide streambank protection (Collins et al. 2002).

Grays River Overview

The Grays River watershed is located within Wahkiakum, Pacific, and Lewis counties in the southwest corner of Washington. The entire Grays River watershed encompasses 322 square kilometers (km^2). The upper Grays River watershed totals 230 km^2. The delineation between the upper and lower watershed is based on the upper extent of tidal influence and is typically defined by the intersection of the main stem Grays River with State Highway 4, located approximately 18.5 km upstream of the Columbia River (see Figure 1). The highest elevation in the watershed is 820 meters. The lower main stem of the Grays River is tidally influenced from approximately State Highway 4 to the point where it enters Grays Bay on the lower Columbia River.

The upper Grays River watershed has been extensively logged over the past 150 years. Land-use activities in the upper watershed (timber harvest, road construction, agriculture, and dike construction) have resulted in landslides, erosion, and channel instability, and the loss of riparian function, which have caused serious damage to salmon spawning habitat and have been largely responsible for the decline in chum stocks (Washington Conservation Commission 2001; WDFW 2001; LCFRB 2003). Currently, most dikes and levees are located in the lower Grays River Valley (e.g. downstream of the SR-4 bridge). However, there are several areas dikes/levees that are located within the Gorley (depositional) reach upstream of the bridge. These dikes and levees are having a significant influence on sediment transport and channel migration throughout the lower river system. In general, disconnecting the river from its floodplain by constructing dikes or levees reduces the opportunity for dissipation of flow energy and the deposition of sediment onto floodplain areas.

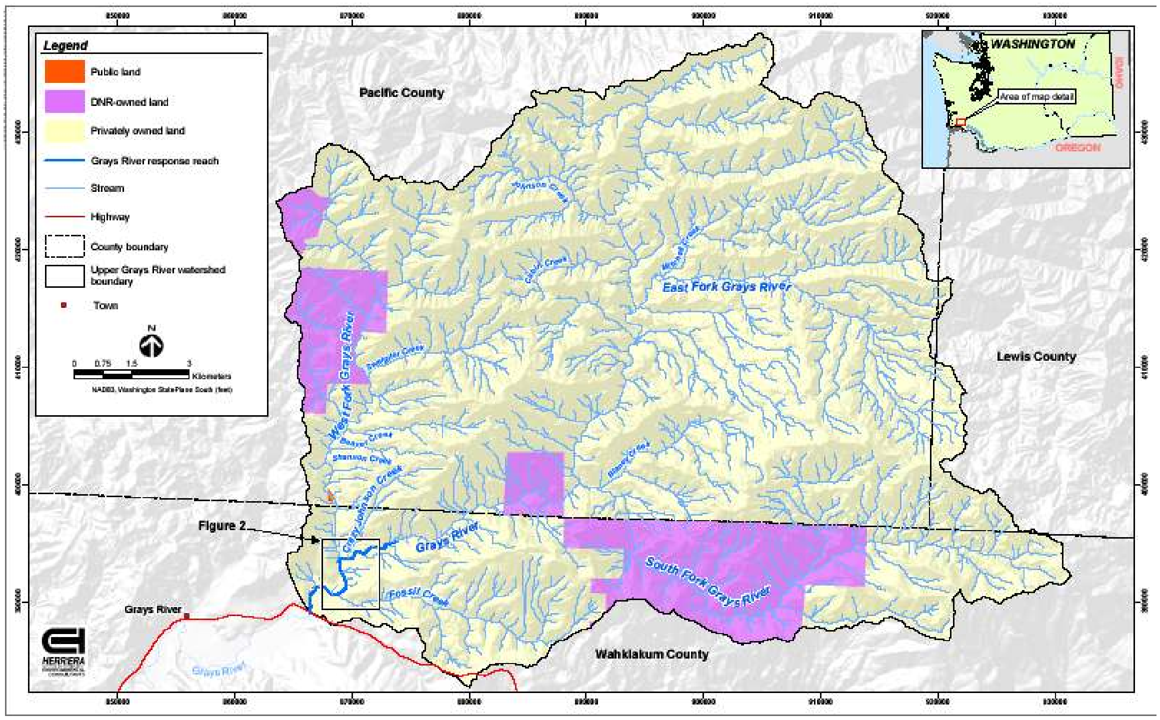

Figure 1. Upper Grays River Watershed – Land Ownership

Steep mountainous uplands, moderately sloping hills and ridges, and unconfined alluvial valleys characterize the topography of the watershed. The main stem and tributary forks of the Grays River form a channel network fed by a dendritic pattern of headwater channels, particularly in the northeast portion of the watershed. Tributary channels are typically steep and confined, whereas the unconfined valley segments occupy broad floodplains.

Eocene marine sedimentary rocks (primarily siltstones and sandstones) overlie the Crescent Formation and occur along an east-west-trending band in the upper watershed. Marine sediments are also found in the lower half of the West Fork Grays River watershed. The southern half of the watershed is underlain by younger Eocene basalt flows and flow breccias. These rocks occur in sub-basins of the South Fork and the middle reach of the main stem Grays River. The contact between the Eocene basalt and marine sediments is associated with an abrupt change in the valley morphology of the main stem Grays River. The Grays River is confined within a narrow valley where it cuts through relatively hard basalts, whereas the river occupies a wide alluvial floodplain downstream where it encounters softer marine sediments. Recent alluvium covers the basement rocks in all of the major river valleys. The most extensive deposits are mapped in the lower Grays River main stem below the contact with the marine sediments and basalt. Older alluvium forms terraces above the floodplain of the lower main stem. Mass-wasting deposits occur throughout the upper Grays River watershed.

Sediment production from hillslopes begins with the chemical and mechanical weathering of bedrock to create colluvium and soil. The rate at which colluvium is produced is dependent on the regional tectonics, bedrock lithology, precipitation, ambient temperature, and vegetation. Much of the bedrock exposed at the surface within the Grays River watershed is highly weathered and prone to erosion where vegetation has been removed. Hence, the watershed has the potential to yield large quantities of sediment. In the past, dense forests that once mantled the watershed moderated both the production of sediment from hillslopes and the routing of sediment through the channel network. Colluvium produced from the weathering of bedrock is transported downslope by soil creep, surface runoff, and mass wasting. Mobilized sediment either is deposited at the base of slopes or enters the channel network where it is routed downstream by fluvial processes.

A “response” reach is located just downstream of the constrained canyon-reach and upstream of the tidally influenced lower mainstem Grays River. Within the channel network of the upper watershed, the Grays River response reach is of particular interest because of its historical and potential future value as salmon habitat and because it is sensitive to disturbances resulting from upstream changes in land-use activity. Recent instability (e.g., the 1999 Gorley reach avulsion) exhibited within the Grays River response reach indicates that the hillslope condition and channel processes within the upper watershed have likely been significantly affected by widespread timber harvest activities (Herrera 2005).

The Grays River watershed receives heavy rainfall from moist frontal systems originating in the Pacific Ocean. Precipitation records have been recorded at the WDFW Grays River fish hatchery since 1962. Approximately 77% of precipitation falls during the winter months from October through March. Annual precipitation measured at the hatchery for the period 1962 to 2004 ranged from 191 to 346 centimeters (cm), with a mean of 279 centimeters. Precipitation increases with elevation in the watershed, from approximately 200 centimeters near the mouth of the Grays River to 300 centimeters in the upper watershed.

Grays River Timber Harvest

Timber harvest is the principal land use in the upper Grays River watershed. Approximately 95% of the watershed is privately owned industrial forestland. The Washington Department of Natural Resources (WDNR) owns the remainder of the land in the upper watershed. Historically, the watershed was dominated by old-growth Sitka spruce, Western hemlock, and Douglas fir. Currently less than 2% of the original old growth forest remains and a dense network of forest roads covers the watershed.

Forest clearing and the associated construction of roads have been shown to significantly affect a variety of landscape processes including watershed hydrology, sediment production, and the morphologic characteristics of stream channels (Megahan and Kidd 1972; Montgomery 1994; Jones and Grant 1996). Swanson and Dyrness (1975) found that timber harvest and road construction appear to have increased landslide activity on road and clear-cut sites five-fold relative to forested areas over a period of about 20 years. Furniss et al. (1991) reviewed nine studies providing estimates of landslides resulting from various sources and found that slides and sediment yield from logging roads were greater than all other forest activities combined, and that these activities resulted in sediment yields 26 to 346 times greater than undisturbed sites. Reid and Dunne (1984) reported a 40% increase in fine sediments from gravel-surfaced logging roads, which were heavily used by logging trucks.

The increased sediment production that results from timber harvest can significantly affect downstream channel processes. A variety of potential channel responses following changes in sediment supply are dependent on channel confinement, sediment transport capacity, slope, and roughness elements (Montgomery and Buffington 1997). Stover and Montgomery (2001) found that channel aggradation and flooding on the main stem Skokomish River followed timber harvesting, road construction, and in-channel debris removal. Additional channel instability results from the harvest of riparian forest vegetation. Micheli et al. (2003) found that unforested, agricultural floodplains are likely to erode twice as fast as forested floodplains. Further, the harvest of riparian vegetation removes the most immediate source of large woody debris, which provides channel stability and habitat complexity and also effectively traps bed material and stores large volumes of sediment (Massong and Montgomery 2000; Lancaster et al. 2001; Abbe and Montgomery 2003).

The history of timber harvest activities within the Grays River watershed is described in detail by Scott (2001). Harvest rates and rotation are summarized in Table 1. This data reflects timber harvest activities mostly in the upper watershed and not on the lower floodplain portion of the river. The lower river valley was almost completely cleared for settlement and agriculture by 1905 when full-scale commercial timber harvest began.

Commercial timber harvest began in the Grays River watershed in 1905 within a land lease located in the central portion of the watershed. Prior to 1942, the average harvest rate was 3.0 km^2/year, or approximately 1.3% of the watershed per year (Table 1). By 1942, approximately 8 percent of the upper watershed had been harvested. Timber harvesting continued at a rate of about 3.3 km^2/year between 1942 and 1953 during expansion of activities into the eastern and northern portions of the study area. Widespread use of roads in harvesting operations began in the 1950s (Scott 2001).

The harvesting of second-growth forest had begun by 1953. Harvest operations expanded throughout the study area and increased to 5.0 km^2/year between 1953 and 1964. During this period (1953 to 1964), the fraction of remaining old growth declined from 59 percent to 39 percent. The period between 1964 and 1976 marked expansion of harvest practices to the northeast portion of the Grays River watershed. During this period, the average harvest rate was 5.3 km^2/year. By 1976, only 18 percent of the original old-growth forest in the watershed remained (Scott 2001).

Between 1976 and 1983, timber harvest rates peaked at 9.1 km^2/year, or 4 percent of the watershed per year, and included the logging of some third-growth forest. Over 95% of the old-growth forest within the Grays River watershed had been harvested by 1983. Annual harvest rates declined thereafter to 5.5 km^2/year between 1983 and 1990, 4.1 km^2/year between 1990 and 1996, and 3.1 km^2/year between 1996 and 2003. About 2%, or 4.6 km^2 (1,137 acres), of the original old-growth forest remained as of 2003 (Scott 2001).

Table 1. Summary of Forest Clearing in the Grays River Watershed (Scott 2001)

Period	Average Harvest Rate (km^2/year)	Total Percentage of Upper Watershed Harvested	Percentage of Harvest Area by Stand-Age Category		
			Old Growth	Second Growth	Third Growth
1905–1942	3.0	8.2	100.0	0.0	0.0
1942–1953	3.3	19.1	94.4	5.6	0.0
1953–1964	5.0	40.7	97.0	3.0	0.0
1964–1976	5.3	73.6	93.2	6.8	0.0
1976–1983	9.1	88.9	83.3	15.7	0.5
1983–1990	5.5	94.4	40.0	58.0	2.0
1990–1996	4.1	97.6	20.1	77.4	1.5
1996–2003	3.1	98.9	0.0	95.0	5.0

Grays River Geomorphic Assessment

The Grays River mainstem has been significantly altered from its natural condition by accelerated sediment supply stemming from historical land use practices (timber harvest and logging road construction) within the upper Grays River watershed and by the construction of floodplain levees in the middle and lower river (Herrera 2005).

Land use practices that alter transport capacity and sediment supply can initiate channel responses through changes in the response variables. Response segments generally have alluvial channels and floodplains but can include bedrock channel segments that periodically store alluvium (in which case there is typically some evidence of periodic sediment storage such as alluvial floodplains or terraces). The larger the size and number of channel response segments, the greater the moderating effect on sediment flux downstream through a basin. Wood debris not only can act as a significant grade control element limiting incision but also can be very effective at trapping bed material and storing large volumes of sediment (Abbe and Montgomery 2003). Response reaches, however, can also be converted to transport reaches when wood debris and riparian vegetation are removed or discharge increases. A reduction in the number and effectiveness of response reaches would result in greater sediment discharge to the lower main stem of the Grays River. Potential responses to land use practices are summarized in Table 2.

Results of the geomorphic assessment indicate that the mainstem of the Grays River is in a state of dynamic adjustment to the altered sediment regime and channel confinement by levees. The mainstem begins at a point of reduction in channel gradient at the transition from the moderately confined bedrock canyon (e.g. response reach) and includes the tidally influenced reach between the State Highway 4 bridge and the Columbia River. The reduction in transport capacity at this break in slope at the canyon outlet, combined with the transition to an unconfined channel type, makes the middle and lower mainstem particularly sensitive to increases in sediment supply (Herrera 2005). This is especially true for the response reach of the Grays River (RM 18.5 to 22.5).

Because fluvial systems are typically threshold-dominated, the response to cumulative effects can be abrupt when threshold conditions are exceeded (Leopold et al., 1964). The 1999 avulsion represents the most significant historical response of the mainstem channel to date, but events of similar magnitude are likely to continue and progress downstream as sediment stored in this response reach is transported downstream to Highway 4 and into the lower mainstem (Herrera 2005).

An assessment of mass wasting and surface erosion in the upper Grays River watershed indicates that the majority of sediment supplied to the channel network is generated by mass-wasting processes brought about by a combination of timber harvest activities on steep, unstable slopes and road construction and road use associated with timber harvest operations. The sediment loading to the river system appears to be at least an order of magnitude greater than the natural, background levels found in undisturbed, forested watersheds of the region (Herrera 2005).

Based mostly on the temporal relations among timber harvest activities and landslide frequency, sediment yield to the channel network appears to lag behind harvest operations by approximately 25 years. For example, the increase in the harvest rate in the 1950s (see Table 1) corresponds to an increase in sediment yield through the late 1970s. Likewise, the relatively stable harvest rate through the 1960s corresponds with only moderate increases in sediment yield in the late 1980s. The sharp increase in harvest rate in the 1970s is also followed by an increase in sediment yield in the late 1990s (Herrera, 2005).

Table 2. Summary of channel response to land use practices (Herrera 2005).

Disturbance	Change	Potential Channel Response
Upland forest clearing	Increase in sediment supply to stream	Aggradation/sedimentation
		Channel widening
	Increase in discharge to stream	Channel incision and widening
Riparian forest clearing and agricultural conversion	Destabilization of banks	Channel widening
	Increase of local sediment supply	Accelerated channel migration
	Reduction in functional wood debris recruitment	Channel sedimentation, increased sediment storage
		Decrease in channel complexity, reduction in roughness
		Increase in turbidity
Roads	Increase in fine sediment production	Infilling of coarse bed sediment with fines, reduction in bed-surface grain size, and roughness
		Increase in turbidity
	Increase in drainage density	Channel incision and widening
Channel clearing	Increase in stream gradient	Down-cutting, incision, and head-cuts
		Channel simplification, reduction in roughness
		Bank destabilization, increase in sediment supply
		Initial channel narrowing followed by channel widening

Field observations indicate that large quantities of sediment are currently stored in headwater transport reaches and tributary floodplain areas of the upper river. The lag time between sediment yield and delivery to response reaches will depend on the distance from the source, as well as transport rates and sediment capacitance (storage potential) within the intervening channel network. Based on an assumed harvest rate and lag time, sediment yield to the channel network should reach a maximum of approximately 290,000 tons/year in 2005 and decline to approximately 24,000 tons/year by 2025, but remain approximately 85 percent higher than the background erosion rate of 13,000 tons/year typical of forested watersheds in the region. The elevated erosion rate is attributed to sediment yield from mass wasting (landslides) and surface erosion from the road network associated with logging operations (Herrera 2005).

Temporal trends in channel form in the mainstem Grays River also provide information on the lag time between sediment yield and the supply of coarse sediment to the mainstem. Changes in channel form have been significantly influenced by floodplain modifications and levee construction. Both sinuosity and bend curvature of the mainstem increased shortly after levee construction in the 1960s and then declined by the early 1980s. The decline in sinuosity may be a response to the increase in sediment yield during the 1970s. If so, this response suggests a lag time of about 10-15 years between the basin-wide increase in sediment yield and the onset of channel adjustment in the main stem channel (Herrera 2005).

When combined with the approximate 20-year lag between harvest and sediment yield, results suggest 35 years as the characteristic response time for the cumulative effects of basin-wide timber harvest to significantly affect the mainstem response reach. Significant channel adjustment is expected to continue beyond this time period, to include reaches downstream of the response reach (Herrera 2005).

This analysis does not account for the effects of climate variability on landslide frequency. The natural variability in annual precipitation between wet and dry years is on the order of 2 to 5 years, which is significantly shorter than the predicted lag times between timber harvest, sediment yield, and channel response (i.e., 25 years). The 1999 avulsion (i.e., a rapid change in channel position within the river valley or floodplain) that occurred just downstream of the Grays River canyon mouth (e.g,. on the Gorley reach) followed 6 years of above-average precipitation but also occurred after 35 years of rising sediment yield within the watershed (see Figure 2). Climate variability may provide a second-order control on channel response by mobilizing stored sediment and forcing channel change when conditions are near a threshold. The correspondence of the 1999 avulsion with the posited 35-year lag time between harvest and the onset of mainstem channel response suggests that the avulsion event was triggered by increased sediment influx combined with channel confinement by levees and the mobilization of stored sediment by above-average precipitation in the years preceding the avulsion (Herrera 2005).

Past and future timber harvest practices will continue to influence the rate of sediment yield to the Grays River channel network. The current trend of second- and third-growth harvest rotation is expected to reduce the reported 10-year lag between the loss of root strength and the peak in landslide frequency, because smaller second- and third-growth roots are typically weaker than roots of old-growth trees. However, sediment yield might decline if the frequency of harvest rotation or the overall harvest rate is reduced. The harvest rate within the upper Grays River watershed has declined since 1980, and future sediment yield to the channel network is predicted to decline as well (Figure 3). Sediment yield could also be reduced by eliminating timber harvest from slopes steeper than about 65 percent, where sediment yield from mass wasting is estimated to be 1,000 times greater than the yield on slopes less than 65 percent (Herrera 2005).

Contemporary rates of sediment production by mass wasting are not sustainable in the context of long-term soil production rates and could lead to the eventual depletion of soil on steep slopes, which in turn would severely impair timber production and other recreational and wildlife uses within the watershed (Herrera 2005). In a comparative study of debris-flow characteristics in old-growth and industrial forests, Bunn (2003) found that the sustained short-rotation harvest of headwater basins and removal of old-growth wood from headwater channels reduced soil depth on hillslopes and left headwater channels with an increased sediment flux and a consequent increase in sediment output to low-gradient response reaches.

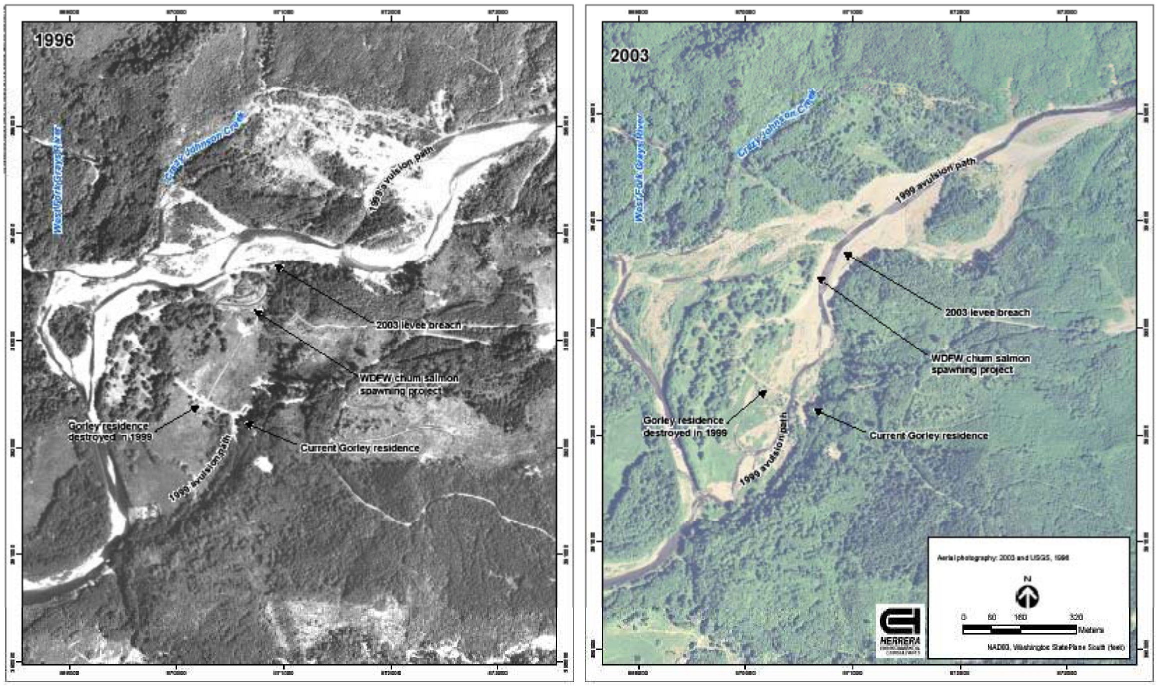

Figure 2. Grays River Gorley Reach – Pre- and Post-Avulsion

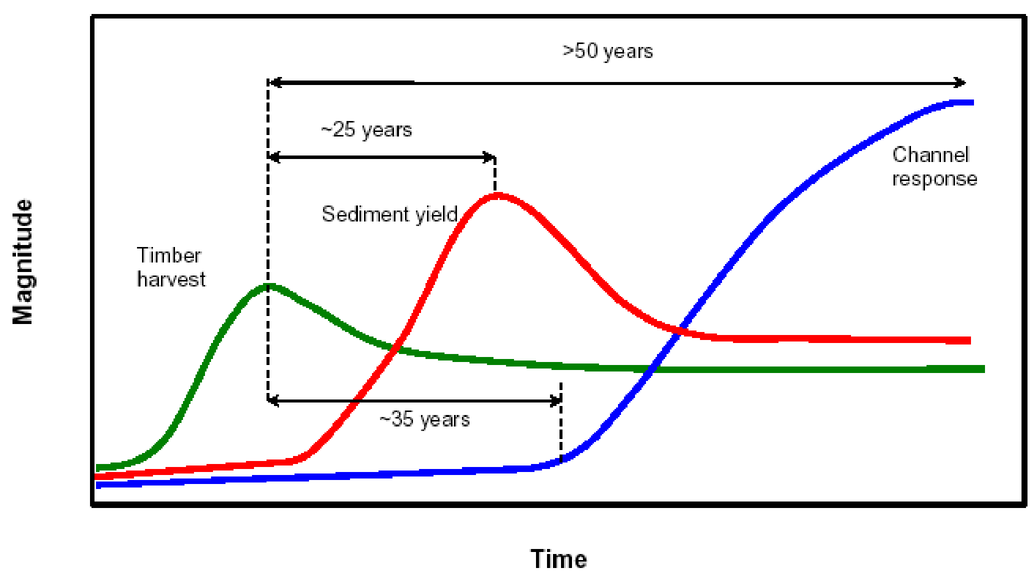

Figure 3. Conceptual Model of Temporal Trends in Sediment Yield to the Upper Grays River Channel Network and Channel Response to an Assumed Historical Timber Harvest.

Field observations in the upper Grays River watershed indicate that some hillslopes have already been stripped to bedrock by widespread mass wasting. Past timber harvest practices that removed instream wood (either by snagging or splash-damming) and stripped floodplains of large trees have severely reduced potential sediment storage sites within channels of the upper Grays River watershed by disrupting the natural, self-sustaining processes that recruit wood to channels. Past timber harvest practices not only increased the rate of sediment yield to the channel network but also accelerated the delivery of this sediment to the main stem response reach by eliminating most of the natural sediment capacitance provided by instream wood. Under these conditions, sediment storage locations within the watershed can be expected to continue to shift from hillslopes to the response reaches of the channel network over time (Herrera, 2005).

If channel response in the Grays River mainstem lags behind harvest by approximately 35 years, as predicted by the Herrera (2005) analysis, the current instability within the main stem (posited to be related to the late 1970s and early 1980s spike in the timber harvest rate) can be expected to continue and possibly increase through 2015 (see Figure 3). Response reaches throughout the watershed may be prone to continued instability and more avulsions so long as sediment supply exceeds threshold transport rates. The remobilization and routing of sediment stored within the channel network may extend this response period through the latter half of the twenty-first century (Herrera, 2005). The current decreasing trend in channel sinuosity and increasing trend in meander bend curvature are also expected to continue within the Grays River mainstem. The reduction in sinuosity and development of a multi-threaded channel visible in the 1996 aerial photograph of the Gorley reach (see Figure 2) signal a shift toward a transport-limited regime (Herrera 2005).

Confinement and straightening of the mainstem by levees increase the local transport capacity (through increases in both slope and flow depth, which in turn increase shear stress) and shift future sediment deposition and channel response downstream. Additional channel avulsions are likely to occur if measures are not taken to maintain and raise existing levees and revetments concurrently with the anticipated sediment aggradation (Herrer, 2005).

Aggradation and natural straightening of the channel are typical morphological responses to an increase in sediment loading. The local increase in slope caused by continued aggradation (as well as confinement by levees) will continue to shift the depositional front of the mainstem downstream. Aggradation is likely to occur in the mainstem at the confluence with the West Fork (WF), where there is a local decrease in slope. Backwater propagation up the West Fork would initiate aggradation in the constrained reaches (levees and dikes) downstream of the WF confluence. The reduction in channel depth that follows would increase the likelihood of an avulsion occurring. Realignment of the channel and continued downstream migration of the depositional front could trigger an additional avulsion and threaten the State Highway 4 bridge crossing (Herrera 2005).

The response to increased sediment supply is compounded by levees within the lower mainstem floodplain. In general, the levees restrict the natural tendency toward channel migration and floodplain sediment deposition. Isolation of the channel from the floodplain accelerates local instream aggradation and increases the potential for channel avulsion. Although levee construction may have initially provided short-term stability to portions of the channel and floodplain, channel confinement and floodplain isolation by the levees has forced channel adjustments to the shorter, unconfined segments of the river. Consequently, the lower mainstem floodplain may experience periods of channel stability punctuated by high-magnitude variability in channel configuration, including avulsions and channel realignment (Herrera 2005).

The observed response of the mainstem Grays River is analogous to historical channel changes in the lower Skokomish River of the southeastern Olympic Peninsula following extensive timber harvesting. Stover and Montgomery (2001) identified three phases of channel response to historical disturbance in the Skokomish River basin. The first phase of this process involved rapid channel incision following riparian timber harvesting and removal of instream wood. The second phase was characterized by fluctuations in bed-surface elevation that coincided with widespread timber harvest and road development in the basin during the 1940s and 1960s. Stover and Montgomery (2001) attributed the oscillations in bed elevation to sediment pulses moving through the channel network. The sediment pulses were linked to concurrent timber harvest activities in the upper basin and the release of sediment stored in tributaries following the harvest of riparian forests and removal of instream wood. Channel filling, increased channel width, and fining of bed sediment characterized the third phase of channel response through at least the end of the study in the late 1990s (Herrera 2005).

In contrast with results of the analysis for the upper Grays River, the onset of channel aggradation on the Skokomish began rapidly, approximately 10 years after the commencement of intense upstream timber harvesting, and continued at a steady pace through 1997, at the end of the study period. Results of the Stover and Montgomery (2001) study suggest a minimum of 50 years for the lower response reach of the Skokomish River to adjust to the influx of sediment from timber harvesting. Timber harvesting and road construction in the headwaters continue to contribute to ongoing aggradation and recurrent flooding within the Skokomish River valley.

These observations can be generalized into temporal relations among watershed disturbance, sediment yield, and channel response within the upper Grays River. Sediment yield to the channel network increases sharply above natural background levels shortly after the onset of timber harvest activities and reaches a peak that lags behind the peak harvest rate by approximately 35 years. Included in this period is the 10-year lag between harvest and peak in landslide frequency. Channel response to increased sediment yield may include aggradation, decreased sinuosity, increased bend curvature, and increased frequency of flooding and channel avulsions (Herrera 2005).

The onset of channel change may occur rapidly in alluvial reaches after timber harvest (10 years in the case of the Skokomish River), or several decades following harvest (35 years as indicated by the Grays River). The magnitude of channel change continues to increase (despite the decline in sediment yield) due to the mobilization of sediment stored within the channel network during high-magnitude storm events. This reduction in sediment storage is magnified by the removal of instream wood and harvest of riparian forests that would otherwise supply large wood to channels. Under this conceptual model, channel adjustment can continue for at least 50 years after widespread harvesting, based on data from the Skokomish study (Stover and Montgomery 2001). Channel response in the Grays River watershed is already 25 years out from the peak in harvest rate. Based on results of Stover and Montgomery (2001), channel adjustment in the lower Grays River will continue for at least another 25 years, and possibly into the second half of the century, under the current timber harvest rate (Herrera 2005).

Conclusions

The magnitude of impacts on fish habitat caused by increased sediment yield and channel instability within the Grays River mainstem response reach will be determined by the ability of restoration efforts to counteract the destructive effects of past and ongoing land use activities within the upper watershed. Rivers with high sediment loads can support productive fish populations if they contain abundant instream wood, which promotes pool formation, protective cover, substrate diversity, and channel migration into floodplain forests for self-sustaining wood recruitment (Herrera, 2005).

The impacts of elevated sediment loads on downstream, tidally influenced reaches of the Grays River include the following:

- Reduction in floodplain storage volume
- Aggradation of the lower mainstem river channel and filling of off-channel wetland areas
- Increased risk of avulsion and catastrophic flooding events
- Increase in the fraction of inorganic sediment contribution to tidal and freshwater wetlands
- Increased turbidity levels, which can reduce photosynthesis within the river and off-channel wetlands
- Degradation of benthic freshwater, estuarine, and tidal wetland habitat
- Loss of estuarine tidal channels due to aggradation.

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Appendix C

Plant Lists

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The complete list of plants found on Vera Slough and Kandoll Farm restoration and reference sites in 2005 and codes for those species used in the Cumulative Effects 2005 annual report are provided below.

Code	Species	Common Name
ACCI	*Acer circinatum*	Vine maple
ALRU	*Alnus rubra*	Red alder
ATFI	*Athyrium filix-femina*	Lady fern
CAHE	*Callitriche heterophylla*	Different leaved water-starwort
CALY	*Carex lyngbyei*	Lyngby sedge
CAOB	*Carex obnupta*	Slough sedge
CASA	*Cascara sagrada*	Sacred bark
CAST	*Carex stipata*	Sawbeak sedge
CIAR	*Cirsium arvense* var. *horridum*	Canada thistle
CISP	*Cicuta spp.*	Water hemlock
COAR	*Convolvulus arvensis*	Morning glory
COST	*Cornus stolonifera*	Red-osier dogwood
ELSP	*Eleocharis spp.*	Spike-rush
EPAN	*Epilobium angustifolium*	Fireweed
FASP	Fabacea family	Legumes
FRSP	*Fraxinus spp.*	Ash
GASH	*Gaultheria shallon*	Salal
GATR	*Galium trifidum* var. *pacificum*	Pacific bedstraw
GEMA	*Geum macrophyllum*	Largeleaf avens
GLHE	*Glecoma hederacea*	Creeping Charlie
HELA	*Heracleum lanatum*	Cow-parsnip
HYRA	*Hypochaeris radicata*	Spotted cat's ear
HYDR	*Hydropyroides*	
IMNO	*Impatiens noli-tangere*	Common touch-me-not
IRPS	*Iris pseudacorus*	Yellow iris
JUBA	*Juncus balticus*	Baltic rush
JUEF	*Juncus effusus*	Soft rush
LIOC	*Lilaeopsis occidentalis*	Western lilaeopsis
LOCO	*Lotus corniculatus*	Birdsfoot trefoil
LOIN	*Lonicera involucrata*	Black twinberry
LYAM	*Lysichiton americanum*	Skunk cabbage
LYNU	*Lysimachia nummularia L.*	Moneywort
MAFU	*Malus fusca*	Crab apple
MG	Mixed Grass	Mixed Grass
MYSP	*Myriophyllum spicatum*	Eurasian water-milfoil
OECE	*Oemleria cerasiformis*	Indian-plum
OESA	*Oenanthe sarmentosa*	Water parsley
PAVI	*Parentucellia viscosa*	Yellow parentucellia
PHAR	*Phalaris arundinacea*	Reed canary grass

PHCA	*Physocarpus capitatus*	Pacific ninebark
PISI	*Picea sitchensis*	Sitka spruce
PLLA	*Plantago lanceolata* var. *lanceolata*	Rib plantain
POAN	*Potentilla anserina ssp. Pacifica*	Pacific silverweed
POHY	*Polygonum hydropiperoides*	mild waterpepper
POHY	*Polygonum hydropiper*	Waterpepper
POMU	*Polystichum munitum*	Sword fern
PREM	*Prunus emarginata*	Bitter cherry
PRSP	*Prunus spp.*	Cherry
PRVU	*Prunella vulgaris*	Self heal
PTAQ	*Pteridium aquilinum*	Bracken fern
PTGL	*Pteridium glycyrrhiza*	Licorice fern
RARE	*Ranunculus repens*	Creeping buttercup
RIBE	*Ribes spp.*	Currants
ROSP	*Rosaceae family*	Rose family
RUCR	*Rumex crispus*	Curly dock
RUDI	*Rubus discolor*	Himalayan blackberry
RULA	*Rubus laciniatus*	Evergreen blackberry
RUPA	*Rupus parviflorus*	Thimbleberry
RUSP	*Rubus spectabilis*	Salmonberry
RUUR	*Rubus ursinus*	Trailing blackberry
SARA	*Sambucus racemosa ssp. Pubens*	Red elderberry
SASP	*Salix spp.*	Willow
SCAC	*Scirpus acutus*	Hardstem bulrush
SCMA	*Scirpus maritimus*	Seacoast bulrush
SODU	*Solanum dulcamara*	Bittersweet nightshade
SPDO	*Spiraea douglasii*	Douglas spiraea
TEGR	*Tellima grandiflora*	Fringe cup
THPL	*Thuja plicata*	Western red cedar
THSE	*Tsuga heterophylla*	Western hemlock
TRDU	*Trifolium dubium*	Small hop-clover
TRPR	*Trifolium pratense*	Red clover
TRRE	*Trifolium repens*	White clover
TYAN	*Typha angustifolia*	Narrowleaf cattail
TYLA	*Typha latifolia*	Common cattail
VAPA	*Vaccinium parvifolium*	Red huckleberry
VECA	*Veratrum calilfornicum*	California false hellebore
VIAM	*Vicia americana*	American vetch