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

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

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Executive Summary

This document describes a set of protocols developed by the National Marine Fisheries Service, the Pacific Northwest National Laboratory, and the Columbia River Estuary Study Taskforce, with the support of the U.S. Army Corps of Engineers. These protocols are designed for researchers and managers monitoring the effectiveness of actions to restore degraded wetland habitat in the lower Columbia River and estuary (CRE). The intent is to promote a standard set of monitoring protocols to assess and compare habitat restoration projects in the region.

The goal of many restoration activities in the CRE is to repair the connectivity and function of wetland habitats and thereby 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 help achieve this, we have developed a standardized set of 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 an optimum suite of metrics that can adequately detail the results of restoration, depending on the goals of the restoration action and financial and logistical limitations of comprehensively monitoring ecological change over extended temporal and spatial scales. We selected core metrics based on criteria that 1) correspond to commonly held restoration project goals; 2) are applicable to all sites; 3) characterize controlling factors, ecosystem structure, and ecosystem function; 4) are relevant to both present and future investigations; and 5) are practical in terms of level of effort.

In this document, we summarize the types of restoration strategies being planned and implemented in the CRE. We then propose a set of metrics and statistical design for restoration monitoring activities based on commonly shared ecological goals. Finally, we provide seven specific protocols for this set of estuary monitoring metrics. Monitoring protocols are provided for 1) hydrology (water surface elevation), 2) water quality (temperature, salinity), 3) elevation (topography), 4) landscape features (remote sensing), 5) Plant species composition and cover (plant community), 6) vegetation plantings (success), and 7) fish community (species, temporal presence, size, and age structure).

Acknowledgments

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The authors thank Ebberts and Putman for supporting the development of these protocols, beginning in 2004 with a process that included workshops, literature review, field-testing, and writing and releasing a first draft for review in 2006. During this process, many individuals with expertise on the Columbia River contributed their knowledge or reviewed the document, which could not have taken the present form without their assistance. The authors are particularly grateful to George Kral of Ash Creek Forest Management, Tigard, Oregon, for permitting the adaptation of his methods for monitoring revegetation.

The authors invited a number of individuals to attend a meeting 23 June 2004 to involve restoration project managers in identifying minimum monitoring indicators and appropriate methods. The meeting was convened by the Lower Columbia River Estuary Partnership, USACE, PNNL, and NMFS at the offices of the estuary partnership in Portland, Oregon. Contributions of the following participants were invaluable foundations for this document: Michael Anderson, Taunja Berquam, Matt Burlin, Tim Counihan, Todd Cullison, Blaine Ebberts, Craig Haskell, Joe Hymer, Jason Karnezis, Scott McEwen, Michelle Michaud, Dave Sahagian, Ian Sinks, Kathryn Sobocinski, Janelle St. Pierre, Robert Warren, Jack Wiles, and Greg Williams.

Following release of the 2006 working draft, we implemented the protocols at field-test sites and are grateful for cooperation by land owners and managers, the Columbia Land Trust, and the Port of Astoria. In addition to field-testing, we received valuable comments from others who implemented the draft protocols in the course of their work: Laura Brophy, Lori Lilly, Kate Norton, Micah Russell, Ian Sinks, and Melissa Rowe Soll. Many individuals assisted us in field testing, including Jimmie Cotton, Kate Hall, April Rouse, Micah Russell, and Kathryn Sobocinski. Following field-testing, we received additional feedback on the draft revised protocols at a meeting convened 8 February 2007 from: Rita Beaston, Laura Brophy, Matt Burlin, Suzi Cloutier, Robert Ellis, Kas Guillozet, Joe Krieter, Jill Leary, Lori Lilly, Margaret Magruder, Scott McEwen, Doug Putman, and Kathryn Sobocinski. We also received valuable review comments on the previous version of this document, a PNNL contract report to USACE (contract DE-AC05-76RL01830), from Krista Jones and Nikki Sather.

Abbreviations and Acronyms

APD	average planting density
BACI	before-after control-impact
BACIPS	before-after control-impact paired series
CPUE	catch per unit of effort
CRE	lower Columbia River and estuary
CRD	Columbia River Datum
CWT	coded wire tag
DO	dissolved oxygen
ESA	Endangered Species Act of 1973
ESU	evolutionarily significant unit
ETOH	ethanol
GIS	geographic information system
GPS	global positioning system
LiDAR	light detection and ranging
LWD	large woody debris
MLLW	mean lower low water
NAVD88	North American Vertical Datum 1988
OPUS	Online Positioning User Service
PIT tag	passive integrated transponder tag
PNNL	Pacific Northwest National Laboratory
RTK	real time kinematic
USACE	U.S. Army Corps of Engineers

1.0 Introduction

The recovery of salmonid stocks requires restoration of estuarine habitats supporting the diversity of life history patterns that historically mitigated for environmental variability (NOAA 2004, Bottom et al. 2005). Research on salmon distribution patterns in the lower Columbia River and estuary (CRE), as well as other West Coast estuarine systems, indicates 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 and 1992, Levings et al. 1991, Levings 1994, Sommer et al. 2001, Tanner et al. 2002, Roegner et al. 2005). Much of this historically abundant habitat has been isolated, degraded, or destroyed (Thomas 1983, Burke 2004).

The goal of many restoration activities is to repair connectivity and function of habitats to allow fish to regain benefits from important rearing and refuge areas. However, researchers and managers require the means to 1) evaluate the effectiveness of individual restoration activities (Roni et al. 2002), 2) compare 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. 2003, Diefenderfer et al. 2005b). This can best be achieved with a standardized set of research and monitoring metrics. The purpose of this document is to provide protocols for monitoring the effectiveness of habitat restoration projects in the CRE.

A review of the literature uncovered many relevant 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 (Diefenderfer et al. 2005b). The intent of this manual, 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 results using these methods—which may be fully realized decades from now—is to compile a compatible time-series database of physical and biological metrics collected from many individual restoration projects. This database 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 the metrics are provided herein.

1.1 Background

The CRE region has been highly modified by human activities that converted tidal wetlands into agricultural and commercial uses. Construction of dikes, docks, and roads; installation of tide gates; and alterations such as dredging and filling have destroyed habitat and disconnected large areas of emergent and forested wetlands from tidal inundation. This has resulted in the loss of 70–90% of the productive wetlands in the estuarine and tidal freshwater regions of the lower Columbia, including important spawning and rearing habitat (Thomas 1983, Simenstad et al. 1992, Weitkamp 1994, Kukulka and Jay 2003a and 2003b) for several evolutionarily significant units (ESUs) of salmonids (Waples 1991).

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 most likely to directly benefit from restoration activities in the CRE are wild and hatchery-reared ocean-type Chinook salmon (*Oncorhynchus tshawytscha*), chum salmon (*O. keta*), and stream-type coho salmon (*O. kisutch*) from lower river tributaries (reviewed in Diefenderfer et al. 2005b). 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, Bottom et al. 2005).

While most individuals from the surviving ESUs of upriver stocks currently migrate rapidly through the estuary to the ocean, some (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, Diefenderfer et al. 2005b). 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.

There is growing momentum to reverse land use patterns and specifically to reconnect historical wetland areas to the influence of tidal inundation. The challenge faced 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, Hillman 2004, Rice et al. 2005, Johnson et al. 2008). Standardized metrics are required to provide the best possible input to managers making decisions regarding habitat restoration in the CRE.

1.2 Restoration Strategies in the CRE

Various types of restoration are occurring throughout the CRE region in an effort to recover lost habitats (see map online at http://www.lcrep.org/habitat_inventory.htm [accessed 27 January 2009]). These activities fall under five broad strategies summarized in Table 1 (Johnson et al. 2003). The protocols herein are applicable to restoration,[1] enhancement, and creation activities, detailed as follows.

- Restoration—Restoration activities are designed to return degraded habitat to a state closer to the historical ecological condition. The most common restoration approaches in the CRE are tidal reconnection through dike breaching, dike removal, culvert upgrades, or culvert installations. The selected monitoring metrics of this manual are specifically chosen to track ecosystem changes resulting from this type of restoration treatment.
- Enhancement—Habitat enhancement is the improvement of a targeted ecological attribute or process or both. Enhancement projects in the CRE include tide gate or

[1] Unless noted otherwise, the term "restoration" refers collectively to all strategies applied in the CRE.

Table 1. Restoration strategies, examples of project types, and targeted ecosystem benefits for the CRE (adapted from Johnson et al. 2003).

Strategy	**Project type**	**Targeted ecosystem benefit**
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 historical slough signatures and can involve tidal channel excavation.
	Culvert upgrades and culvert installation	Provides similar benefits to above restoration activities through 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.
Enhancement	Riparian plantings	Promotes water temperature reduction, contaminant removal, connection of terrestrial habitat corridors, sediment reduction, and water storage; future source of LWD input.
	Tide gate and culvert replacement	Promotes water temperature reduction, dissolved oxygen availability, and increased habitat access.
	Invasive species removal	Increases opportunities for native species propagation.
	Bioengineered stream bank stabilization	Reduces sediment load, diffuses hydrologic energy.
	Riparian fencing	Protects riparian zones from disturbances.
Creation	Material placement	Mimics habitat function and complexity through the placement of material at a given elevation.
	Tidal channel modification	Increases tidal flows, mimics tidal channel structure.
Conservation	Land conservation	Limits land use impacts harmful to salmon habitat such as sediment, contaminants, and 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.
Protection	Land acquisition	Preserves existing intact ecological features, functions, and processes at site scale or enables the application of additional strategies without human land use constraints or both.
	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.

culvert replacement, riparian plantings and fencing, invasive species removal, and stream bank stabilization.

- Creation—Habitat creation involves constructing or placing habitat features where they did not previously exist to foster development of a functioning ecosystem. Examples include tidal channel excavation and the placement of dredge material intended to create marsh or other habitat.

In addition, conservation and protection activities ongoing in the CRE include acquisition of land or development rights, regulations on land use such as zoning designations and protection ordinances, and financial incentives for landowners to manage land for conservation. Improved management techniques being encouraged through such means include riparian setbacks as well as agricultural practices such as manure management, the addition of riparian buffer strips, integrated pest management, and off-stream livestock watering techniques.

1.3 Conceptual Model

A conceptual model representing the existing ecological condition of a restoration project site and its landscape can be used to forecast alternative future conditions based on different restoration planning scenarios and environmental conditions (Fischenich 2008). Conceptual model development is also a useful tool for identifying which metrics to monitor. During restoration planning phases, conceptual models often serve to enhance communication between parties involved with the project. Five types of conceptual models commonly used in ecosystem restoration planning are described in Diefenderfer et al. (2005a): landscape, ecosystem, ecosystem performance, ecosystem services, and subsystem.

Conceptual models should help identify features of the site that require study. For example, if a site is predicted to recover to a tidal marsh, elevation relative to water level is critical. In order to assure that elevation is correct, some elevation measurements are required in addition to collection of water level data proximal to the site. If elevation is too low or too high relative to the water level, the effectiveness of the restoration action toward satisfying the project goal will be poor. Further, monitoring water level relative to marsh development may help provide an explanation if the marsh is not developing as expected.

It is important that each project document knowledge of ecosystem structures and processes at the site, relationships between the site and landscape, and expected changes following the implementation of restoration actions (Diefenderfer et al. 2003). An effective vehicle for this documentation is the conceptual model. Understanding such information is foundational to determining the relative success of a restoration project (Thom 1997, Thom 2000).

Simple conceptual models depict environmental factors or processes occurring in an ecosystem and represent the magnitude and direction of their relationships and interactions. Examples of factors and processes include 1) anthropogenic stressors, such as passage barriers; 2) controlling factors, such as topography; 3) ecosystem structures, such as emergent marshes; 4) ecosystem processes, such as sediment trapping; and 5) ecosystem functions, such as providing salmonid rearing habitat. Key landscape factors that may influence system performance or be influenced by the restoration project include land use, roads, boats, air or waterborne contamination, domestic or wild animals, fishing, and water diversion.

Examples of the Columbia River Estuary Conceptual Model adapted from Thom et al. (2004) and applied to both status and trends and action effectiveness monitoring in the estuary can be found in Johnson et al. (2008, Appendix B). A simple example of a conceptual model can be found in Diefenderfer et al. (2003). A general conceptual model for action effectiveness of a tidal reconnection project is shown in Figure 1.

1.4 Report Contents

In the following sections, we propose a set of metrics for restoration monitoring activities based on commonly shared ecological goals (Section 2), discuss design considerations (Section 3), and provide specific protocols for this set of estuary monitoring metrics (Section 4), followed by the list of references (Section 5).

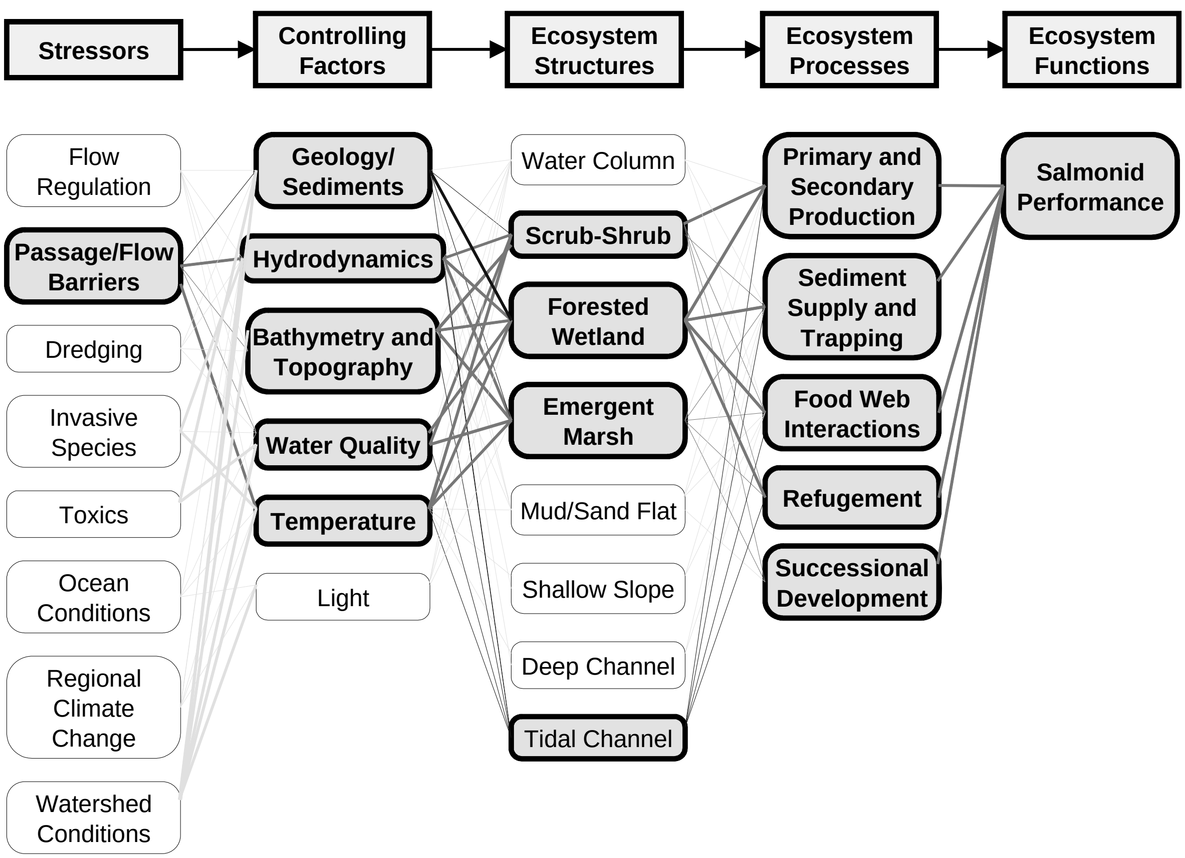


Figure 1. Columbia River estuary conceptual model applied to estuary research, management, and evaluation action effectiveness research for tidal reconnection projects (adapted from Johnson et al. 2008). The shaded boxes are relevant to restoration in the lower Columbia River and estuary.

2.0 Core Monitored Metrics

The CRE comprises a unique continuum of wetland ecosystems strongly influenced to varying degrees by river flow, tidal amplitude, and salinity. Unlike streams in nontidal upland regions, semidiurnal and spring neap tide variation in water level in the CRE impose a structuring force on both geophysical features and biota, especially as distance to the mouth of the river decreases. Water elevation fluctuations, keyed to site topography, directly determine periods of inundation and salinity intrusion (Kukulka and Jay 2003a, 2003b) and this in turn structures plant communities and fish habitat use (Thomas 1983, Fox et al. 1984, Small et al. 1990). The tidal cycle controls the magnitude and duration of bidirectional current velocities that cause sedimentation and erosion and the evolution of geomorphological features such as 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 and physical and biological responses of the floodplain wetlands.

2.1 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 also 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., vegetation growth), and one for functional factors (e.g., fish community structure). Third, metrics should be potentially applicable to all sites with measurements that result in comparable data sets relevant to both present and future investigations (Tegler et al. 2001). Finally, measurements and data analysis must be practical in terms of funding, personnel, and processing requirements (Callaway et al. 2001).

This last factor necessitates limiting the number of metrics to a core[2] set and selecting measurement methods that are straightforward and economical to use. 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. However, we recognize that funding even these core metrics may not be feasible. In this case, an even smaller set of metrics may be usefully employed as part of a broader, extensive sampling effort (see Johnson et al. 2008 and Johnson and Diefenderfer 2008). Project goals for the biological variables (e.g., fish use or vegetation cover) may vary between studies.

[2] By "core" we mean a suite of metrics that can adequately detail the effectiveness of restoration while acknowledging the financial and logistical limitations of comprehensively monitoring ecological change over an extended temporal and spatial scale.

We also encourage researchers to make additional measurements, especially process-related derivations of the core metrics (e.g., fish growth rate, primary productivity, and material flux). The relevance of various metrics such as these to the CRE is under investigation at this time, as described in the series of reports from this project: Diefenderfer et al. 2005b, Diefenderfer et al. 2006, Johnson 2007, and Johnson and Diefenderfer 2008. Structure and process oriented indicators of the effects of CRE wetland ecosystems range from materials flux to large woody debris (LWD) to sediment accretion rates. Those under review include salmonid growth, residence time, and prey; organic matter and nutrient fluxes; hydraulic geometry; swamp and marsh macrophyte productivity; species diversity and distribution; and hydrological and flood storage modeling. Research and monitoring on higher order metrics such as these will help reduce fundamental uncertainties in existing knowledge of the ecosystem of the lower Columbia and improve restoration project design and future monitoring.

The selection of relevant core metrics according to the above criteria was based on 1) a review of pertinent literature, 2) a meeting with local restoration managers (Diefenderfer et al. 2005b, Appendix A), and 3) past iterations of this document based on our field results. We strove to keep the protocols useful not only to scientists but to 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 projects implementing tidal reconnection, a key ecological driver for a wide 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. 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 meetings with regional restoration managers and monitoring practitioners in June 2004 and February 2007.

2.2 Metrics

Table 2 outlines the set of core monitored metrics, their collection method, sampling frequency, and indicator category. We recommend a combination of data logging instruments, on-site survey and sampling methods, and remote sensing techniques.

2.2.1 Hydrology

Hydrology is a main controlling factor of wetland evolution in the CRE, and it influences habitat structure and processes as well as 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 and 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 variation. This method of data collection generates a time series of

Table 2. Summary of core metrics for CRE restoration projects.

Indicator category	Monitored metric	Collection method	Sampling frequency
		Physical	
Hydrology	Surface water elevation	Data-logging instrument	Hourly
Water quality	Temperature, salinity	Data-logging instrument	Hourly
Habitat	Landscape features	Photography, GIS	Annually
	Elevation	Ground survey	Annually
		Biological	
Plants	Species composition Percent cover Elevation Planting success	Ground survey	Annually
Fish	Species composition Size structure Temporal presence	Ground survey	Monthly-seasonally

measurements that can be compared between habitats and across seasons. Sensors can be stand alone or integrated into a water quality instrumentation package.

2.2.2 Water Quality

Water quality parameters such as temperature, salinity, dissolved oxygen (DO), pH, and turbidity play deterministic roles influencing species abundance and distribution in the CRE (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 and pH can control the distribution of many organisms. Turbidity can limit the depth distribution of submerged aquatic vegetation.

While all these parameters, and others such as specific dissolved constituents, are important and worthy of monitoring, we recommend temperature and salinity (in saline and brackish regions) as the core water quality metrics based on importance and methodological consistency. We advocate the use of automated data logging multiprobe instruments for measuring time-series of water quality parameters. Additional transect surveys with conductivity-temperature-depth probes can provide vertical and horizontal spatial scale perspectives useful for augmenting the spatially fixed time-series data (Callaway et al. 2001).

2.2.3 Elevation

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. It is helpful if detailed topographic or bathymetric surveys are conducted by professional surveyors during the restoration planning phase. This information can be useful to predict restoration outcomes, plan invasive species management, identify areas appropriate for plantings, and identify areas that may require elevation increases or decreases to achieve desired species composition. Limited elevation surveys recommended in this manual include channel cross sections, vegetation plots, vegetation community boundaries, water level instruments, and sediment accretion stakes. These techniques have well-established methodologies and should be coordinated with biological surveys described below.

2.2.4 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 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 Light Detection and Ranging (LiDAR). Ground truthing the imagery is necessary to ensure accurate analysis. Repeated measures over time are best analyzed using a geographic information system (GIS) to quantify the progress of restoration.

2.2.5 Plant Species Composition and Cover

Plant species composition and cover 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 measurement of changes in vegetation community structure be accomplished at both landscape scale (described above) and through transect or ground survey techniques.

2.2.6 Vegetation Plantings

Some restoration projects include revegetation in riparian zones or across broader areas, which may be used to achieve a variety of objectives such as accelerating reestablishment of native plants, suppressing invasive plants, providing environmental conditions such as shade, or affecting the biota through, for example, salmonid prey production (Simenstad and Thom 1996, Naiman et al. 2005). The effectiveness of plantings can be assessed by tracking plant survival and growth. It is important to determine a criterion for success to ensure that project goals are being achieved, and this criterion will dictate specific monitored metrics. Typical metrics include a quantitative count (for density), height measurement (for growth), and qualitative estimation of condition (for survival) (Erwin 1990, Simenstad and Thom 1996).

2.2.7 Fish Community

The incentive for many restoration activities in the CRE involves increasing rearing and refuge habitat for juvenile salmonid ESUs listed as threatened or endangered under 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 reference areas. Measurements of fish density (individuals per m^2) provide the most robust comparative value. We advocate conducting the most intense sampling effort logistically possible across sites, habitat types, and time. Additionally, it is highly desirable to determine higher order metrics (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. 2005).

3.0 Design Considerations

3.1 Statistical Design

Monitoring data from individual restoration projects throughout the estuary is important for assessing project-specific outcomes and for analyzing changes in the broader estuary ecosystem. The roles of project monitoring data in the estuary-wide statistical design for ecosystem restoration in response to the biological opinion (NOAA 2007) are detailed in the document Research, Monitoring, and Evaluation for the Federal Columbia River Estuary Program (Johnson et al. 2008). The program incorporates both intensive monitoring of a small number of restoration projects and extensive monitoring of a smaller number of metrics at a larger number of projects (e.g., Trexler and Busch 2003). Through the efforts of the Lower Columbia River Estuary Partnership (Estuary Partnership) and the Bonneville Power Administration, a suite of reference sites is being established and monitored to allow comparison to restoration projects (see Borde et al. 2007); paired reference sites specific to a project are also recommended by Johnson et al. (2008).

3.1.1 Reference and Control Sites

The definitions of reference and control sites are used variously in the literature, so key elements distinguishing them are reiterated here, following Downes et al. (2002) and consistent with Johnson et al. (2008). Reference sites represent the state of an environment undisturbed by human activity, while control sites are as similar as possible in all respects to the impact location, except for the presence of the putative impact. One apparent source of confusion in the literature arises from the fact that the impact under consideration in ecological restoration is expected to be of a positive nature. Thus for example, in the case of hydrological reconnection of floodplain areas to the mainstem Columbia, a typical reference site would be a tidal wetland, while a typical control site would be a diked pasture. The best possible design is to monitor both reference and control sites relative to the restoration site; however, this will rarely be possible with limited monitoring funds. For most projects in the CRE, we therefore advocate concentrating on monitoring reference sites in conjunction with restoration sites. Conditions at restoration sites can be assessed in respect to the trajectory of their development against the target states represented by the reference sites (Johnson et al. 2008).

The selected reference site should be spatially situated near the restoration site and subjected to similar large-scale climatic and environmental conditions, but be independent of activities affecting the restoration site to the extent possible. Ideally it represents a natural, minimally modified, or target condition and would be chosen to measure specific habitats or processes, such as tidal channels or marsh communities. It is widely recognized that choosing the reference site in regions that have been highly modified is challenging. The Estuary Partnership's set of reference sites should be consulted. Within each hydrogeomorphic reach of the CRE, regional reference sites are being monitored to provide a range of target conditions for restoration activities.

In general for projects in the CRE, the goal will be the return of the restored site to close approximation of its natural, undisturbed condition. Therefore, the key information needed to evaluate progress toward this goal is some measure of the similarity of the restored site to either predisturbance conditions or the conditions existing at nearby reference sites that are a reasonable approximation of predisturbance conditions. Because quantitative data on site conditions prior to disturbances are rarely available, reference sites are the only viable option. However, qualitative comparisons to information on predisturbance conditions using old photographs, land surveys, topographic surveys, etc., can be useful in concluding whether the site is actually returning to its former condition.

3.1.2 Before and After Sampling

The ability to detect ecological change due to restoration in a naturally varying environmental system is problematic (Osenberg et al. 1994). For restoration monitoring in the estuary, we considered two basic sampling designs, before-after control-impact (BACI, Green 1979) and accident recovery (recovery, Skalski et al. 2001). BACI incorporates before and after sampling at control and restoration (impact) sites, while the recovery method incorporates after-only sampling at reference and restoration sites. Because the original BACI design is susceptible to confounding project effects with other factors causing site-by-time interactions, the use of the modified before-after control-impact paired series (BACIPS) has recently been recommended for restoration monitoring (Osenberg et al. 2006). The essential difference between BACIPS and the recovery method is that BACIPS estimates the effect of the restoration based on the amount of effect, while recovery assesses the endpoint relative to target conditions. As Osenberg et al. (2006) suggest, "A combination of both approaches is likely ideal—we would like to know how much of an effect we have produced (effect-size-based outcomes) and if that change is sufficient (endpoint-based outcomes)."

One measure of restoration success or performance is for values of the postrestoration parameters (the monitored attributes) to converge with those of the reference site (Kentula et al. 1992, Simenstad and Thom 1996, Raposa 2002). The recovery model tests the parallelism hypothesis (Skalski et al. 2001): how a treatment site recovers in comparison to a relatively undisturbed reference site, as opposed to comparison to before conditions at a control site (cf Miller and Simenstad 1997, Skalski et al. 2001, Hood 2002, Thom et al. 2002, Steyer et al. 2003). This analytical method is discussed in more detail and diagrammed in Johnson et al. (2008, their Figure 5). While the recovery model does not require multiple data collection times before implementation of restoration actions, before data is highly desirable for documenting the initial response of the system to the restoration process, as well as to assess interannual or seasonal variability in the reference and restoration sites (Skalski et al. 2001). See Hillman (2004) for further discussion of these types of statistical comparisons.

Within either BACIPS or recovery 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. In contrast to the time-series measures described above, 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 to evaluate changes in metrics.

3.1.3 Recommendations

The choice of sampling design will depend on site-specific circumstances and the availability of funding for before- and after-project implementation periods. However, whatever the sampling design, it should be determined early in the restoration planning process. We recommend that in all cases the following occur during the project planning phase: 1) select a subset of reference sites from the existing suite, if reference sites comparable to target project conditions are being sampled; 2) establish a paired reference site, if possible, and secure access; and 3) determine whether monitoring will include a control and, if so, select the location and secure access. The recovery design is recommended for all restoration projects, using either a subset from the existing suite of restoration sites, a paired site, or both. If a control site is also selected, then use of the BACIPS design in addition to the recovery design is also recommended on a modular basis, that is, for those metrics to which such analysis is applicable.

In general, we recommend a sequence of sampling events such as that listed in Table 3. Monitored parameters are sampled simultaneously at two or more locations (reference vs. restoration) before and after the restoration action (before vs. after). All sampling techniques and sampling periods should be identical between reference and restoration sites to the extent possible. 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). It should be emphasized that the ecological processes associated with a given restoration activity, such as breaching a dike, evolve for many years after 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 many decades.

3.2 Sampling Design

Generally, resources for restoration monitoring are too limited to permit random sampling of any parameter across an entire restoration site at a sufficient density to draw statistically defensible conclusions. Therefore, we recommend that most field sampling be concentrated on transects proximal to expected changes, for example, near a culvert replacement or a dike breach. This intensive monitoring at a small spatial scale can be complemented through mapping using an aerial photo and ground truthing methods (Erwin 1990) or other remotely sensed information such as LiDAR data to characterize aspects of the restoration site in its entirety. The use of georeferenced surveys wherever possible will permit the integration of hydrology, vegetation, fish, elevation, and other data at multiple scales. To maximize possibilities for integrating data, the following design is recommended (see Protocol 5, plant species composition and cover, subsection 4.5.3 Design).

- channel cross sections surveyed along vegetation sampling baselines
- elevation data collected at vegetation plots
- data logging sensors deployed year-round to acquire water level and temperature information near where the vegetation baseline crosses the restored channel
- fish collection efforts located in the same channels

Table 3. The sequence of sampling events.

Steps before restoration activity

1. Acquire and process available restoration and reference site data (Protocol 4).
   a. Locate elevation and tidal benchmarks from Web site (Protocol 3).
   b. Acquire digital aerial photograph of site (Protocol 4).
   c. Create and ground truth vegetation community map.
   d. Acquire LiDAR or topographic survey and local bathymetry (if available).
2. Select field sampling areas.
   a. Choose reference and restoration sampling areas.
   b. Choose survey transect locations.
3. Ground survey (at reference and restoration sites).
   a. Deploy and maintain water elevation and water quality data loggers at surveyed locations (Protocols 1, 2, and 3).
   b. Conduct cross-section and sediment-accretion surveys (Protocol 3).
   c. Conduct vegetation-elevation and fish community surveys (Protocols 3, 5, 6, and 7).
4. Time series (before, if time permits).
   a. Maintain data loggers.
   b. Repeat steps 3b and 3c.

Steps after restoration activity

1. Repeat steps 1b, 1c, 3a, 3b, and 3c (above) to acquire the after data set.
2. Evaluate change in hydrology and water quality (Protocols 1 and 2).
3. Determine change in physical features (Protocols 3 and 4).
4. Compute vegetation structure analysis (Protocol 5).
5. Evaluate planting success, if applicable (Protocol 6).
6. Compute fish community structure analysis (Protocol 7).
7. Repeat steps 1–6 at designated frequencies.

In summary, wherever possible, spatially link the location of data logging instrumentation, elevation and vegetation transects, and fish surveys 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 as tidal elevation and channel morphology affect biological metrics such as vegetation and fish communities. The specific elements of such sampling designs relevant to each metric are described in more detail in each of the following protocols.

4.0 Monitoring Protocols

Seven monitoring protocols are described in detail in this section: 1) hydrology, 2) water quality, 3) elevation, 4) landscape features, 5) plant species composition and cover, 6) vegetation plantings, and 7) fish community. For each protocol, we describe purpose, goal, design, equipment needed, site selection, sampling periodicity, sampling protocol, calculations and analysis, and site-specific contingency considerations, if any. Examples are provided from field research and monitoring at the Vera Slough (Figure 2) or Kandoll Farm (Figure 3) restoration sites. While selected literature or other additional information sources are provided with each

Figure 2. Tide gates at Vera Slough before (left, open) and after (right, closed) replacement with experimentally modified designs.

Figure 3. Tide gate at Kandoll Farm before (left) and after (right) culvert replacement.

protocol, these represent only a small fraction of the available number of related protocols and the number of examples of published research using similar methods. Hillman (2004) and Brophy (2007) provide thorough explanations of monitoring approaches in Pacific Northwest freshwater and estuarine environments, respectively. Among the most recent references generally applicable to most of the protocols herein, we recommend Callaway et al. 2001, Neckles et al. 2002, and Rice et al. 2005.

4.1 Hydrology (Protocol 1)

4.1.1 Purpose

Water level variation in wetlands is a function of river flow 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 and erosion patterns and tidal creek evolution, and the distribution of vegetation and fishes. In general, restoration sites on the Columbia Estuary are not close enough to existing NOAA water level stations for the data to reflect water levels at the site, thus field measurements will be necessary.

Water level data should be properly georeferenced to local topographic data (Protocol 3, elevation) that is related to an established vertical elevation datum (e.g., North American Vertical Datum 1988 [NAVD88] or mean lower low water [MLLW] if applicable; see Additional Information subsection in Protocol 3). Water level information and topographic information combined can be used to determine inundation periods and vegetation response (Protocol 3, elevation, and Protocol 5, plant species composition and cover). In addition, tidal stage parameters for the site (i.e., MLLW) can be computed from each recording station. Elevation is thus a priority metric and is best measured with automated data logging pressure sensors. Current technology offers multiple parameter probes that combine measurements like depth with others such as temperature and salinity (see Protocol 2, water quality). Although we present separate protocols for hydrology and water quality, for most purposes a single instrument will perform both sets of measurements.

4.1.2 Goal

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

4.1.3 Design

Recovery or BACIPS time-series design or both should be used to evaluate changes in water elevation caused by the restoration activity. At a minimum, two instruments would be deployed, one at the reference and the other at the restoration site. Where logistically possible, prerestoration (baseline) measurements are desirable to evaluate natural variations in the system. Comparing ranges and fluctuations of the reference and restoration time series gives a measure of the effectiveness of the restoration project. In addition, if atmospheric pressure correction data is not locally available, an additional instrument will be needed that is exposed to air to collect this. Comparisons to conditions in the nearest river channel can also be informative if an additional instrument can be deployed there.

4.1.4 Equipment

Field: Continuous water level recorders (pressure transducer) or multiple parameter probe (see Protocol 2, water quality), laptop computer and data logger launching and downloading software (or waterproof shuttle), monumenting equipment (T-post, surveying equipment), a measuring device to determine heights sensor on post and water level at time of deployment, hammer, global positioning system (GPS), and extra batteries.

Lab: Data logger software, and calibration and maintenance manual.

4.1.5 Site Selection

The primary site for data loggers in both restoration and reference sites is near the mouth of the tidal reconnection site (but within the hydrological constriction). These positions would ideally be located where other monitoring activities take place (i.e., channel cross section). Additional instruments, if available, should be placed upstream of the reconnection to evaluate the extent of hydrological reconnection, especially to gauge for lags in period and reductions in tidal amplitude.

4.1.6 Sampling Periodicity

The preferred sample frequency is 1 hour; try to initiate logging on the hour to simplify alignment with other time-series data.

Download or change batteries at less than 6-month intervals during spring and autumn to limit data loss and maximize recovery opportunities due to seasonal variation in daylight and tidal amplitude.

Note that while tidal parameters may be predicted after a 2- to 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.

4.1.7 Sampling Protocol

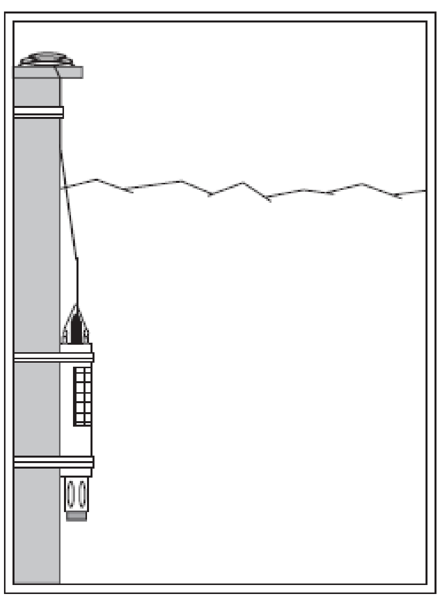
Automated instruments require proper placement to ensure comparable monitoring. Data loggers should be secured subtidally with sensors positioned at least 25–50 cm below the anticipated lowest tide level and at least 10–20 cm above the substrate to prevent sedimentation or excessive abrasion in high-velocity areas. Remember that hydrologic reconnections that increase tidal amplitudes may convert subtidal areas to intertidal zones.

Instruments can be attached directly to existing structures such as pilings, although it is prudent to encase the instruments in a protective plastic sleeve (e.g., PVC) to minimize metal-to-metal contact that can cause corrosion. The sleeve can be simply the length of the sensor and attached by cable ties, or as shown in Figure 4 to allow for deployment and retrieval at higher water levels. If the length of PVC used for deployment is longer than the sensor, be sure to drill holes in the pipe to allow water to drain easily.

For each deployment, the height of the sensors relative to a known elevation point must be determined to relate water level fluctuations to topography. To accomplish this, determine the vertical elevation of a surveyed point (usually the top of the post structure) (see Protocol 3, elevation). During deployment, measure the distance from the sensor to the top of the permanent attachment post. This will tie the sensor position to the actual elevation. Note: Add the length of the instrument body to the measurement if the measured distance is from the top of the instrument and the sensor is at the bottom.

A measurement from the sensor to the water level at the time of deployment and retrieval provides a means of verifying the water level data during postprocessing. Additionally, record the location of the data logger with GPS and periodically visit data loggers as stipulated by the factory user's manual to check for fouling or damage. When removing or redeploying the data logger, record the vertical position on the piling or post so that it can be replaced at the same position. Waterproof shuttles are available with the capability to download and relaunch water level loggers in the field, reducing time lapses in the data. Where necessary, calibrate sensors before each deployment.

Water level data is affected by atmospheric pressure; therefore, data collected in the field needs to be corrected for atmospheric pressure. One method is to deploy an additional sensor at the site, above water. Generally, this will be required unless atmospheric pressure is available from another source (e.g., NOAA weather station) within a 10-mile radius of the site, per recommendations at www.onsetcomp.com [accessed 6 October 2008].



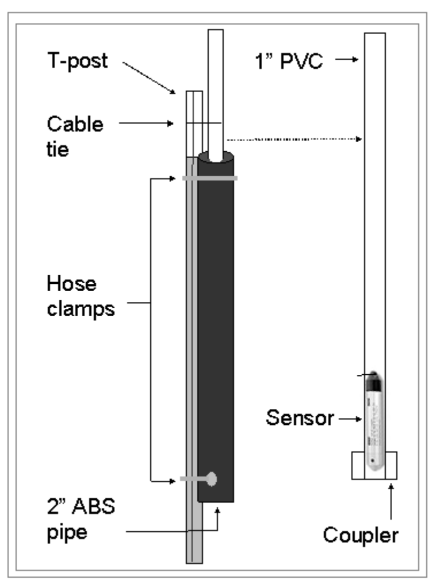


Figure 4. Deployment options for data logging instruments: attached to a pile (left) and attached to T-post and inserted in PVC pipe (right).

4.1.8 Calculations and Analysis

The primary output from data loggers is a time series of water levels. These relative heights should first be corrected for atmospheric pressure following guidelines specific to the data logger. Next, they should be converted into elevation relative to the standard topographic datum (NAVD88) using field surveyed elevation data; this references hydrology to site topography and also facilitates comparison between sites. Data storage requirements quickly increase with 1-hour interval data collection, and data management and archiving can require a substantial time investment.

Data should be presented to contrast water level fluctuation at reference and restored sites prerestoration and postrestoration (Figure 5).

Inundation period (percent of time inundated) can be calculated for any elevation within the site and used to generate an exposure-height curve, which relates percent inundation by vertical height (Figure 6). 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.

Percent inundation data can be integrated with topographic surveys to create percent inundation maps in GIS.

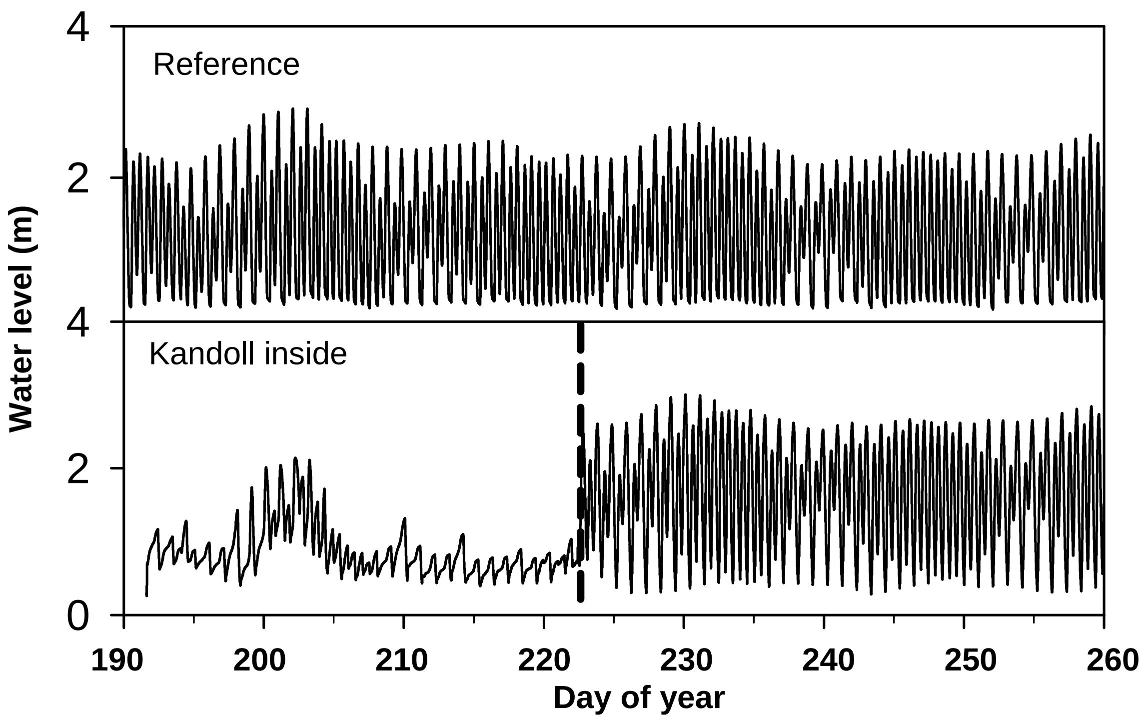


Figure 5. Water level variations surrounding a tide gate removal at Kandoll Farm, 2005. Top, reference hydrograph; bottom, restoration hydrograph. The timing of the tide gate removal is indicated by the dashed vertical line. Tide gate removal resulted in reestablishment of the semidiurnal tidal pattern.

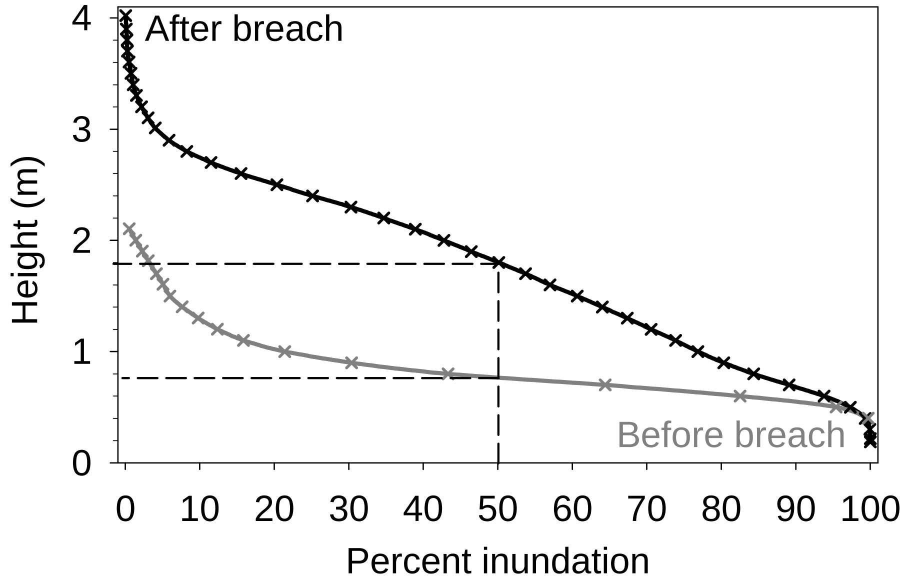


Figure 6. Exposure-elevation (hypsographic curve) plot for prerestoration and postrestoration periods at Kandoll Farm restoration site, 2005.

4.1.9 Site-specific Contingency Considerations

Observe bank conditions of the water body where equipment is deployed; assess its potential for slope failure that can place equipment at risk and affect data quality.

Ensure probes' metallic elements are not in close proximity to other metallic structures; this can cause electrolysis and instrument malfunction, especially in saline areas.

Forecast tidal fluctuations and set up a maintenance schedule accordingly so that equipment can be deployed and retrieved safely.

Review first sets of data carefully and use them to make inferences of unexpected site conditions.

Data loggers should be from the same vendor when possible to facilitate data downloads and consistency with inherent variability of readings.

4.1.10 Additional Information

For planning purposes, real time and predicted water level data is online at http://tidesonline.nos.noaa.gov/ [accessed 6 October 2008]. In addition, tidal prediction software is available that provides more options for graphic and data outputs.

Climate (atmospheric pressure) correction data is online at http://www.ncdc.noaa.gov/oa/ncdc.html [accessed 6 October 2008].

4.2 Water Quality (Protocol 2)

4.2.1 Purpose

Organisms have varying tolerances to water quality parameters such as temperature, salinity, turbidity, pH, and DO (OWEB 1999). Measuring variations in prestoration and postrestoration water quality conditions are a direct measure of changes in habitat opportunity (Callaway et al. 2004), and are important for explaining floral and faunal changes that may accompany hydrologic reconnection. 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 the vegetation community structure. As with water elevation (Protocol 1, hydrology), we advocate the use of autonomous data logging equipment to measure water quality parameters. Some water level loggers also record temperature or salinity or both. While DO is an important metric, data collection is often problematic; therefore, the minimum recommended core metric is temperature in tidal freshwater regimes and temperature and salinity in estuarine habitats.

4.2.2 Goal

Measure time series of water quality parameters at reference and restoration sites and relate to biotic changes.

4.2.3 Design

The design follows Protocol 1, hydrology. A recovery or BACIPS time-series design or both should be used to evaluate changes in water quality caused by the restoration activity. At a minimum, two instruments would be deployed, one at the reference and the other at the restoration site. Position the latter in a reach near the site of the hydrological reconnection, which would ideally be located where other monitoring activities take place (i.e., fish abundance). Where logistically possible, prerestoration (baseline) measurements are desirable to evaluate natural variation in the system. Comparing ranges and fluctuations of the reference and restoration time series gives a measure of the effectiveness of the restoration project.

4.2.4 Equipment

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

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

4.2.5 Site Selection

Install data loggers in both reference and restoration sites. Additional instruments, if available, should be placed upstream of the reconnection to evaluate the extent of hydrological reconnection.

Choose locations that are representative of the overall reach with some assurance of repeatability under changing conditions from the restoration treatment (e.g., increased water level fluctuations and velocities).

4.2.6 Sampling Periodicity

The preferred sample frequency is 1 hour; try to initiate logging on the hour to simplify alignment with other time-series data.

Download or change batteries at less than 6-month intervals during spring and autumn to limit data loss and maximize recovery opportunities.

4.2.7 Sampling Protocol

Attach monitoring the probe on secure structure at least 25–50 cm below the lowest anticipated water levels and 10–20 cm from channel bottom. If possible, install the data logger at a position relative to a known surveyed elevation (Protocol 1, hydrology) to ensure all data is collected at the same position in the water column. This will provide comparable data sets for the reference and restoration sites. Record the GPS location to aid in retrieval. Clean and maintain monitoring probe using factory recommendations and ensure equipment is placed in a consistent location in the water column after download or maintenance.

4.2.8 Calculations and Analysis

The primary output from data loggers is a time series of parameters which can be analyzed with methods such as spectral analysis to capture trends in the data. Data should be inspected for data outliers (±3 SD of the mean). Time series from reference and restoration site should be temporally aligned and graphed together.

Comparisons between sites can be made with difference time-series plots (reference value/restoration value). Mean daily maximum values may be used to examine periods where temperatures exceed organism tolerances (Figure 7).

4.2.9 Site-specific Contingency Considerations

Observe bank conditions of the water body where equipment is deployed; assess its potential for slope failure that can place equipment at risk and affect data quality.

Monitoring probes should be from the same vendor when possible to facilitate data downloads and consistency with inherent variability of readings. Ensure probes' metallic elements are not in close proximity to other metallic structures, as this can cause electrolysis and instrument malfunction, especially in saline areas.

Forecast tidal fluctuations in advance and set up a maintenance schedule accordingly so that equipment can be deployed and retrieved safely.

Review first sets of data carefully and use them to make inferences of unexpected site conditions.

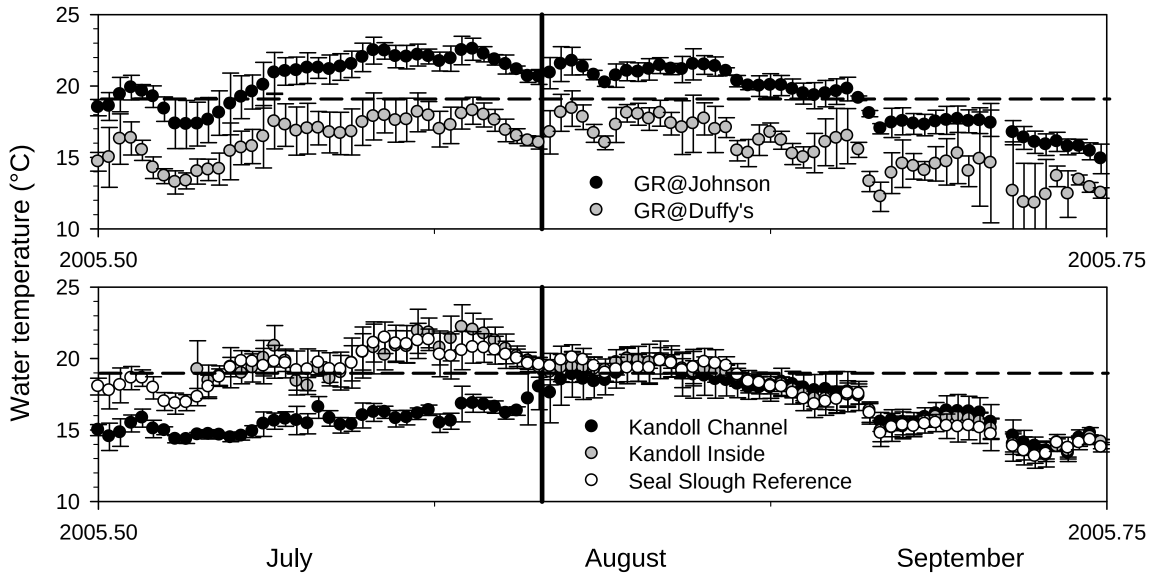


Figure 7. Time series of mean daily temperature (±SD) for reference and restoration sites surrounding tide gate removal, Grays River system, 2005. Upper plot: time series from upstream and downstream monitoring stations illustrating strong temperature gradient. Lower plot: time series from stations at Seal Slough reference and within restoration site monitoring stations. The timing of the tide gate removal is indicated by the black vertical line. The 19°C temperature threshold is indicated by the dashed horizontal line.

4.3 Elevation (Protocol 3)

4.3.1 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 often accompany hydrologic reconnection of sloughs and backwaters with tidal forcing (Coats et al. 1995, Zedler 2001). Establishing the extent and rate of change of elevation at a restoration site is important for evaluating the progress of the restoration effort.

4.3.2 Goal

Quantify changes in elevation before and after restoration actions on portions of the site within the area influenced by tidal inundation; link data logging instruments to topography and biotic surveys.

4.3.3 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 MLLW; see Additional Information subsection below). Established survey benchmarks, however, 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.

If elevation surveys are not conducted in combination with vegetation surveys or in other specific areas of interest such as tidal channels, they may not be useful for evaluating vegetation patterns or analyzing channel formation and change. At a minimum, surveys should establish a series of elevation benchmarks at the restoration site with line-of-sight 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 can then be used to survey elevation differences between the established benchmarks and the areas of interest.

4.3.4 Equipment

Field: Autolevel, tripod, stadia rod, meter tape, radio communications, GPS, PVC or rebar, and mallet or sledge hammer.

4.3.5 Site Selection

Sampling station locations may be generated from aerial photography. Elevation measurements should be constrained by the boundaries of expected change and should include the following locations:

Fixed points
- Along vegetation transects
- Water level sensors
- Cross section endpoints
- Sediment accretion stakes

Site features
- Natural levees and channels
- Created features that may be part of the restoration effort (e.g., added soils or excavated areas)
- Boundaries between vegetation communities
- Upper and lower elevation range of site

In addition to taking elevation measurements, channel cross sections should be measured to determine channel volume and relative changes over time. Channel cross sections should be sited at the locations of water pressure sensors (proximal to restoration action) and near the expected boundary of postrestoration inundation.

4.3.6 Sampling Periodicity

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

4.3.7 Sampling Protocol

Elevations should be surveyed at 1) the location of data logging instruments (Protocol 1, hydrology, and Protocol 2, water quality), 2) at selected channel cross sections, 3) at the location of vegetation transects (Protocol 5, plant species composition and cover), and 4) at sediment accretion stakes. It is advantageous to use PVC or rebar to permanently mark transect endpoints as defined in Protocol 5 and the channel cross section endpoints. Elevations should be measured at the top of the stakes because the ground surface elevation can change over time. Additionally, a GPS should be used to determine the location of each stake.

Water level sensors

Water level sensor elevation is critical to linking the relative water level changes to a known elevation datum (Protocol 1, hydrology). 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 moved, the elevation must be reestablished.

Channel cross sections

Set transect end posts. 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. 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, points can be established in areas offset from the original location with measurements of distance, azimuth, and elevation difference.

Attach measuring tape to fixed endpoints. Level the 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 m) in areas of low slope and smaller (0.5 m) in areas of steeper slope. Hand held radios are useful when distances make communication difficult.

Repeat at each measurement interval. This procedure is useful for determining two-dimensional change across an intertidal or tidal creek profile (Figure 8).

Vegetation transects

Elevation surveys at vegetation sampling areas are best conducted in a grid using transects along a baseline as outlined in Protocol 5, plant species composition and cover. If resources are limited, fewer points may be surveyed for elevation than for vegetation, for example, at the endpoints of the transects, borders between plant communities, or 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:

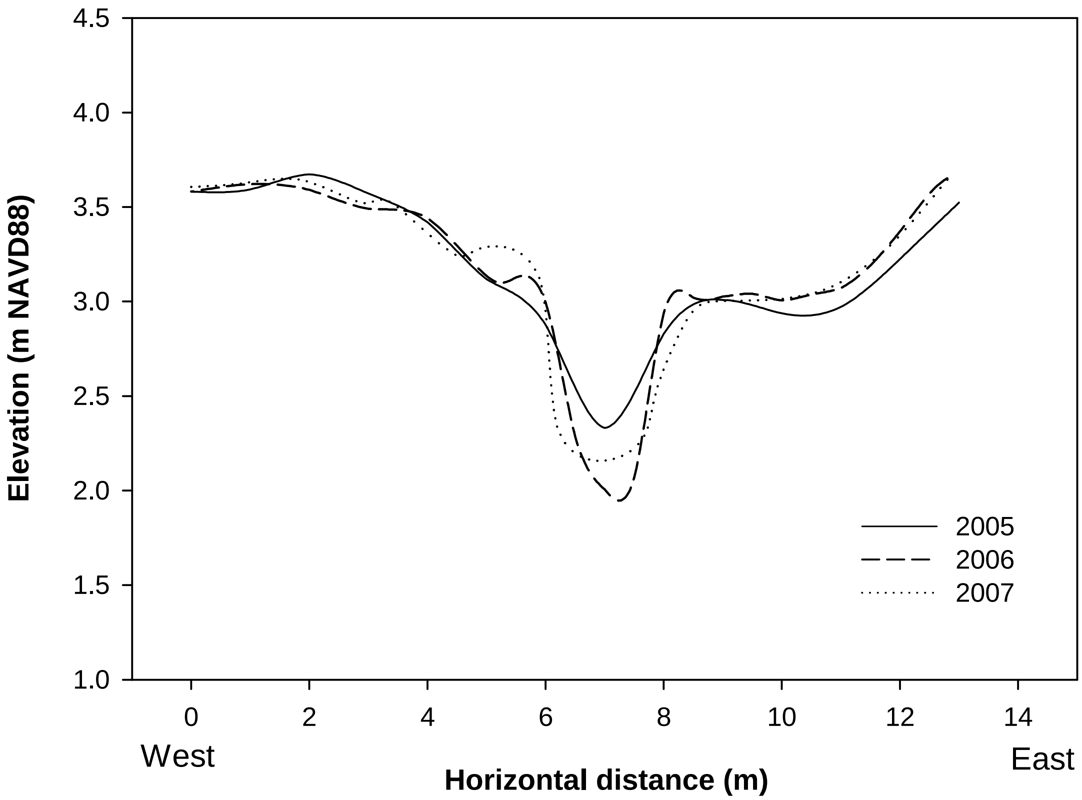


Figure 8. A channel cross section surveyed within a dike breach at Kandoll Farm on the Grays River, 2005–2007.

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 the vegetation percent cover is determined (see Protocol 5, plant species composition and cover) and measuring the elevation difference from the established benchmark with the autolevel.

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 being 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.

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.

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

Sediment accretion stakes can be made from 1-inch schedule 40 sunlight-resistant PVC conduit (gray). If possible, the stakes should be driven into the ground at least 1-m deep to ensure their stability against hydrological forces following restoration. Stakes are placed 1-m apart. The tops of the stakes must be leveled; this is accomplished by laying a construction level between them (Figure 9).

To measure sediment accretion, a meter stick is set across the top of the sediment accretion stakes. A second meter stick is held vertically with the 0-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.

It is useful but not necessary to measure the elevation of the top of one sediment stake by leveling the stadia rod on top of the post.

4.3.8 Calculations and Analysis

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

Difference plots are derived by subtracting the before from the after elevations (or time series). Positive values indicate accretion and negative values indicate erosion.

Figure 9. Sediment accretion stakes leveled and measured in a pasture to collect baseline rates prior to hydrological reconnection with the mainstem river.

Elevations and vegetation can be plotted to show the means and ranges of elevation for species or communities. This information can be used prior to restoration to predict postrestoration vegetation colonization.

Channel condition metrics calculated from above are:

- Change in cross sectional area of tidal channel at selected transects.
- Change in channel gradient (elevation change per unit of horizontal distance, dz/dx).
- Wetted width: width of water surface perpendicular to flow (modeled from water elevation data). Water elevation analysis as described in Protocol 1, hydrology.

4.3.9 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 transects measuring distance and elevation across areas of interest can be made using the total station, this system can also generate 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 rod. The instrument uses infrared light to measure the distance and angle from instrument to reflector, then calculates the relative position and elevation. Two benchmarks are required for a total station to provide accurate information. The instrument manual should be consulted for calibration and other procedures specific to the instrument employed. Similar to the autolevel method, the total station requires line of sight to points of interest and operation typically requires two people.

In addition, real time kinematic (RTK) GPS technology is a useful means of establishing benchmarks and can be used for elevation surveys. Two GPS receivers are linked via a radio connection: the base unit is stationary and the mobile unit (rover) 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 satellite reception problems in areas of heavy tree or shrub cover. In addition, surveyed elevations using an RTK and NOAA’s Online Positioning User Service (OPUS) processing may differ from traditional field surveys using local benchmarks (see Additional Information subsection, below). NOAA’s height modernization program is designed to improve vertical control throughout the United States and, while there is no definite plan to update Columbia River region, efforts are underway in Oregon to implement the program.

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.

4.3.10 Additional Information

Two types of vertical datums relate elevations in the Columbia River estuary. Tidal datums, including MLLW, are based on data collected at tidal benchmarks over a 19-year period. Fixed geodetic datums, such as NAVD88, are based on a fixed set of constants and are generally used for terrestrial elevation surveys. The Columbia River Datum (CRD) is a fixed datum; however NOAA has linked the CRD to a tidal datum for eight locations on the river (Stolz et al. 2005). The corrections between these datums are available at selected sites in the Columbia River, but interpolation of the corrections between sites should be done cautiously and is not recommended for locations away from the main channel of the river (e.g., up tributaries and sloughs). Tidal benchmarks information and datum correction information are online at http://tidesandcurrents.noaa.gov/ [accessed 6 October 2008].

Survey procedures are online at http://www.usace.army.mil/usace-docs/eng-manuals/em1110-1-1005/toc.htm [accessed 6 October 2008].

Real Time Kinematic (RTK) GPS information is online at http://geodesy.noaa.gov/OPUS/ [accessed 6 October 2008].

LiDAR information is online at http://pugetsoundlidar.ess.washington.edu/ [accessed 6 October 2008].

4.4 Landscape Features (Protocol 4)

4.4.1 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 the intertidal area) and vegetation communities (e.g., agricultural meadow vs. 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.

4.4.2 Goal

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

4.4.3 Design

Imagery

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 (Protocol 3, elevation, and Protocol 5, plant species composition and cover), locations for data logging instruments (Protocol 1, hydrology, and Protocol 2, 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 to assess changes in geomorphological features and vegetation communities.

Specifications—The three sources of aerial imagery are 1) publicly available (free of charge), 2) commercially available (with a fee), or 3) data flown specifically for a site (individually contracted). Further, a variety of types of imagery useful to site-scale restoration project monitoring are available including 1) orthorectified black and white or color aerials, 2) stereo-paired aerials, 3) digital multispectral orthorectified aerials (including infrared), and 4) satellite imagery. Aerial imagery requires sufficient detail to identify features of interest (e.g., 1-m resolution) and should be full color, near infrared to distinguish plant communities and vigor, or both.

Tidal stage, time of day, and seasonality are also important factors to consider. 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 light contrast. Late summer season maximizes vegetation growth and has a better chance of favorable weather in the Pacific Northwest. 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.

Interpretation—Interpretation of the acquired imagery can be conducted manually by digitizing polygons, lines, or points using a GIS platform. This method requires ground truth data to evaluate the photos and determine where features should be delineated. 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.

Analysis—GIS techniques may be employed to quantify changes in landforms and vegetation patterns. For example, polygons of vegetation classes can be developed from interpretation of the imagery and can be evaluated to determine the area of each classification and the change in area over time. Additionally, tidal channel delineations 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, compass, 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. A reference stake placed in the frame of the photo can provide scale and a consistent feature in all photos. In addition, bringing photos from prior years into the field makes it easier to replicate the exact frame. Photo points are best permanently marked with PVC or rebar. Using the same camera also increases consistency.

4.4.4 Equipment

If publicly available aerials are insufficient, overflights of target sites may be arranged through commercial vendors. Ideally, large areas of the CRE can be acquired during one flight, thus maximizing coverage and cost efficiencies.

Desktop analysis requires GIS.

Equipment includes camera, map, compass, stakes for marking and for reference in photo, and GPS.

4.4.5 Site Selection

Imagery should include the restoration and reference sites in their entirety and be collected concurrently. Photo points should be located at vantage points offering views of expected areas of change.

4.4.6 Sampling Periodicity

The frequency of imagery 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 time immediately following implementation of restoration actions. Photo point periodicity depends on sampling objectives, that is, comparing seasonal differences or annual variability.

4.4.7 Sampling Protocol

Step 1. Before:

- Obtain aerial photos of reference and restoration sites.
- Examine photos for hydrologic barrier locations.
- Assess vegetation patterns and channel locations.
- Plan location of random or stratified sampling grid.
- Collect GPS coordinates and corresponding photographs to ground truth landform and vegetation patterns.

Step 2. After:

- Repeat Step 1 above.
- Compare before and after images of reference and restoration sites for changes in landforms and vegetation using GIS.

4.4.8 Calculations and Analysis

GIS-based measurements include site area; width, sinuosity, density, and total edge of tidal channels; as well as area and configuration of landforms and broad vegetation communities.

4.4.9 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 using image analysis software. The 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 explicit method of determining broad vegetation categories and the 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 LWD. These data sets are important to correlate with monitoring attributes related to water elevation, passage barriers, and tidal channel edge.

4.4.10 Additional Information

Imagery

Aerials from multiple years for Oregon, including most of the Columbia River estuary are online at http://www.oregon.gov/DAS/EISPD/GEO/data/doq.shtml [accessed 6 October 2008].

A source for aerial imagery (recent and historical) and satellite imagery is online at http://edcsns17.cr.usgs.gov/EarthExplorer/ [accessed 6 October 2008].

Aerials are available for purchase from the Washington Department of Natural Resources, online at http://www.dnr.wa.gov/BusinessPermits/Topics/Maps/Pages/orthophotography.aspx [accessed 6 October 2008].

Photo points

The Oregon Watershed Enhancement Board (OWEB) photo point monitoring protocol is online at http://www.oregon.gov/OWEB/docs/pubs/PhotoPoint_Monitoring_Doc_July2007.pdf [accessed 6 October 2008]. See also Hall 2002.

4.5 Plant Species Composition and Cover (Protocol 5)

4.5.1 Purpose

Tidal reconnections can 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 and tidal freshwater 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 Protocol 1, hydrology, Protocol 3, elevation, and Protocol 4, landscape-scale GIS data.

4.5.2 Goal

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

4.5.3 Design

Vegetation monitoring at restoration sites in Pacific Northwest estuaries is typically designed to quantify changes in species percent cover (e.g., Frenkel and Morlan 1990 and 1991, Thom et al. 2002). Measurements are usually made along transects. We recommend sampling be concentrated on transects proximal to expected changes, for example, near a culvert replacement or dike breach. For comparability, vegetation sampling on reference sites is best conducted at portions of the site with similar hydrology, for example, at similar distances from channels. 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 (Figure 10).

A subset of plots may be fixed (i.e., sampled repeatedly) to track trends, while others are 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. While soil surveys and groundwater monitoring can provide additional information for stratification, these data sources may not be available. If a considerable elevation gradient is present at the site, multiple baselines may be required to encompass the different plant communities present at different elevations.

Vegetation along transects is sampled in plots with plot size and shape depending on the type of dominant vegetation at the site: 1 m^2 plots are used for herbaceous plant communities (Thom et al. 2002), belt transects for shrubs (Havens et al. 2003), and large circular plots for forested wetlands. When multiple plant communities are present at a site, the sampling design selects smaller herbaceous plots from both within and outside of larger plots to represent a greater portion of the study area and improve precision. While the 10-m diameter tree plot size recommended here is smaller than some comparable methods (Havens et al. 2003), it approximates line-of-sight in Columbia River swamps and for this reason is highly efficient, enabling a greater number of plots to be sampled and increasing precision.

4.5.4 Equipment

Field: 1 m^2 quadrat, 100-m tapes, site map, rebar or PVC stakes, mallet or hammer, plant identification books, bags for unidentified plant collection, and GPS. Additional tools for forested wetland and shrub/scrub communities include diameter tape, calipers, increment borer, clinometer, 10-m tape, and meter stick.

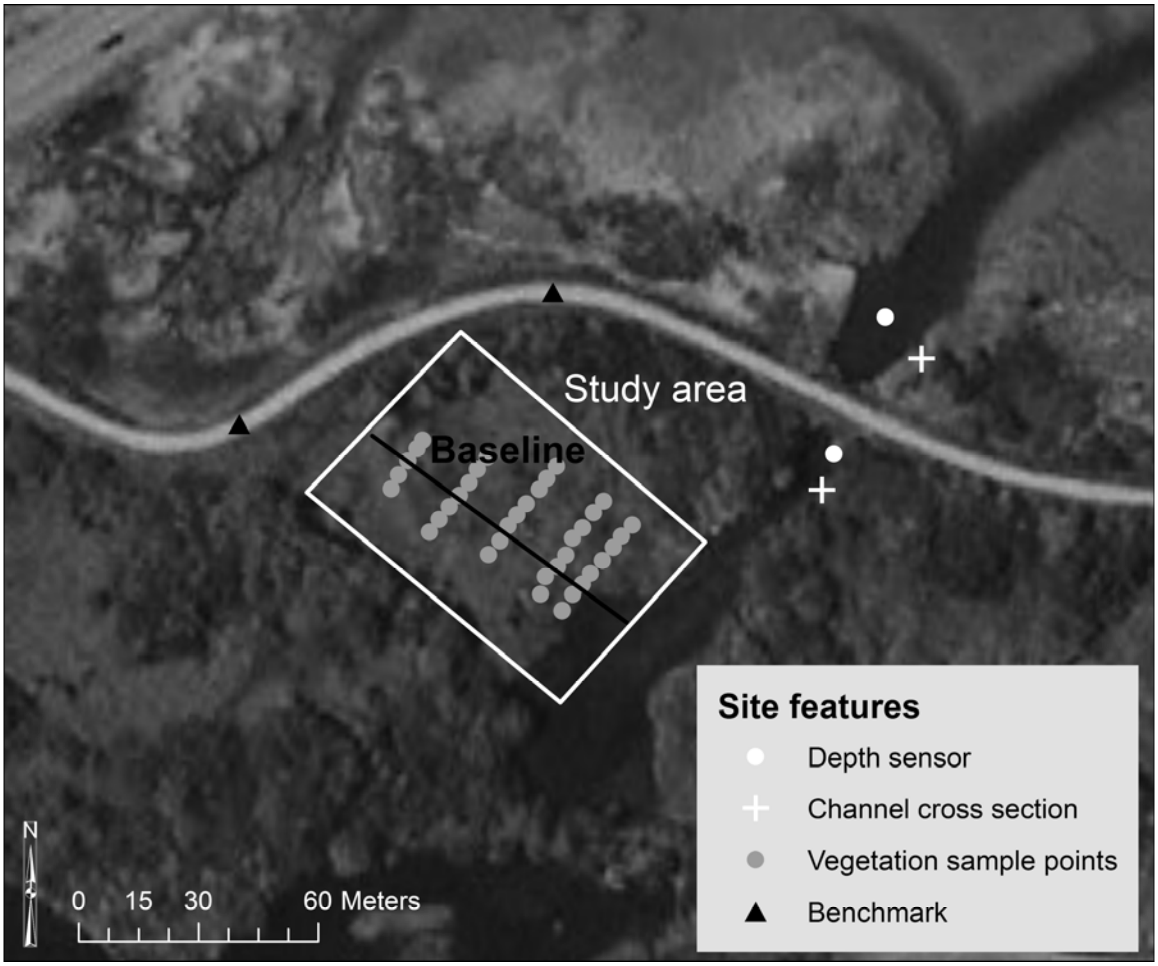


Figure 10. Example of baseline and transect sampling design in an herbaceous area.

Lab: Aerial photos, GIS (if available).

4.5.5 Site Selection

General site selection considerations

A sampling site is selected proximal to the proposed restoration action (e.g., dike breach). At the reference site, a sampling site similar to the restoration sampling site is selected, particularly with respect to proximity to the channel, channel size, and the width of the area sampled, allowing comparison between the two sites. If multiple plant communities are present (along elevation gradients), the sampling may need to be stratified by plant community.

For herbaceous communities

Step 1. A linear baseline is established that is oriented perpendicular to the elevation gradient and runs through the entire sampling site (Figure 10). This baseline transect should be 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.

Step 2. Several transects are established at intervals perpendicular to the baseline. The position of the first transect is chosen at random from all possible points along the baseline (systematic sampling with a random start). The additional transects are equally spaced relative to the first transect (e.g., 5 transects at 20-m intervals along a 100-m baseline).

Step 3. On each transect, monitoring plots (1 m^2) are established at equally spaced intervals depending on the size of the site (Figure 11). As with the positioning of transects along the baseline, the plots are spaced relative to the first plot, which is positioned at random along the transect and thus avoids a grid pattern. Typically 5 to 10 plots per transect are sufficient to adequately sample the cover of the vegetation.

Forested wetland and shrub/scrub communities

Step 1. The length of the focal channel to be sampled is determined (e.g., 300-m) and a random number between 0 and the length of the channel is chosen as the start point for placement of the first transect. Transects cross the channel encompassing the riparian area on both sides (e.g., 50 m on each side of the channel). Remaining transects are located parallel to the first and systematically spaced (e.g., 5 transects at 50-m intervals) (Figure 12).

Step 2. Monitoring plots (10-m diameter circles) are then established at equally spaced intervals along each transect starting at the channel bank (Figure 13). In this example, a random

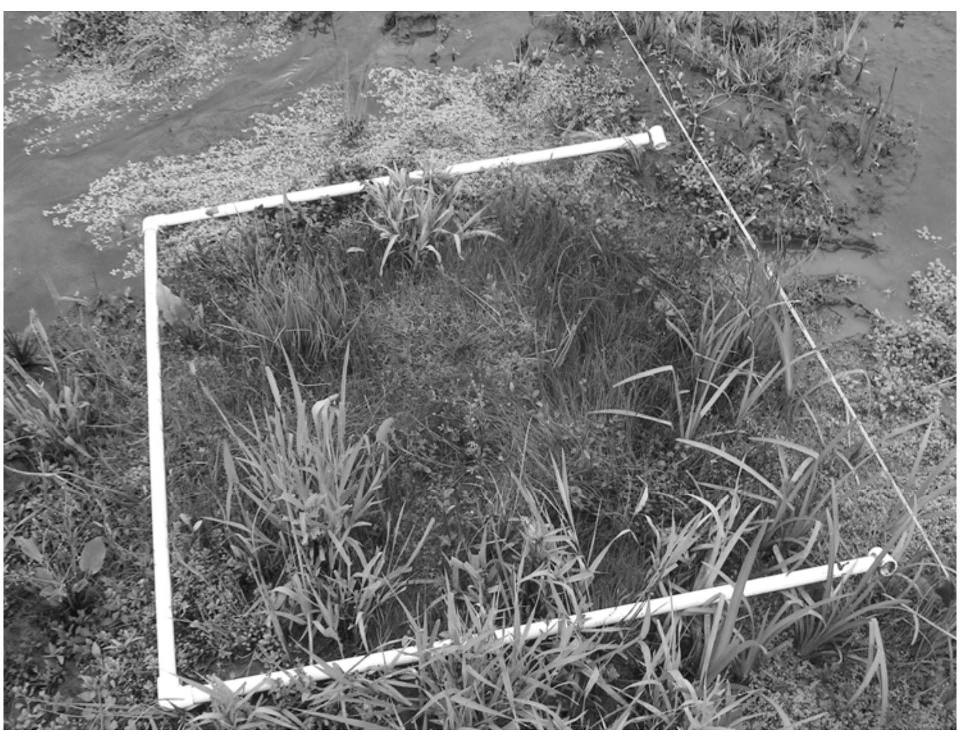


Figure 11. Baseline tape and collapsible three-sided quadrat form a 1-m^2 herbaceous vegetation sampling plot.

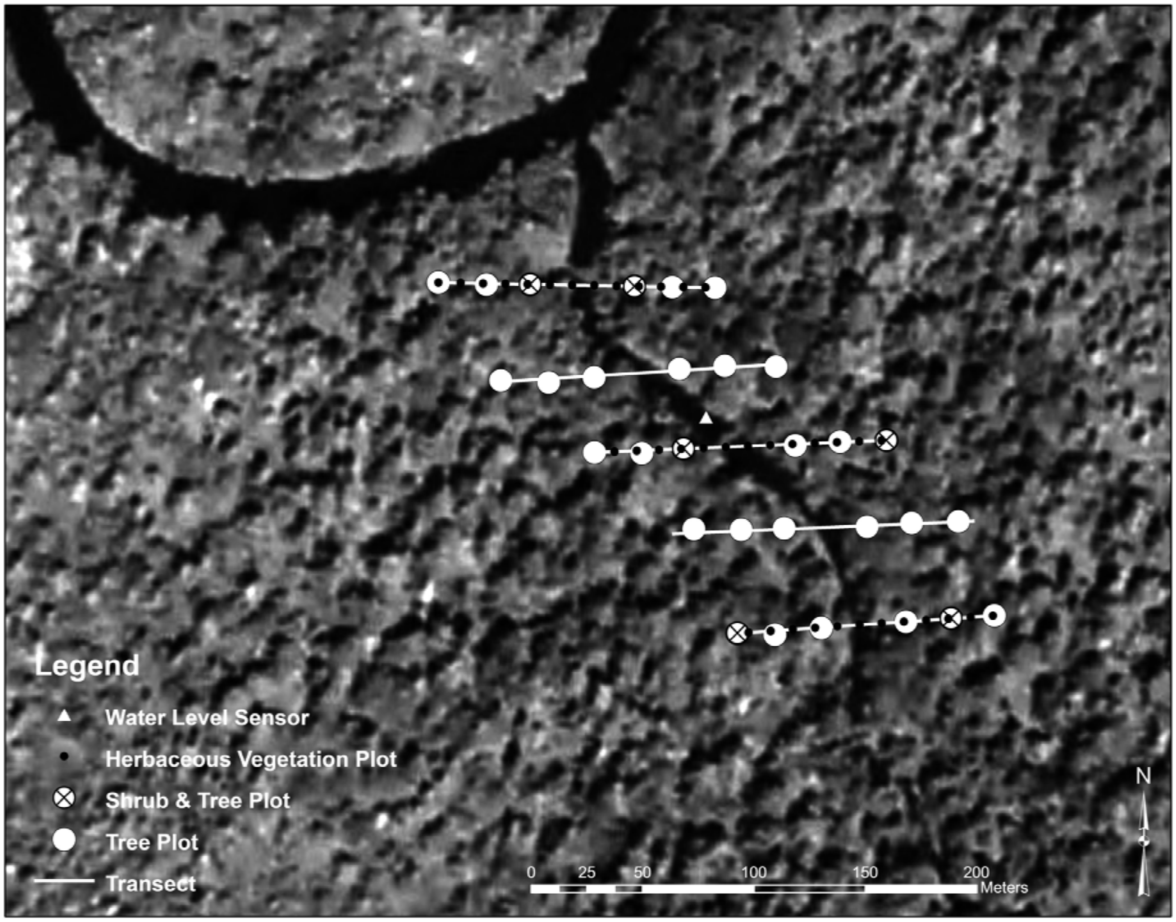


Figure 12. Example of sampling design in a forested wetland.

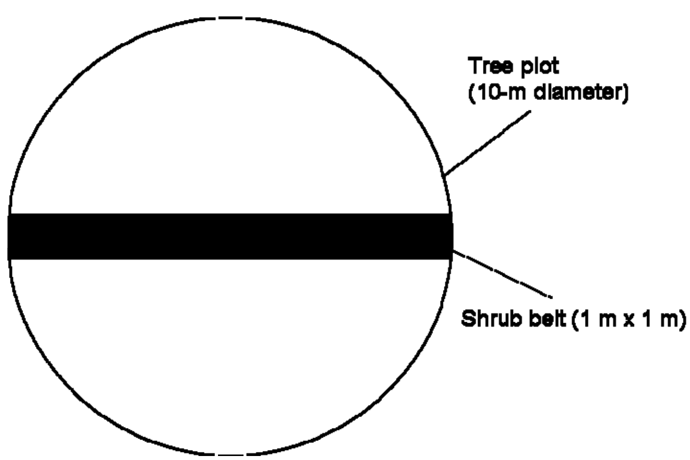


Figure 13. Plot design for forested wetlands.

number between 5 and 50 would be used to locate the center of the first plot (numbers 4 or below would cause a portion of the channel to be included in the 10-m diameter plot). A very high number of plots may be required to achieve high precision in some of these communities (e.g., 695 tree plots for alpha = 0.05 and precision = 0.05 in Sitka spruce [*Picea sitchensis*] swamps). Typically, such sampling is not economically feasible for restoration practitioners and a lower precision is accepted for reference purposes (e.g., 6 plots per transect on 5 transects yields 30 plots).

4.5.6 Sampling Periodicity

If possible, sampling should occur at least once before restoration treatments and in 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 vegetation communities. With limited resources, it is best to sample vegetation in midsummer to capture the period of greatest biomass and cover, although additional sampling in spring and late summer generally increases the number of species found on the site.

4.5.7 Sampling Protocol

Initial assessment

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. The boundaries between plant communities can be mapped using a GPS in the field or from aerial photography with ground truthing (Protocol 4, landscape features). This technique is being used in the Columbia Estuary Ecosystem Monitoring Program and is most effective when clear elevation gradients are present (Leary et al. 2005).

Step 1. Define the study area boundaries (Figure 10) based on the extent of expected inundation and proximal to the proposed restoration action.

Step 2. Use aerial photos (Protocol 4, landscape features) to broadly characterize existing plant communities (e.g., herbaceous, shrub/scrub, forested).

Step 3. Establish baselines based on broad plant communities and elevation strata. Mark baseline endpoints with permanent stakes (rebar or PVC) and record GPS positions.

Herbaceous-only vegetation communities

Step 1. Establish transects at intervals along the baseline with a density of approximately 5 transects per 100 m.

Step 2. Select plots along each transect (5–10 plots per transect are often sufficient). The total number of plots depends on the size and homogeneity of the area.

Step 3. In each 1 m^2 plot, visually estimate percent cover in 5% increments, using a "trace" category for species that cover less than 5% of the area within the quadrat (e.g., 25%

Lyngbye's sedge (*Carex lyngbyei*), 50% reed canary grass (*Phalaris arundinacea*), 20% broadleaf cattail (*Typha latifolia*), 5% water plantain (*Alisma plantago-aquatica*), and trace, threepetal bedstraw (*Galium trifidum*).

Step 4. 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 two diagonal or all four corners of each permanent plot with 1.2–2.0 m, 1.9-mm (3/4-inch) PVC pipe driven to a depth of at least 1 m. Flag the pipe so that it can be easily identified from a distance and record GPS positions.

Step 5. Repeat sampling using the same design at the reference site.

Forested wetland and shrub/scrub communities

The sampling methods for these community types are far less defined in the literature and are still under development by many organizations in the Pacific Northwest. The recommendations here are based on our investigations of Sitka spruce swamps in the vicinity of Grays Bay on the Columbia River. Tree, shrub, and herbaceous layers may be present in these communities and require sampling with different methods. Conditions in these systems are challenging at best, making many measurements difficult and time consuming relative to sampling precision objectives. The shrub belt transect method described here was efficient but did not capture as many species as a point-intercept method. Each situation needs to be considered individually for hazards, feasibility, and resources.

Step 1. Establish transects as described in Site Selection above.

Step 2. Place tree, shrub, and herb plots along each transect, systematically spaced from random starting points:

- Starting at the channel bank, place 10-m circular tree plots along each transect; the number and spacing is dependent on the size and homogeneity of the area. In the Site Selection example from the Sitka spruce swamp research above, 30 plots or 3 plots on each side of the channel on five transects was sufficient to provide tree cover precision within 20% of the mean 80% of the time (i.e., 20-m spacing between 10-m plot centers).
- Select a random subset of the tree plots in which to sample the shrub belt. The size of the subset depends on available resources; a randomly selected subset of 10 of the 30 tree plots was sufficient to provide shrub cover precision within 20% of the mean 80% of the time in some but not all of the Sitka spruce swamps that we sampled.
- Place 1 m^2 herbaceous plots systematically spaced from a random start on each transect. The systematic spacing will place some herbaceous plots within and others outside of the tree plots and shrub belts. In the previous example, 50 plots may be sufficient to provide herbaceous cover precision within 20% of the mean 80% of the time.

Step 3. Measure species cover for each plot using the following techniques:

- For trees lay a 10-m tape perpendicular to the transect tape to delineate the 10-m diameter circular tree plot. Identify all trees in the plot to species, then measure diameter at breast height (dbh) with calipers or a dbh tape. Measurement of dbh is made at 1.4 m above the duff layer upslope of the tree, not including woody debris.

- If the construction of site tables correlating age with height and dbh is desired, core these trees or a randomly selected subset of them with an increment borer and preserve the cores for later ring counts (drinking straws provide a convenient storage method), then measure the angle from the observer's eye to the top of the tree with a clinometer, along with the distance from the observer to the tree for calculation of height. For more accurate dating or to analyze disturbance history, collect two cores from each tree and use cross-dating methods (Stokes and Smiley 1968, Kipfmueller and Swetnam 2001).
- For shrubs lay a 10-m tape perpendicular to the transect tape to delineate a 1 m by 10 m belt across the tree plot. Identify all shrubs that are rooted within the belt to species and count number of stems at 1.4-m height and record by species. If level of effort permits, record stems by diameter class (at dbh) following Peet (1998): 0–1 cm, 1–2.5, 2.5–5, 5–10, 10–15, 15–20, 20–25, 25–30, 30–35, and 35–40; stems greater than 40 cm should be measured. Following Peet (1998), individuals are defined as stems at 0.5 m: "Multiple stems arising from a common root system are recorded separately if they branch below 0.5 m above ground level (stems branching above 0.5 m and below 1.4 m are measured at the narrowest point below the branch)."
- For herbaceous vegetation, sample the percent cover of the herbaceous layer on 1 m^2 plots as described above in herbaceous-only vegetation communities.

Step 4. Repeat sampling using the same design at the reference site.

4.5.8 Calculations and Analysis

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

For herbs construct a table with a species list containing the mean with SD or 80% confidence limit for 1) cover of each species over the entire site, 2) cover of each species along each transect, and 3) total vegetation cover (±SD) for the entire site (Table 4).

Table 4. Average percent cover of the dominant plant species at two sampling locations on a restoration site (SSE and SSW) before and after a restoration action.

Scientific name	Common name	SSE 2005	SSE 2006	SSW 2005	SSW 2006
Juncus effusus	Soft rush	0.88	1.51	14.2	3.92
Phalaris arundinacea	Reed canary grass	27.1	57.0	33.1	56.3
Ranunculus repens	Creeping buttercup	21.5	13.7	6.78	1.85
Rubus discolor	Himalayan blackberry	0.00	0.00	16.8	3.42
Trifolium pretense, *T. repens*, and *T. dubium*	Red clover, white clover, and small hopclover	19.4	0.28	0.00	0.00
n/a	Mixed grass	49.7	22.5	4.19	3.13

For shrubs construct a table with a species list containing 1) the number of stems of each species over the entire site along with the SD or 80% confidence limit, and 2) the stem density of each species (stems per hectare).

For trees create a table with the basal area of each species, percent frequency, density, basal area per hectare (dominance), relative frequency, relative density, and relative dominance.

Construct a species time x-y plot showing the mean cover of one to three selected species vs. sampling period at the restored site.

Create 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.

Calculate the similarity of species composition at the restored site vs. the species composition at the reference site and between years using the formula presented in Thom et al. 2002 (Table 5).

Correlate dominant plant community with elevations, if elevation data are collected (Figure 14, see also Leary et al. 2005).

4.5.9 Additional Information

See Frenkel and Morlan 1990 and 1991, Cornu and Sadro 2002, Thom et al. 2002, Havens et al. 2003, and Leary et al. 2005.

Useful plant identification books include Hitchcock and Cronquist 1973, Pojar and MacKinnon 1994, Cooke 1997, and Washington Department of Ecology 2001.

Table 5. Example of a weighted similarity index. This assesses the similarity of the vegetation cover between baseline conditions in 2005 and postrestoration conditions in 2006 at two restoration sites (SSE and SSW), and compares baseline and postrestoration conditions at each site with a reference site (KR).

	SSE 2005	**SSW 2005**	**SSE 2006**	**SSW 2006**	**KR**
SSE 2005		72.6	92.8	–	23.4
SSW 2005			–	94.0	30.6
SSE 2006				86.3	23.4
SSW 2006					53.2

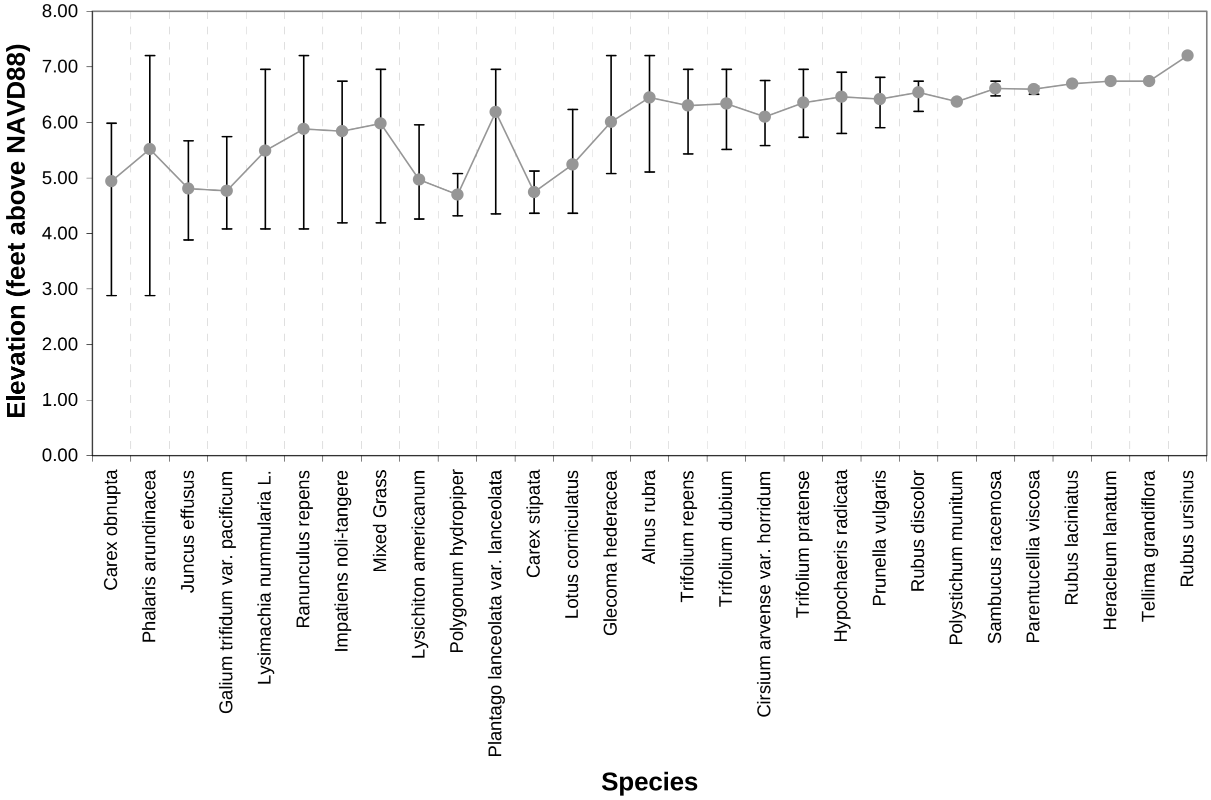


Figure 14. Elevation of dominant flora, Kandoll Farm, 2005.

4.6 Vegetation Plantings (Protocol 6)

4.6.1 Purpose

Vegetation planting[3] can increase the rate at which desired species become established at a restoration site. Planting native vegetation can reduce erosion, increase cover and shade, and often reduce nonnative invasive species (e.g., reed canary grass). To date, native vegetation plantings in the Columbia River estuary have been primarily trees and shrubs (woody species); however, this protocol outlines methods for monitoring woody species and herbaceous species (e.g., emergent wetland vegetation) to meet potential needs as restoration efforts increase in scope and diversity. The effectiveness of habitat vegetation plantings can be determined by assessing survival, overall health, and growth of the plantings over time. Often, invasive species management is a critical component to ensure the success of native species. 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, adaptive management corrections should be implemented. Examples of success criteria are 1) percentage of tree or shrub survival (stems per unit area) of

[3] Substantial elements of this protocol have been drawn directly from previously released methods developed and written by George Kral of Ash Creek Forest Management in Tigard, Oregon. While we have not field-tested this method, it is currently in use by others monitoring revegetation planting success in the lower Columbia River and estuary.

initial planting stock, 2) amount of area covered by vegetation plantings, or 3) similarity to reference system within an established time period.

4.6.2 Goal

Measure percent cover and density of vegetation prestoration and postrestoration to determine whether a site is meeting success criteria and identify any needed corrective actions.

4.6.3 Design

The aim of the monitoring design is to capture the range of plantings that may occur in the Columbia River estuary, including herbaceous and woody vegetation. The sampling design is very similar to that described in Protocol 5, plant species composition and cover. Systematic sampling with a random start is recommended to achieve results that are representative of the conditions at the site. Transects are established at equal intervals from a random point along an established baseline; likewise plots are spaced at equal intervals from a random point on each transect (Figure 15). A subset of plots may be fixed (i.e., sampled repeatedly) to track trends, while others are randomized anew for each sampling event to assess status. The baseline remains the same each year. Photo points are also recommended to capture qualitative changes on the site over time (see Protocol 4, landscape features).

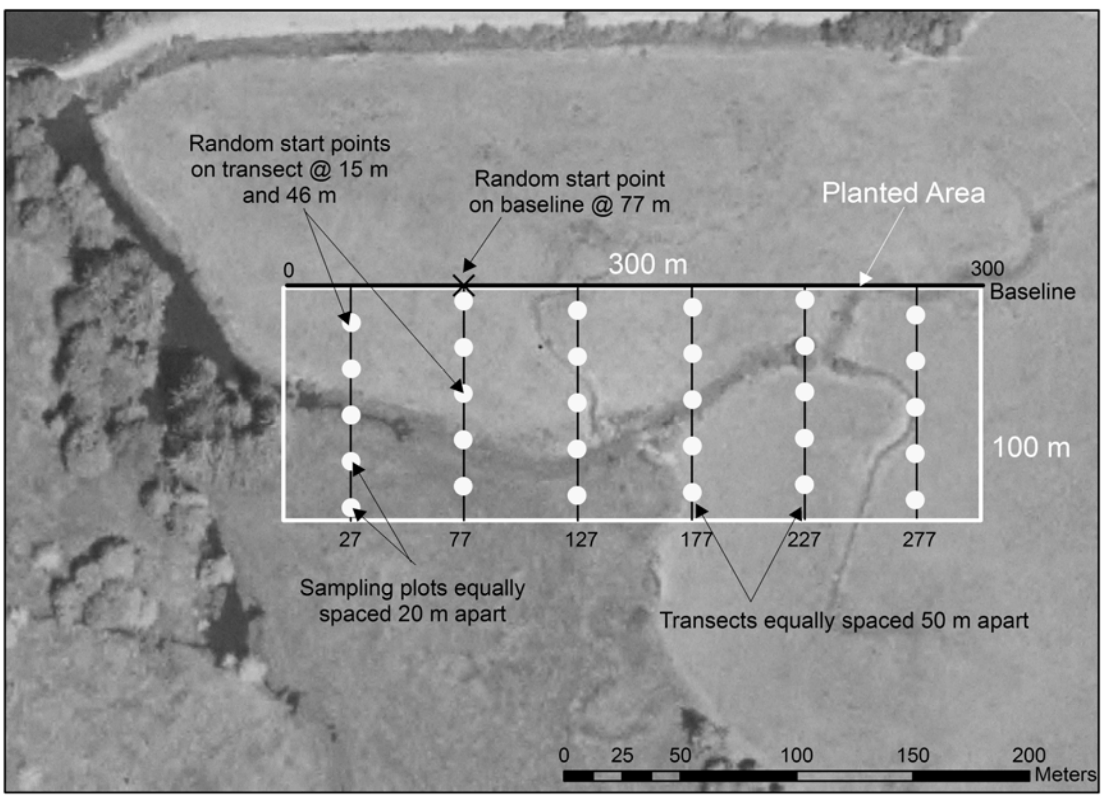


Figure 15. Example of a woody vegetation planting site showing location of sample area, baseline, transects, and sample plots (note: example only, not an actual planting site).

4.6.4 Equipment

Field: Field notebook, meter tapes (100 m for baseline and transects, 10 m for tree and shrub plots), densiometer (a small, hand-held curved mirror grid used for canopy cover measurements; see Additional Information subsection below), rebar or PVC stakes, GPS, camera, and 1 m^2 quadrats.

Lab: Aerial photos, GIS to assess GPS coordinates and create maps.

4.6.5 Site Selection

General site selection considerations

Using aerial photos or other site information, stratify sites by vegetation community or potential planting areas. If the area has already been planted, identify the planted areas. If possible, a reference site with desired species composition also should be identified. The reference site can be monitored using the methods outlined in Protocol 5, plant species composition and cover, or an existing reference site can be used (e.g., Lower Columbia River Estuary Partnership Reference Site Study or City of Portland, Bureau of Environmental Services, Watershed Revegetation Program Reference Sites).

Determine location of baseline, transects, and sample plots.

The location of the sample plots can be determined in the office, based on the aerial photos or site maps as follows.

For each area to be monitored (e.g., potential or existing planting site), determine the dimensions and area of the site. The recommended number of sample plots per site is:

Size	Woody plots	Herbaceous plots
<0.1 ha (1,000 m^2)	3	10
0.1–1.0 ha	10	20
1–5 ha	10 per ha	20 per ha

For sites greater than 5 ha, a portion of the site that is representative of the whole area should be sampled, with a maximum of 50 woody plots and 100 herbaceous plots.

The size of the area will determine how many sample plots are needed, while the dimensions will influence the length of the baseline, number and length of transects, and placement of the plots. For the following discussion, assume the area of a site is 3 ha (300 m by 100 m) and therefore requires 30 woody plots or 60 herbaceous plots.

Determine the length and width of the site and establish a baseline along the longest part of the planted area. In our example, the baseline would be 300 m.

Transects should encompass the width of the planted area (e.g., 100 m) and should be spaced to cover the entire monitoring site. The spacing between transects and sample plots does not need to be equal and can be closer within transects than between transects. The main factor to consider is the distribution throughout the site. At an irregularly shaped site, the length of transects will need to be adjusted to stay within the site boundaries; it is acceptable for transects on irregular portions of the site to have different lengths. In the above example, 6 transects would be spaced 50 m apart along the baseline.

To determine the location of transects, choose a random number between zero and the length of the baseline and place a cross transect perpendicular to the baseline at the location of the random number. Remaining cross transects are located parallel to the first and systematically spaced. In the example above, if the baseline random number were 77 then cross transects would be set at 27, 77, 127, 177, 227, and 277 meters. In excessively narrow sites, such as some riparian plantings, other methods may be used to select plot locations provided that they are random and unbiased.

Sample plots (8-m diameter circles for woody species and 1 m^2 quadrats for herbaceous species) are located at equally spaced intervals along each transect, with the start point chosen randomly for each cross transect. In the example above, 5 plots per transect on 6 transects yields 30 plots with the plots spaced 20 m apart. For herbaceous vegetation monitoring, 10 plots per transect at 10-m spacing would be needed to yield 60 plots.

4.6.6 Sampling Periodicity

A prerestoration assessment is recommended to determine existing stems per area, canopy cover, and herbaceous cover. Sites will also be stratified into vegetation communities at this time.

Comprehensive monitoring for woody species will occur the first year after planting, then every 5 years (at least years 1, 5, and 10), and for herbaceous wetland species every 2 years (at least years 1, 3, and 5) until the project can be evaluated for relative success.

Rapid monitoring of vegetation planting success is also recommended to ensure potential failure is identified, so that contingency management can be implemented if needed. Rapid monitoring would be conducted every year for the duration of the project, including comprehensive monitoring years.

Monitoring should be conducted at the end of the growing season before leaves begin to fall to capture maximum growth for the season.

4.6.7 Sampling Protocol

Prerestoration assessment

The prerestoration assessment should happen as soon as the site is accessible and cleared of any restrictive vegetation (e.g., dense blackberries).

Step 1. Define the study area boundaries (see example above) based on extent of expected restoration.

Step 2. Use aerial photos (Protocol 4, landscape features) to broadly characterize existing plant communities (e.g., herbaceous, shrub/scrub, forested).

Step 3. Assess sites in the field prior to restoration to verify existing vegetation communities, size, soil characteristics, and topography.

Step 4. Establish baselines based on broad plant communities and elevation strata. Mark baseline endpoints with permanent stakes (e.g., rebar or PVC) and record GPS positions.

During this assessment, at least two sample plots (8-m diameter) should be sampled per existing vegetation strata, with plots located to best represent the strata. A list of common species for each strata can be developed from the sampling and observations at the site. Recommended measurements in the plots are 1) tree and shrub density, 2) canopy cover (using a densiometer), and 3) an estimate of herbaceous cover by species. The herbaceous and canopy cover data can be collected using cover classes such as outlined in Daubenmire (1959) as follows:

Class	Cover (%)
1	0–5
2	6–25
3	26–50
4	51–75
5	76–95
6	96–100

The information collected during this assessment is useful for determining a treatment plan, if necessary, and the planting scheme.

Comprehensive monitoring

For woody plants, the steps are:

Step 1. Establish overall size of the planting area and mark boundaries with GPS (all four corners of site and more points if the shape is irregular).

Step 2. Select sample plots throughout the site as described in Site Selection above, record each with GPS, and establish an 8-m diameter circular plot by laying an 8-m tape perpendicular to the transect tape to delineate each 8-m diameter tree plot with crosshairs.

Step 3. To monitor trends at the site, choose a randomly selected subset of approximately one-third of the total number of plots to be permanent plots. These plots will be resampled each year. Mark the center of the plot with rebar or a PVC stake and record the GPS position. (Note: If a subset is chosen as permanent plots, then the number of sample plots will increase in future years in order to include new randomly selected plots and existing permanent plots.)

Step 4. Identify and count all woody plants in all plots by species and record the following:

- Live or dead

- Natural or planted
- Plant vigor as defined in three categories.

Category	Description
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

This measurement yields plant density as discussed in the Calculations and Analysis subsection below.

Step 5. For sites 5 or 10 years old, record dbh for the stem closest to the center of the plot (must be at least 2-m tall).

Step 6. Take four densiometer readings, using the Daubenmire Cover Classes described above at 1.4 m above the ground and 2 m from the plot center, facing north, east, south, and west. Record average measurement.

Step 7. Estimate herbaceous cover by estimating the percentage of plot occupied by all species using Daubenmire Cover Classes. (Note: This is the herbaceous cover within an area planted with woody species, not to be confused with the section below describing monitoring methods for herbaceous plantings.) The information gathered in this step is important in identifying potentially competing vegetation.

Step 8. Record observations on causes of plant mortality, animal activity, and other significant natural or anthropogenic occurrences.

Step 9. Establish permanent photo points of the area planted as described in Protocol 4, landscape features.

For herbaceous plants, the steps are:

Step 1. Establish overall size of planting area or seeded area and mark the boundaries with GPS (all four corners of the site and more points if the shape is irregular).

Step 2. Select sample plots throughout the site as described in Site Selection above, record each with GPS, and center 1 m^2 quadrat on cross transect meter tape so that the tape acts to divide the quadrat in two halves (this aids in estimating cover classes).

Step 3. Estimate herbaceous cover by percentage of plot occupied by all species using Daubenmire Cover Classes.

Rapid monitoring

At each site, establish the location of sample plots as described in the Site Selection section above using the previously established baseline. The sample plots should be established using a new random start point along the baseline and new random start points on each transect.

Identify and list native and nonnative species at the site.

If woody species were planted, count the number of stems per plot as outlined above, but not by species. Calculate average number of trees and shrubs per acre (see below).

Estimate percentage cover within the plot of nonnative weedy species.

Recommend maintenance treatments such as removal of invasive species, additional planting, seeding, and animal damage control.

4.6.8 Calculations and Analysis

Obtain the number of plants installed per hectare (i) from the planting contractor. Sum the total number of live, installed plants (T) observed on all plots. Divide the total number of live, installed plants (T) by the number of plots sampled (n) to obtain the average number of live, installed plants per plot (T_p).

$$T_p = T/n \quad (1)$$

Multiply the average number of live, installed plants per plot (T_p) by 200 to obtain the total number of live, installed plants per hectare (T_h). Note: A 4-m radius plot equals 1/200th of a hectare.

$$T_h = T_p \times 200 \quad (2)$$

Divide the total number of live, installed plants per hectare (T_h) by the number of plants installed per hectare (i) to obtain the survival rate of installed plants.

$$\text{Survival rate} = T_h/i \quad (3)$$

Multiply the survival rate by 100 to assess percent survival against the performance goal for survival of initial planting stock (Figure 16). Use T_h to compare total number of live plants to a reference site.

4.6.9 Additional Information

A densitometer is a small hand-held curved mirror grid. The canopy cover can be predicted by estimating the percent of the grid that is covered by the image of the canopy.

Figure 16. Replanting with native shrub and tree species at a Columbia River estuary restoration site.

4.7 Fish Community (Protocol 7)

4.7.1 Purpose

The incentive for many restoration activities in the CRE is to increase habitat available for rearing and migrating juvenile salmonid ESUs listed as threatened or endangered under ESA. One measure of success in effectiveness evaluations is a demonstration of increased habitat use by salmonids at restored locations relative to reference habitat. The minimum protocols for fish monitoring include abundance and size measurements of species at each site. From these basic data, species composition and size-frequency histograms can be produced. However, we advocate higher order measurements for quantitative assessment of habitat utilization by different salmon stocks and life history types, which require analysis of, for instance, genetics, marks and tags, and prey availability and consumption (see Additional Measurements subsection, below). Ultimately, relation of fish habitat use to physical conditions such as water quality (Protocol 1, hydrology, and Protocol 2, water quality) will be important for evaluating and predicting restoration success in the CRE.

4.7.2 Goal

Evaluate species composition (lowest practical taxon), temporal abundance patterns (catch per unit effort [CPUE] by date), and fish size (fork length or total length) in prerestoration habitat, postrestoration habitat, and reference sites.

4.7.3 Design

The BACIPS/recovery survey design with prerestoration measurements should be utilized whenever possible to establish baseline community structure (see 3.1 Statistical Design subsection, above). However, fish presence or absence in restored vs. reference sites is the minimal metric for comparing habitat use. Repeated sampling allows a time series of abundance to be generated, information that is used to calculate migration timing and overall habitat use for juvenile salmonids. Fish lengths are used to construct size-frequency histograms that help determine which life history stages are utilizing the various habitats (e.g., fry, smolt-sized subyearling, or yearling salmon). Standard indexes of community structure (catch, number of species, diversity) provide an assessment of the recovery trajectory of restoration relative to reference sites. Fish community metrics can be correlated with physical (Protocol 1, hydrology, and Protocol 2, water quality) and biological (Protocol 4, landscape features, and Protocol 5, plant species composition and cover) features to characterize habitat opportunity and capacity.

4.7.4 Equipment

There are a variety of gear types used for sampling juvenile salmon and other fish in the CRE, including seines, fyke (trap) nets, barrier nets, and pit traps, discussed in detail below. Particular gear choices depend largely on the physical conditions and constraints at the sites. Terrain, bottom contour, hydrography, and debris load will influence the gear type as well as the sampling location at a given site. For comparative purposes, it is highly desirable to utilize the same gear type throughout the monitoring program; however, the varied topography of wetland habitats may render this impossible, and often more than one gear type will be required to sample all sites of interest.

Ancillary hardware and materials: Plastic buckets or garbage cans for holding containers (with 3/16-inch holes drilled in side for water overflow), battery powered aerators, plastic dish pan for anesthetic bath, buffered anesthetic solution (MS 222 solution at a concentration of about 50 mg/liter), dip nets, measuring boards, portable scale for weights, and standardized waterproof data forms.

Permits: Annually, a state fish sampling permit must be obtained from the Oregon Department of Fish and Wildlife or the Washington Department of Fish and Wildlife to conduct sampling in the Columbia River and its tributaries. An Endangered Species Act permit from NOAA Fisheries Service must also be obtained because of the likelihood that threatened or endangered Chinook, coho, and chum salmon and steelhead (*Oncorhynchus mykiss*) will be captured.

4.7.5 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 within the reference area should be as similar as possible to those of the restoration area. Fixed or random stations can be established. Fixed sites offer the benefit of generating time-series measurements at locations where other monitoring metrics are being collected (e.g., data logging instruments or vegetation plots). Randomizing sampling sites allows measurement of sample variability across habitats.

4.7.6 Sampling Periodicity

The minimum sampling frequency is 1 day per month at each selected site during the March through October timeframe that encompasses the time period most salmonids are residing in or passing through the lower river and estuary. To the degree possible, the tide cycle and time of day for all samples should be standardized.

4.7.7 Sampling Protocol

Seines and nets of various shapes, sizes, and methods of deployment are used to sample fish community structure. Net type and size are dependent on the width, breadth, and depth of the water body. Ideally, catch measurements should be standardized to density (fish per m^2), although accurate determination of area swept may not be possible due to variability between sets. Abundances expressed as CPUE are therefore often reported, and it is important to be cognizant that CPUE values are not strictly comparable between different gear types. Below we discuss protocols for commonly used net types.

Beach seines

Beach seines (Figure 17) require a shoreline area with sloping beach for ease of collection. The length of the seine depends on the area to be sampled. General dimensions are: 10–30 m long by 2 m deep using 1–2 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.

Use pull-to-shore haul for smaller tidal channels.

Step 1. Deploy the seine on the bank parallel to the channel and situate personnel on opposite shore.

Step 2. Retrieve net by pulling the two wings simultaneously to shore, being careful to maintain the leadline at the bottom. Crowd fish into the center bunt for capture, and transfer fish with a dip net to holding containers for measurement.

Step 3. Area sampled is net length multiplied by channel width, $A = L \times W$. Density = CPUE/A.

Use semicircular haul for larger channels or unenclosed habitats.

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 the free end to anchor end, forcing fish into the bunt for capture. Use a dip net to transfer fish to holding containers for measurement.

Figure 17. Beach seining near the Kandoll Farm culvert replacement at a forested wetland.

Step 3. Area sampled is a half circle with radius equal to the net length, $A = 0.25 \pi r^2$. Density = CPUE/A.

Pole seines

Pole seines are usually smaller nets that can be fished in areas of topographic complexity that would foul larger nets. General dimensions are: up to 10-m length (but often smaller) and 1.5-m depth (1–2 cm stretch measure with 0.6-cm mesh bunt in the middle). The fishing procedure is similar to seine nets. These versatile nets are easily adjustable for size of area, and can be utilized in many locations. However, CPUE may be correspondingly small.

Fyke trap nets

Fyke trap nets provide a method for sampling shallow, low velocity tidal channels. This gear type works best in blind tidal channels, but can also be used in conjunction with barrier nets (described in the following section) in open-ended tidal systems. The general trap design consists of a cylindrical trap tunnel ending in a sanctuary area, which is positioned in the main section of the tidal channel. For fish retrieval, it is convenient to have the cod end of the fyke constructed into a live floating box. Net wings stretch from either side of the trap mouth to the shoreline. As the tide ebbs, water and fish are funneled into the trap, where they are periodically recovered and measured. This gear is dependent on volitional entry and water current for entrapment, and works best in sections of tidal channel that drain completely, thus providing good estimates of fish utilization upstream of the trap. Sufficient depth for sanctuary of captive fish during low water periods is necessary. This method is useful for time-series measures of fish habitat use.

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

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

Step 3. Periodically empty the trap and process catch. After the tidal channel has drained, continue sampling in the remaining upstream pools, if any, with pole seines and dip nets.

Step 4. Density of fish is a function of wetted surface area, which is dependent on tidal amplitude. Area is best estimated by linking the water level (Protocol 1, hydrology) to marsh elevation (Protocol 3, elevation). Fish density = CPUE/area.

Barrier nets or screened panels

These nets are used in conjunction with traps and nets to close off all or portions of a sampling area to acquire greater precision of fish density calculations. Nets and panels are constructed of 1–2 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 panels to completely enclose upstream and downstream ends of channel. Measure area of channel enclosed. $A = L \times W$.

Step 2. Fish are collected within the blocked section with pole, pull-seines or beach seines. Continue seining until the catch approaches zero (depletion sampling). Catches should show an exponential decay pattern with increasing sweep number.

Step 3. This technique provides a direct measure of fish density in discrete areas: Density (fish/m^2) = CPUE/area of channel.

Pit traps

Pit traps can be employed in shallow water marsh areas where small fish may reside but are not accessible by boats and are too shallow for seines. Brown plastic dish pans make an appropriate pit trap. The concept is to deploy the trap flush with the substrate during low tide. The trap samples over the next high water period and is recovered on the ensuing ebb tide. Fish are stranded or seek refuge in the water filled plastic dish pan. The disadvantage with this technique is that it is behaviorally based and not quantitative; but it may provide qualitative data on small juvenile fish underrepresented by other methods. Natural impoundments may be analogously sampled.

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 pit traps.

4.7.8 Sample Processing

After collection of fish by the gear types described above, use a dip net to transfer the catch into a darkened and covered holding container (to diminish stress). Ensure that the water quality (especially temperature and DO) of the holding container is maintained near river conditions during processing. Portable air bubblers are useful. If the numbers of fish are too large and must be subsampled (>100 salmon; >30 other species), ensure a random and unbiased subsample by crowding the fish together to limit stratification of different sizes and species.

It is crucial to anesthetize active and energetic fish (such as salmon) to minimize stress or physical damage during measurements. Place a few fish at a time into anesthetic solution (e.g., 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 fork length or total length (tip of snout to end of caudal fin) of other fish. After measurement, let the fish recover in a container of fresh river water, and maintain water quality prior to reintroducing the fish back to the river. For depletion sampling and trap nets, remember to release fish outside of area being sampled.

4.7.9 Additional Measurements

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. Some additional measurements commonly made during fish sampling surveys are presented below.

All marks and tags should be recorded. External marks include fin clips (especially adipose fin), latex beads, freeze branding, and variously colored paint marks. Internal tags require detection equipment and include coded wire tags (CWT) and passive integrated transponder (PIT) tags. CWT data requires sacrificing the fish to collect the tag; data from PIT tags can be deciphered in the field with the appropriate instrument.

Collection of genetic data: Small fin clips can be taken from anesthetized fish for subsequent analysis of stock identification. Clip tissue samples from a pelvic fin and preserve in separate plastic vials with 70% ethanol (ETOH), labeled with date, time, location, species, and size.

Nonlethal collection of stomach contents by gastric lavage: This technique entails flushing a fish’s stomach with a stream of water and collecting and preserving the contents for laboratory analysis. Gut contents should be preserved in the field using ETOH and stored in individual vials labeled with species and site-specific data.

Capture efficiencies can be determined by mark and recapture techniques. This requires releasing a known number of marked fish above a trap net or within a blocked barrier net section, and calculating the percent recaptured.

4.7.10 Calculations and Analysis

Absence or presence of catch is a minimum metric. Plot CPUE by time for a time series of abundance. To highlight timing of migration between sites or years, standardize CPUE by annual total (Figure 18). Wherever possible, report catch as density (fish/m^2) as described above in the subsection on barrier nets or screened panels.

Size-frequency histograms are used to evaluate salmon life history categorization. Plot the length in 5-mm increments. Columbia River stocks vary in their size-at-age characteristics. In general, salmon are categorized as fry at less than 60-mm fork length and fingerlings between 60 and 130 mm. Yearling salmon range in size from 90 to greater than 130 mm (Figure 19).

Compute time series of mean size and SDs by species for each date sampled. This data may be indicative of residence time and growth.

Compute standard measures of fish community structure.

- Number of fish, N
- Number of species, S
- Shannon-Weiner diversity index, H' = $-\Sigma p_i \ln(p_i)$, where p_i is the proportion of species i.

4.7.11 Additional Information

Fish identification sources are McConnell and Snyder 1972, Scott and Crossman 1973, Carl et al. 1977, and B.C. Ministry of Environment, Lands, and Parks 1997. For two-sweep depletion method, see Seber and LeCren 1967.

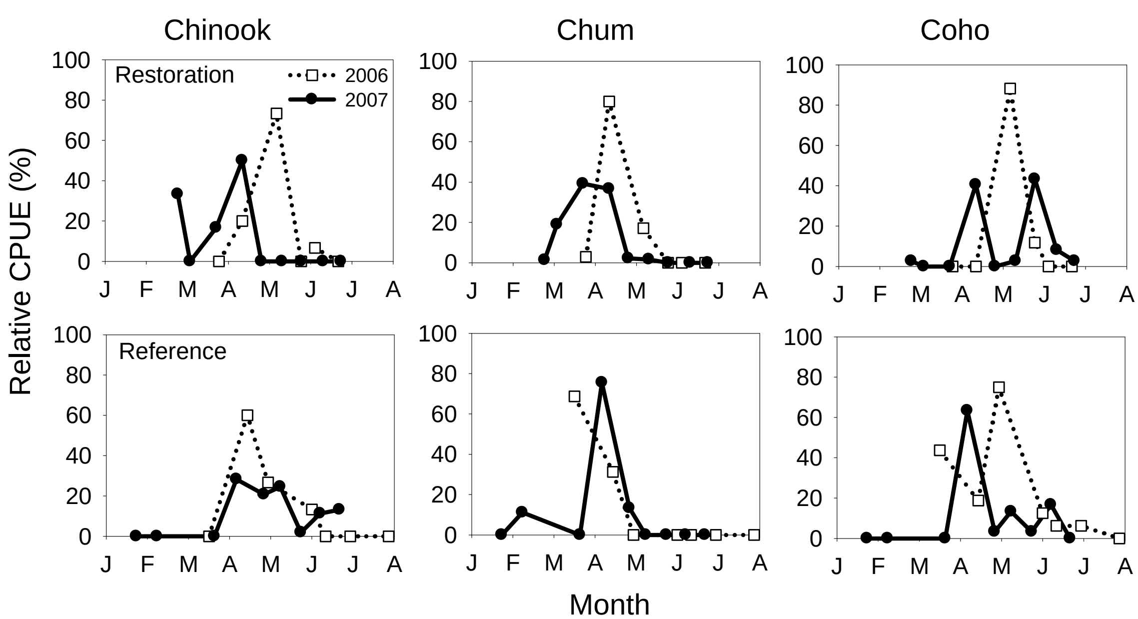


Figure 18. Time series of relative CPUE for salmonids sampled at restoration and reference sites, Grays River system, 2006 and 2007. This plot emphasizes migration timing. Upper row, restoration trap net samples; lower row, reference beach seine samples.

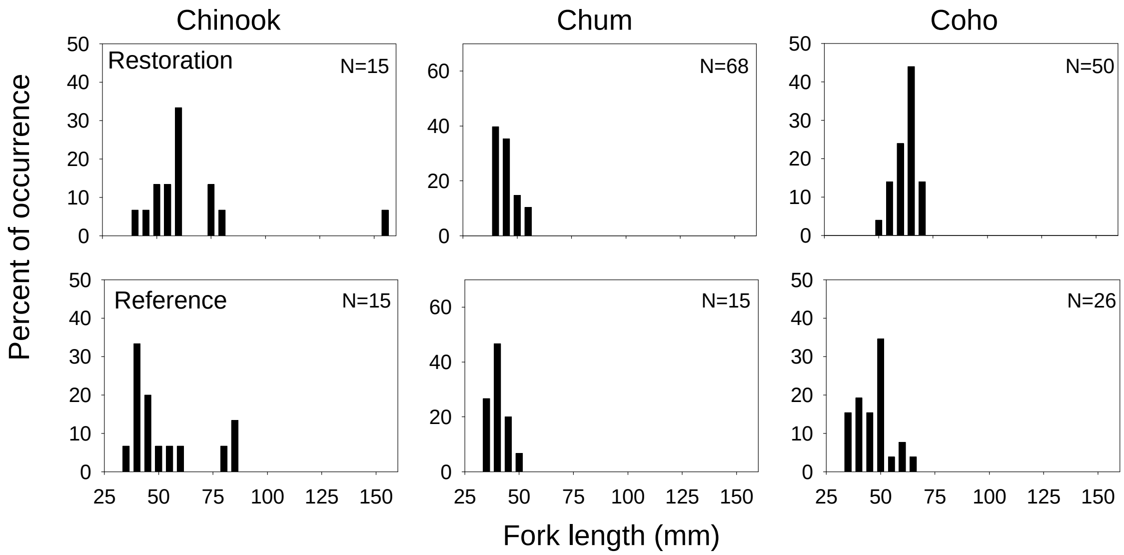


Figure 19. Size frequency of juvenile salmonids captured in restoration and reference sites, Grays River system, 2007. Upper row, restoration trap net samples; lower row, reference beach seine samples.

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