DRAFT

STANDARD MONITORING PROTOCOLS AND METHODS TO ASSESS RESTORATION OF SALMON HABITAT IN THE LOWER COLUMBIA RIVER AND ESTUARY:

AN EXCERPT FROM THE CUMULATIVE EFFECTS PROJECT DRAFT FINAL REPORT, DATED APRIL 2005

PNNL-15102

Evaluating Cumulative Ecosystem Response to Restoration Projects in the Columbia River Estuary, First Annual Report 2004

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April 1, 2005

Prepared for:
U.S. Army Corps of Engineers, Portland District
Under a Related Services Agreement with
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Prepared by:
Pacific Northwest National Laboratory, Marine Sciences Laboratory
NOAA Fisheries, Pt. Adams Biological Field Station
Columbia River Estuary Study Taskforce

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

PNNL-15102

Evaluating Cumulative Ecosystem Response to Restoration Projects in the Columbia River Estuary, First Annual Report 2004

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Abstract

The restoration of wetland salmon habitat in the tidal portion of the Columbia River is accelerating and is anticipated to improve habitat quality and to affect hydrological reconnection between existing and restored habitats. Currently, multiple groups are implementing a variety of restoration strategies. However, the region lacks a standardized means of evaluating the effectiveness of individual projects, and methods for assessing estuary-wide cumulative effects. This project is establishing a framework for such evaluations. A priority has been to develop a protocol manual for minimum monitoring of physical and biological metrics, intended to standardize data collection critical for analyzing changes following restoration treatments. The manual is a practical technical guide for the design and implementation of restoration monitoring from Bonneville Dam to the river mouth. Additionally, the project's literature review and synthesis identified ways that effects can accumulate (e.g., cross-boundary effects, compounding effects) as well as analytical tools (e.g., models, matrices) for assessing them. Field studies are planned to test the protocols and to evaluate additional potential indicators for detecting a signal in the estuarine system (e.g., organic matter production, sedimentation, food webs, biodiversity, salmon habitat usage, and allometry). In subsequent work, this information will be used to estimate net effects.

Preface

This report is a deliverable for the 2004 study. As such, it includes all of our work products for the 2004 study year. Future annual reports will be prepared for the remaining study years 2005-2009. In this report we introduce the research problem (Chapter 1), review the literature (Chapter 2), summarize CRE habitat use by juvenile salmon (Chapter 3), describe a conceptual model for the CRE ecosystem (Chapter 4), develop standard monitoring protocols for CRE restoration projects (Chapter 5), and provide recommendations and discuss management implications (Chapter 6). The report provides a foundation for subsequent research on the cumulative effects of habitat restoration in the CRE.

We organized the report in compendium style because we wanted each chapter to be able to stand alone. Our intent is eventually to publish Chapter 2 (cumulative effects literature review) as a journal article and Chapter 5 (standard monitoring protocols) as a manual.

This is a draft report. The material will be undergoing technical peer review and, therefore, is subject to change.

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5.0 Standard Monitoring Protocols and Methods to Assess Restoration of Salmon Habitat in the Lower Columbia River and estuary

The recovery of salmonid stocks requires supporting the diversity of life history patterns that historically mitigated for environmental variability (Bottom et al. in press; NOAA 2004). Research on salmon distribution patterns in the lower Columbia River and Estuary (Chapter 3) as well as other West Coast estuarine systems (e.g. Reimers and Loeffel 1967; Healey 1980; Levy and Northrote 1982; Shreffler et al. 1990, 1992; Levings et al. 1991; Levings 1994; Sommer et al. 2001; Tanner et al. 2002), indicates protracted use of tidal freshwater and estuarine habitats by diverse stocks of subyearling and yearling salmonids. Much of this historically abundant habitat has been isolated, degraded, or destroyed (Thomas 1983; Burke 2004). The goal of restoration activities is to repair conductivity and function of these habitats, to thereby allow fish to regain benefit from these important rearing areas. However, researchers and managers require the means to 1) evaluate the effectiveness of individual restoration activities (Roni et al. 2002), 2) allow comparison between projects (Neckles et al. 2002; Williams and Orr 2002), and 3) determine the long-term and cumulative effects of habitat restoration on the overall ecosystem (Chapter2; Steyer et al. 2002). This can best be achieved with a standardized set of research and monitoring metrics. A review of the literature uncovered many excellent examples of restoration monitoring theory and design (eg. Simenstad et al. 1991; Callaway et al. 2001; Hillman 2004; Rice et al. 2005), yet none concisely outlined procedures particular to the CRE. The intent of this chapter, therefore, is to provide the rationale and procedures for standardized metrics specific to the tidal waters of the Columbia River estuary. The ultimate goal for applying these methods, to be fully realized perhaps decades from now, is to compile a compatible time series database of physical and biological metrics collected from many individual restoration projects. This dataset will enable evaluation of the effectiveness of individual restoration projects, as well as the cumulative effects of many restoration projects, on improving salmon habitat in the CRE. Protocols for sampling the monitored attributes are provided in Section 5.5.

5.1 Background

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

Today there is growing momentum to reverse these land use patterns and specifically to reconnect historical wetland areas to the influence of tidal inundation. The challenge we face is how to evaluate the effects of various restoration projects on wetland function, given that the goals, scales, resources, and managing partnerships of projects vary greatly. To this end, there has been a regional movement in the

Pacific Northwest and elsewhere to standardize measurement metrics and techniques that will facilitate comparison between restoration studies over time (Neckles et al. 2002; Callaway et al. 2001; Action Agencies 2003; Hillman 2004; Rice et al. 2005). Standardized metrics are required to provide the best possible input to managers making decisions regarding habitat restoration.

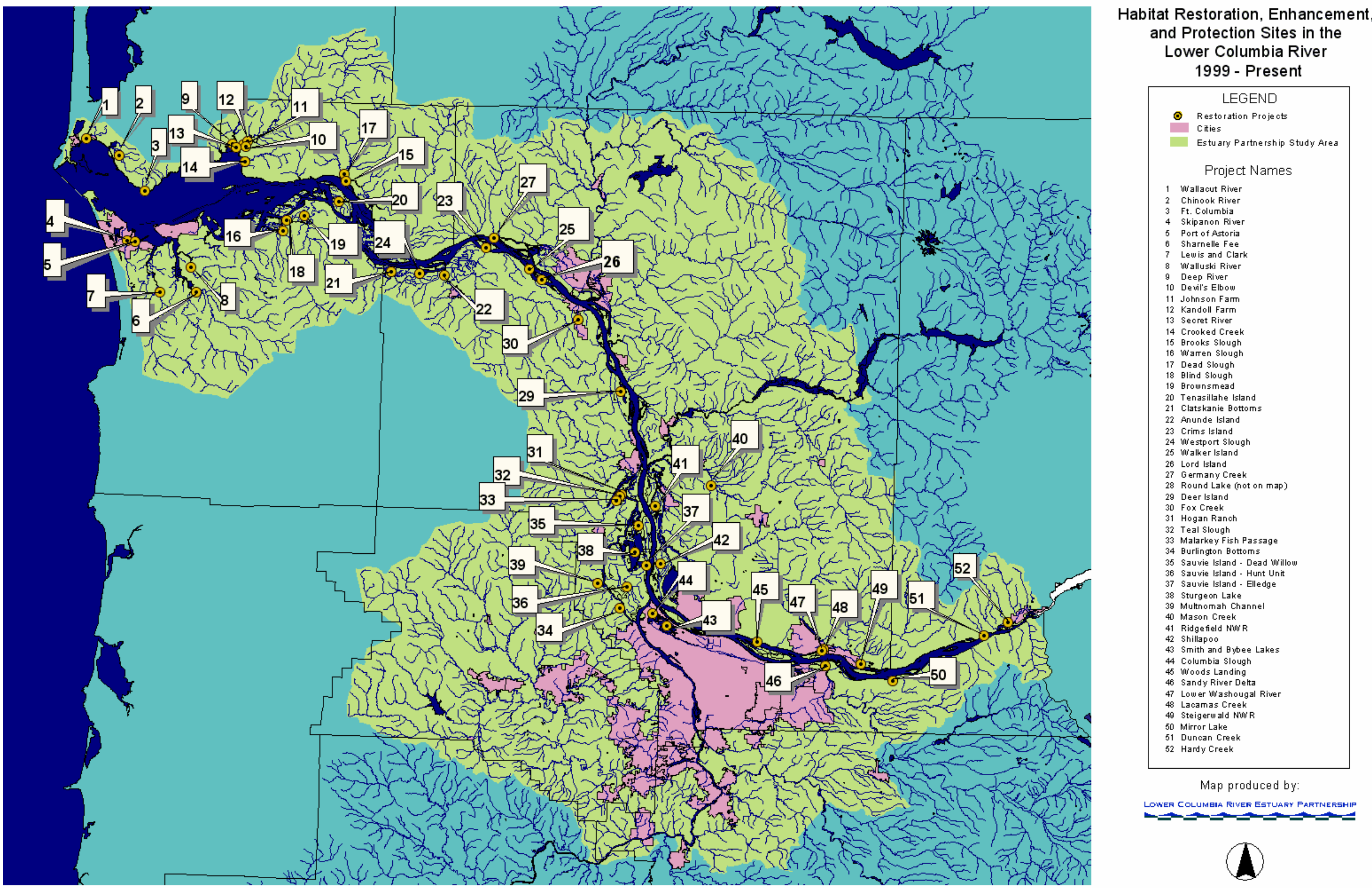
The incentive for many restoration activities in the CRE involves increasing habitat for rearing and migrating juvenile salmonids listed as threatened or endangered under the Endangered Species Act (ESA). Salmon stocks that will most directly benefit from restoration activities in the CRE are the wild and hatchery-reared ocean type Chinook salmon, chum salmon, and stream-type coho salmon from lower river tributaries (Reviewed in Chapter 3). 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; Burke 2004; Lichatowich and Mobrand 1995). While most individuals from the surviving ESUs of upriver stocks currently migrate rapidly through the estuary to the ocean some individuals of those groups (usually the smallest and latest migrants) display a protracted migration to and through the estuary and presumably gain enhanced growth and survival prior to ocean entry (Dawley et al. 1986, Chapter 3). Thus, while greatest use of estuarine habitats is expected from fish originating in lower river tributaries, threatened and endangered salmon from upriver tributaries are also expected to benefit from increased habitat opportunity.

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

5.2 Types of Restoration Strategies in the CRE

Various types of restoration activities are occurring throughout the CRE region in an effort to recover lost habitat types (Figure 5.1). These activities fall under five broad strategies as described below and summarized in Table 5.1 (Johnson et al. 2004). The protocols we provide deal specifically with creation, enhancement, and restoration activities. Unless stated otherwise, the term “restoration” includes the various strategies described below.

Figure 5.1. Extent of restoration activities in the Columbia River Estuary.



5.2.1 Conservation

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

5.2.2 Creation

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

5.2.3 Enhancement

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

5.2.4 Restoration

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

5.2.5 Protection

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

Table 5.1. Restoration Strategies, Examples of Project Types, and Targeted Ecosystem Benefits for the CRE (from Johnson et al. 2003)

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

5.3 Minimum Monitored Metrics in the CRE

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

5.3.1 Metric Selection Criteria

The decision-making process culminating in the suggested monitoring metrics was based on several interrelated criteria. First, metrics need to be diagnostic of some relevant ecosystem function and directly need to correspond to commonly held goals among the restoration projects in the CRE (Thom and Wellman 1996). Second, we followed NRC (1992) guidelines that at least three classes of monitoring attributes be tracked: one for controlling factors (e.g., tidal regimes), one for structural factors (e.g., fish community structure), and one for functional factors (e.g., vegetation growth). Third, metrics should be potentially applicable to all sites with measurements that result in comparable datasets relevant to both present and future investigations (Tegler et al. 2001). Finally, measurements and data analysis must be practical in terms of funding, manpower, and processing requirements (Callaway et al. 2001). This last factor necessitates limiting the number of metrics to a "minimum" set and selecting measurement methods that are straightforward and economical to use. By "minimum," we mean the smallest suite of metrics that can adequately detail the status and trends of restoration while acknowledging the financial and logistical limitations of comprehensively monitoring ecological change over an extended temporal and spatial scale. Ideally, all projects in the region would perform the minimum physical measurements, which we view as encompassing the fundamental forces on, and responses to, changes in the affected systems. Project goals for the biological variables (fish use or vegetation cover) may vary between studies. We encourage researchers to make additional measurements, especially process-related derivations of the minimum tier of monitored metrics (e.g., fish growth rate, consumption rate, and residence time). Higher order protocols such as these are under development at the time of this draft and are described in more detail in Chapter 2.

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

5.3.2 Metrics

Table 5.2 outlines the proposed set of minimum monitored metrics, their collection method, sampling frequency, and type, as well as their contribution to one of the three categories in an estuarine monitoring framework developed by Simenstad and Cordell (2000). We are advocating a combination of data logging instruments, on-site survey methods, and remote sensing techniques.

5.3.2.1 Hydrology (Water elevation)

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

5.3.2.2 Water Quality (Temperature, Salinity, Dissolved Oxygen)

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

5.3.2.3 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

LIDAR. Ground truthing during topographic/bathymetric surveys (below) is also required. Repeated measures over time are best analyzed using GIS to quantify the progress of restoration.

5.3.2.4 Bathymetry and Topography

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

5.3.2.5 Vegetation Changes Resulting from Tidal Reconnection

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

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

The incentive for many restoration activities in the CRE involves increasing habitat for rearing and migrating juvenile salmonid 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 control areas. We advocate conducting the most intense sampling effort across sites, habitat types, and time logistically possible. Additionally, it is highly desirable to determine “realized function” attributes, such as residence time, growth, and survival, which necessitate measuring metrics such as prey availability, prey consumption, age assessment, genetic stock identification, parasite load, and mark-recovery data (e.g., Roegner et al. 2004).

Table 5.2. Summary of monitored attributes for lower Columbia River and estuary restoration projects. OPP = Opportunity metric = CAP, Capacity metric = FCT, Function metric.

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

5.4 Sampling Design

The ability to detect ecological change due to restoration in a naturally varying environmental system is problematic (Osenberg et al. 1994). We advocate an effectiveness monitoring approach (Hillman 2004) which relies on comparisons between measured values from sites separated both temporally (before versus after) and spatially (control versus impact). The Before After Control Impact (BACI) sampling scheme integrates both temporal and spatial elements into the effectiveness monitoring experimental design (Underwood 1991; 1992; 1993; Stewart-Owen and Bence 2001). The sequence of sampling events in BACI design is listed in Table 5.3. Monitored parameters are sampled simultaneously at two (or more) locations (control versus impact) before and after the restoration action (before versus after). It is recognized that difficulties can arise when choosing the control site in areas that have been highly modified, whereas at other sites there may be no opportunity to conduct adequate Before sampling (Steyer et al. 2003). One solution is that, within the various ecological zones of the CRE, regional reference sites be identified and monitored. These areas can then provide a range of "target" conditions for restoration activities.

In a typical BACI design, one selects a control site that ideally represents a natural, minimally modified, or target condition. This site should be located in a nearby reference area subjected to similar large-scale climatic and environmental conditions, but be independent of activities affecting the impact site. The impact site would be within the restoration system and would be chosen to monitor target habitats or processes, such as tidal channels or marsh communities. All sampling techniques and sampling periods should be identical between control and impact sites. These paired measurements are to be made before and after the restoration activity: the spatial and temporal replication of the measurements is dependent on the monitoring metric, the size of the restoration area, and logistics (Table 5.2). One measure of restoration "success" or performance is for values of post-restoration impact parameters (the monitored attributes) to converge with those of the control site (Kentula et al. 1992, Raposa 2002). It should be emphasized that the ecological processes associated with a given restoration activity, such as breaching a dike, evolve for many years post-impact. 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). See Hillman (2004) for further discussion of these types of statistical comparisons.

Within the general BACI design, two primary data collection categories are likely to be employed in the CRE, depending on the parameter of interest: survey type and time series type of measurements. Survey type measurements are "snap shots" in the temporal frame and can include aerial photos, topographic surveys, vegetation surveys, and fish community sampling. Within the BACI concept, repeated measures over time fulfill the Before versus After requirement for survey type measurements. Time series measurements, in contrast, consist of regularly timed recordings, usually from fixed spatial stations, and are typified by data logging instrumentation used to monitor water quality parameters. Time series analysis techniques, such as spectral analysis or cross-correlation with comparisons performed in the BACI framework, most effectively capture trends in the data.

Table 5.3. The Sequence of Sampling Events in BACI Design

A. Before Impact

1. Acquire digital aerial photograph of site (Protocol 3)
   a. Locate elevation and tidal benchmarks from website.
   b. Choose control and impact study areas.
   c. Choose survey transect locations.
2. Ground survey (at control and impact sites)
   a. Conduct topographic/bathymetric survey (Protocol 4)
   b. Deploy water quality and water elevation data loggers at surveyed locations (Protocol 1-2)
   c. Conduct vegetation/fish community survey (Protocol 5-6).

B. Interim

1. Maintain data loggers.
2. Repeat vegetation/fish community surveys.

C. After Impact

1. Repeat Steps A2b-c to acquire After data set.
2. Lab analysis using GIS to create:
   a. Layer digital (hyperspectral) photograph with topography/bathymetry to create a digital elevation map (DEM).
   b. Layer vegetation (if available) to create vegetation map.
   c. Use Before and After data sets to quantify physical and biological changes to site.
3. Compute fish community structure analysis (Protocol 6).
4. Repeat C 1-3 at designated frequency.

5.5 Monitoring Protocols for Columbia River Estuary Habitat Restoration Projects

1. Protocol for Assessing Hydrology (Water Elevation)

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 aerial exposure, circulation patterns in tidal creeks (including the distribution of water quality parameters such as salinity, temperature, and DO), sedimentation/erosion patterns and tidal creek evolution, and the distribution of vegetation and fishes. Water level data should be properly georeferenced (Protocol 3) and related to topography and vegetation patterns (Protocols 4 and 6) to determine inundation periods and vegetation response. This is thus a priority metric best measured with automated data logging pressure sensors.

GOAL

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

DESIGN

BACI time series design.

EQUIPMENT

A. *Field*: Continuous water level recorders (Pressure Transducer), monumenting equipment (t-post, surveying equipment)

B. *Lab*: Laptop computer, calibration and maintenance manual

SITE SELECTION

Primary site for data loggers in both impact and control sites is near the mouth of the tidal reconnection site (but within the constriction). Additional dataloggers, if available, can be placed further in the system to gauge for lags in period and reductions in tidal amplitude.

SAMPLING PERIODICITY

A. Minimum sample frequency of 1 hr.

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

SAMPLING PROTOCOL

Automated instruments require proper placement to ensure comparable monitoring. Dataloggers should be secured subtidally with sensors positioned 50 to 75 cm below the anticipated lowest tide level but at least 25 cm above the substrate. Remember that hydrologic reconnections that increase tidal amplitudes will convert subtidal areas to intertidal zones. The instruments can be attached to existing structures such as pilings or attached to permanent monument made of PNV or aluminum poles driven into the substrate. The vertical height of the sensor needs to be accurately surveyed (Protocol 3). Record location of data logger with GPS, and periodically visit data loggers to check for fouling or damage. Where required, be sure to calibrate sensors before each deployment.

CALCULATIONS & ANALYSIS

A. Primary output from dataloggers is time series of water levels. These relative heights should be converted into height relative to the standard elevation datum (mean lower water level (datum?) for comparison between sites and as a reference to site topography. Within BACI design, data should be presented to contrast water level fluctuation pre- and post-restoration, as well and with the control.

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

REFERENCES

Neckles et al. 2002; Hume and Bell (1993).

2. Protocol for Assessing Water Quality (temperature, salinity and dissolved oxygen)

PURPOSE

Organisms have varying tolerances to water quality parameters such as temperature, salinity, and dissolved oxygen (EPA; OWEB 1999). Measuring variations in pre- and post-restoration conditions is a direct measure of changes in habitat opportunity (Callaway et al 2004), and are important for explaining floral and faunal changes. Increased circulation due to tidal reconnection may reduce excessive temperature and help maintain suitable DO levels, but allow increased salinity intrusion. As with water elevation (Protocol 1), we advocate the use of autonomous data logging equipment to measure water quality parameters. (Many newer multiprobe instruments include pressure sensors). Paired deployments provide comparative time series between habitats and over time.

GOAL

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

DESIGN

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

EQUIPMENT

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

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

SITE SELECTION

A. Install data loggers in both reference and restoration sites. If possible, install both loggers at the same position relative to mean sea level (Protocol 2).

B. Choose a location that is representative of the overall characteristics of the reach.

SAMPLING PERIODICITY

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

SAMPLING PROTOCOL

See Protocol 1.

CALCULATIONS & ANALYSIS

A. Primary output from dataloggers is time series of parameters. Data, especially DO, should be inspected for data outliers (+/- 3 sd of the mean). Time series from control and impact site should be temporally alingned and graphed together.

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

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

REFERENCES

Callaway et al. (2001); Schuett-Hames et al. (1999)

3. Protocol for Assessing Bathymetry and Topography

PURPOSE

Wetland topography is a critical determinant of geomorphological evolution, vegetation recolozination, and fish habitat use (Rice et al. 2005. Dynamic alterations of topographic and bathymetric features usually accompany hydrologic reconnection of non-tidal sloughs and backwaters to tidal forcing (Zedler 2001; Coats et Al. 1995). Establishing the time course of morphological change at a restoration site is crucial for evaluating the progress of the restoration effort. Field measurements can include surveys or transects. All data should be converted to a GIS.

GOAL

To quantify changes in topography and bathymetry before and after action at a specific site.

DESIGN

To accurately monitor changes to bathymetry and topography in an intertidal area, one must conduct a precise elevation survey tied to a primary benchmark (mean sea level), and then link the survey to the local tidal datum. The locations of survey benchmarks and local tidal datum for sites in the CRE can be found at the National Ocean Surface site (**http://co-ops.nos.noaa.gov/bench.html).**

Topographic Surveys

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

Newer kinesmatic GPS technology will likely supersede these optical techniques in the near future. This method utilizes two GPS receivers linked via a radio connection. The base unit is stationary and the mobile unit is used to make position and elevation measurements. This technique is advantageous in that measurements are made rapidly and only one individual is required. One possible drawback is that there may be reception problems in many areas.

Bathymetric Surveys

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.

EQUIPMENT

A. Topography: Total station.

B. Bathymetry: Narrow beam (5^{o}) sonar transducer, differential GPS, motion reference unit.

SITE SELECTION

Sampling station locations should be generated from aerial photography.

SAMPLING PERIODICITY

Annually

SAMPLING PROTOCOL

Topography

The Total Station method is used to record X-Y-Z coordinates along a horizontal transect or grid. The total station system consists of an electronic instrument stabilized on a leveled tripod and a reflecting mirror affixed to the end of a graduated stadia. The total station uses infrared light to measure the distance and angle from instrument to reflector, then calculates the relative position and elevation. The total station position needs to be referenced to an established benchmark. The users manual should be consulted for calibration and other procedures specific to the instrument employed. Generalized procedures are outlined below.

Step 1.

Calibrate total station x-y-z coordinates to a benchmark of known location and vertical height (usually mean sea level (MSL)).

Step 2.

A. To measure elevations along a permanent horizontal transect, mark endpoints (rebar, ect) and predetermine measurement intervals.

B. Attach measuring tape to fixed object. Level stadia at each interval and log position and elevation on total station.

C. Repeat at each measurement interval. This procedure is useful for determining 2D change across an intertidal/tidal creek profile.

Step 3.

To map elevations within a grid, one must only determine resolution of gridpoints. The grid can be filled as a series of transects or a set of random or regularly selected xy coordinates. Use digital image to select points (Protocol 2).

Bathymetry

Bathymetric 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. Check tide.

CALCULATIONS AND ANALYSIS

Data should be entered into a GIS. Topographic and bathymetric survey data should be used to calculate changes in the following parameters:

A. Difference plots compare changes of elevation over time.

B. Channel condition metrics calculated from above

1. Stream gradient. Elevation change per unit horizontal distance (zd/x)

2. Width/depth ratio: cross-sectional area of tidal channel at selected transects.

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

4. Bankfull width. Wetted width at bankfull stage.

5. Thalweg profile = along-stream profile @ deepest point.

REFERENCES

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

Kinesmatic GPS: http://www.usace.army.mil/usace-docs/eng-manuals/em1110-1-1003/toc.htm

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

4. Protocol for Assessing Landscape Features

PURPOSE

Landscape-scale measurements are possible with remote imagery techniques. Documenting the spatial changes in geophysical features (such as tidal channel evolution or intertidal area) and vegetation communities (for example agricultural meadow versus emergent marsh) can be accomplished using hyperspectral imagery, multispectral imagery (4 band; i.e., digital aerial photography or high resolution (1-m or 4-m) satellite imagery), or full color and near infrared aerial photography. The latter generally provides a low-cost alternative for evaluating environmental change without requiring image-analysis software and remote sensing expertise. If funds and expertise are available, hyperspectral or multispectral imagery can provide additional information at a higher resolution. A digital imaging technique, coupled with ground-truthing (Protocol 3 and 5), will be analyzed using GIS to quantify the progress of restoration. In addition, LIDAR information is currently scheduled for analysis for selected areas of the Estuary. LIDAR is a remote sensing tool that can identify landscape features at a very high resolution. Examples of such features include topography, drainage signatures, and large woody debris. These data sets are important to correlate with monitoring attributes related to water elevation, passage barriers, and tidal channel edge.

GOAL

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

DESIGN

Prior to restoration, photos should be analyzed to identify hydrological barriers, to establish baseline vegetation conditions, and to make preliminary determinations of topographic sampling transects and grids (Protocol 2) and locations for datalogging instruments (Protocol 5-6). Before and after photographs will be compared to assess changes in georeferenced topographic bedforms and gross vegetation patterns.

Ground Control Points

All imagery should be georeferenced and orthorectified. To aid in georeferencing the imagery, ground control points (GCPs) should be placed in the field prior to image acquisition. These must be constructed of a material that will be visible in an aerial photo, such as a 1 m^2 white board. There should be a minimum of four GCPs at each site, dispersed as far apart as possible (e.g., at four corners of the site). Highly accurate GPS coordinates need to be collected at the center points of the GCPs and provided to the imagery contractor. If possible the GCPs should remain in place and will need to be cleared each year that the imagery will be aquired.

Imagery Specifications

Minimum photographic standards include full color and near infrared wavelength at a scale of 1:2400. If multispectral digital photography is employed, the resolution should be at least 1 m, with 0.25-m resolution providing an increased level of detail.

Interpretation

Interpretation of the acquired imagery can be conducted "manually" by digitizing polygons using a GIS platform. This method requires ground-truth data to evaluate the photos and determine where polygons should be drawn. A brief tutorial on this method will be provided in the final protocol manual. LIDAR data can be used to supplement this interpretation to determine the location of tidal channels in the restored marsh (Lohani and Mason 2001).

Wherever possible, multispectral imagery should be used because a true classification of the imagery can be conducted based on the collection of ground-truth data. This kind of image classification provides a spatially accurate method of determining broad vegetation categories and location of tidal channels that is not subjective and is repeatable in subsequent years. Algorithms can be developed to identify pixel values in an image. Those pixel values are then applied to the whole image to get a classified representation of the site.

Change Analysis

GIS techniques will be employed to quantify changes in areas of landform and vegetation type. Polygons of vegetation classes and tidal channel locations will be developed from interpretation of the imagery. These vegetation polygons can be evaluated to determine the area of each classification and the change in area over time. Tidal channel polygons can be evaluated to assess the amount of marsh area that is accessible via the channels, channel order, and channel sinuosity. In addition, an analysis of vegetation patterns relative to the tidal channels should be conducted (Sanderson et al. 2000).

EQUIPMENT

1. Overflights of target sites will have to be arranged through commercial venders. Ideally, large areas of the CRE can be imaged during one flight, thus maximizing coverage/cost.
2. Laboratory analysis will require GIS technology.

SITE SELECTION

Control and impact sites need to be imaged concurrently.

SAMPLING PERIODICITY

Ideally, annual aerial surveys should be made to acquire the highest temporal resolution feasible. Tidal stage, time of day, and seasonality are important factors to maximize data interpretation and between-date comparisons. Conditions should be as similar as possible. We recommend 1) low water at spring tide (to maximize exposed landforms and vegetation patterns), 2) morning or afternoon periods to increase contrast, and 3) late summer season to maximize vegetation growth (with better chance of favorable weather in the Pacific Northwest).

SAMPLING PROTOCOL

Step 1. *Before*

A. Establish ground control points (GCPs).

B. Obtain before aerial photograph of control and impact sites.

C. Examine photos for barriers locations.

D. Assess vegetation patterns.

E. Plan location of topographic transects. Record GPS coordinates.

Plan random or stratified sampling grid for topographic surveys. Record GPS coordinates. Ground truth landform and vegetation patterns during topographic and vegetation surveys (Protocols 2, 8, and 9).

Step 2. *After*

A. Obtain after aerial photograph of control and impact sites.

B. Analyze before and after images of control and impact sites for changes in topography and vegetation using GIS.

CALCULATIONS AND ANALYSIS

GIS-based measurements:

A. Total area restored

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

C. Area of landforms and vegetation patterns

D. Influence of tidal channels on vegetation distribution.

REFERENCES

Coats et al. (1995); Hillman (2004); Finkbeiner (2003); Hood (2002).
http://www.microimages.com/getstart/pdf/hyprspec.pdf for hyperspectral imagery.

5. Protocol for Assessing Vegetation Changes Resulting from Tidal Reconnection

PURPOSE

Tidal reconnections usually result in substantial change in vegetation species abundance and distribution (Cornu and Sadro 2000; Roman et al. 2002; Thom et al 2002). Vegetation is recognized as a key indicator of ecological health in a restored environment (Zedler et al. 2001; Rice et al. 2005), and floristic measurements can be used to document plant successional stages towards the desired ecological state. There are both structural and functional benefits of native estuarine plant communities on estuarine ecosystem health, and we concentrate here only on structural elements. We encourage measurements of functional benefits (i.e. primary productivity), and while equally important, are often difficult to measure and require a more rigorous and labor intensive sampling design. These functional attributes are recommended in this document as a higher order of metrics to monitor (Chapter 6). To measure vegetation changes, we advocate georeferenced floral surveys that can be integrated into water level (Protocol 1) topographic (Protocol 3), and landscape-scale (Protocol 4) GIS data.

GOAL

Measure vegetation species composition and dominance changes to assess successional evolutionary trajectories toward estuarine plant communities resulting from reconnection to the tidal prism.

DESIGN

Gleaning from other estuarine vegetation monitoring efforts in Pacific Northwest estuaries (Frenkel and Morlan 1990; Thom et al. 2002), monitoring design is focused to quantify the relative abundance and percent cover of individual species for a given site. Information compiled from measuring Landscape Features serves as the foundation for more intensive ground truthing and mapping of plant community assemblages and structure. Monitoring design will be directed toward statistically valid outcomes through the application of systematic sample from a random start. Resolution of the data plots will vary depending on the size of the site. Transects are established at set intervals along established 'baseline' (see image and recommended size below) determined in part by the sites conditions (usually parallel to stream channel).

EQUIPMENT

- **A.** *Field*: 1m^2 quadrat, plant identification book, tape measure, site map
- **B.** *Lab* Digital Orthophoto Quads (DOQs), ArcView (if available)

SITE SELECTION

- **A.** Transects are established at intervals perpendicular to baseline linear features on site (random) with a series of plots for each
- **B.** For each transect, establish monitoring plots at equally spaced intervals depending on size of site. (Minimum recommended interval between each plot should be 50 meters)

SAMPLING PERIODICITY

At least once before restoration treatments and at subsequent intervals of 2-3 years.

SAMPLING PROTOCOL

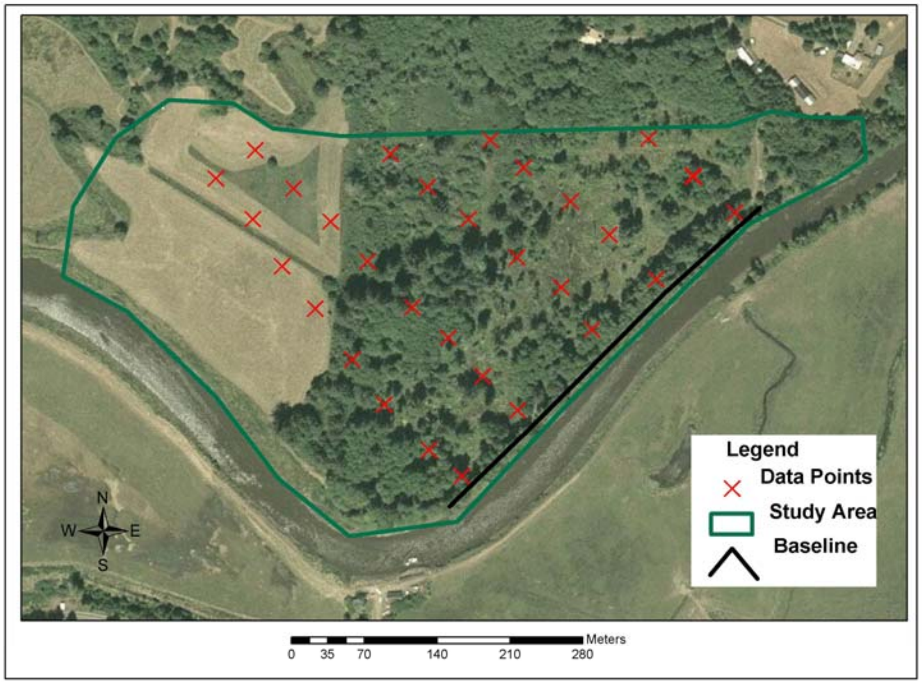


FIGURE 1: Example of Vegetation Sampling Design on Diked Pastureland.

Step 1.

Define Study Area (see example above) boundaries based on extent of expected inundation.

Step 2.

Use existing digitized vegetation dataset (i.e., C-CAP, LandSat, National Wetland Inventories) to broadly characterize existing plant communities.

Step 3.

Repeat same methods at chosen reference site to characterize functioning estuarine plant community under tidal influence.

Step 4.

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

Baseline Length (feet)	***Number of Segments***
>50-500	3
>500-1,000	3
>1000-5,000	5
5,000-10,000	7
>10,000	variable

Step 5. Select plots along each transect at a minimum of 50 meter intervals.

Step 6. Measure species dominance for each vegetation strata at the plot using the following techniques:

- **A.** 1m^2 quadrat for percent cover of herbaceous layer
- **B.** If applicable use a rope that extends 3m radius from center of quadrat to record shrub/scrub layer measuring both number and height for each species found
- **C.** If applicable use a 10m rope from center of quadrat to capture woody species layer and record DBH for each species encountered in that area

Step 7. Mark center of plot with 4-6 foot, ½ inch PVC pipe driven to at least a depth of 3 feet. Flag the pipe, so that it can easily identified from a distance.

Step 8. Repeat sampling protocol design at reference site

CALCULATIONS & ANALYSIS

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

- **A.** Dominance-diversity graphs
- **B.** Correlation of dominant plant community with elevations (from topographic survey)
- **C.** Mean percent cover of major plant communities expressed over time
- **D.** Compare with data from reference site

REFERENCES

Frenkel and Morlan 1990; Frankel and Morlan 1991; Thom et al. 2002; Washington Salmon Recovery Funding Board 2004; Wetland Training Institute 1987. Zedler, J. B. 2001 ed.. Rice et al. 2005.

6. Protocol for Assessing Success Rate of Vegetation Plantings

PURPOSE

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

GOAL

Measure percent cover of vegetation pre and post restoration.

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

DESIGN

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

EQUIPMENT

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

SITE SELECTION

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

SAMPLING PERIODICITY: study dependent

A. Formal woody plant monitoring in years 1 and 5

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

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

D. Upland herbaceous monitoring is conducted in year 1 and 5 from June to July

SAMPLING PROTOCOL

Step 1. Establish overall acreage of riparian plantings Establish overall acreage of riparian plantings and mark boundaries with GPS (all 4 corners of site).

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

Step 3. Pivot around the point with the 2.4m pole and count all plantings under the pole.

(see calculations section)

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

Plant Vigor categories:

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

Step 3.

Measure height for woody species plantings

Step 4.

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

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

On project sites age 5+

Step 5.

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

B. Four densiometer measurements are taken at 1.4 meters above the plot center facing, N, E, S, and W.

C. Average measurement is recorded.

Informal woody plant monitoring

Step 6.

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

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

C. Identify and list weed species

Upland herbaceous vegetation monitoring: sites age 1 to 5

Step 7.

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

B. Record percent cover of vegetation within each plot.

CALCULATIONS & ANALYSIS

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

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

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

REFERENCES

Washington Salmon Recovery Funding Board 2004; Wetland Training Institute 1987.

7. Protocol for Assessing Fish Temporal Presence, Size/age-structure, and Species Composition

PURPOSE

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

GOAL

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

DESIGN

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

EQUIPMENT

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

Permits--Annually, a state fish sampling permit must be obtained from the Oregon Department of Fish and Wildlife or Washington Department of Fish and Wildlife to conduct sampling in the Columbia River and its tributaries. An Endangered Species Act permit from NOAA Fisheries must also be obtained because there is a strong likelihood that naturally spawned tule stock Chinook salmon and chum salmon emanating from tributaries downstream from Bonneville Dam will be captured. At present those stocks are listed under the ESA; additionally, naturally spawned coho salmon may soon be listed.

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

SITE SELECTION

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

SAMPLING PERIODICITY

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

SAMPLING PROTOCOL

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

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

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

Step 2. Retrieve it by pulling the two wings simultaneously to shore and crowd fish into the center bunt for capture.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Calculations & Analysis

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

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

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

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

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

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