Tidal Wetland Restoration in the Lower Columbia River and Estuary

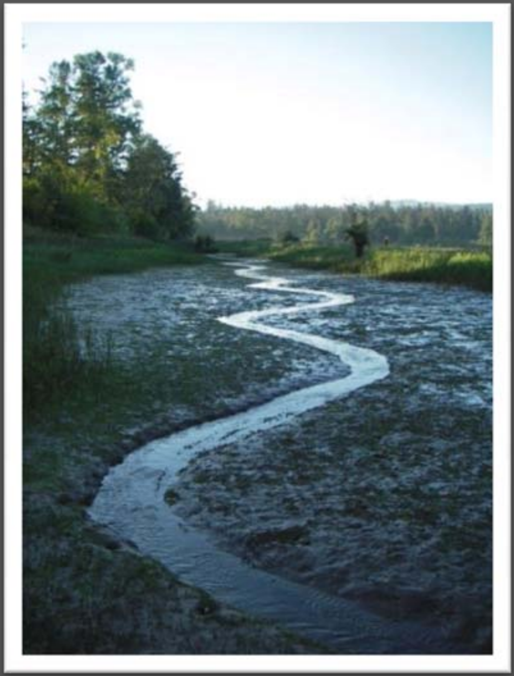
The Water Center Seminar, May 12, 2009

Heida L. Diefenderfer, Ph.D.

Marine Sciences Laboratory
Pacific Northwest National Laboratory

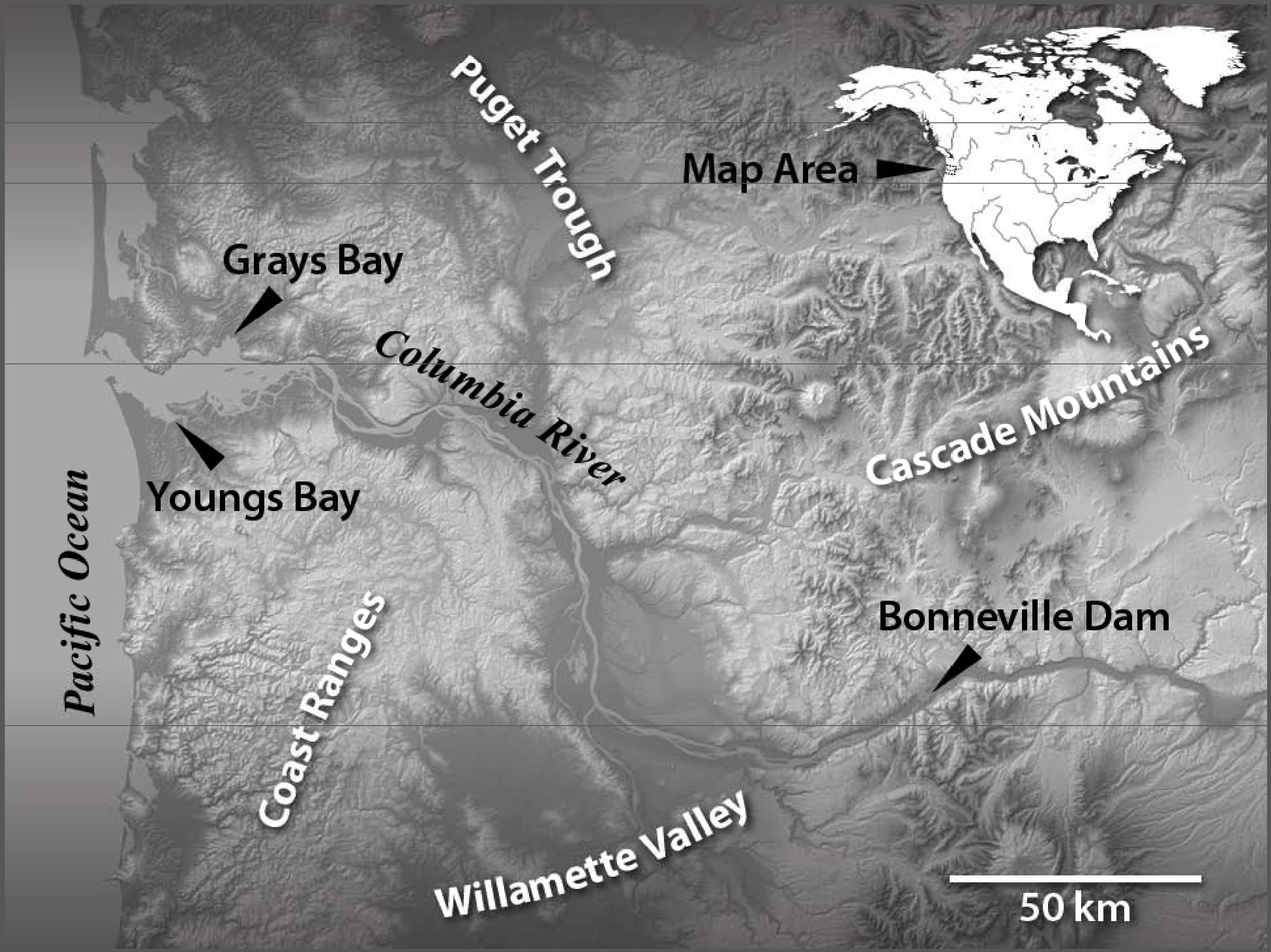
Presentation Overview

- Study Area: Ecological and Policy Context
- Cumulative Ecosystem Effect: Levels-of-Evidence Approach
- Multi-Scale Analyses: Restoration & Reference Sites



Study Area and Context

Study Area: Lower Columbia River



Global Context: The Restoration of Estuaries and Large Rivers

Estuaries—

- Large Spatial Scales
- Multiple Agencies and Jurisdictions
- All Coasts of the Continental U.S.A.:
  - Puget Sound, Columbia River, San Francisco Bay-Delta, Tijuana Estuary
  - Coastal Louisiana, Galveston TX
  - Florida Everglades
  - Chesapeake Bay, Gulf of Maine

Rivers—

- Loss of Freshwater Biodiversity
- Loss of Lateral Connectivity (Main Stem - Floodplain)
- Floodplain Dynamics Change with Inundation Regime
- Environmental Flows/Pulse
- Riverscapes Analogous to Landscapes
- Floodplain Forest Coupling

Little Research on Floodplain Forest Effect on Hydrogeomorphic Processes in Tidal areas of Large Temperate Zone Rivers

— Junk et al. 1989; Poff et al. 1997; Bunn and Arthington 2002

Lower Columbia River Characteristics

- **Drowned River Valley**
- **Tidal to Bonneville Dam (Rkm 235)**
- **2nd to Mississippi in Discharge to Ocean**
- **~15-km wide @ Rkm 32, & 3-km at jetties**
- **Range of Historical Unregulated Flows: 2,237 m^3/s (79,000 cfs) in the fall to maximum flood flows of over 28,317 m^3/s (1 million cfs) during spring freshets (Sherwood et al. 1990)**
- **Seawater intrusion variable (~Rkm37)**
- **660,480 km^2 Basin**

<u>Altered Hydrograph:</u>

- **30 major dams and numerous minor dams throughout the basin**
- **Diking & >40% flow reduction during spring freshet → 62% reduction in shallow water juvenile salmon habitat in the estuary.**

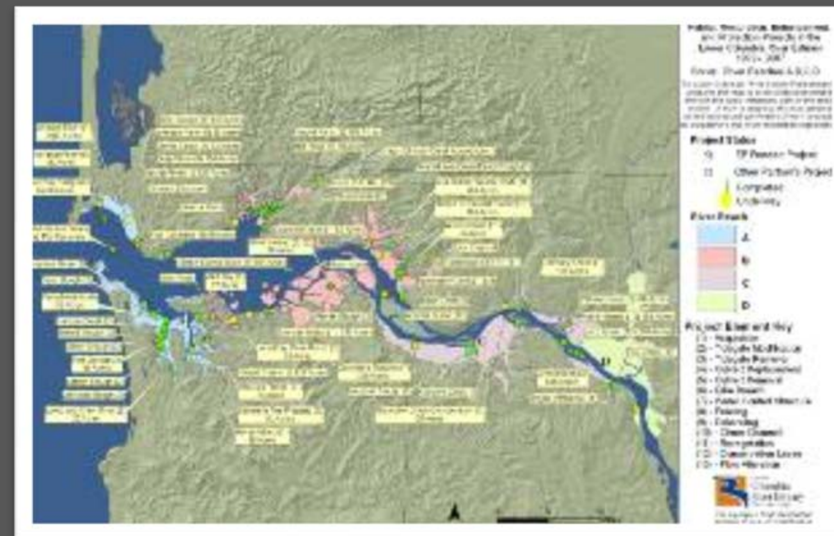
(Kukulka and Jay 2003a)

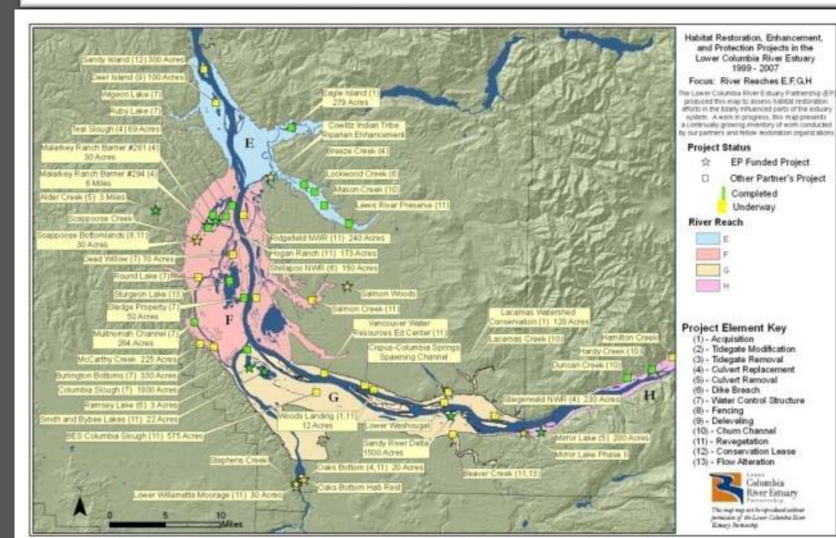
Key Habitat Restoration Drivers on the Lower Columbia River & Estuary

- Endangered Species Act (ESA) (16 U.S.C. 1531-1544)
- **NOAA Biological Opinions** (BiOp) on the effects of Federal Columbia River Power System Operations on Threatened and Endangered Salmon (2000, 2004, 2008): 10,000 acre restoration recommendation (www.salmonrecovery.gov/implementation)
- Other Corps of Engineers Restoration Authorities
- State/Private/NGO efforts & Watershed Councils
- Mitigation (e.g., for Port, State, and Federal transportation system development)

How to Implement and Assess Restoration in an Understudied, Complex System

- Multiple Agencies and NGOs
- Both Species and Ecosystem Goals
- Various Restoration Methods
- Ecological Gradients
- Uncertain Ecological Relationships
- Interlocked Human Communities





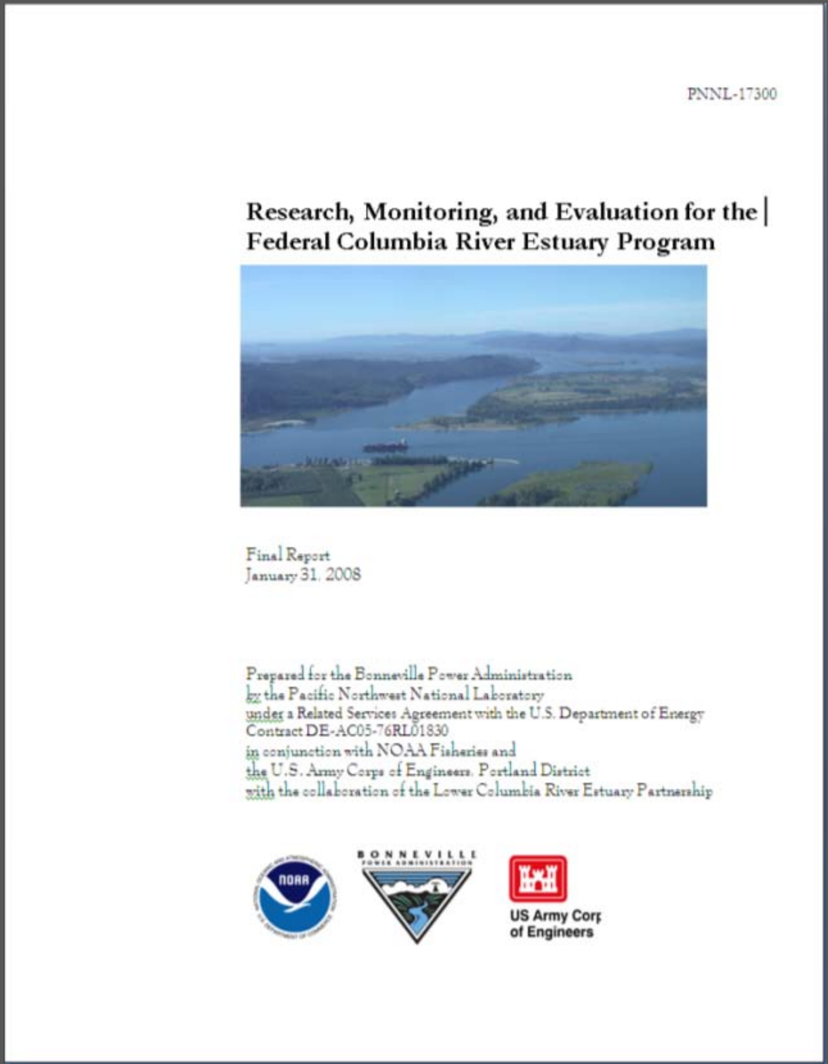
Courtesy Lower Columbia River Estuary Partnership

Accountability: Quantitative Reporting of Restoration Outcomes

- By Action Agencies to NMFS
- By Implementers to Funder-Sponsors
- By Agencies/NGOs to Stakeholders
- By Federal Agencies to Congress
- By State Agencies to State Legislatures
- By Elected Representatives to the Public

Federal Columbia River Estuary Program: Research, Monitoring & Evaluation Plan

- **Program Goal**: Understand, conserve, and restore the estuary ecosystem to improve the performance of listed salmonid populations.
- **RME Objectives:**
  - Status and Trends Monitoring
  - Action Effectiveness Monitoring and Research
  - Critical Uncertainties Research
  - Implementation and Compliance Monitoring
  - Synthesis and Evaluation


PNNL-17300

Research, Monitoring, and Evaluation for the Federal Columbia River Estuary Program

Final Report
January 31, 2008

Prepared for the Bonneville Power Administration
by the Pacific Northwest National Laboratory
under a Related Services Agreement with the U.S. Department of Energy
Contract DE-AC05-76RL01830
in conjunction with NOAA Fisheries and
the U.S. Army Corps of Engineers, Portland District
with the collaboration of the Lower Columbia River Estuary Partnership

Johnson et al. 2008

Approach

Biological Opinion, Action Effectiveness Research, Reasonable and Prudent Action #3

"Develop and implement a methodology to estimate the cumulative effects of habitat conservation and restoration projects in terms of cause-and-effect relationships between ecosystem controlling factors, structures, and processes affecting salmon habitats and performance."

USACE Cumulative Effects Study Purpose

To standardize methods to evaluate the effectiveness of Columbia River estuary hydrological reconnection ecosystem restoration projects, and the secondary and cumulative effects of these projects at larger scales, i.e., on-site, local, and landscape scale effects.

Cumulative Effects Terminology

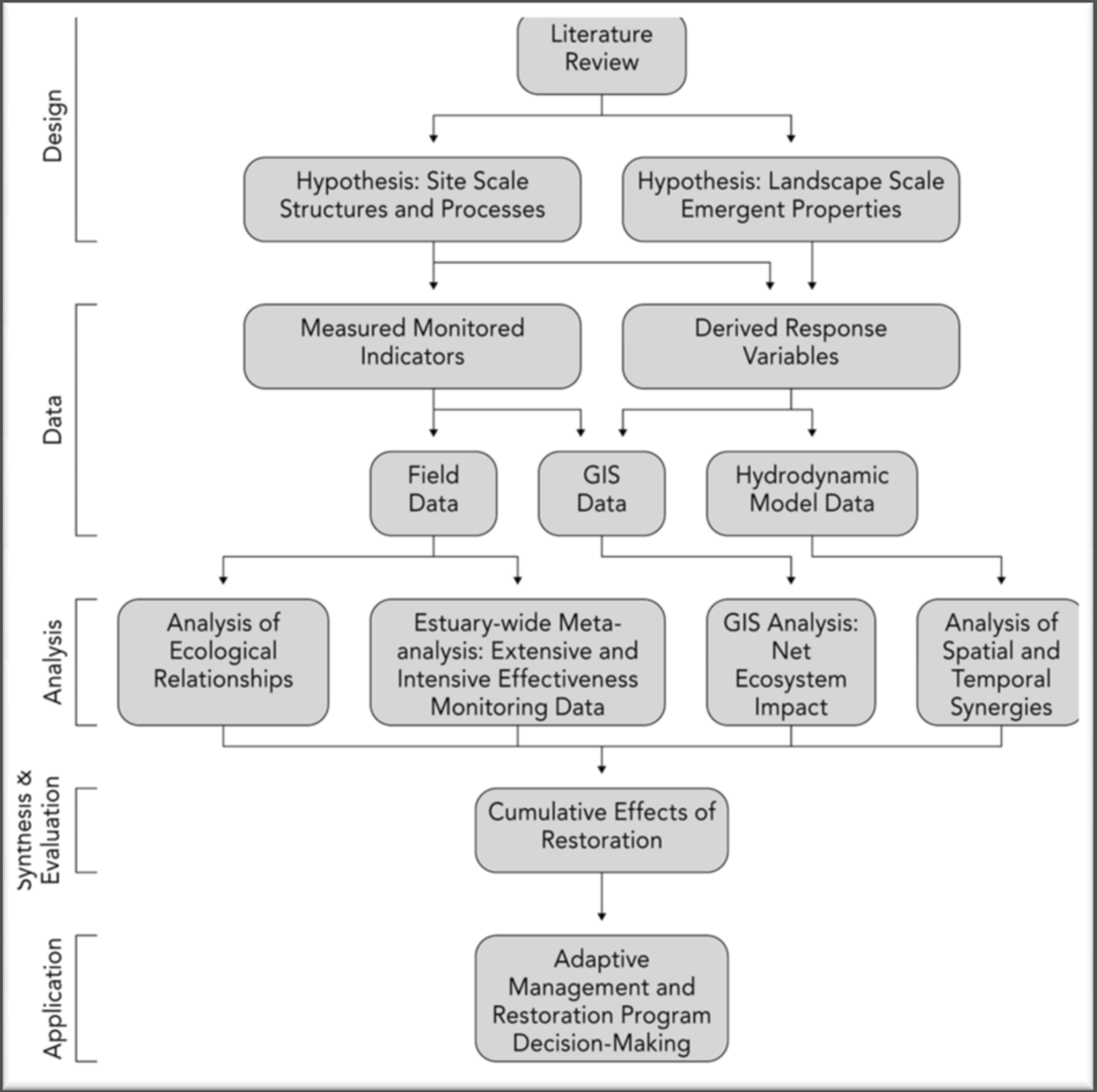
"The impact on the environment which results from the incremental impact of the action when added to other past, present, and reasonably foreseeable future actions regardless of what agency (Federal or non-Federal) or person undertakes such other actions" (40 CFR § 1508.7).

Fields Reviewed Watersheds, Land-margin ecosystems, Fisheries, Wetlands, Forests, Ecotoxicology

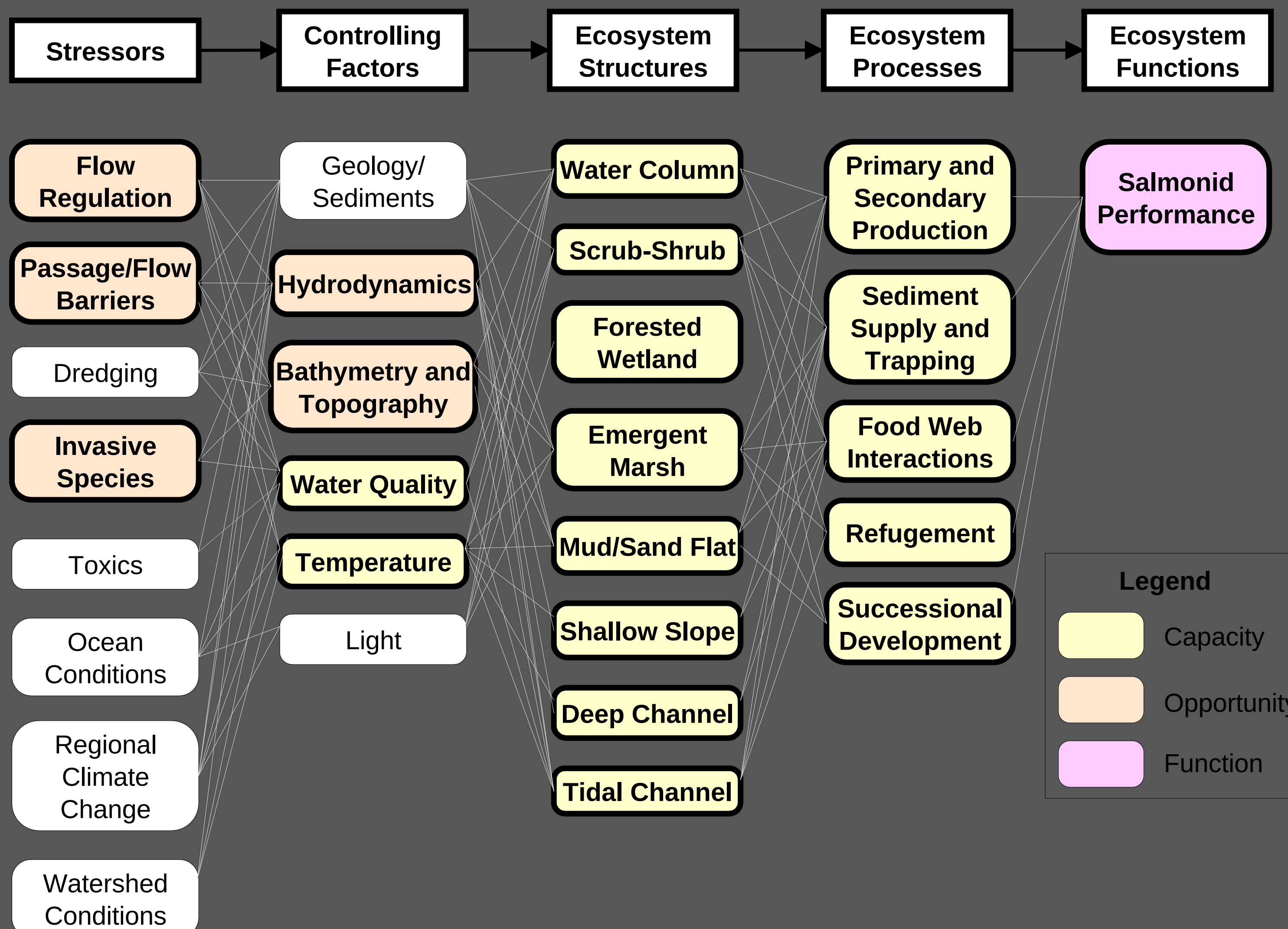
Modes of Accumulation Time crowding, Space crowding, Time lags, Cross-boundary, Landscape pattern, Compounding, Indirect, Triggers and thresholds (President's Council on Environmental Quality 1997)

Adaptation of an Impact Assessment, Levels-of-Evidence Approach

Baird and Burton (2001)
Downes et al. (2002)



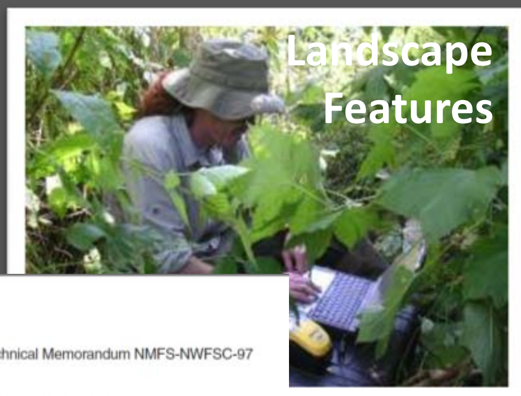
Selecting Indicators Relative to Restoration Goals: Ecosystem vs. Salmon Approach

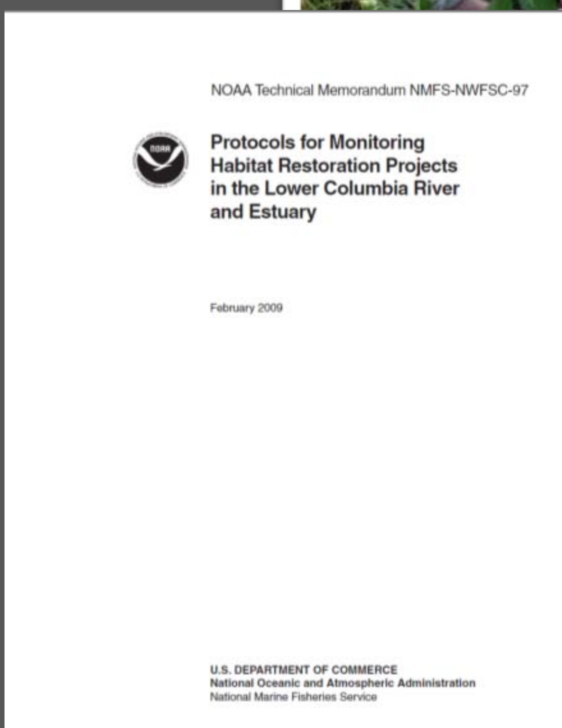


Predict Effects of Typical Restoration Actions

Restoration Measure	Direct Effects	Indirect or Long-Term Effects	Cumulative Effects	Salmon Effect Category
Dike Breach	Tidal Inundation	Land use, Plant comm., Channels	Exchange, Food web, Hab. area	Opportunity & Capacity
Tidegate or Culvert Replacement	Tidal Inundation Fish Passage	Spawning area increase	Habitat area	Opportunity
Channel Excavation	Channel area, morphology	Increased wetted area	Habitat area	Opportunity & Capacity

Field-Tested, Collaboratively Developed Monitoring Protocols for Salmon Habitat Restoration Projects in the Lower Columbia River and Estuary, 2009





NOAA Technical Memorandum NMFS-NWFSC-97

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

February 2009

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service

NOAA Technical Memorandum, NMFS-NWFSC-97
http://www.nwfsc.noaa.gov/publications/index.cfm

Key Indicators of Cumulative Effects

Macro-detritis and prey, production and export–

Fundamental Shift in Food Web (Sherwood et al. 1990)

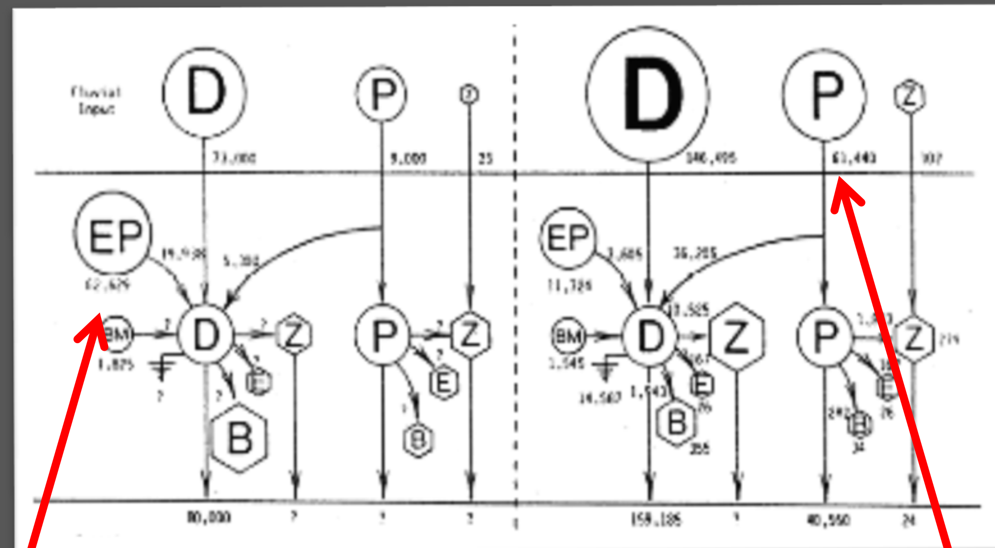
Connected channel edge availability

Nexus of terrestrial and aquatic productivity

Wetted area (inundation)

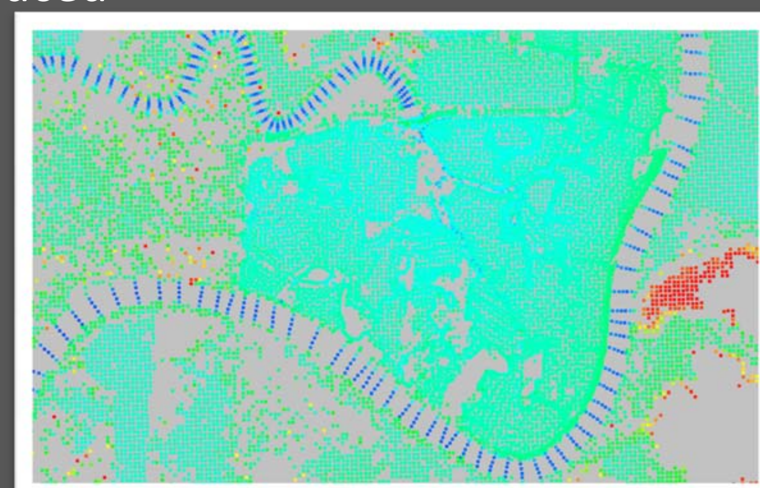
Merged LiDAR, Cross-Sections, Topographic Survey Data

Pre-1870 Recent



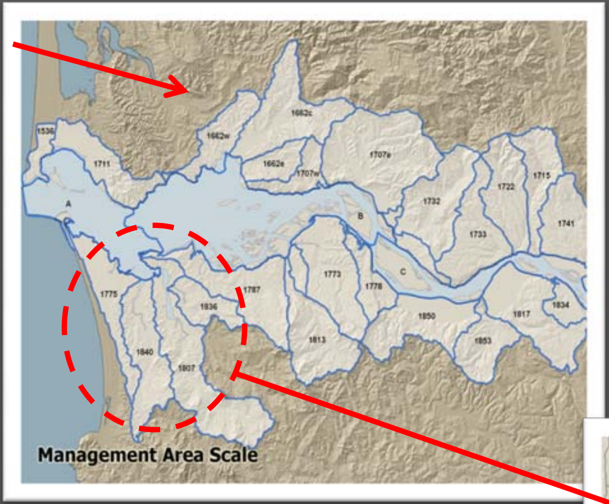
Emergent plant input reduced

Phytoplankton input from reservoirs increased

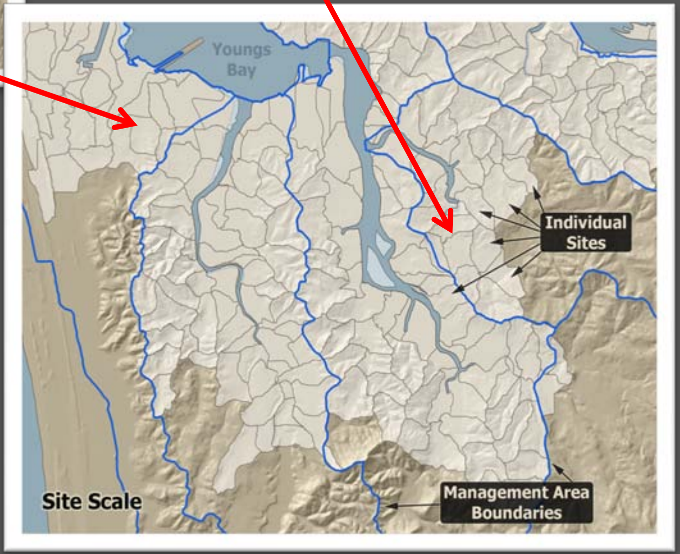


Base Model

Management Units = HUC 6 hydrological units. There are ~60 MUs in the 235-km tidal floodplain.



Site Units = definable hydrologic divisions. There are ~2,300 SUs in the 235-km tidal floodplain.



Data:

- Stressor and Landscape Indicators
- Site Evaluation Cards

Net Restoration Effect:

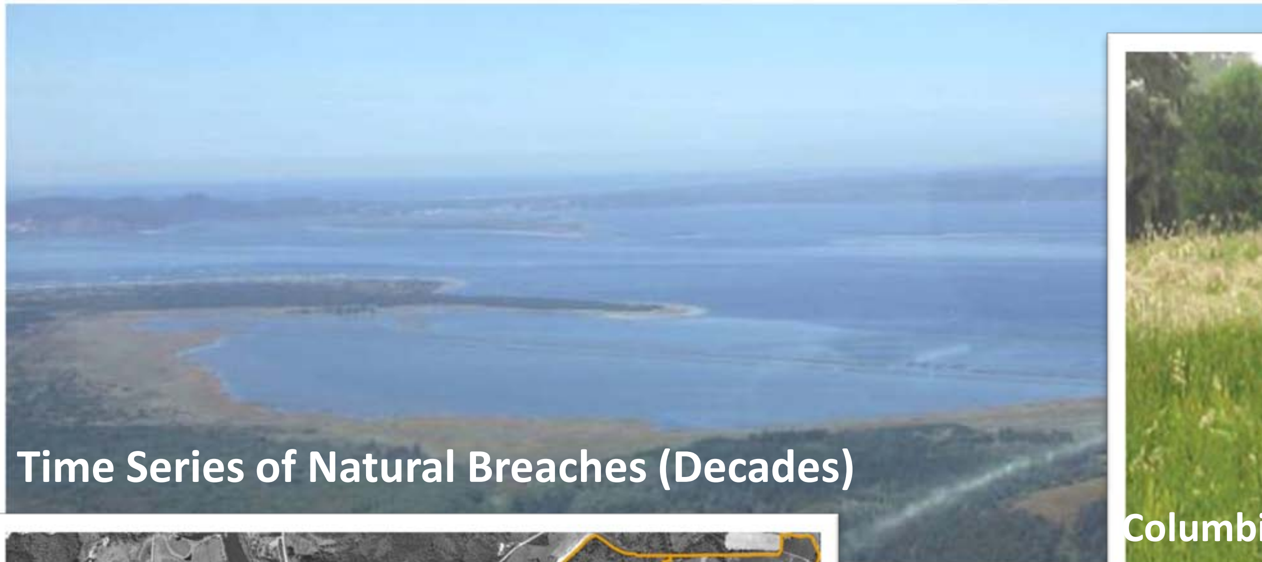
NRE = (Δfunction) (area) (probability)

Cumulative Net Ecological Impact:

CNEI = ∑(Δfunction x area x probability)

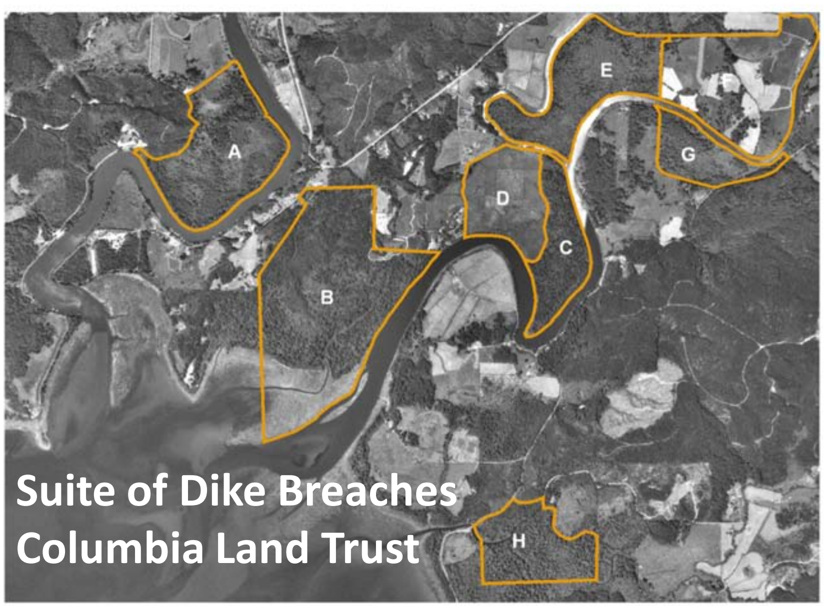
-Thom et al. *Rest.Ecol.* 13(1) 2005; Diefenderfer et al. *Env. Man.* In Press

Project Spatial and Temporal Sequencing



Time Series of Natural Breaches (Decades)

Columbia White-Tailed Deer, USFWS



Suite of Dike Breaches
Columbia Land Trust

Suite of Tide Gates Julia Butler Hansen NWR

Predicting Restoration Outcomes for Fish and Habitat Capacity: “Natural” Dike Breach Dates

Karlson Island, prior to 1981

Fort Clatsop, ~1960

Trestle Bay, 1995

2008: Began Time Series

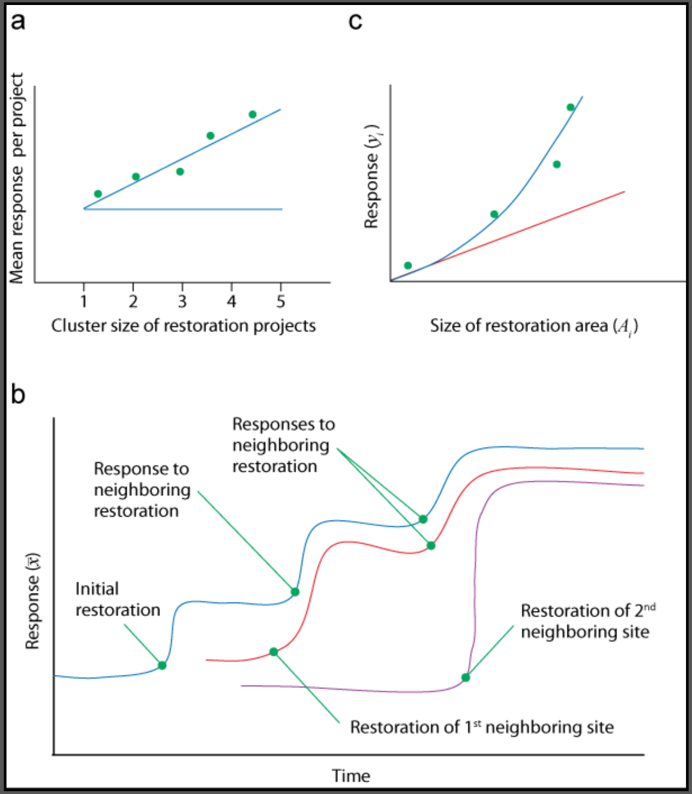
Rapid Assessment Indicators:

- Vegetation
- Channel Morphology
- Sediment Accretion
- Water Levels
- Elevation
- Fish

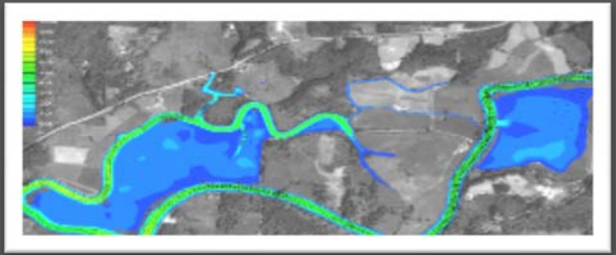
Cumulative Effects Statistical Tests

-Hypothetical responses to space crowding (project cluster size), project size, and restoration of neighboring sites.

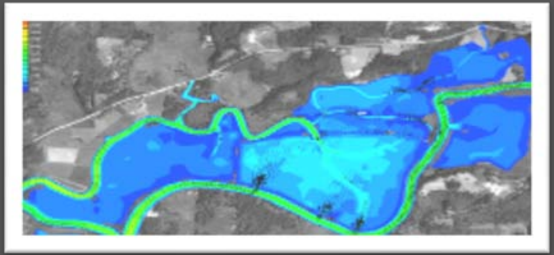
-Data may be from experimental restoration installations … or simulations of wetted area from hydrodynamic model.



Pre Construction



Post Construction



Paired Site Study Design: Ongoing Research

Habitat Types:

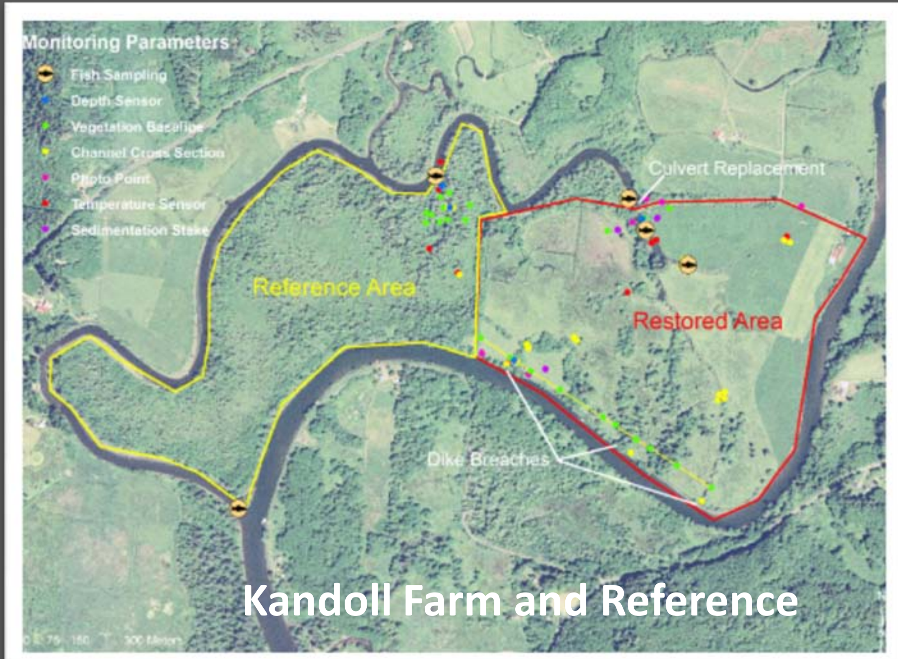
Tidal Swamp vs. Marsh

Trajectory:

Restoration vs. Reference

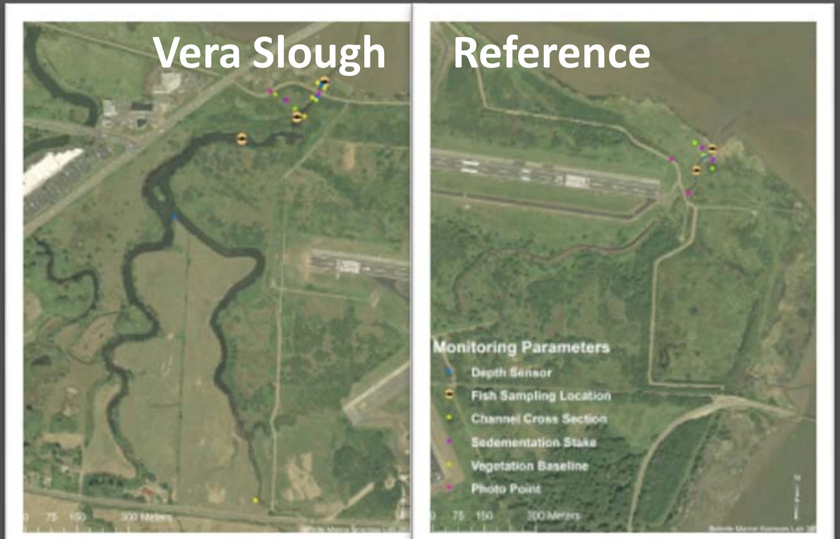
Restoration/Enhancement Action:

Tide Gate vs. Culvert vs. Breach

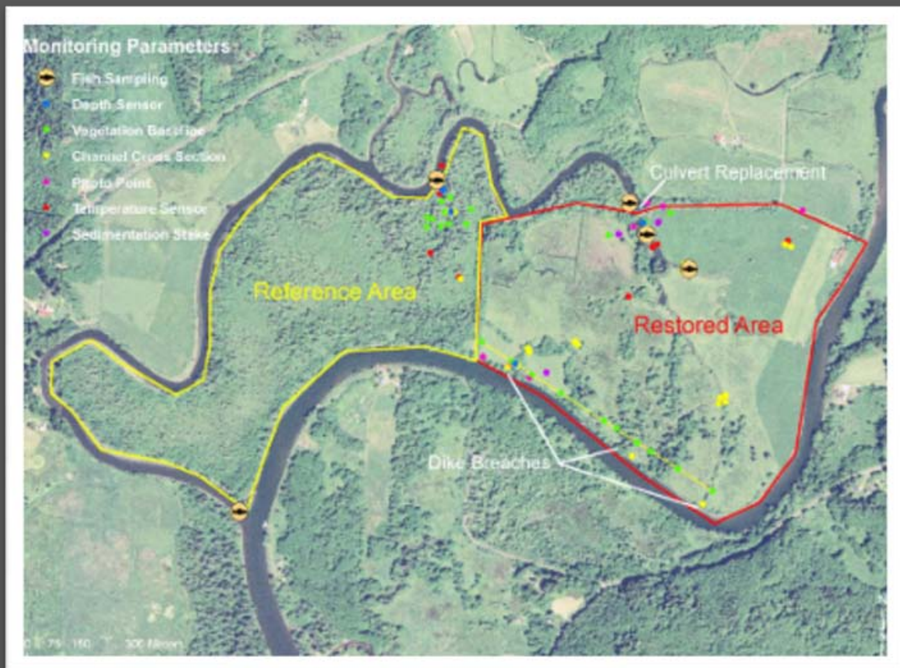


Timeline and Indicators:

Baseline (Pre-Restoration) Data Collected in 2005; Post-Restoration Data Collected Annually: Core Indicators (Protocols) and Cumulative Effects Indicators



Developing Predictive Ecological Relationships



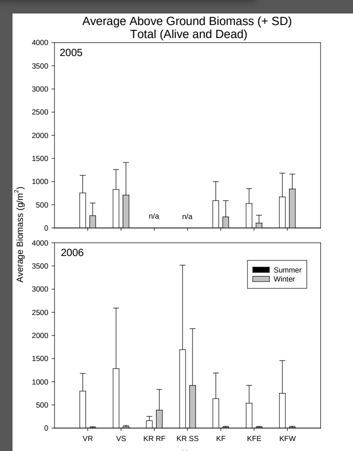
Paired Reference/Restoration

	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
	VS 2005	VR 2005	VS 2006	VR 2006	
VS 2005		24.5	94.1	-	
VR 2005			-	98.2	
VS 2006				13.1	

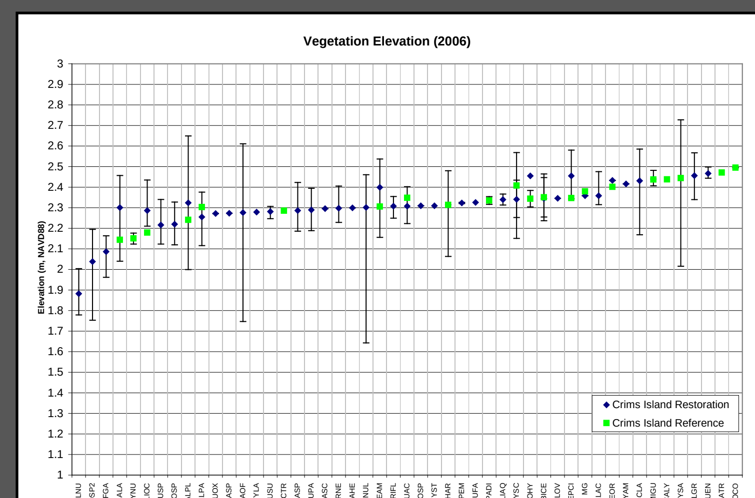
Similarity Index: Plant Cover

Site	Stake Pair	Accretion Rate (cm/y)
Kandoll Farm	1	1.3
	2	3.1
	3	3.5
Johnson Property	1	1.8
	2	2.2
	3	2.3
Grand Mean		2.4

Sediment Accretion Rate



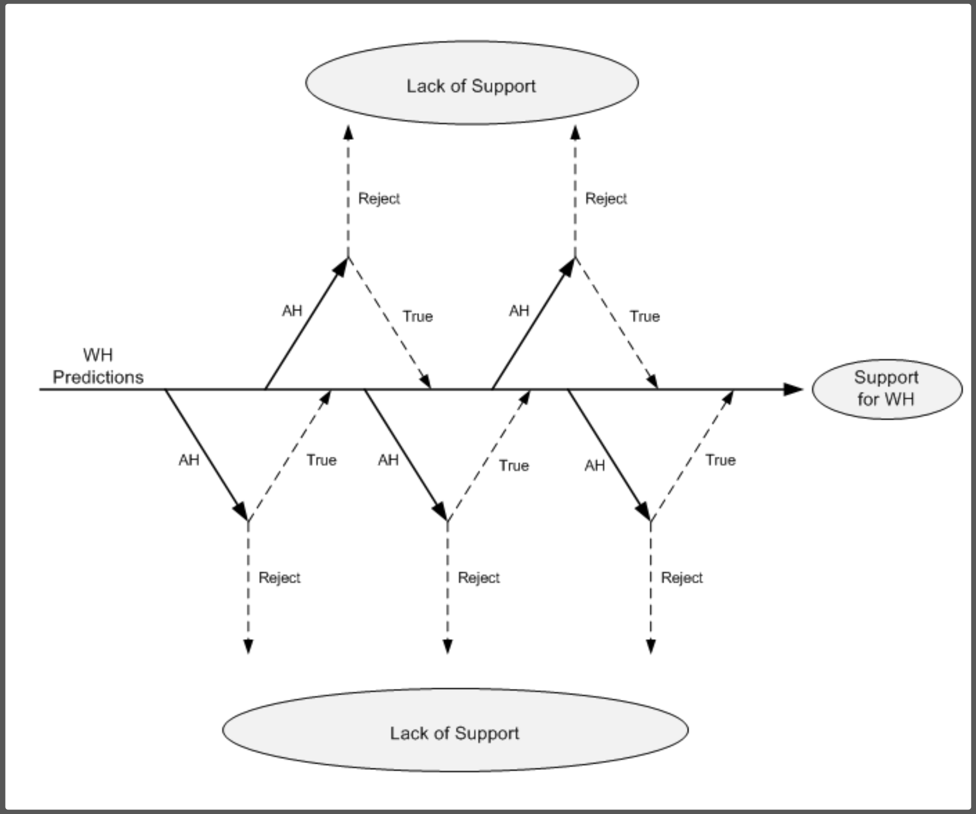
Organic Matter Export



Vegetation-Elevation Relationships

Potential Cumulative Effects on *Ecosystem Processes & Functions*

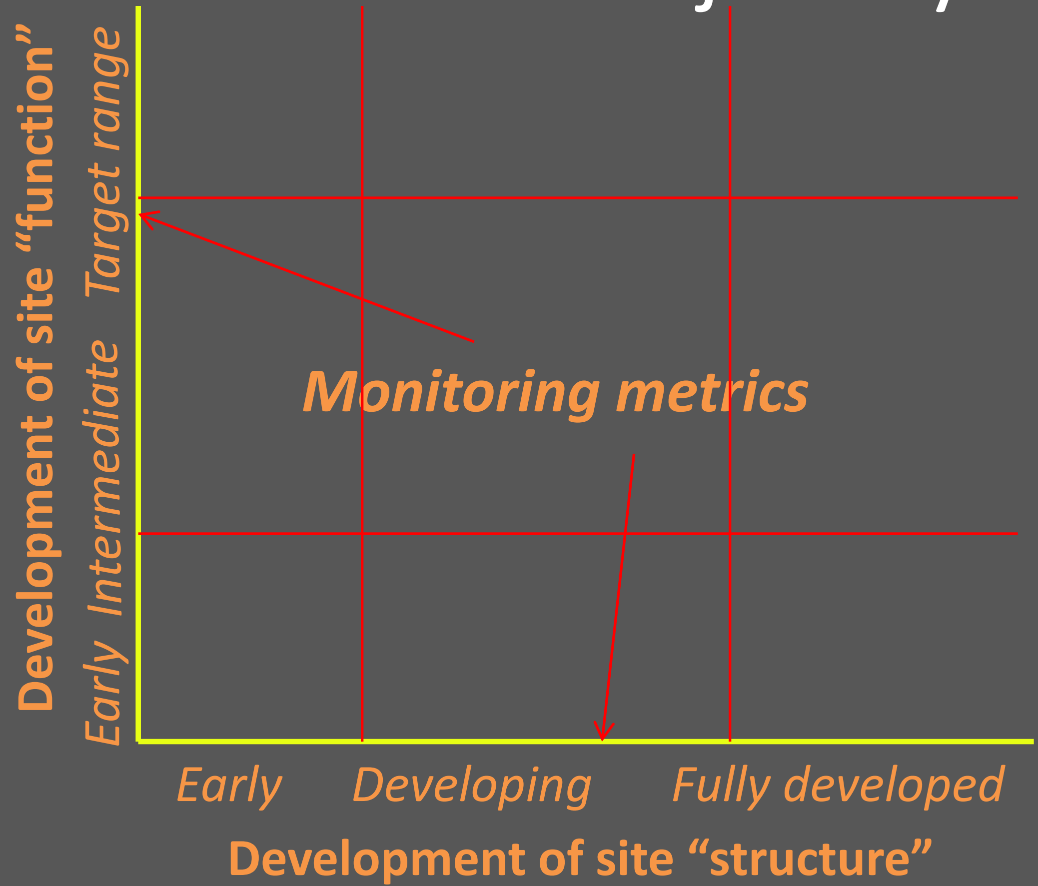
- Return of marsh macro-detritus to the system
- Decrease in fragmentation
- Increase connectivity
- Increase habitat opportunity or capacity for juvenile salmon
- Enhance flood attenuation, sediment trapping, nutrient processing capacity



Measurement, Assessment & Adaptive Management of the Restoration Trajectory

Causal Criteria:

- Strength of Association
- Consistency of Association
- Specificity of Association
- Temporality
- Biological/Ecological Gradient
- Biological/Ecological Plausibility
- Experimental Evidence
- Plausibility

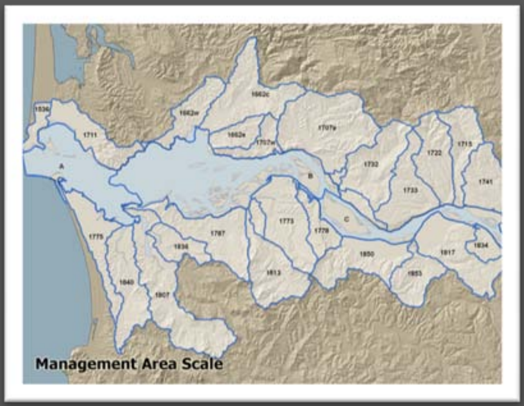


(Thom 1997 adapted from Bradshaw 1987)

Levels of Evidence: Correlative data used to make the case for causal inference and against alternative hypotheses.

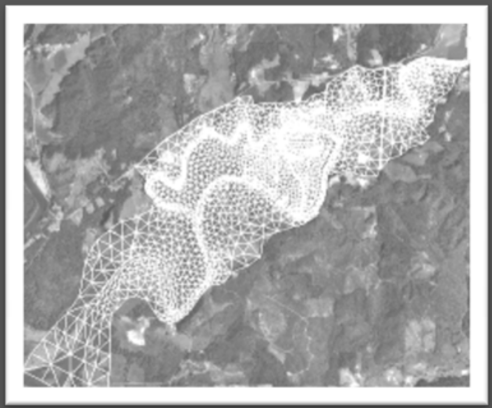
Summary: Levels of Evidence Approach

Base Model



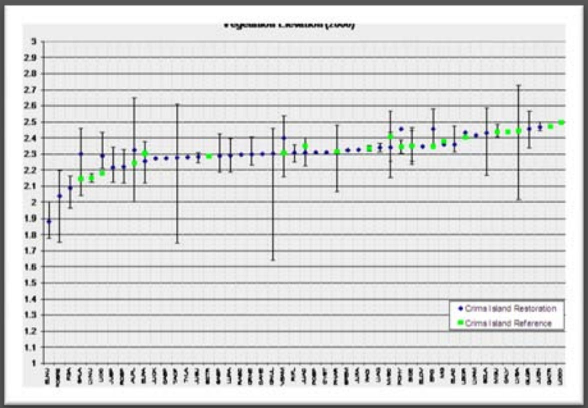
Base GIS Model/Adaptive Management Framework

Synergy



Hydraulic Modeling & Statistical Tests for Cumulative Effects

Predictive/Meta-analysis



Ecological Structure & Function Relationships

Cumulative Effects Evaluation

Baird and Burton (2001)
Downes et al. (2002)

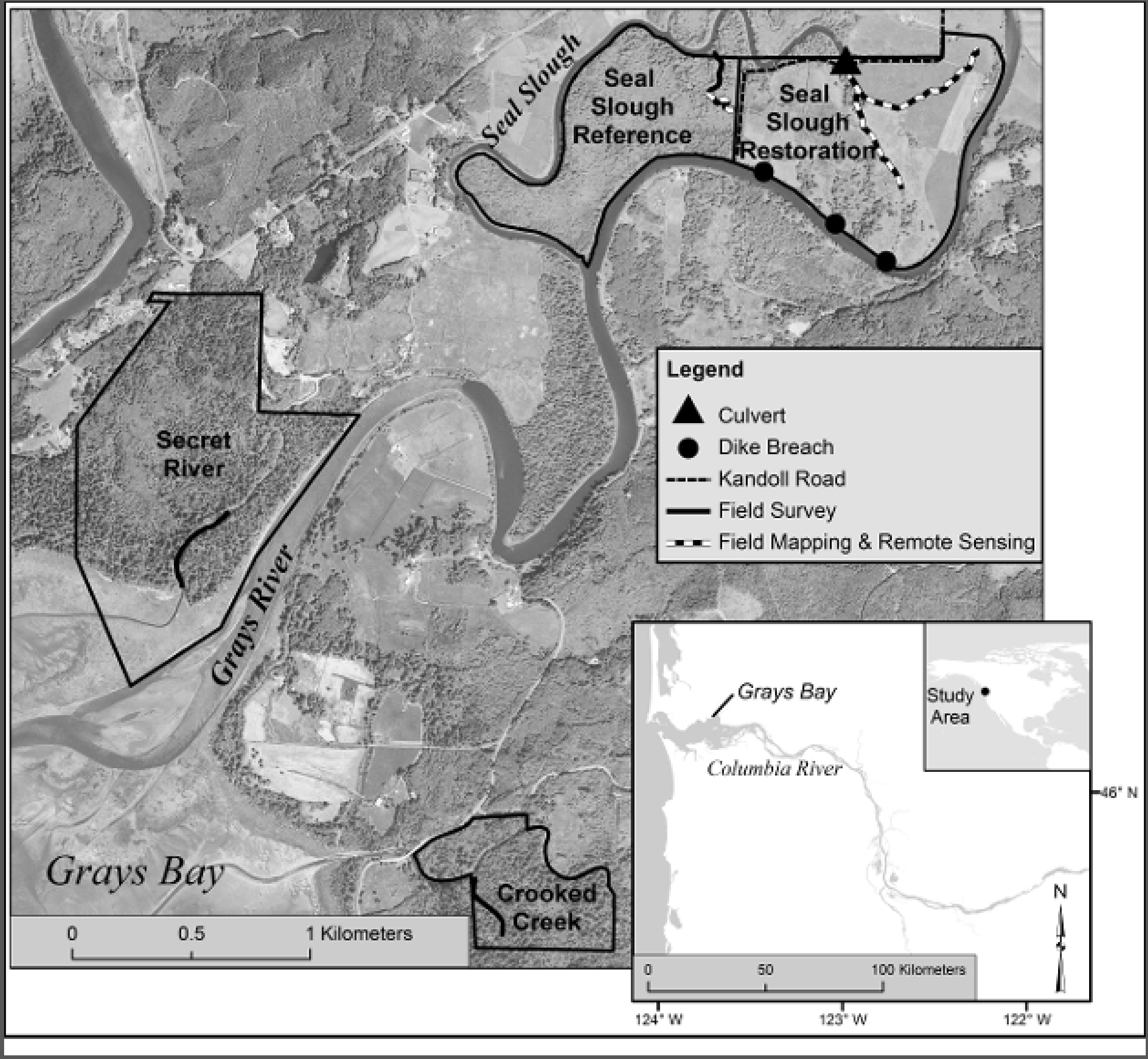
Multi-Scale Analyses: Restoration & Reference Sites

Using ecological research at paired restoration and reference sites to identify:

- Controlling factors on the system;
- Achievable restoration targets;
- Appropriate monitoring indicators.

Grays R. Swamp and Restoration Survey Areas

Purpose:
To identify controlling factors on channel networks in *P. sitchensis* tidal freshwater swamps.



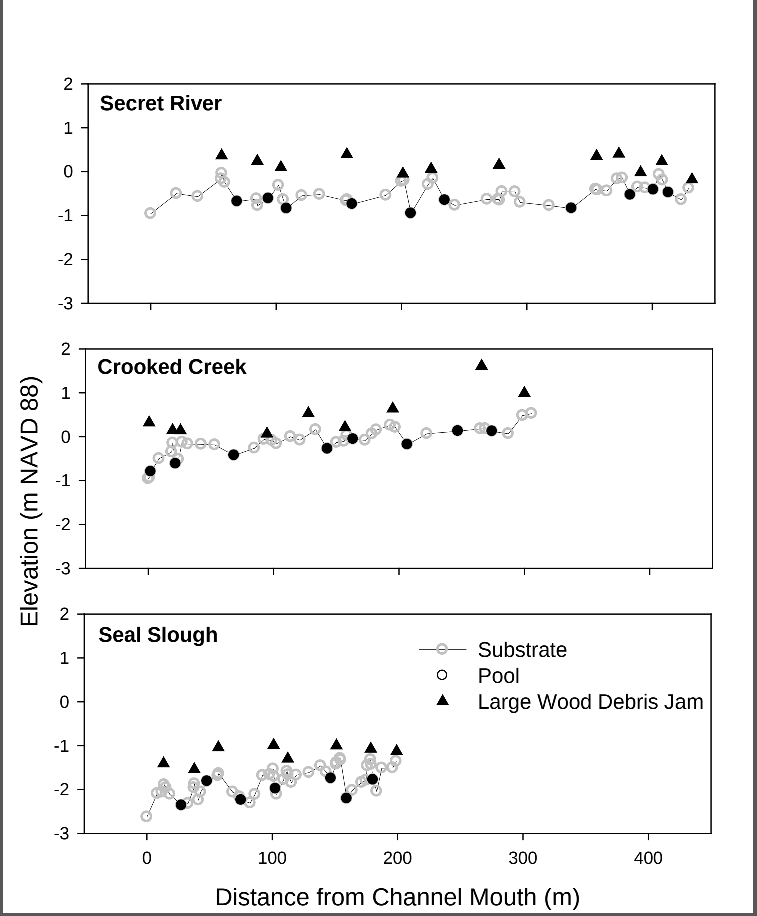
Reach Scale Pool Spacing:

Hypothesis & Methods

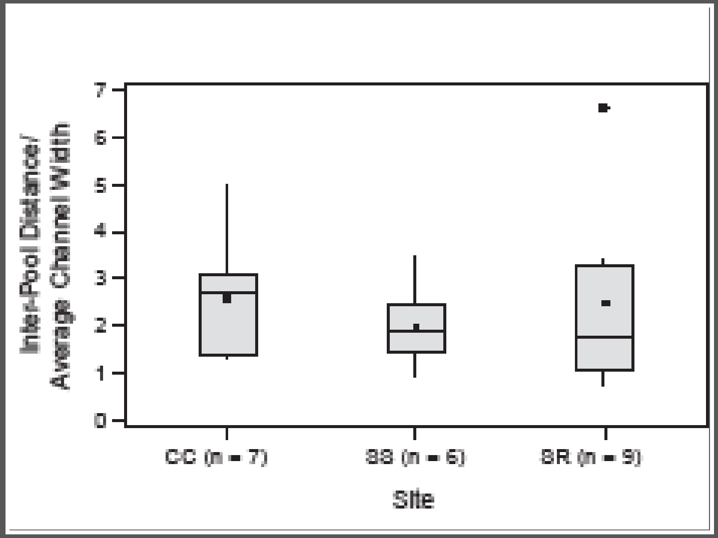
Development of *P. sitchensis* freshwater tidal forested wetland channels incorporates large woody debris to form a low-gradient step-pool system

Longitudinal survey and photo-documentation of channels in 3 *P. sitchensis* tidal forested wetlands

Reach Scale Pool Spacing Results: Survey and Classification



- 2.3 Channel Widths/Pool (See Montgomery *et al.* 1995; Montgomery and Buffington 1998)
- Large Wood Forced Step Pool Channel Type



Diefenderfer & Montgomery, 2009. "Pool Spacing, Channel Morphology, and the Restoration of Tidal Forested Wetlands." *Restoration Ecology* 17:158-168.

Catchment Scale: Hydraulic Geometry Background

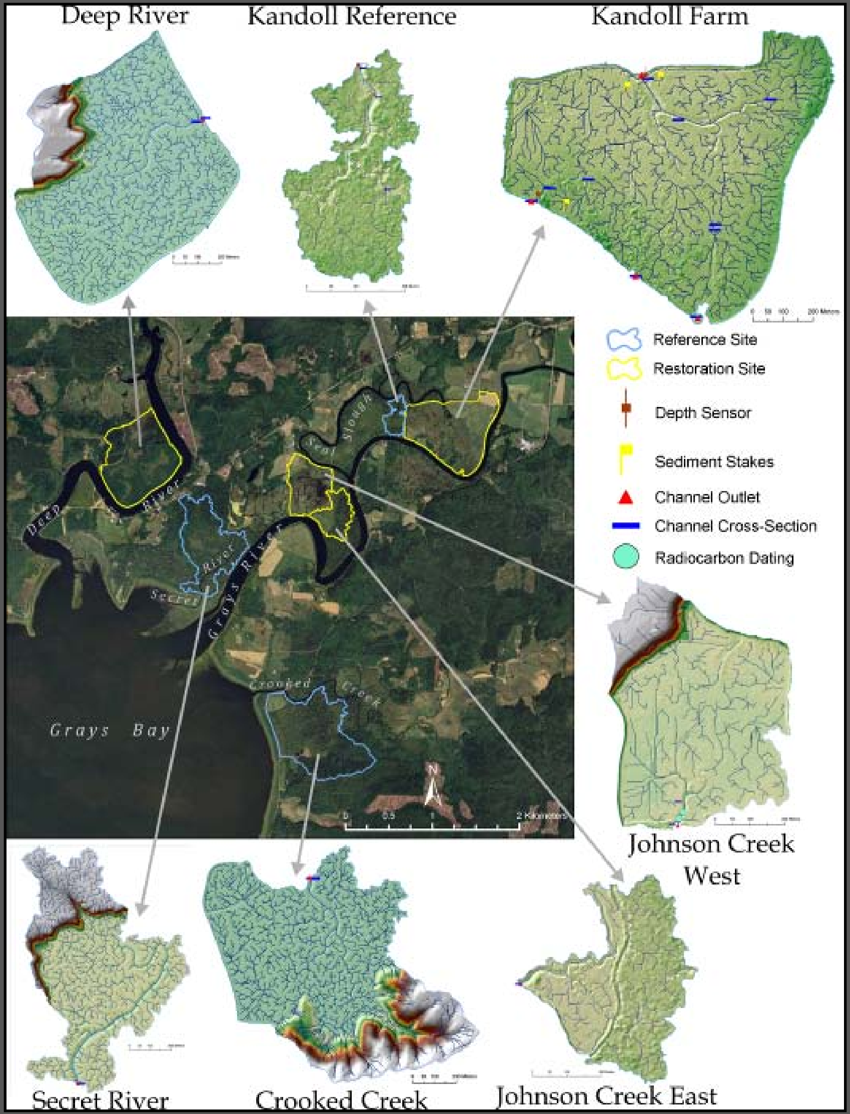
1) Cross-sectional geometry a dependent variable in tidal inlet stability research in estuaries and bays (O'Brien 1931; Escoffier 1940)

3) Surrogates for Q in salt marshes: tidal prism, catchment area, and total length of tidal channels (Steel and Pye 1997; Williams *et al.* 2002)

2) Channel cross-sectional geometry as a function of discharge (Q) in

- fluvial systems (Leopold and Maddock 1953)
- tidal systems (Myrick and Leopold 1963)

Hydraulic Geometry Hypotheses



I. H_0: *P. sitchensis* swamps do not exhibit correlations between

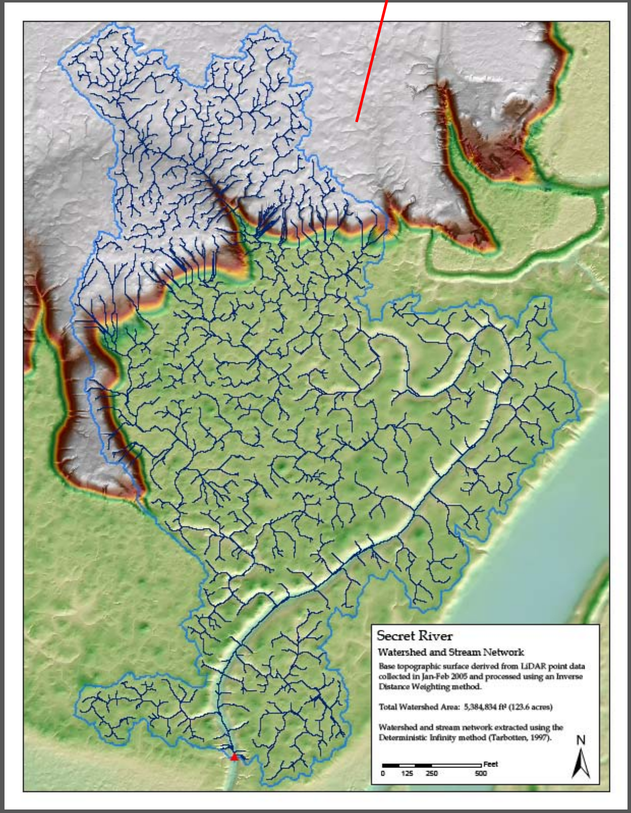
- channel cross-sectional area at outlet and catchment area;
- catchment area and total length of channels; and
- total length of channels and channel cross-sectional area at outlet.

II. H_0: Hydraulic Geometry not comparable to other regions

Hydraulic Geometry Methods

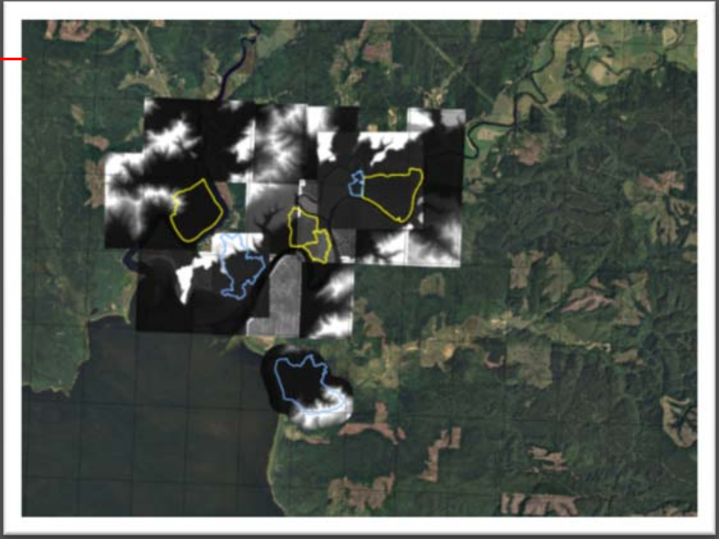
Surveys of channel cross-sectional areas at outlet and up-channel

GIS-based topographic analysis of LIDAR data using Deterministic Infinity model (Tarboton 1997) to derive catchment boundaries and stream networks

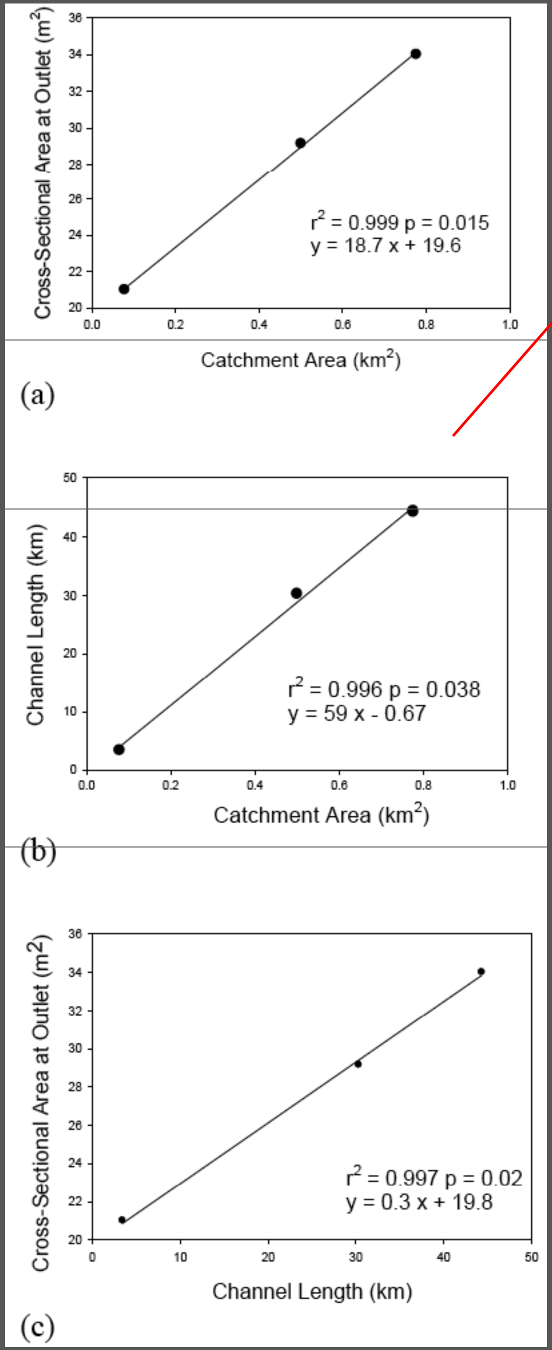


GIS-based topographic roughness analysis (Blaszczynski (1997) and Riley et al. (1999))

Ground-Truth

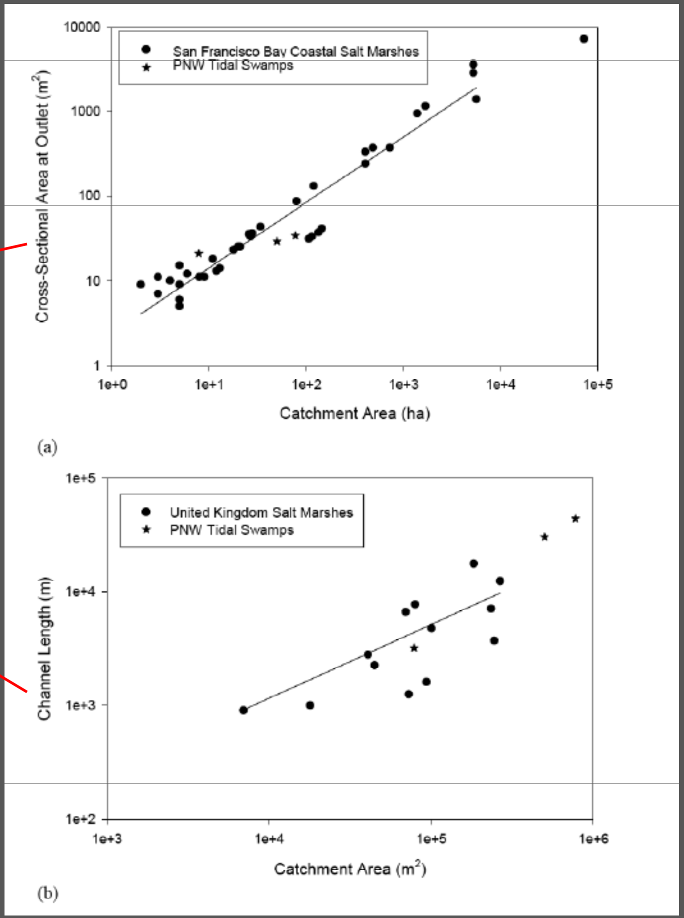


Hydraulic Geometry Results



Spruce Swamp Correlations

- San Francisco Bay-Delta (Williams et al. 2002) and United Kingdom (Steel & Pye 1997) Salt Marsh Hydraulic Geometry Compared with Spruce Swamps of Pacific Northwest



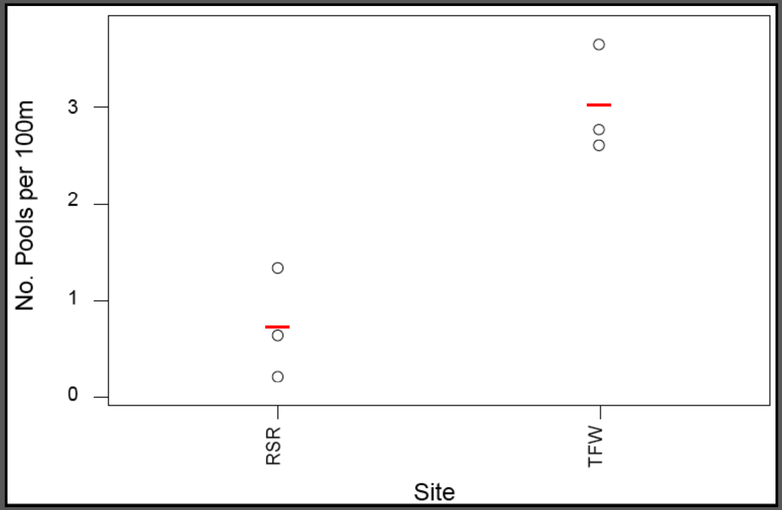
Diefenderfer, HL, AM Coleman, AB Borde, and IA Sinks. 2008. Hydraulic geometry and microtopography of tidal freshwater forested wetlands and implications for restoration, Columbia River, U.S.A. *International Journal of Ecohydrology and Hydrobiology* 8.

Restoration Sites Research Questions

Equivalency of Pre-Restoration and Reference Sites: Mean Pool Spacing, Mean Land Elevation, Microtopography

Pre- vs. Post-Restoration Conditions: Large Wood Forcing Pools? Hydraulic Geometry Trending toward Swamp Reference Sites? Sediment Accretion Rates Changed by Hydrologic Disconnection (Diking) and Reconnection (Breaching)?

Restoration Sites Results I: Pool Spacing and Large Wood

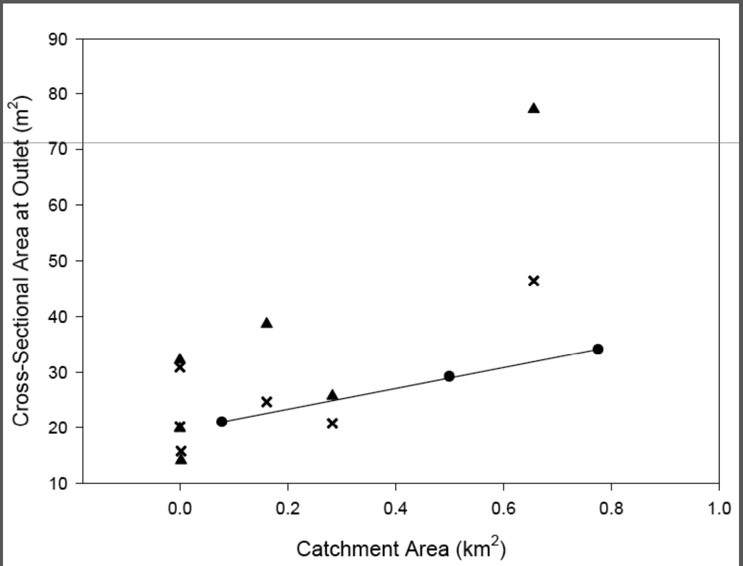


Buried and Fallen Wood Recruitment

Restoration site reaches (RSR) have significantly fewer pools/100m than spruce swamp tidal freshwater reaches (TFW).

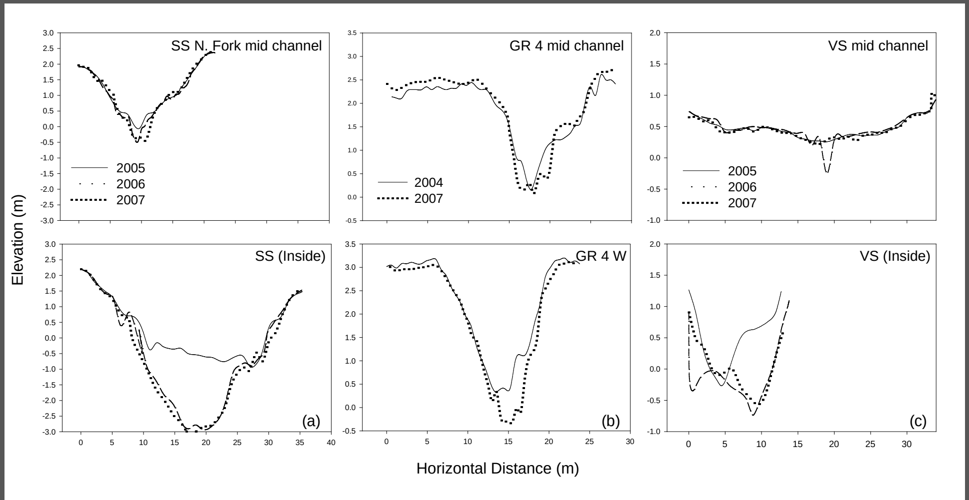
Restoration Sites Results II: Observed Channel Outlet Changes

Comparative Hydraulic Geometry: Restoration Site Channel Outlets, Before (x) and After (▲)



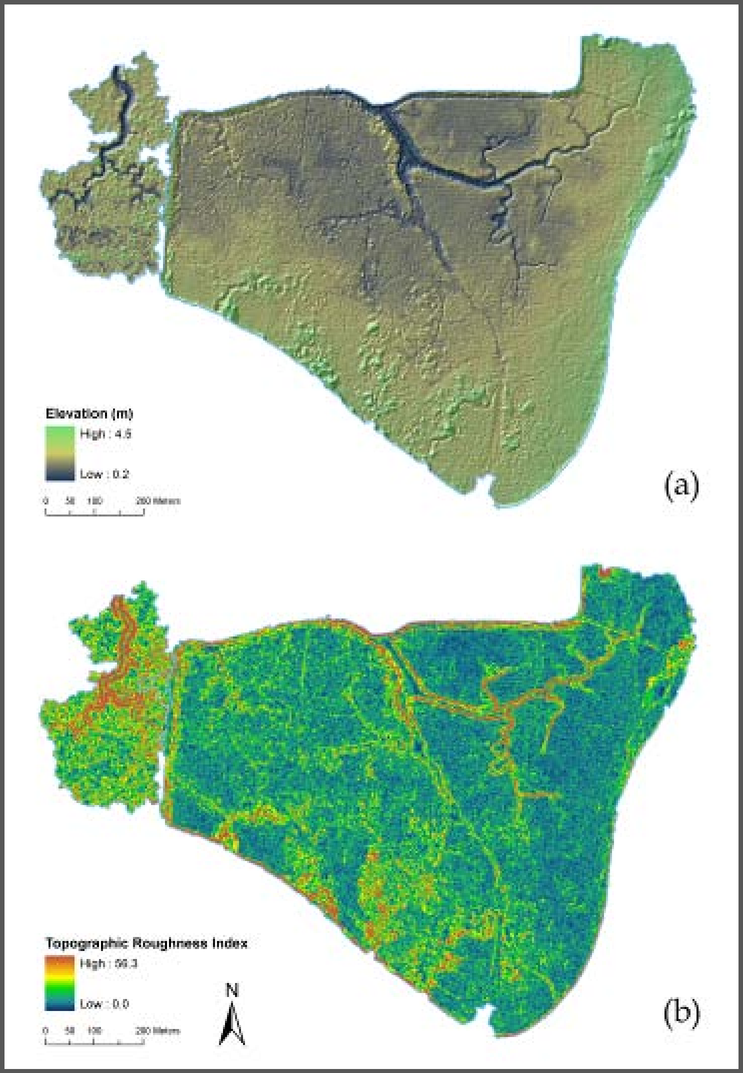
Deep River Outlet:
Time of Construction

Example Cross-Sections



Deep River Outlet:
2 years post Construction

Restoration Sites Results III: Subsidence, Compaction, Grading

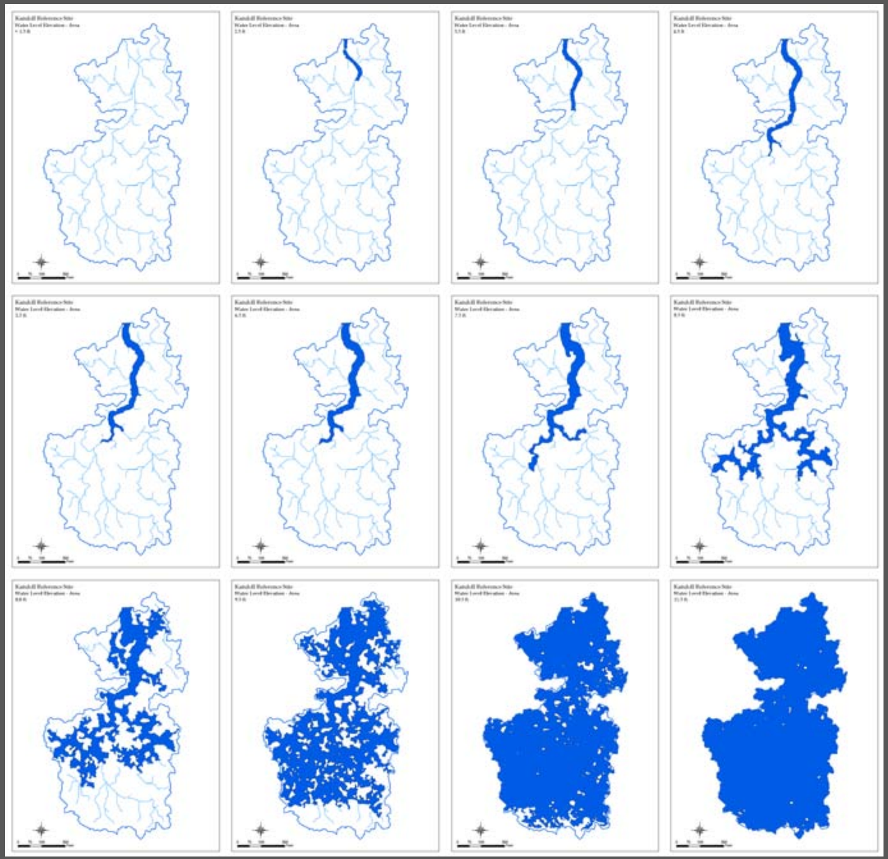


Pre-Restoration: Mean elevation of Seal Slough restoration site = 2.2 m
Mean elevation of adjacent Seal Slough swamp reference site = 2.9 m
Mean roughness index of the restoration site = 1.40; of the swamp reference = 2.63

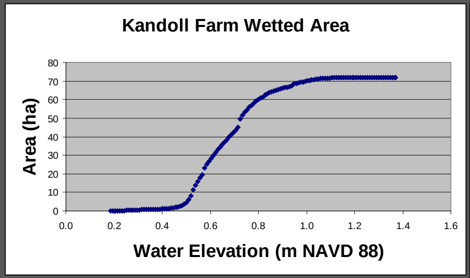
Sedimentation Rates at Restoration Site:
Evidence from Radiocarbon Dating, vertical-
- 1.38 cm/yr 1810-1890
- 0.83 cm/yr 1890-1950

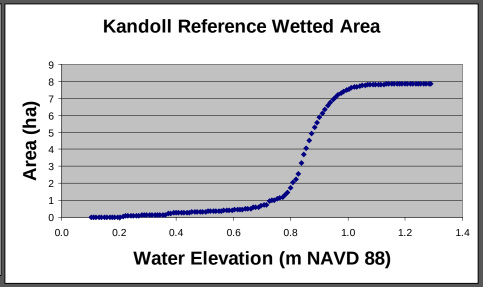
Evidence from sediment accretion stakes-
Since dike breaching, 2-year grand mean at 6 pairs = 2.4 cm/yr, s.d. 0.8

Restoration Sites Results IV: Area-Time Inundation Index



Post-Restoration: The area-time inundation index was 34% at Kandoll Farm in contrast to 9% at Kandoll Reference. Frequency of floodplain inundation at Kandoll Farm was 54% compared with 18% at Kandoll Reference

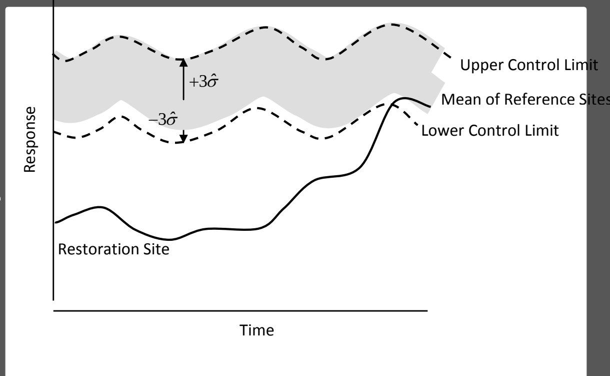




Summary: Clarifying Restoration Targets with Reference Site Ecological Data

Control Chart Method

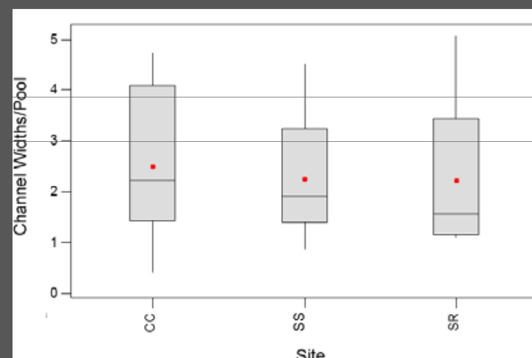
Response



Time

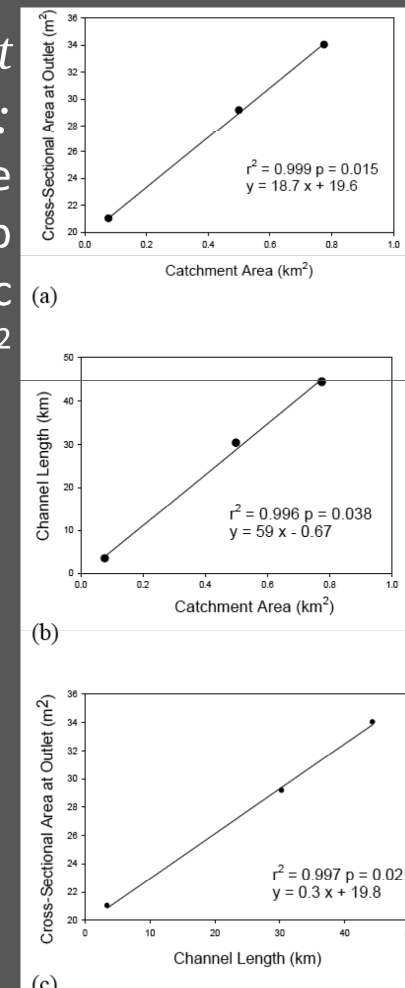
Control Chart Method For Restoration Site Evaluation

Reach Scale: Spruce Swamp Pool Spacing[1]

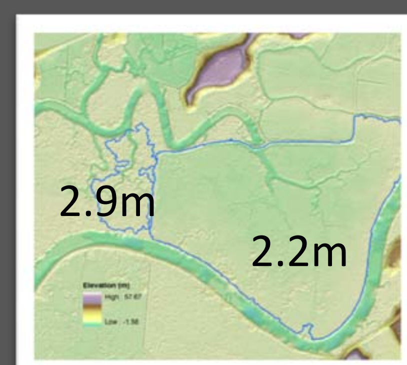


2.3 Channel Widths/Pool

Catchment Scale: Spruce Swamp Hydraulic Geometry[2]



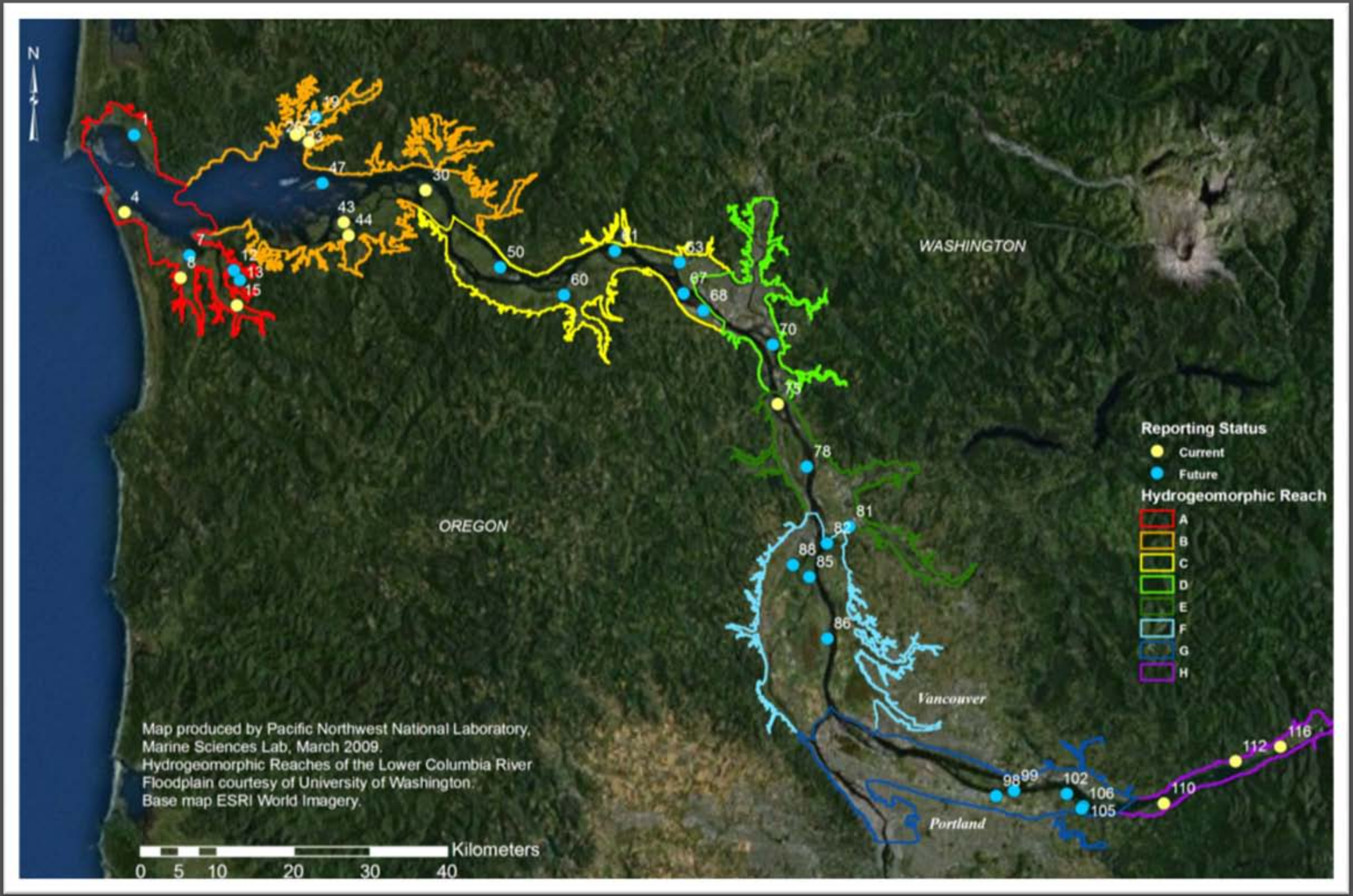
Mean Elevation[2]



[1] Diefenderfer & Montgomery. 2009. *Restoration Ecology* 17.

[2] Diefenderfer, Coleman, Borde, & Sinks. 2008. *Int'l. J. of Ecohydrology and Hydrobiology* 8.

Suite of Reference Sites Helps Define the Range of Possible Values/Outcomes



Implications for Hydrological Reconnection Restoration Planning

- Controlling factors can be identified from reference sites that are subject to existing conditions under altered CR hydrograph.

- Project designs at the site scale need to be informed by catchment-scale hydrological network data and reach-scale pool spacing and large woody debris data.

- Large Woody Debris is important in tidal systems; but LWD available to diked restoration sites is insufficient.

Implications for Hydrological Reconnection Restoration Monitoring: Selection of Indicators

- Prior land use (subsidence and compaction) shapes restoration trajectory of channels and plant community; therefore sediment budget & sediment accretion rates are important indicators; with “fossilization,” channel density may not be.
- Inundated area likely to change (e.g. to decrease for 20-54 years), but “restored area” is a commonly reported early indicator for tidal wetlands.

Evaluation & Application: 2011, 2013, 2017 and Beyond

1) Would the *Preponderance of Evidence* from base, synergy, and predictive lines…convince a reasonable person that the combined restoration projects and programs achieve measurable change toward the restoration goal in the Columbia River Estuary (CRE)?
2) If so, how does this positive effect compare to continuing land conversion & degradation in the CRE?
3) What steps are necessary to achieve greater effectiveness in restoring habitats? What needs to be implemented to produce synergistic effects of multiple projects in CRE ecosystem?
4) What suite of projects produces most significant return of marsh macrodetritus to the CRE ecosystem, an increase in connectivity, an increase in habitat opportunity for juvenile salmon, and maximum flood attenuation, sediment trapping, nutrient processing, etc?

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Co-authors:
Amy Borde, Andre Coleman, Earl Dawley, Blaine Ebberts, Gary Johnson, Dave Montgomery, Curtis Roegner, John Skalski, Ian Sinks, Ron Thom, Kristiina Vogt
Other Contributors:
Val Cullinan, Kern Ewing, Nathan Johnson, Scott McEwen, Lee Miller, Doug Putman, Micah Russell, Kathryn Sobocinski, Allan Whiting, Shon Zimmerman
Field Assistance:
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