National Conference on Ecosystem Restoration

Pre-Conference Technical Workshop: Assessing Cumulative Ecosystem Effects of Multiple Restoration Projects

Monday, August 1st, 2011 - 9:00 – 12 noon

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Portland District

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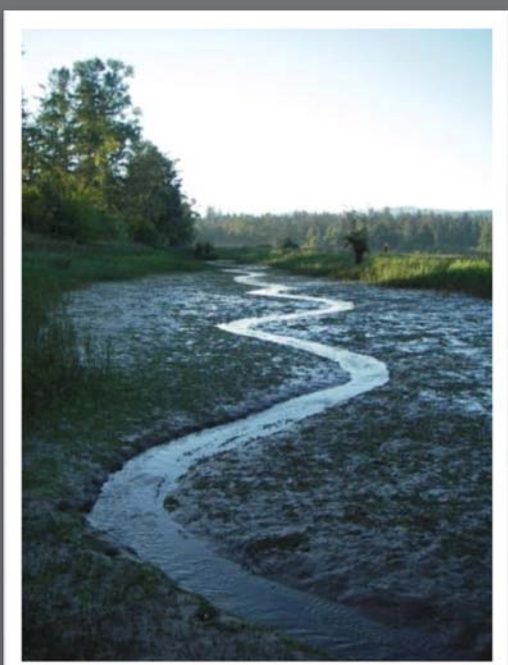
Presentation Overview

I. Study Area: Ecological and Policy Context
II. Levels-of-Evidence Approach to Cumulative Effects Analysis
III. Multi-Scale Analyses: Restoration & Reference Sites
IV. Cumulative Ecosystem Effects: 2005-2009 Research Findings



I. Study Area and Context

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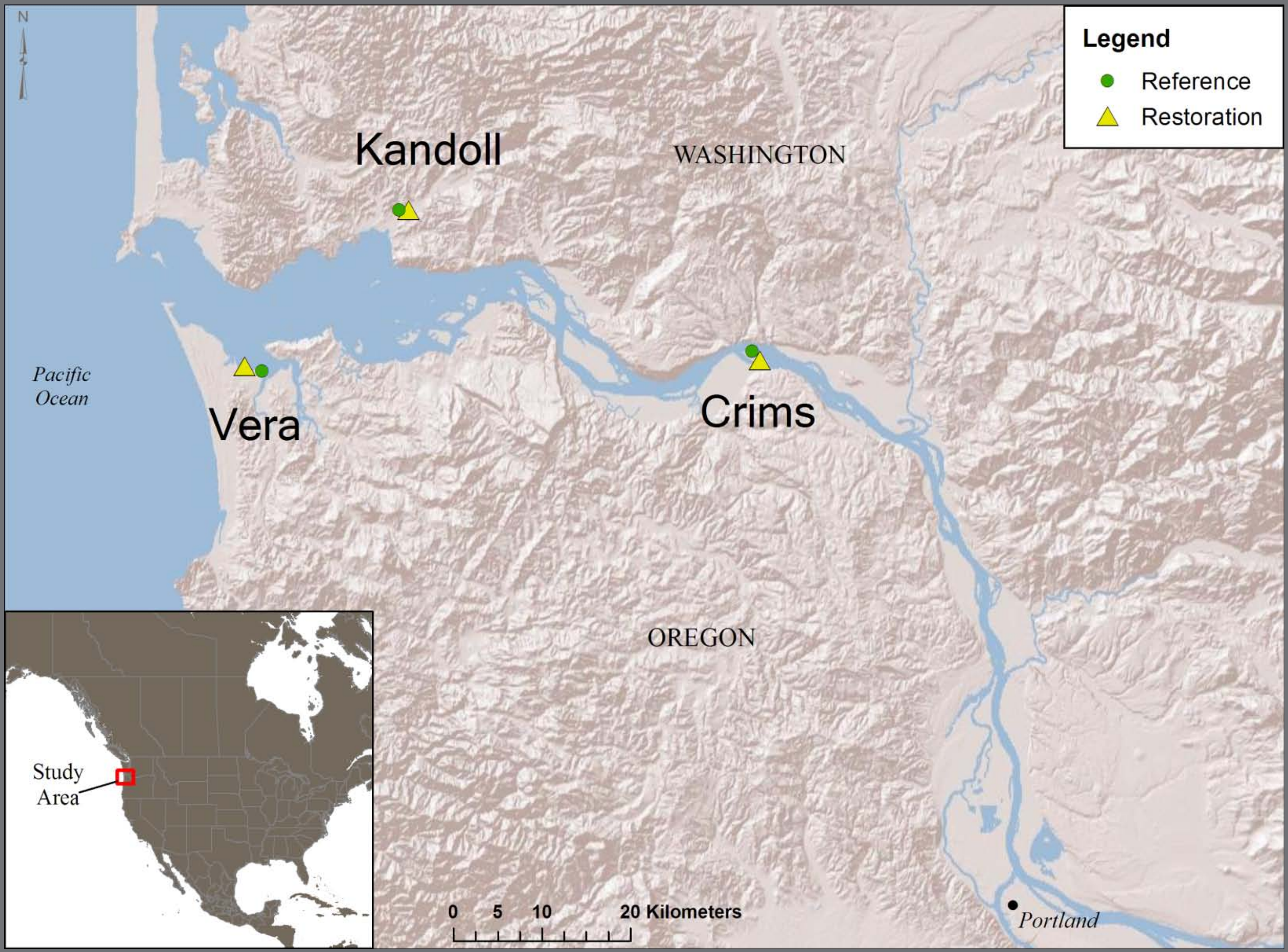
Study Area: Lower Columbia River



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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

Junk et al. 1989; Poff et al. 1997; Bunn & Arthington 2002

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

Characteristics of the Lower Columbia River and Estuary

- **Drowned River Valley**
- **Tidal to Bonneville Dam (Rkm 235)**
- **2nd to Mississippi in Discharge to Ocean**
- **~15-km wide @ Rkm 32, & 3-km at the jetties at the river mouth**
- **<u>Historical</u> 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 with season (Rkm 20-40)**
- **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.**

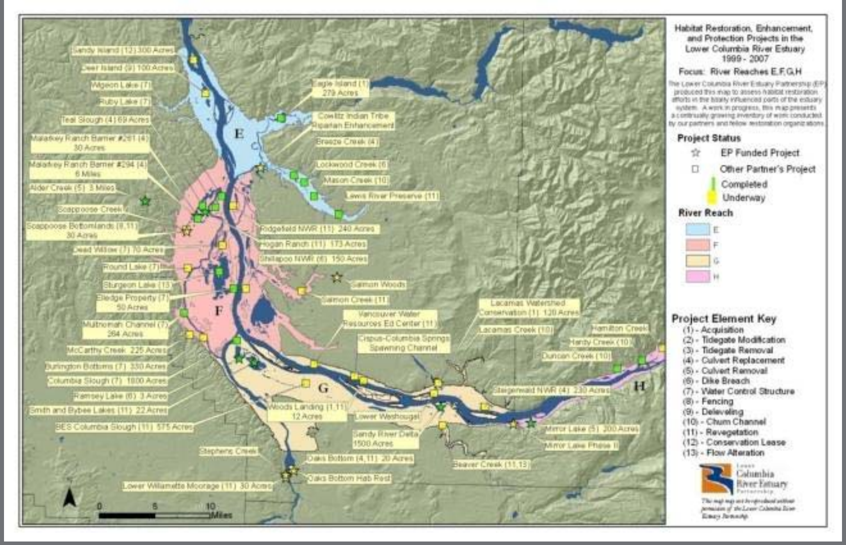
(Kukulka and Jay 2003)

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, 2010): 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

Planned Restoration Projects in the Upriver Portion of the Lower Columbia River and Estuary



Courtesy Lower Columbia River Estuary Partnership

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

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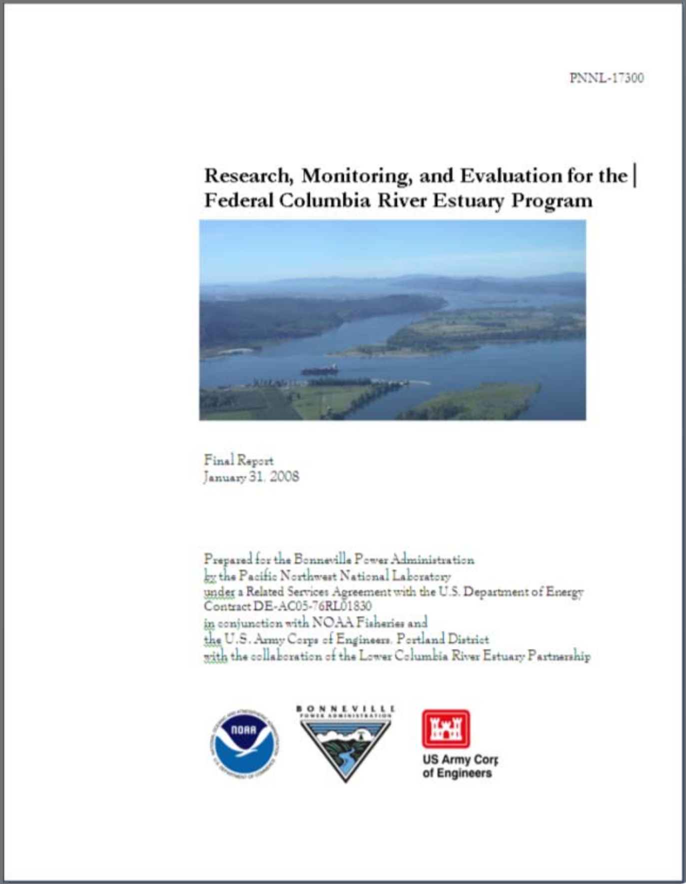
Accountability: Quantitative Reporting of Restoration Outcomes

- 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

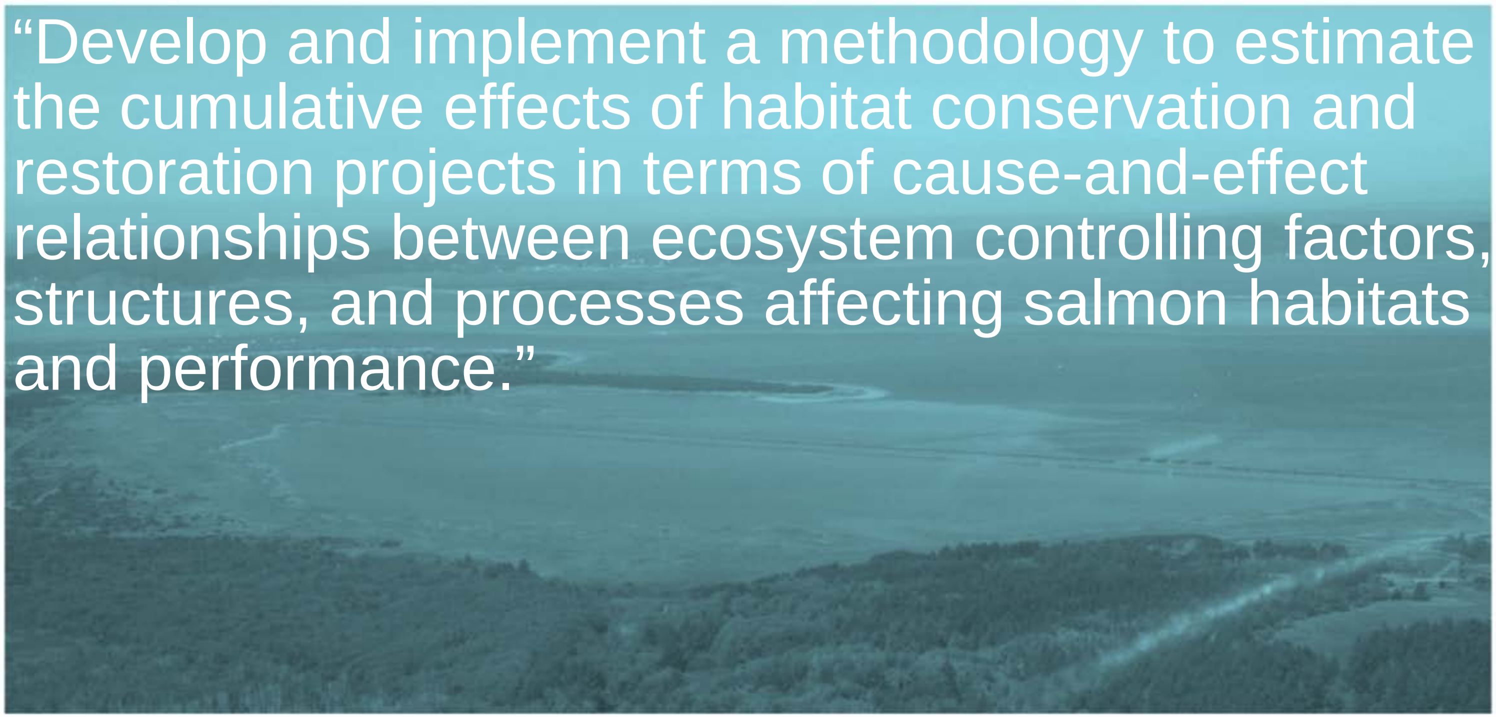
Prepared for the Bonneville Power Administration
by the Pacific Northwest National Laboratory
under a Related Services Agreement with the U.S. Department of Energy
Contract DE-AC05-76RL01830
in conjunction with NOAA Fisheries and
the U.S. Army Corps of Engineers, Portland District
with the collaboration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

Johnson et al. 2008

www.salmonrecovery.gov/researchreportspublications

II. 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"

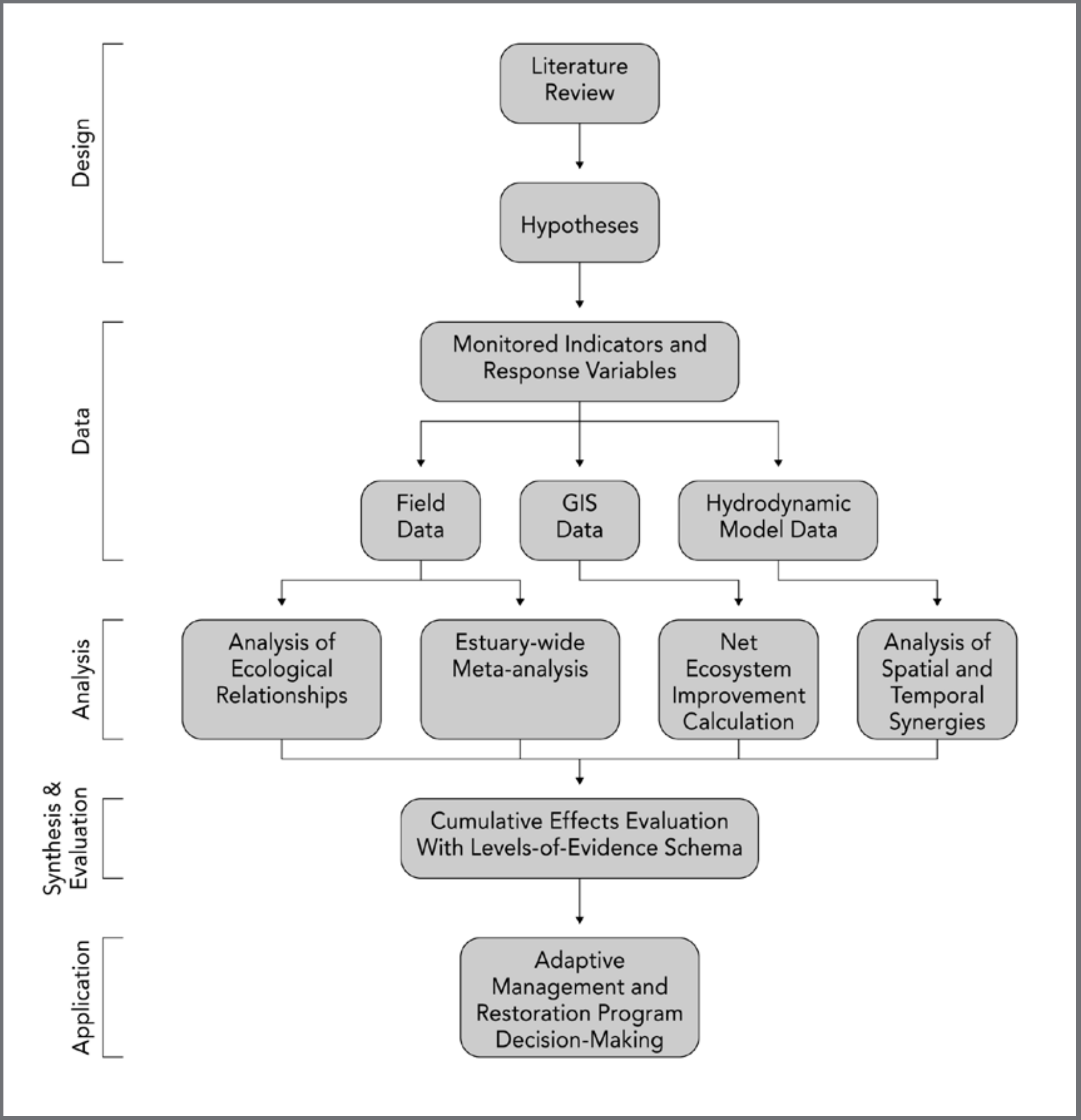
(40 CFR § 1508.7).

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

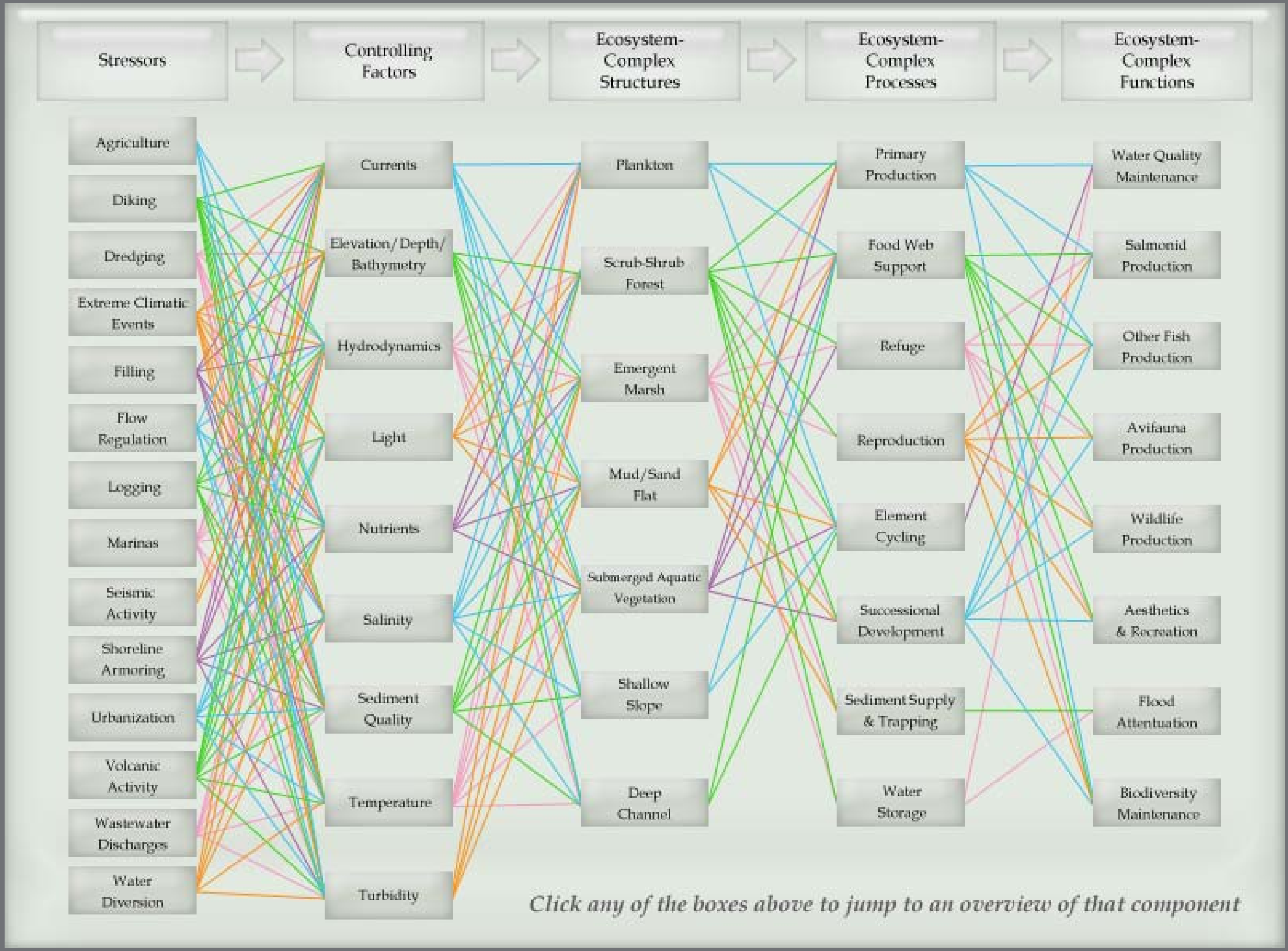
(President's Council on Environmental Quality 1997)

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



Background:
Baird and Burton (2001)
Downes et al. (2002)
This Approach:
Diefenderfer et al. (2011) Ecological Restoration 29:111-132 (see notebook)

Selecting Indicators Corresponding to Restoration Objectives: Ecosystem vs. Salmon Approaches



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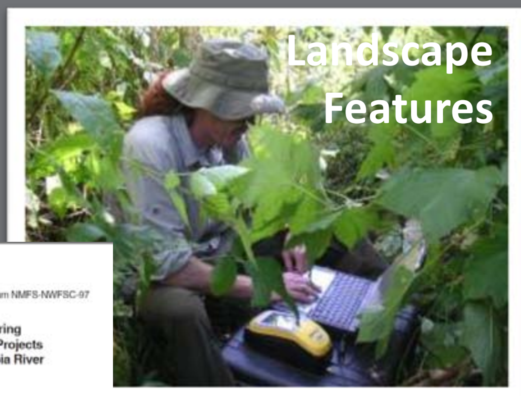
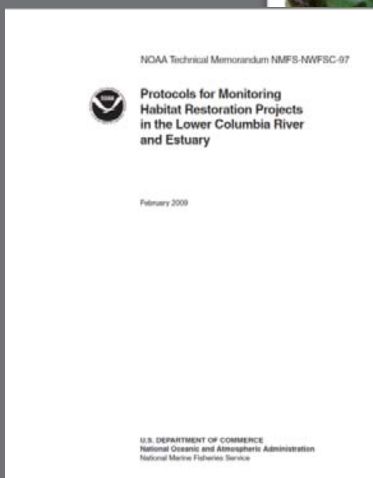
Predict Effects of Typical Restoration Actions

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

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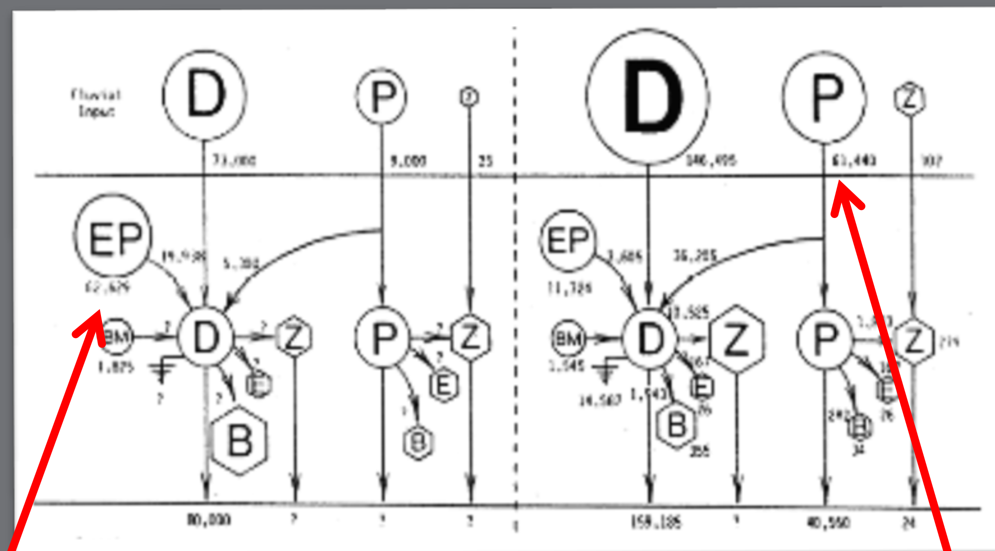
Key Indicators of Cumulative Effects

Pre-1870 Recent



Emergent plant input reduced

Phytoplankton input from reservoirs increased

Macro-detritis and prey, production and export

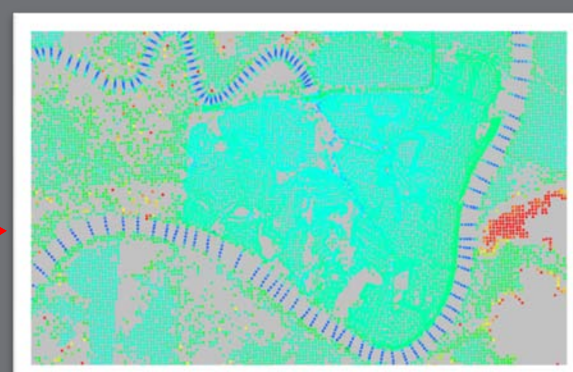
Fundamental Shift in Food Web (Sherwood et al. 1990)

Connected channel edge availability

Nexus of terrestrial and aquatic productivity

Wetted area (inundation)

Merged LiDAR, Cross-Sections, Topographic Survey Data, GIS Modeling



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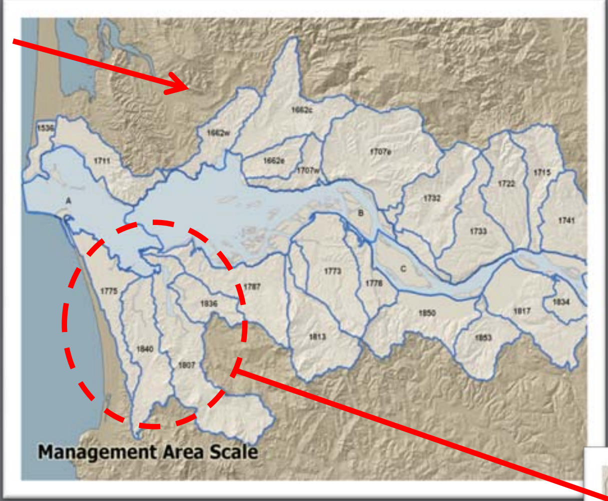
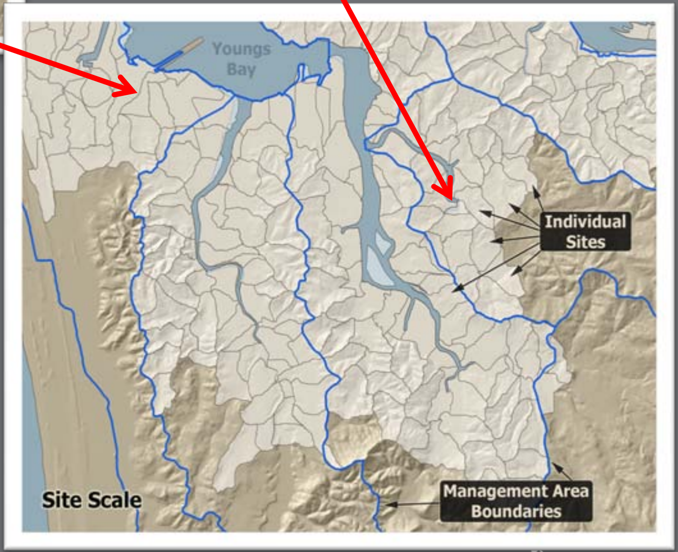
Base Model

<u>Management Units:</u> HUC 6 hydrological units. There are ~60 MUs in the 235-km tidal floodplain.



<u>Site Units:</u> Definable hydrologic divisions. There are ~2,300 SUs in the 235-km tidal floodplain.



Sources of <u>Data</u>:

- ▶ Stressor and Landscape Indicators
- ▶ Site Evaluation Cards

Thom et al. 2005 Rest.Ecol. 13:193-203; Diefenderfer et al. 2009, Env. Man. 44:712-731.

Organizing Model:
Net Ecosystem Improvement (NEI)
(Thom et al. 2005)

Net Ecosystem Improvement:

NEI = f(Δ function • Δ area • probability)

Cumulative Net Ecosystem Improvement:

CNEI = ∑NEI Across Sites

Net Restoration Effect (NRE): Site Scale

NRE is a function of the change in ecological function, the size, and probability of working

$$\text{NRE} = (\Delta\text{function})\ (\text{area})\ (\text{probability})$$

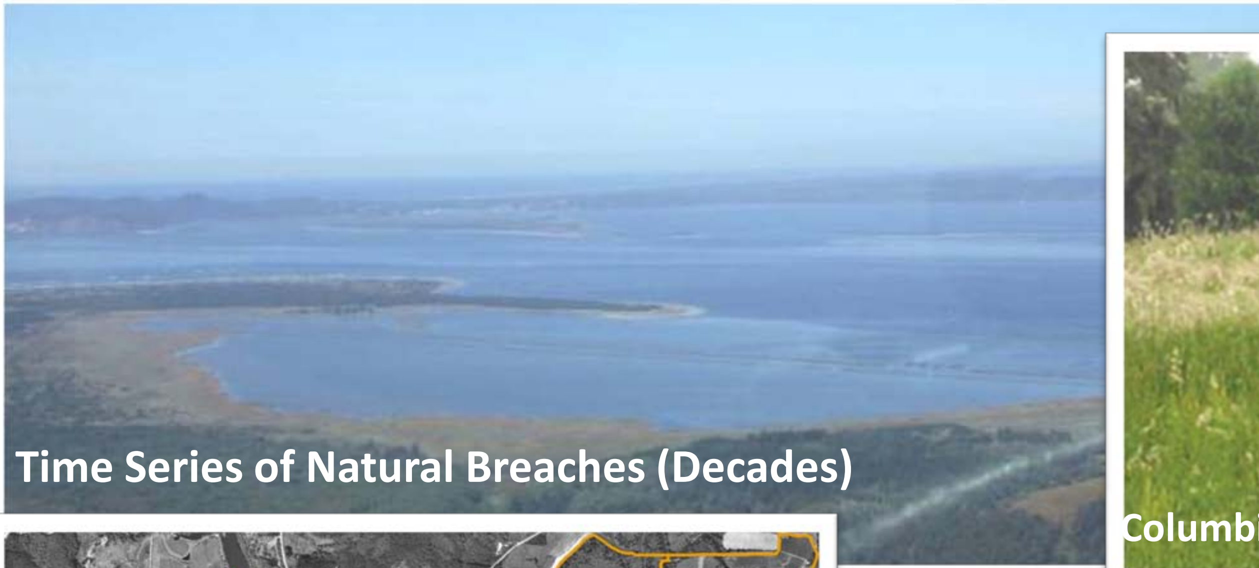
Primary production
Fish opportunity
Fish capacity
Organic matter export
Biodiversity

Habitat size
Wetted area
Channel area
Channel edge
Tidal prism

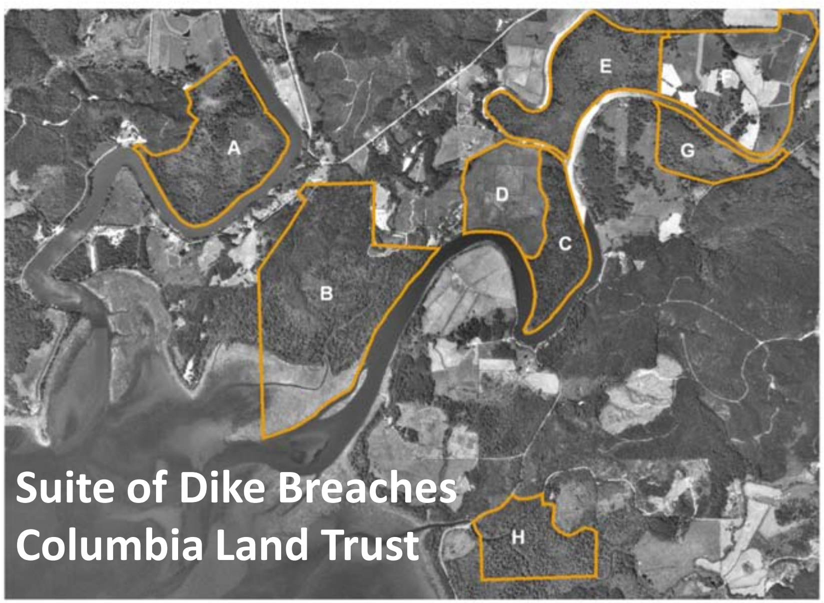
Level of disturbance
Strategy employed
Stochastic events
Past results in system

CE research results, literature, on-going research of others provides these data

Project Spatial and Temporal Sequencing


Time Series of Natural Breaches (Decades)


Columbia White-Tailed Deer, USFWS



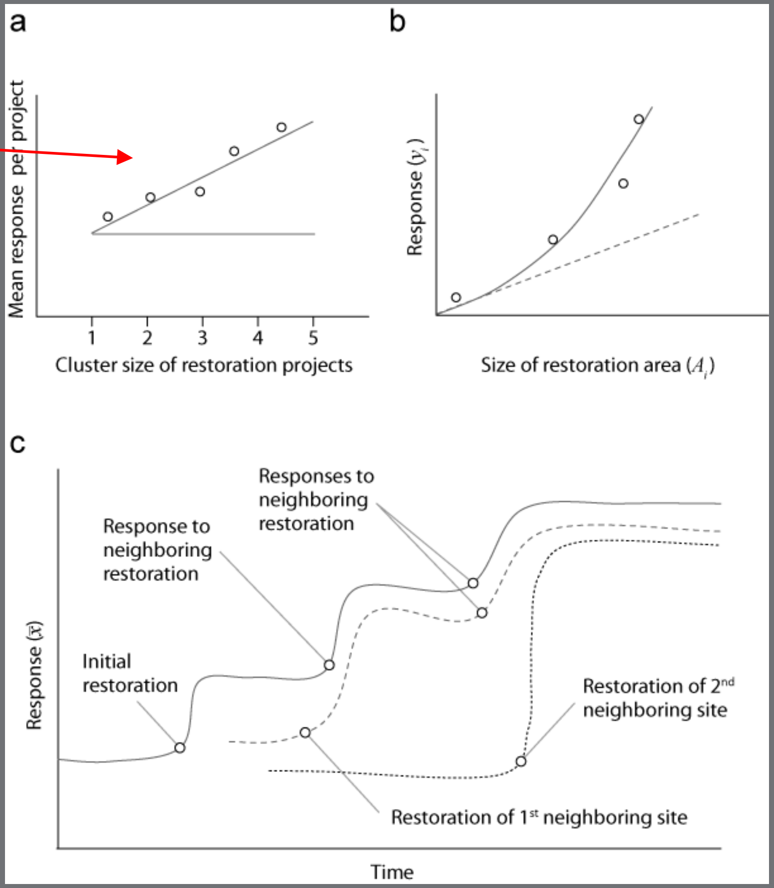
Suite of Dike Breaches
Columbia Land Trust

Suite of Tide Gates Julia Butler Hansen NWR

Cumulative Effects Statistical Tests

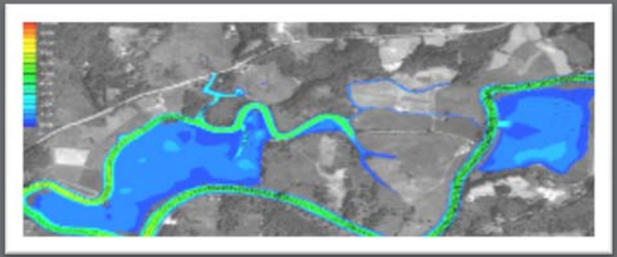
-Hypothetical responses to space crowding (project cluster size), project size, and restoration of neighboring sites.

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

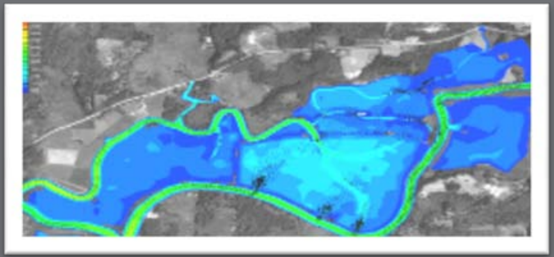


Diefenderfer et al. 2011

Pre Construction



Post Construction



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Paired Site Study Design

Habitat Types:

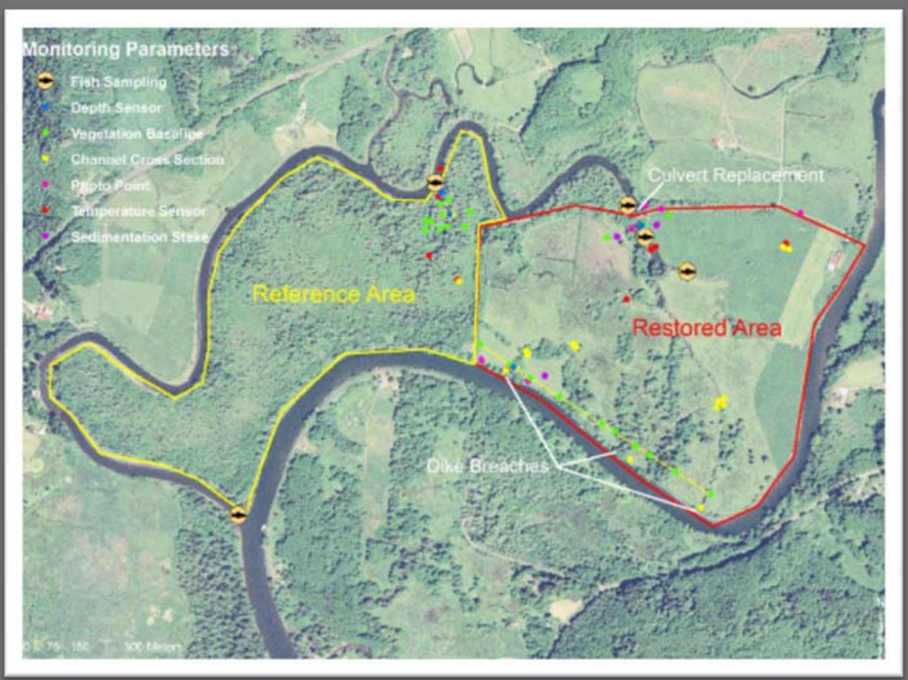
Tidal Swamp vs. Marsh

Trajectory:

Restoration vs. Reference

Restoration/Enhancement Action:

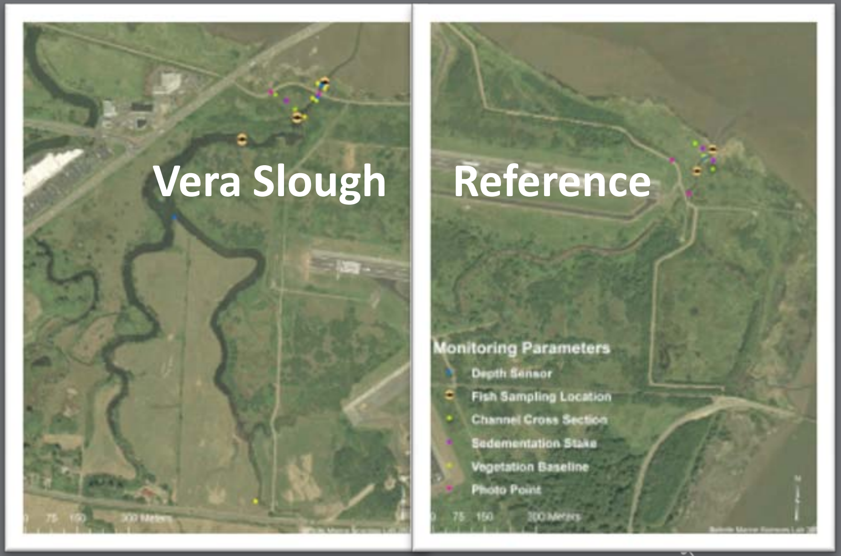
Tide Gate vs. Culvert vs. Breach



Kandoll Farm and Reference

Timeline and Indicators:

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



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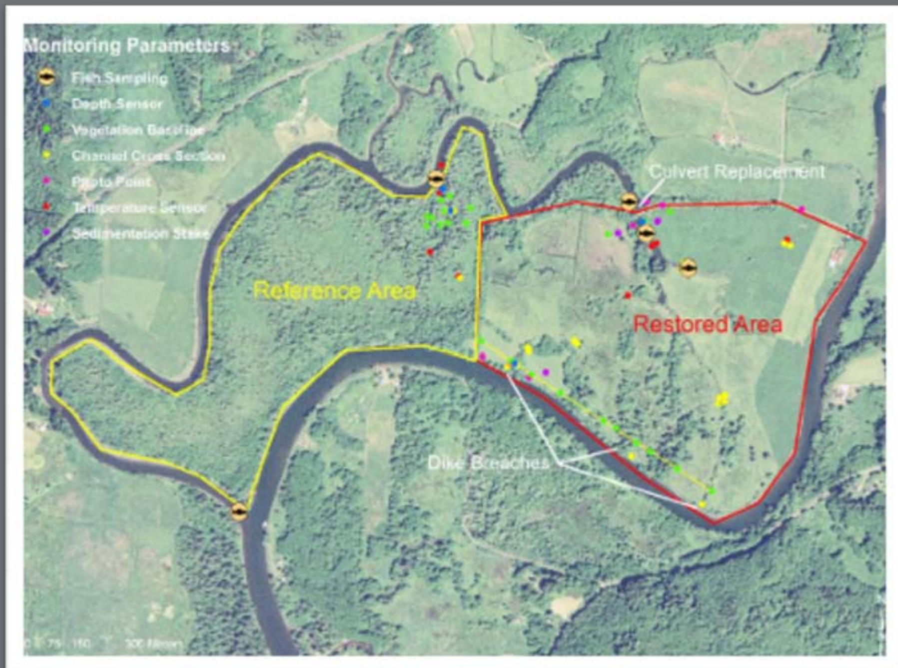
Developing Predictive Ecological Relationships

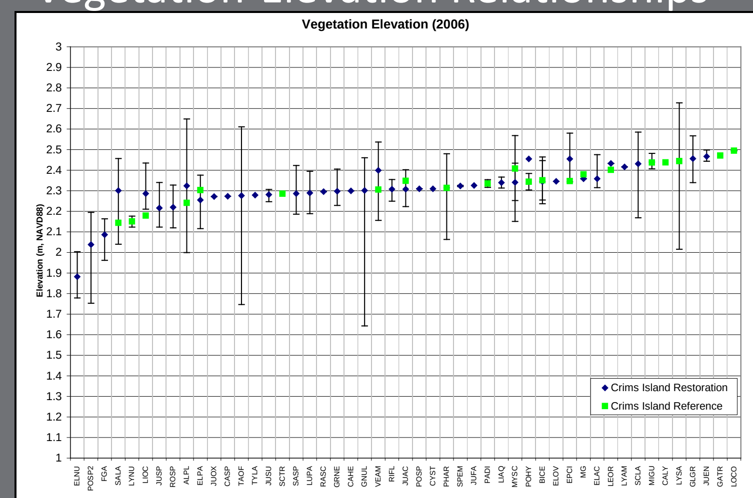


Paired Reference/Restoration

Similarity Index: Plant Cover

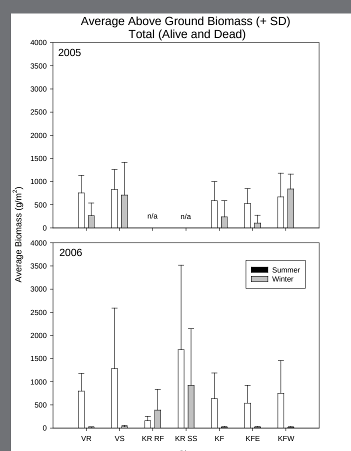
	SSE 2005	SSW 2005	SSE 2006	SSW 2006	KR
SSE 2005		72.6	92.8	-	23.4
SSW 2005			-	94.0	30.6
SSE 2006				86.3	23.4
SSW 2006					53.2
	VS 2005	VR 2005	VS 2006	VR 2006	
VS 2005		24.5	94.1	-	
VR 2005			-	98.2	
VS 2006				13.1	

Vegetation-Elevation Relationships



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

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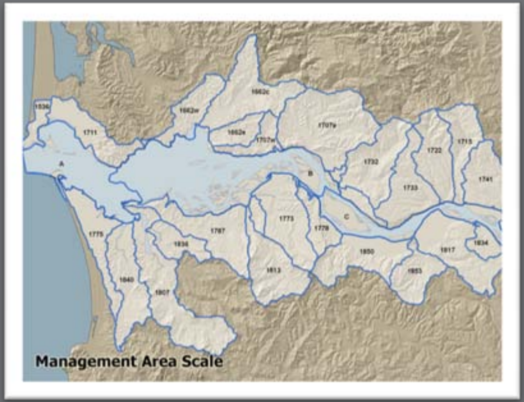
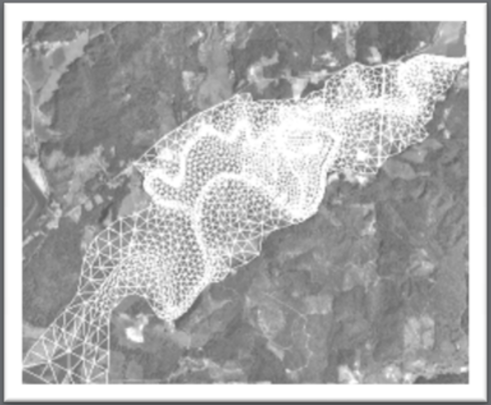
Summary: Levels of Evidence Approach

Base Model



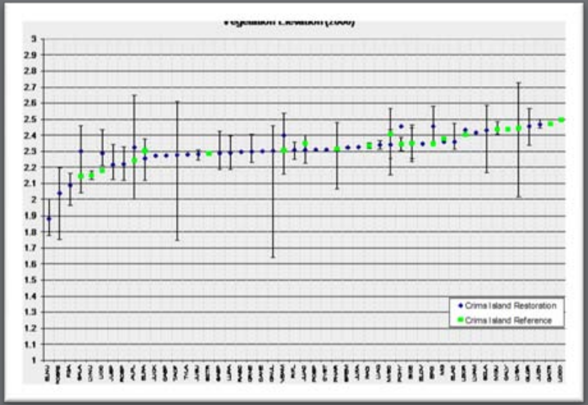
Base GIS Model/Adaptive Management Framework

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)
Diefenderfer et al. (2011)

III. Multi-Scale Analyses: Restoration & Reference Sites

Problem Statement: *How do we restore a historically understudied ecosystem under a changed hydrologic regime?*

Use multi-scale ecological research at paired restoration and reference sites to identify:

- Controlling factors on the system;
- Ecosystem structure and function;
- Achievable restoration targets;
- Appropriate monitoring indicators.

History

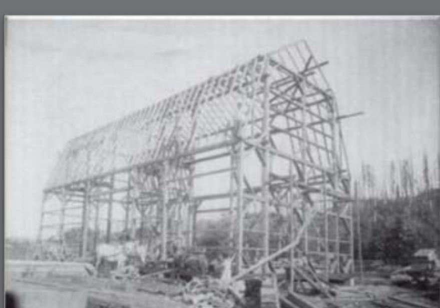
(Or, “Why was this ecosystem understudied in the first place?”)

77% of LCRE spruce wetlands lost
(Thomas 1983); or *>90% (Christy & Putera 1992)*

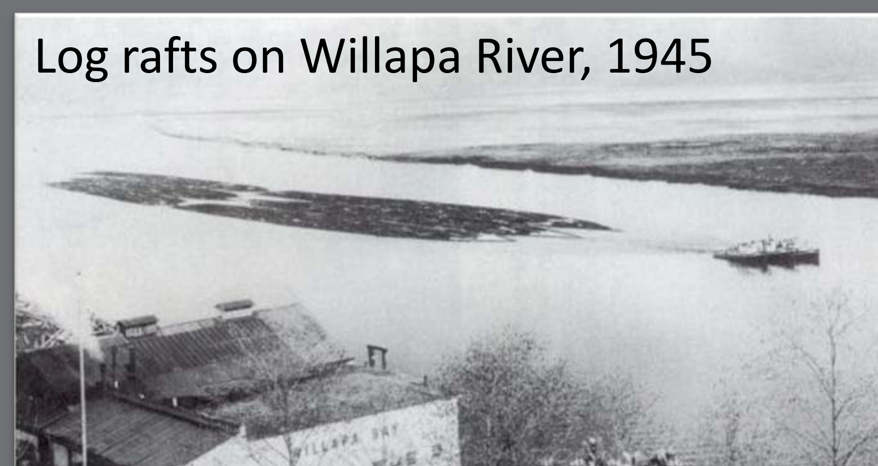
Steam locomotive hauling logs to Chehalis R. for Grays Harbor mills, 1916.

Soldier-loggers sent to the PNW for Sitka spruce during WWI, 1917-18.

Mill and farm on opposite sides of North Fork Willapa R., 1904-05.



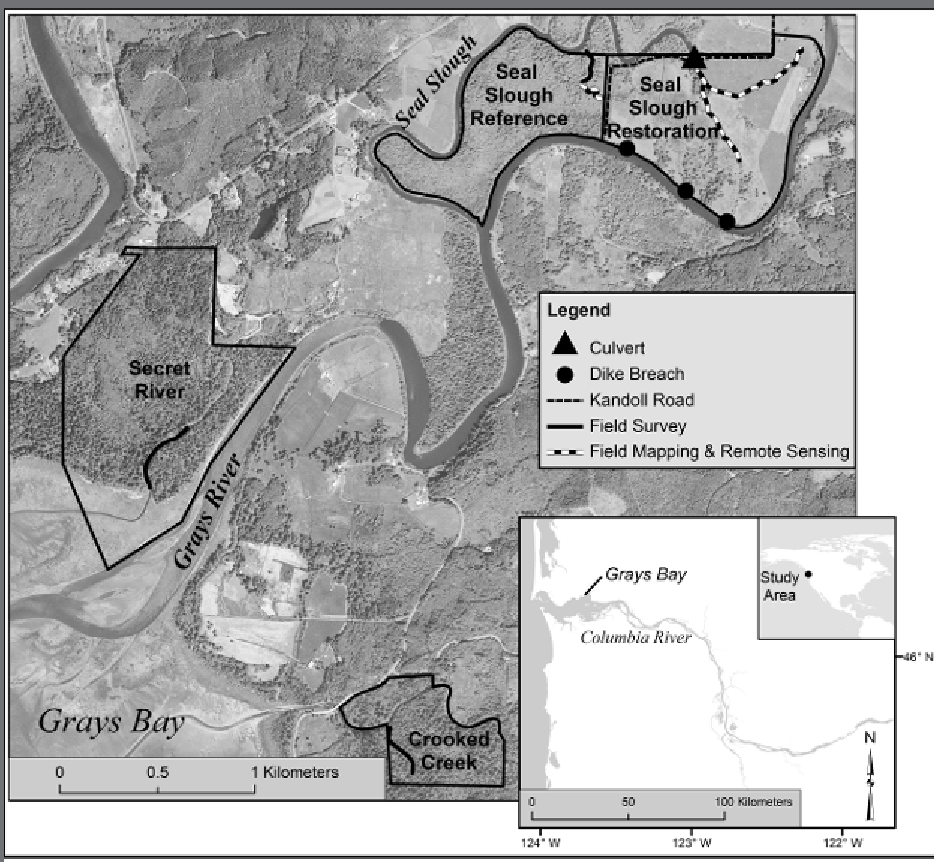
Framing a barn, 1907.

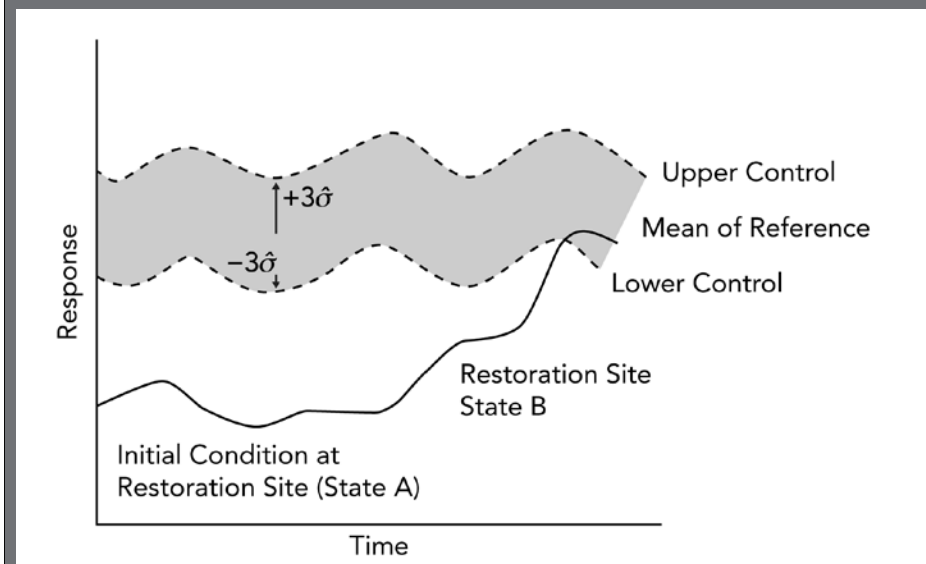


Log rafts on Willapa River, 1945

Grays R. Swamp and Restoration Survey Areas

Purpose: To use reference sites to identify controlling factors on channel networks, and ecosystem structure and function, in *Picea sitchensis* tidal freshwater swamps; thereby, to clarify restoration targets.





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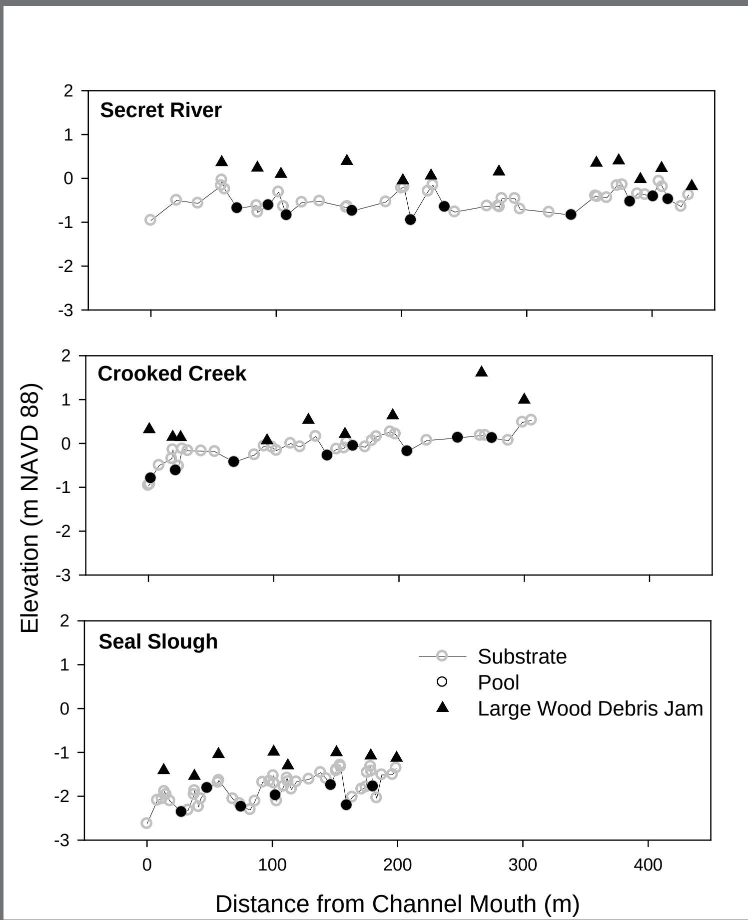
Reach Scale Pool Spacing: Hypothesis & Methods

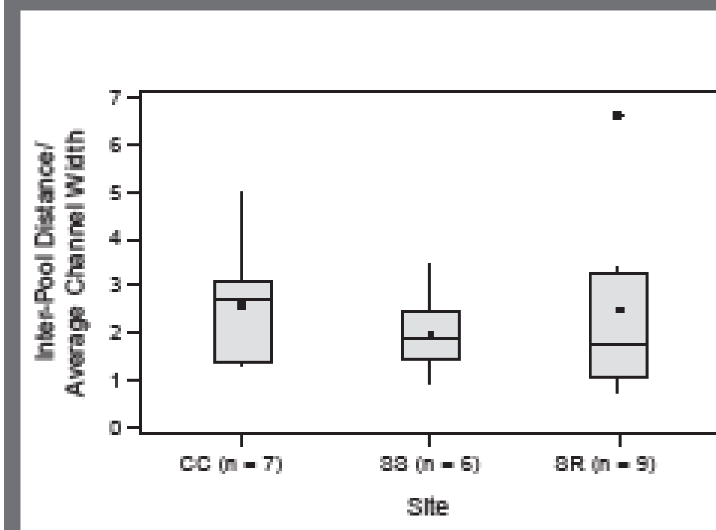
Development of *P. sitchensis* freshwater tidal forested wetland channels incorporates large woody debris to form a low-gradient step-pool system

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. Restoration Ecology 17:158-168.

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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)

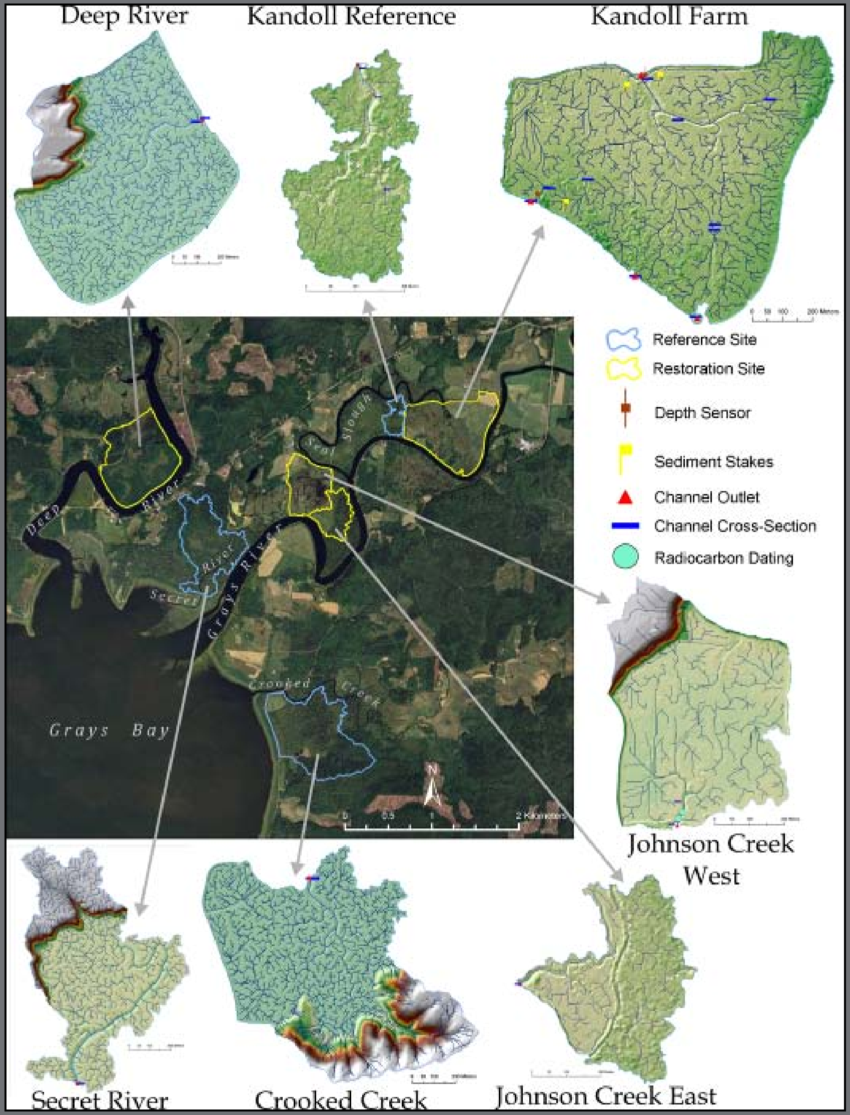
3) Surrogates for Q in salt marshes: tidal prism, catchment area, and total length of tidal channels (Steel and Pye 1997; Williams *et al.* 2002)

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

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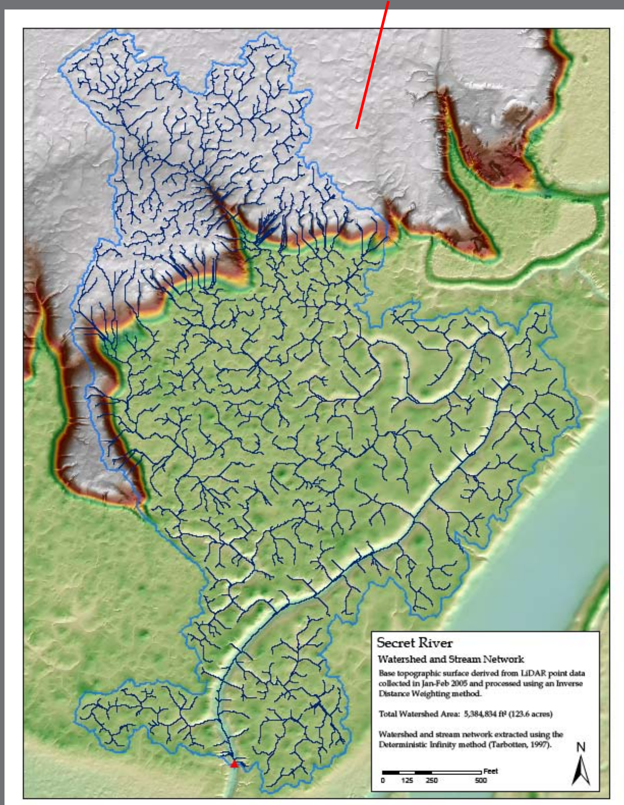
Hydraulic Geometry Methods

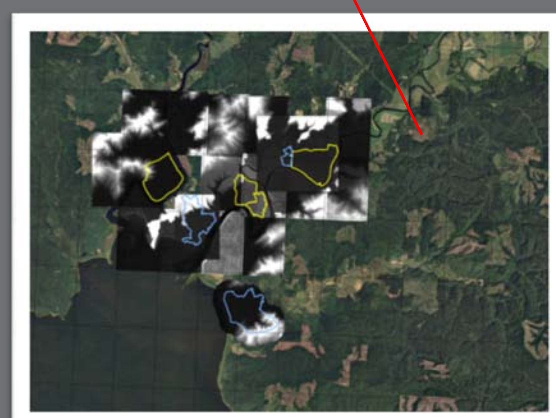
Surveys of channel cross-sectional areas at outlet and up-channel

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) & Riley et al. (1999))

+ Ground-Truth



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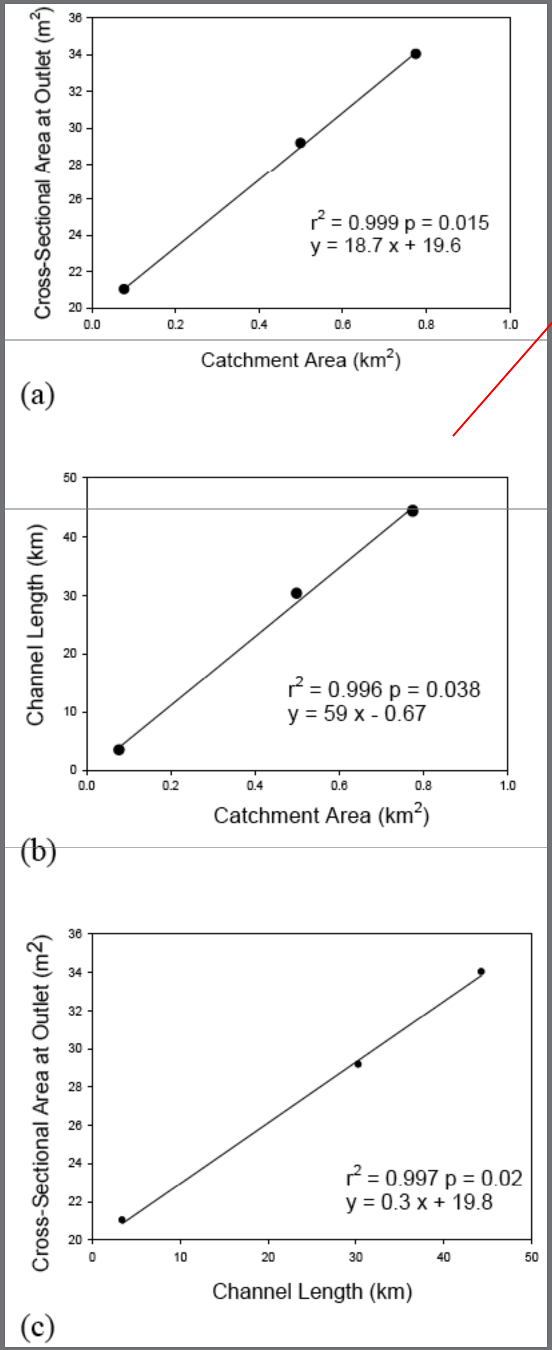
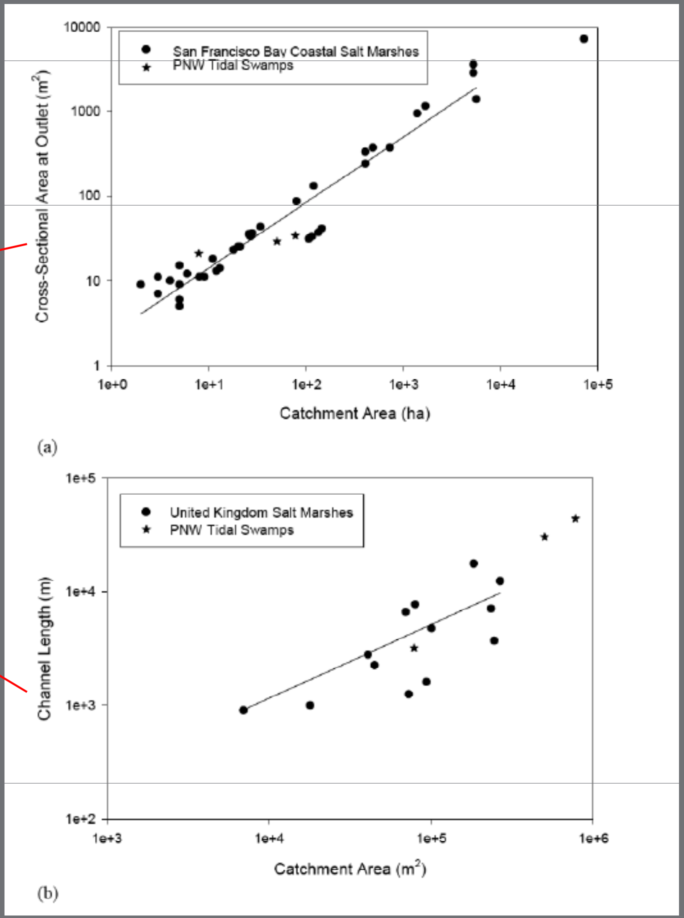
Hydraulic Geometry Results



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. *Ecohydrology and Hydrobiology* 8.

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Restoration Sites Research Questions

How do Reference Sites Compare to Restoration Sites, Before and After Restoration Actions are Implemented? •Pool Spacing •Land Elevation •Microtopography •Plant Species •Salmon Prey Production •Sediment Accretion

Does Large Wood Force Pools? Does Hydraulic Geometry Trend Toward Swamp Reference Sites? Are Sediment Accretion Rates Changed by Hydrologic Disconnection (Diking) and Reconnection (Breaching)?

Restoration Sites Results I: Topographic Evolution

1) Pre-Restoration

2) After Dike Breach

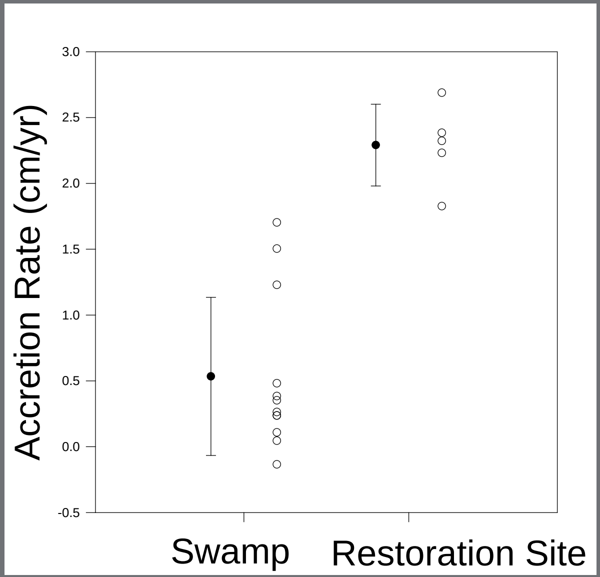
Goal: Sitka Spruce Swamp

2005-2009 Accretion Rate (cm/yr):

12 Swamp Sites: Mean 0.53, s.d. 0.60, Range -0.13-1.70

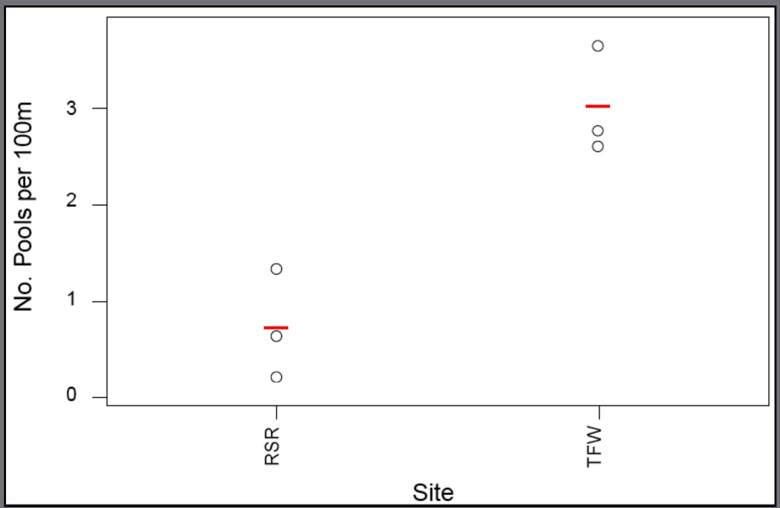
5 Swamp Restoration Sites:

Mean 2.29, s.d. 0.31, Range 1.83-2.69



<u>Swamps accrete slowly, and restoration sites quickly (high sediment loads), but restoration sites have a long way to go to catch up!</u>

Restoration Sites Results II: Pool Spacing and Large Wood



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

Buried and Fallen Wood Recruitment

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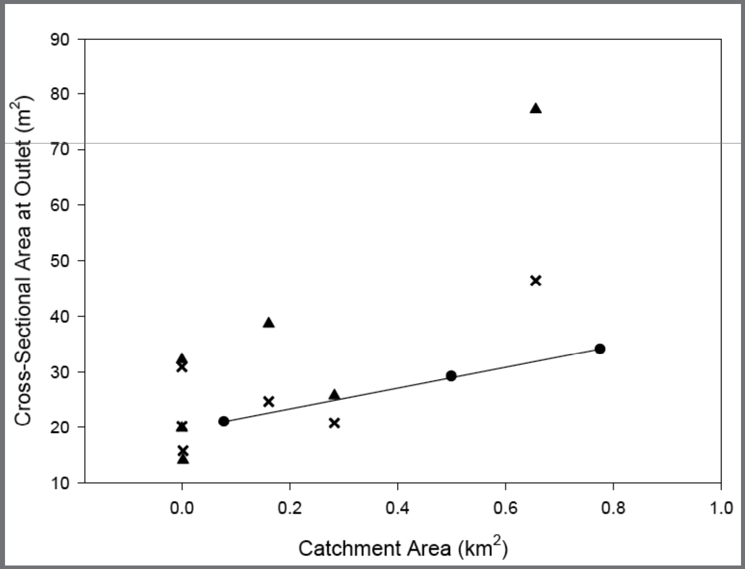
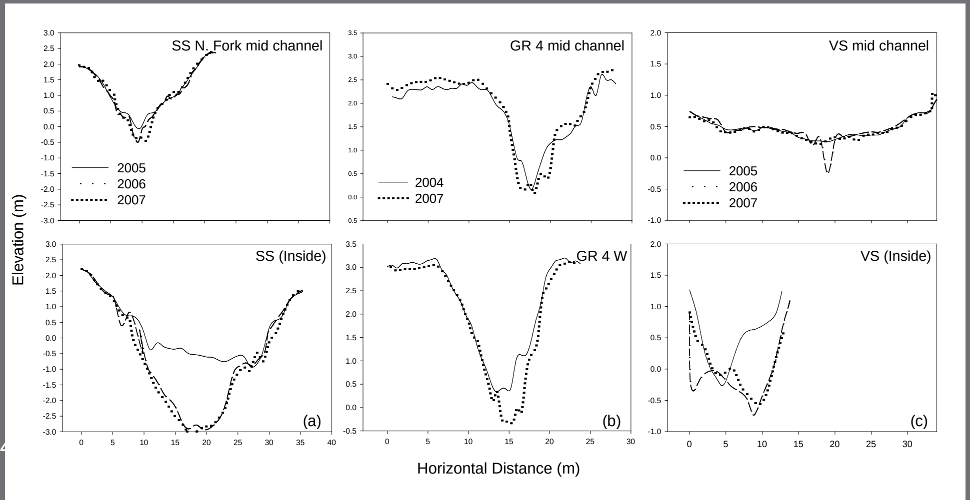
Restoration Sites Results III: Observed Channel Outlet Changes

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

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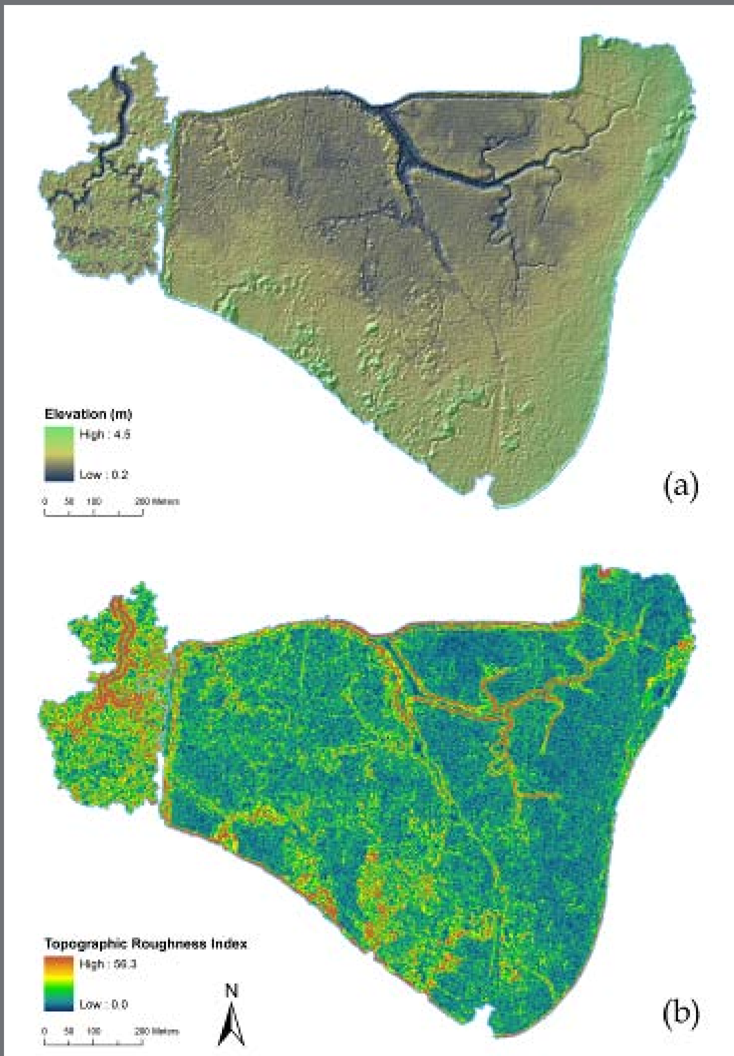
Results IV: Microtopography: Subsidence, Compaction, & Grading of Forested Wetlands

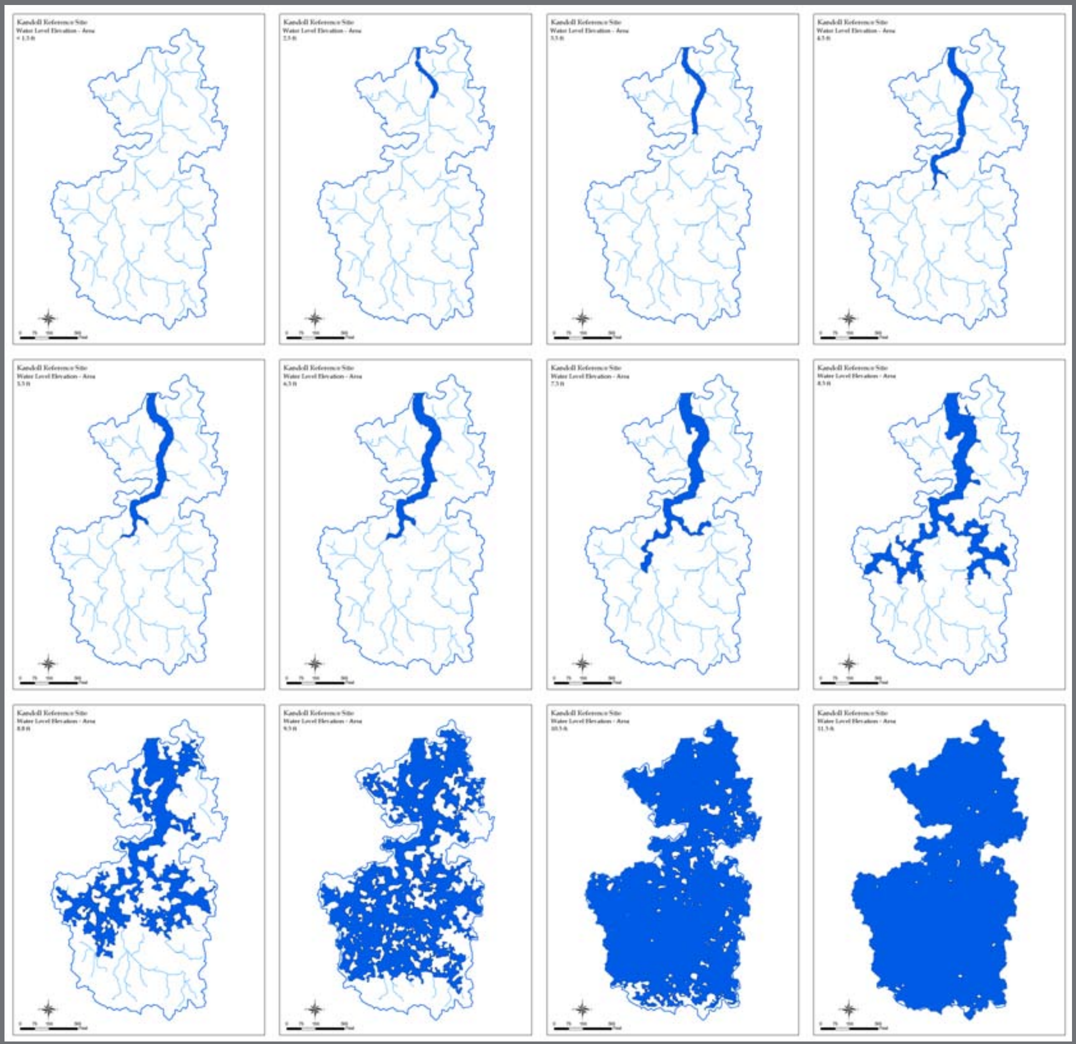


- Mean elevation of Seal Slough restoration site (prior to hydrologic reconnection) = 2.2 m
- Mean elevation of adjacent Seal Slough swamp reference site = 2.9 m
- Mean roughness index of the restoration site = 1.40; of the swamp reference = 2.63

<u>Role of large wood in producing a hummocky swamp microtopgraphy and substrate for tree reproduction.</u>

Diefenderfer, HL, AM Coleman, AB Borde, and IA Sinks. 2008. *Ecohydrology and Hydrobiology* 8:339-361.

Results V: Swamp Area-Time Inundation Index or “Wetted Area Model”

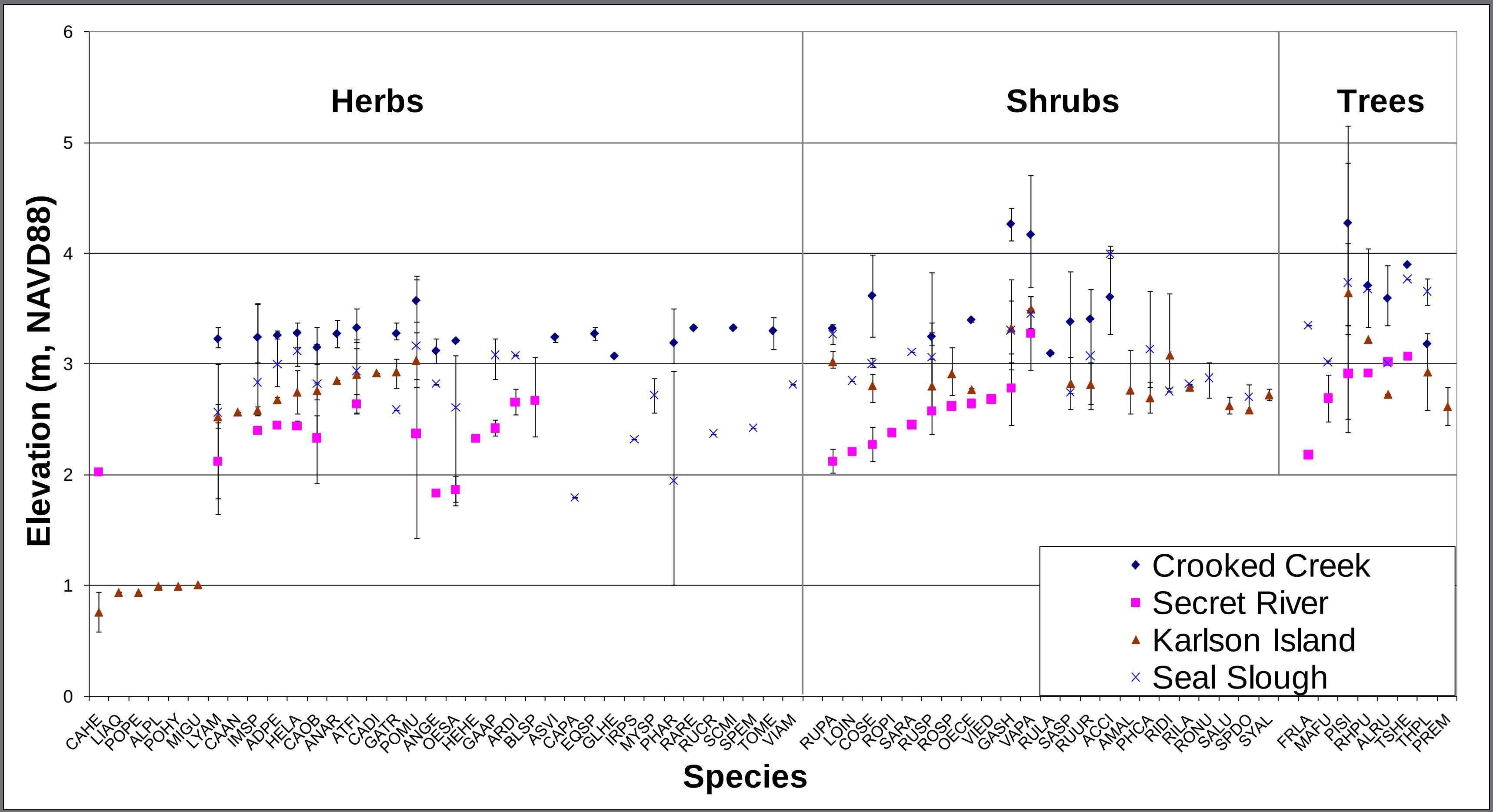


- The area-time inundation index was 34% at Kandoll Farm (a restoring site) in contrast to 9% at adjacent Seal Slough Swamp.
- Frequency of floodplain inundation at Kandoll Farm was 54% compared with 18% at Seal Slough Swamp.

<u>Methods</u>: GIS-based topographic analysis of LiDAR using Deterministic Infinity model (Tarboton 1997) integrated with hourly time-step pressure data.

Diefenderfer et al. 2008. Ecohydrology and Hydrobiology 8:339-361

Restoration Sites Results VI: Plant Species-Elevation Relationships



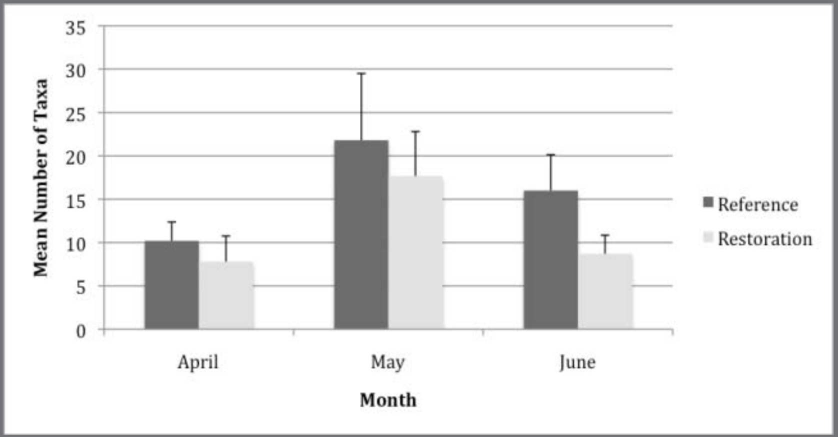
Sitka Spruce Swamp Species Richness: Herbs = 42, Shrubs = 22, Trees = 9. Methods: RTK-GPS, and vegetation surveys (Roegner et al. 2009).

Restoration Sites Results VII Juvenile Salmon Prey Resources

(April-June, monthly)

Insect fallout traps: 58 Insect Taxa in Insect Fallout Traps & ½ of these present in juvenile salmon diets- suggests consumption of prey produced in the swamp system.

Benthos of both restoring site and swamp: dense nematodes and oligocheates, and some chironomid and ceratopogonidae fly larvae.



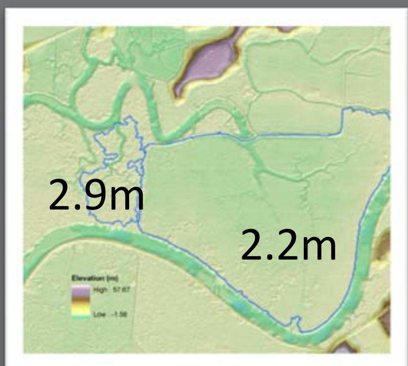
Insect fallout traps: 11 taxa occurred in >50% of samples (six are families of dipteran flies and three are families of collembolans):

Chironomidae adult	1.00
Isotomidae adult	0.93
Sminthuridae adult	0.93
Acari adult	0.87
Araneae adult	0.67
Ceratopogonidae adult	0.60
Dolichopodidae adult	0.60
Entomobryidae adult	0.60
Ephydridae adult	0.60
Hypogastruridae adult	0.60
Tipulidae adult	0.60

Small neuston samples: Forty-six taxa including several insect families, crustaceans, molluscs and nematode and oligochaete worms (most numerous taxa were cladocerans and copepods, both planktonic organisms)

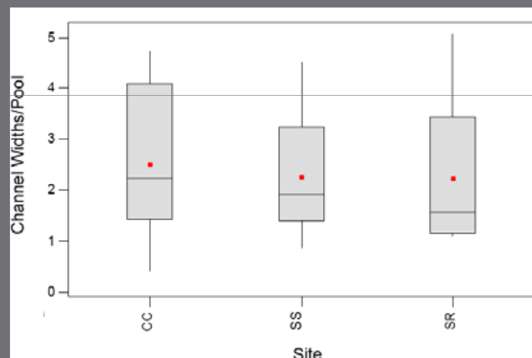
Summary: Clarifying Restoration Targets with Reference Site Ecological Data

Site Scale



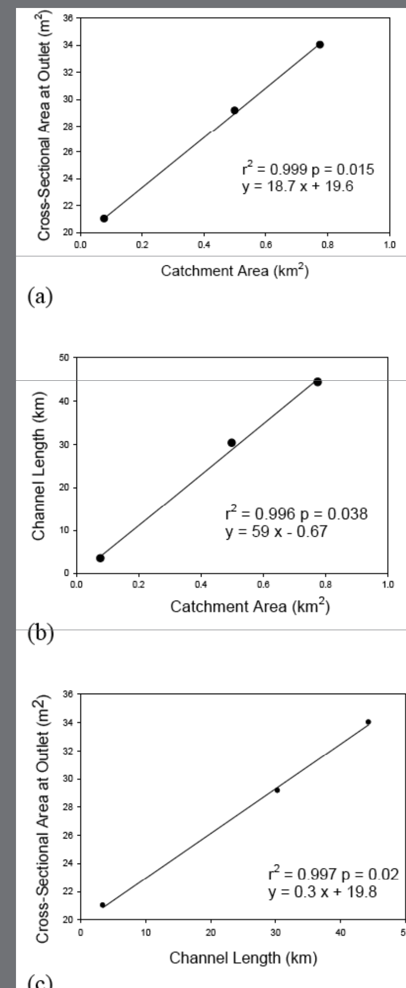
Mean Elevation[2]

Reach Scale



Spruce Swamp Pool Spacing[1]
2.3 Channel Widths/Pool

Catchment Scale



Spruce Swamp Hydraulic Geometry[2]

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

[2] Diefenderfer, Coleman, Borde, & Sinks. 2008. *Ecohydrology and Hydrobiology* 8.

Implications for Hydrological Reconnection Restoration Planning:

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

Implications for Hydrologic Reconnection Restoration Monitoring: Indicator Selection

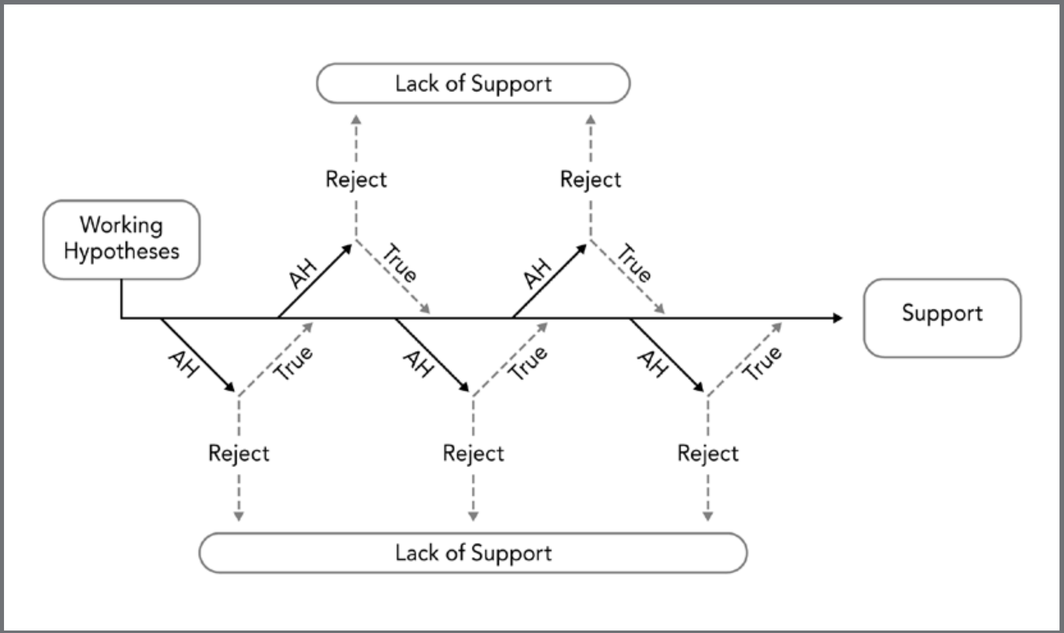
- Prior land use (subsidence and compaction) shapes restoration trajectory of channels and plant community; therefore sediment budget & sediment accretion rates are important indicators; with “fossilization,” channel density may not be.
- Inundated area likely to change (e.g. to decrease for 20-54 years),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

IV. Cumulative Ecosystem Effect: Selected 2005-2009 Research Results

- Hypotheses & Key Management Questions
- Salmonid Prey & Food Web: Marsh Macro-detritis Export
- Hydrologic Regime Change: Tide Gate vs. Dike Breach
- Topographic Change: Sediment Accretion
- Biotic Change: Vegetation and Salmon
- Restoration Project Planning: Effects of Multiple Dike Breaches
- Summary

See: Johnson et al. 2011. "Evaluation of Cumulative Ecosystem Response to Restoration Projects in the Lower Columbia River and Estuary."
PNNL Report 20296 to the Army Corps of Engineers, Portland District.
http://www.nwp.usace.army.mil/environment/home.asp
(Select "Lower Columbia River and Estuary")

Potential Cumulative Effects on *Ecosystem Processes & Functions*



- Decrease in fragmentation
- Increase connectivity
- Increase habitat opportunity/capacity for juvenile salmon

- Return of marsh macro-detritus to the system
- Enhance flood attenuation, sediment trapping, nutrient processing capacity

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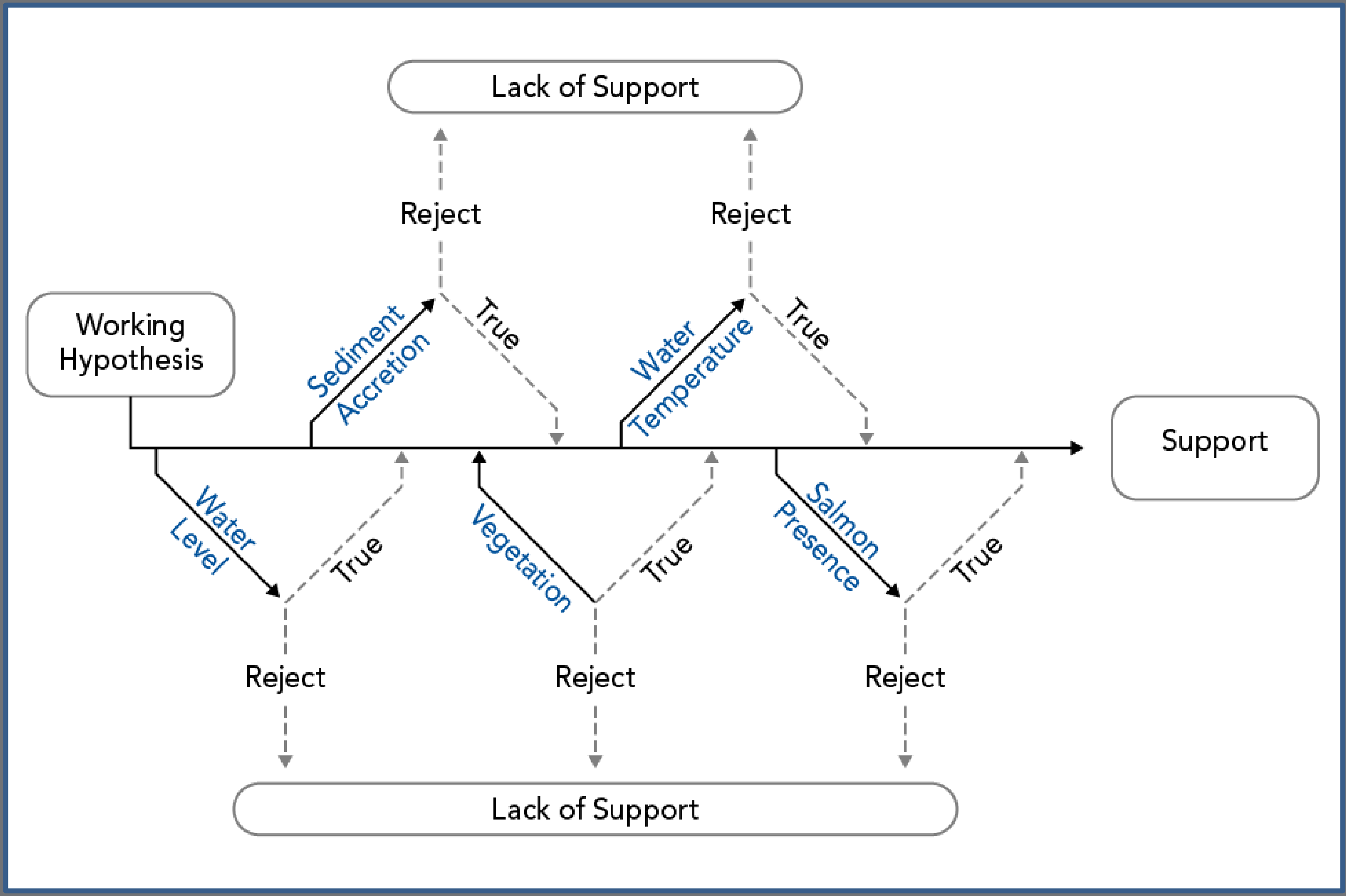
Working and Ancillary Hypotheses

- **Working H_1** = Habitat restoration activities in the estuary will have a cumulative beneficial effect on salmon
- **Landscape-scale H_1** = …will produce an increasing number of hectares and connectivity of floodplain wetlands trending toward historical levels prior to land conversion…
- **Ancillary H_1** = Monitored indicators will trend toward reference conditions
  - Hydrology – area time inundation index
  - Water quality – temperature
  - Topography/bathymetry – land elevation, sedimentation rate
  - Vegetation – percent cover by species
  - Fish – presence, abundance, res. time, diet, growth rate, fitness
  - Exchange – plant biomass, TOC, nutrients, chlorophyll, macro-invertebrates

Core Indicators from Protocols Viewed as Testable Ancillary Hypotheses



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Measurement, Assessment & Adaptive Management of the Restoration Trajectory

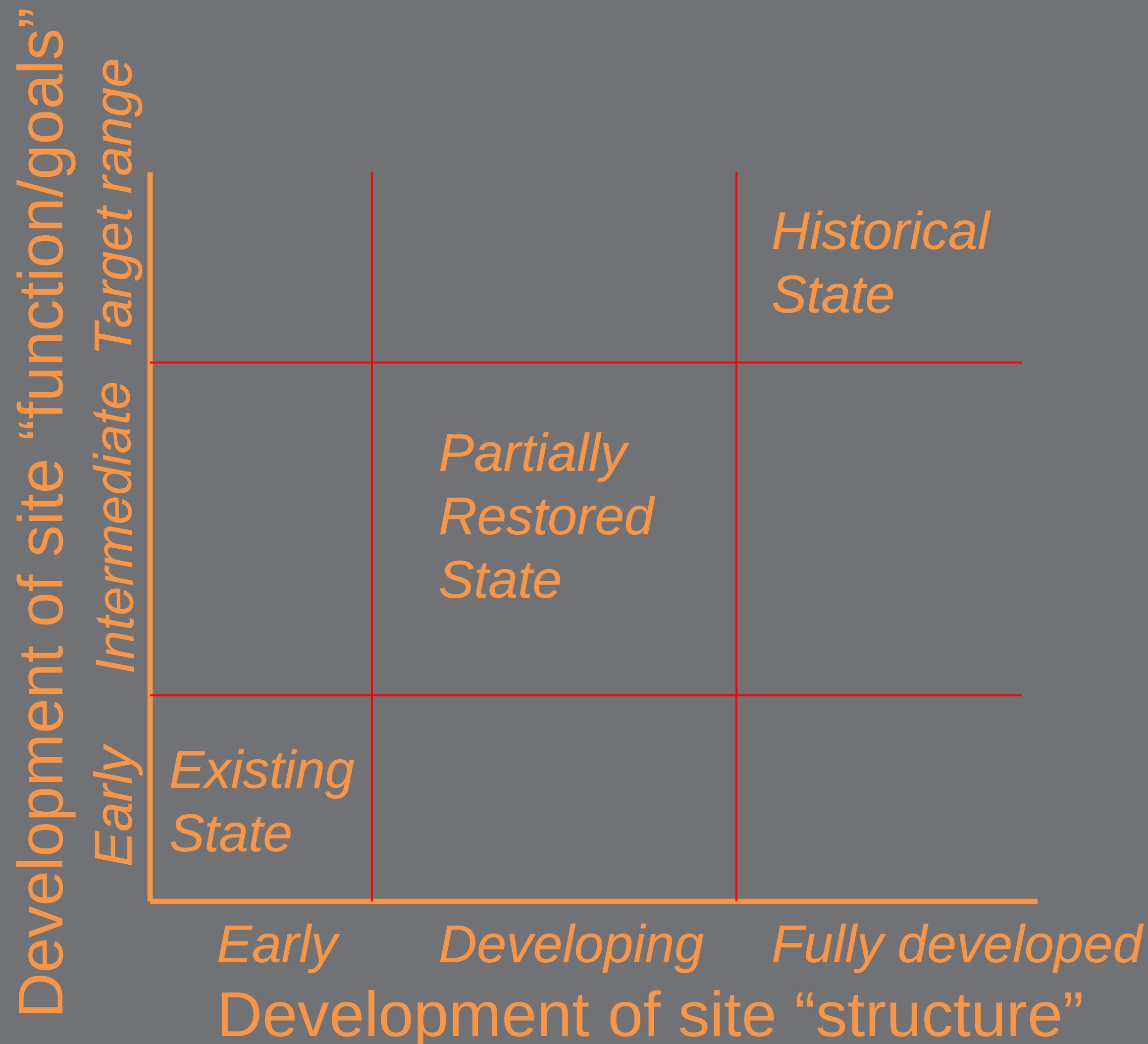
Causal Criteria:

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

Levels of Evidence:

Correlative data used to make the case for causal inference and against alternative hypotheses.

The Restoration Trajectory



(Thom 1997 Environ. Engineering 8:219-232; adapted from Bradshaw 1987)

Marsh Macro-detritis: Organic Matter Export

- Loss of marsh macrodetritus could have dampened the life history diversity in the CRE (Bottom et al. 2005)
- Vascular plant detritus and hatchery food are the dominant sources of OM to subyearling Chinook (Maier and Simenstad 2009)
- CE Findings –
  - 96 ha (237 acres) of restoring sites in Grays River could be exporting 391 metric tons (dry wt) (~431 tons) of marsh macro-detritus each year;
  - The macro-detritus drift contains insects;
  - Inference is that the restored wetland in contributing OM and salmon prey;
  - Sampling indicates source and sink functions depend on hydrology;
  - Major pulsed events force major export of OM into estuary.

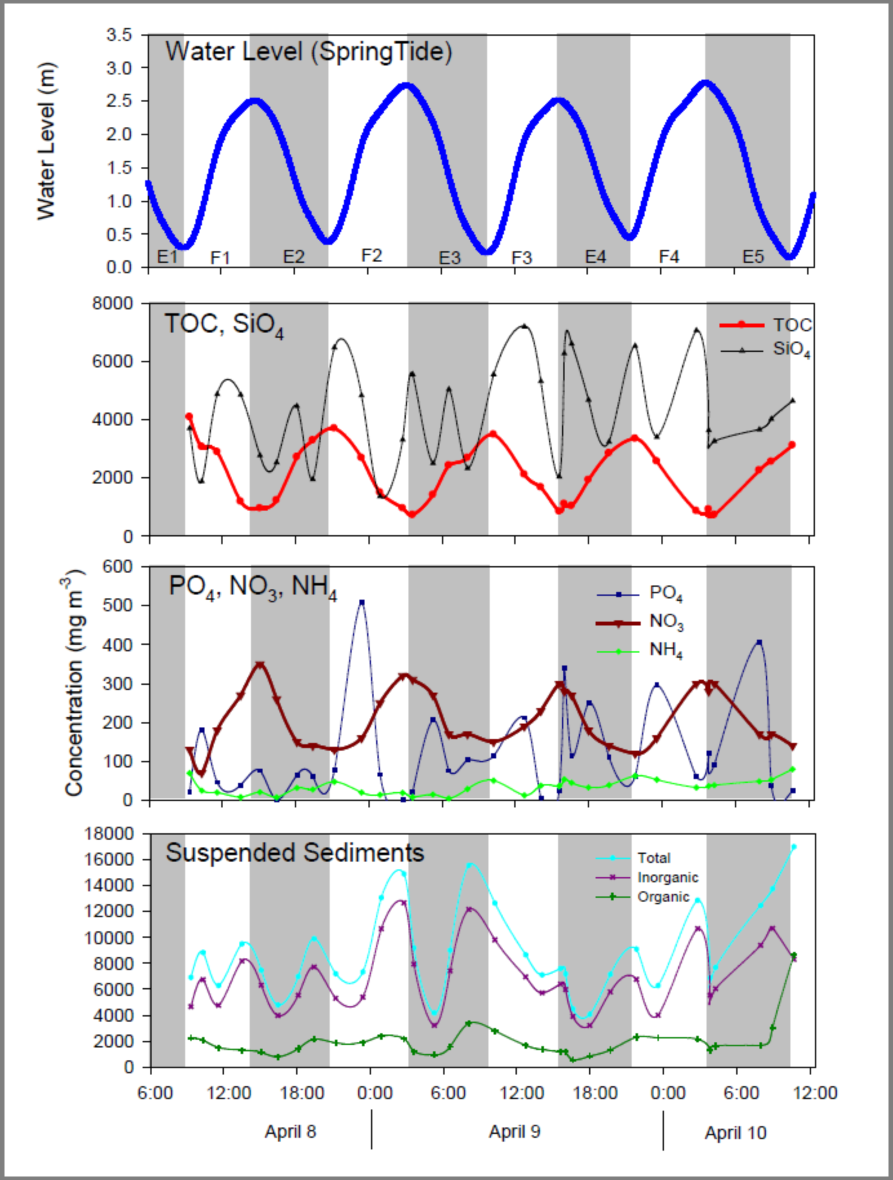
Ratio-based Estimators

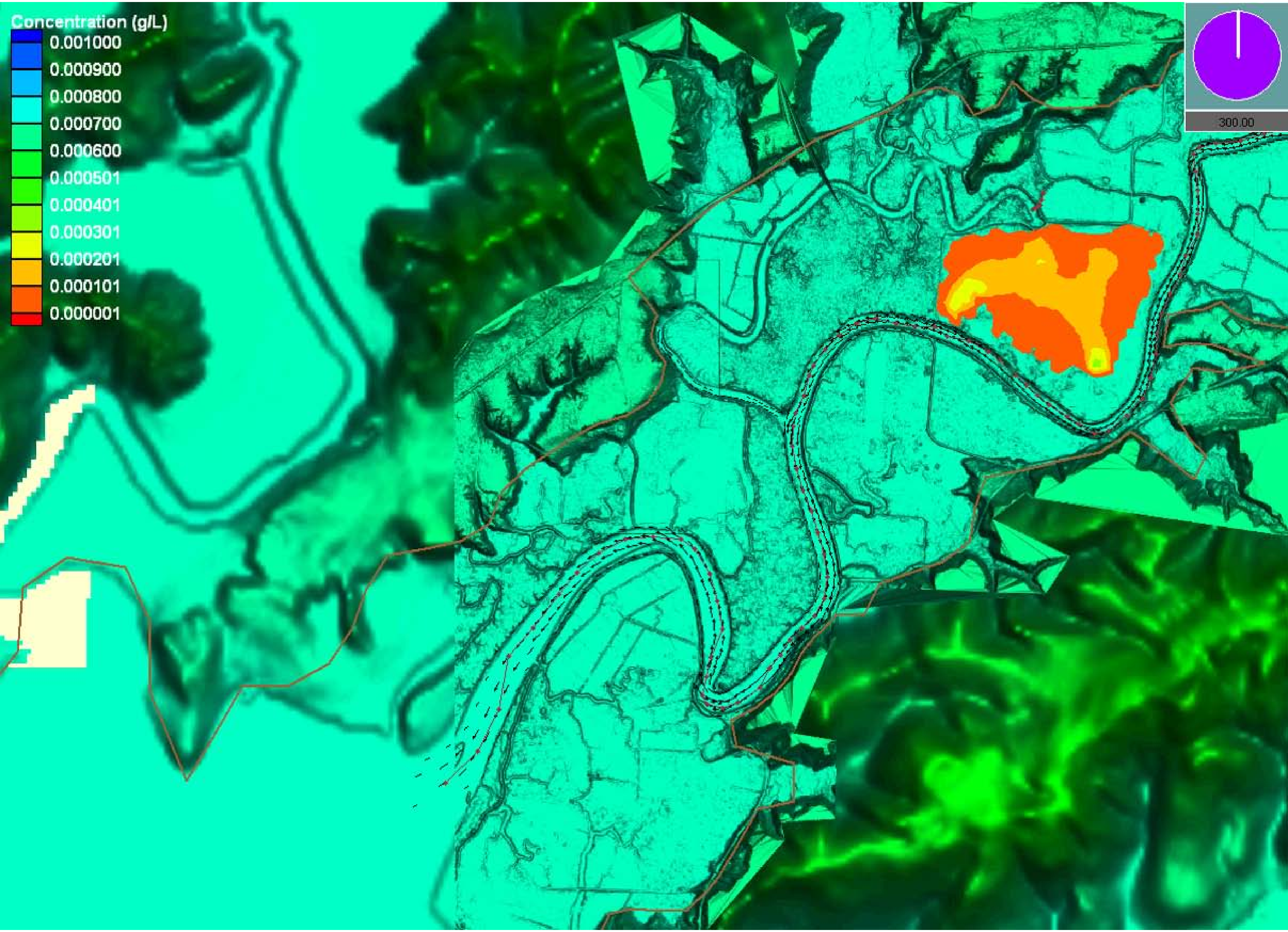
Proportion of mass =
0.969 – 0.062 (distance, km) ($n = 3$; r^2=0.87)

This suggests that POM exported from tidal wetlands between the mouth and about 15.5 km upstream would reach Grays Bay.

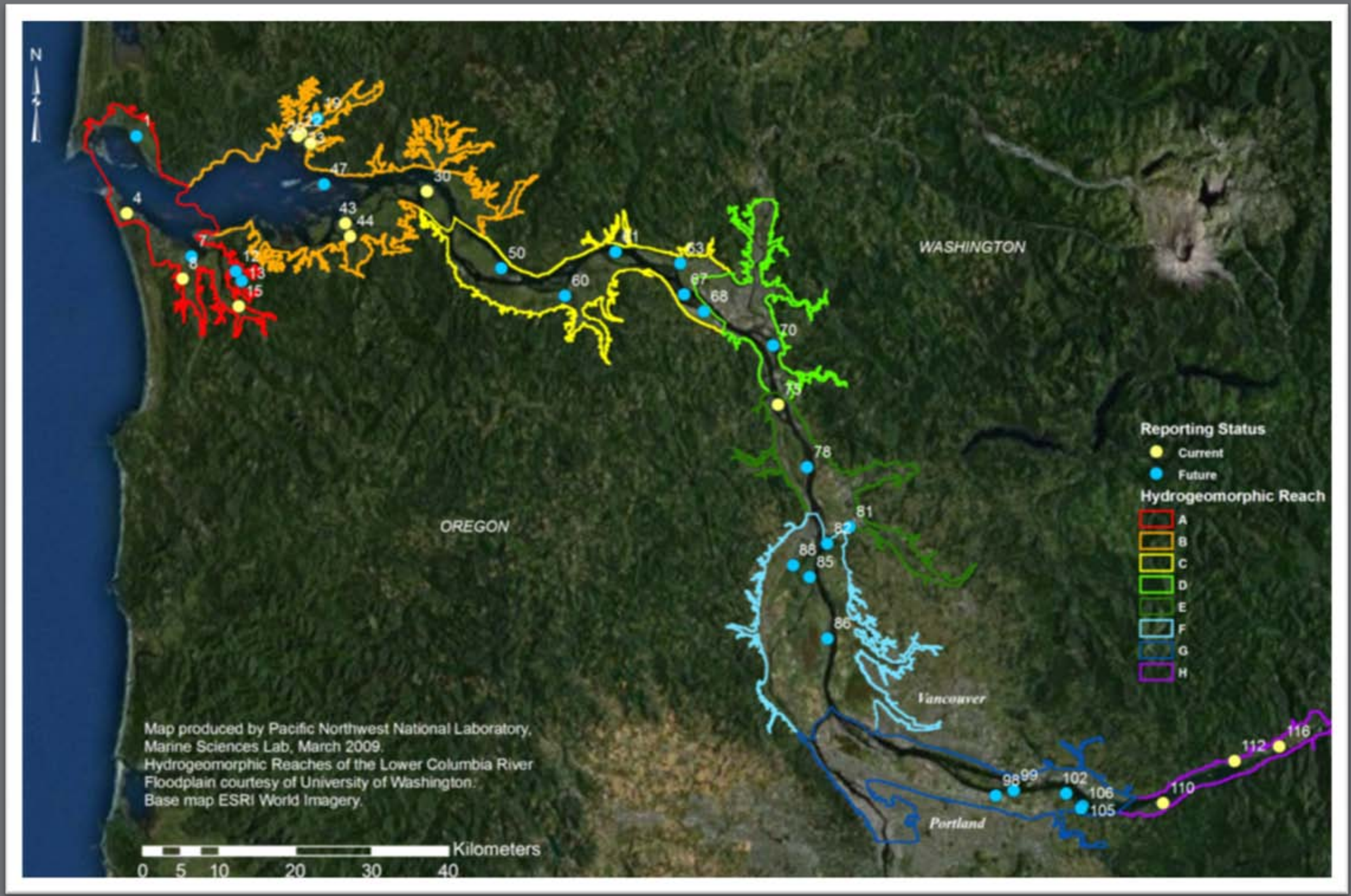
Water Properties and Flux

- Water Level
- TOC, SiO_4
- PO_4, NO_3, NH_4
- Suspended Sediments




Concentration (g/L)
0.001000
0.000900
0.000800
0.000700
0.000600
0.000501
0.000401
0.000301
0.000201
0.000101
0.000001
300.00

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



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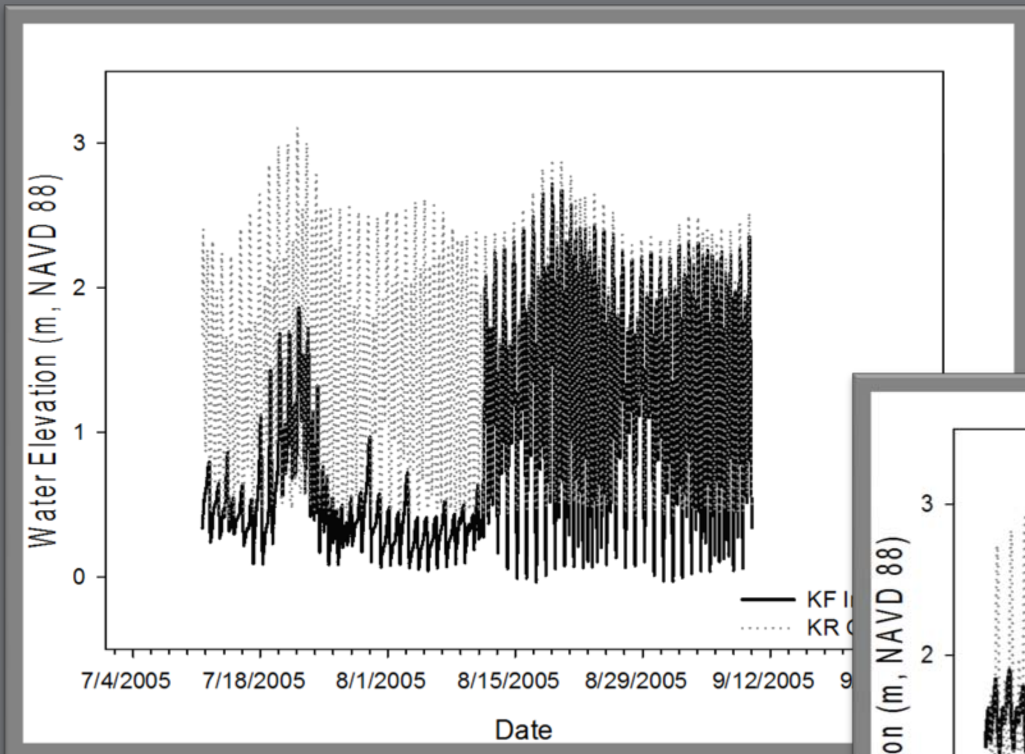
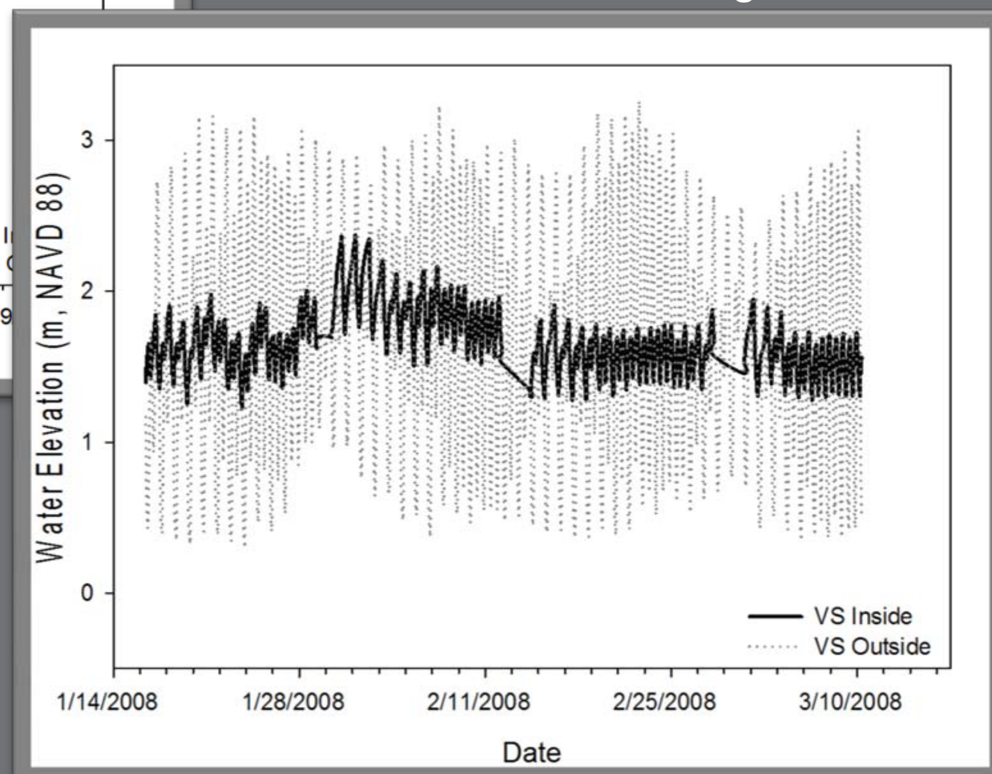
Hydrologic Regime Change: Tidal-Fluvial Signals at Restoration and Reference Sites



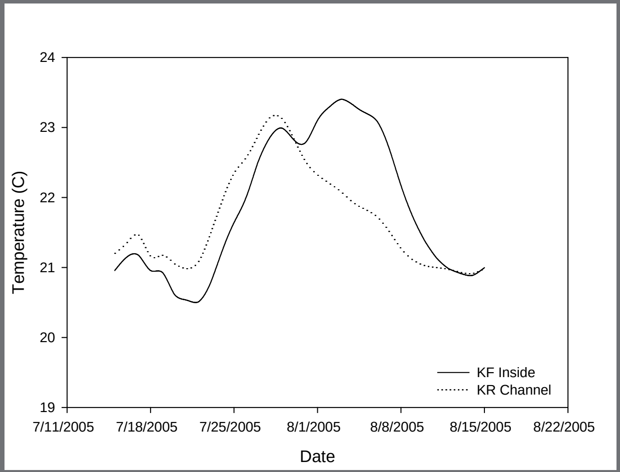
Below:
After **Tidegate Installation**, 2008.
Black = Diked Pastureland
Dotted = Outside Tidegates



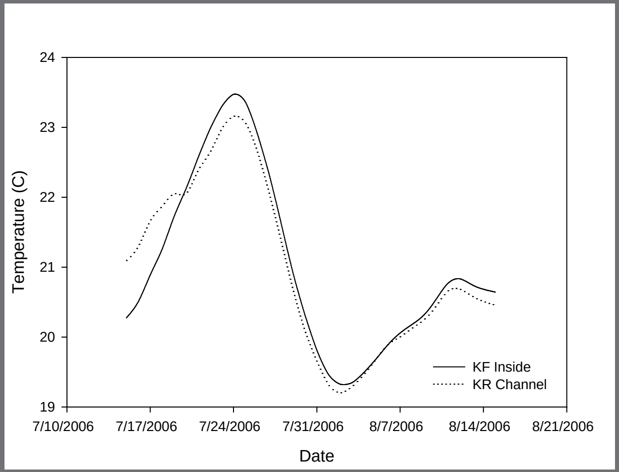
Above:
Before and After **Dike Breach**, 2005.
Black = Diked Pastureland
Dotted = Paired Reference Site

Implications for Aquatic Organisms: Water Temperature Change

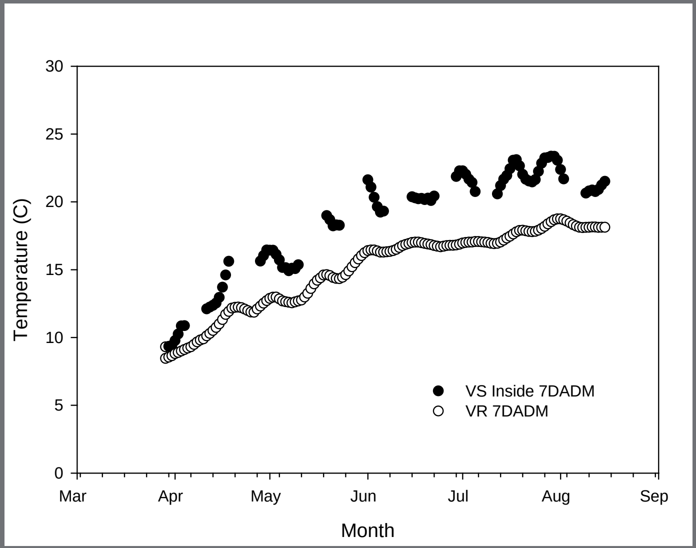
Before Dike Breach: 2005



After Dike Breach: 2006



Right: July-August Water Temperatures (7-DAD Maximum) Before and After Dike Breaching, at Restoration (Black line) and Reference (Dotted line) Sites.



Left: Spring and Summer Water Temperatures (7-DAD Maximum) After Tidegate Installation At Restoration (Black circle) and Reference (White circle) Sites.

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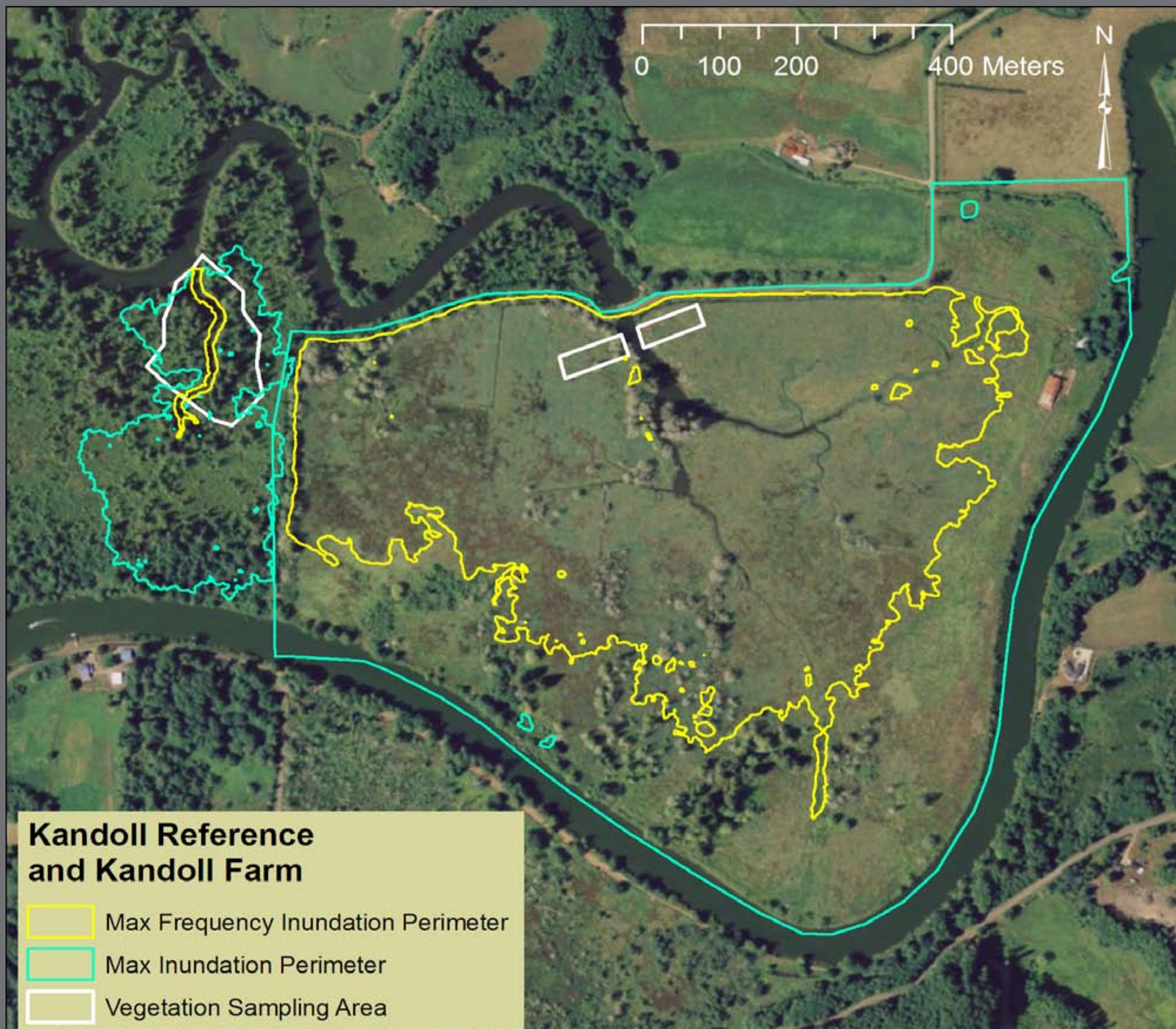
Hydrologic Metrics Relative to Functions for Salmon

Site	Site Area (m^2)	Site Perim. (m)	Max. Freq. WSE (m)	Total Channel Density	Total Channel Edge Length (m)	Habitat Opp. at Max. Freq. WSE (%)	Habitat Perim. at Max. Freq. WSE (m)	Channel Edge Length at Max. Freq. WSE (m)	Mean TRI	Mean MTWI
CI	1,180,969	6,756	2.1	30.6	77,085	16.7	13,842	14,199	0.029	7.7
CR	111,048	1,720	2.1	22.8	9,741	33.6	2,036	3,277	0.029	7.5
KF	655,994	5,015	2.2	20.8	19,287	66.0	7,468	12,726	0.007	11.9
KR	78,452	2,083	1.4	79.3	6,494	14.6	780	945	0.023	8.0
VS	1,060,332	11,591	1.7	83.2	41,780	14.2	15,203	5,950	0.004	7.1
VR	71,404	7,173	2.1	11.4	26,652	26.1	2,317	6,950	0.053	6.2

Elevation based on NAVD88 (North American Vertical Datum of 1988).

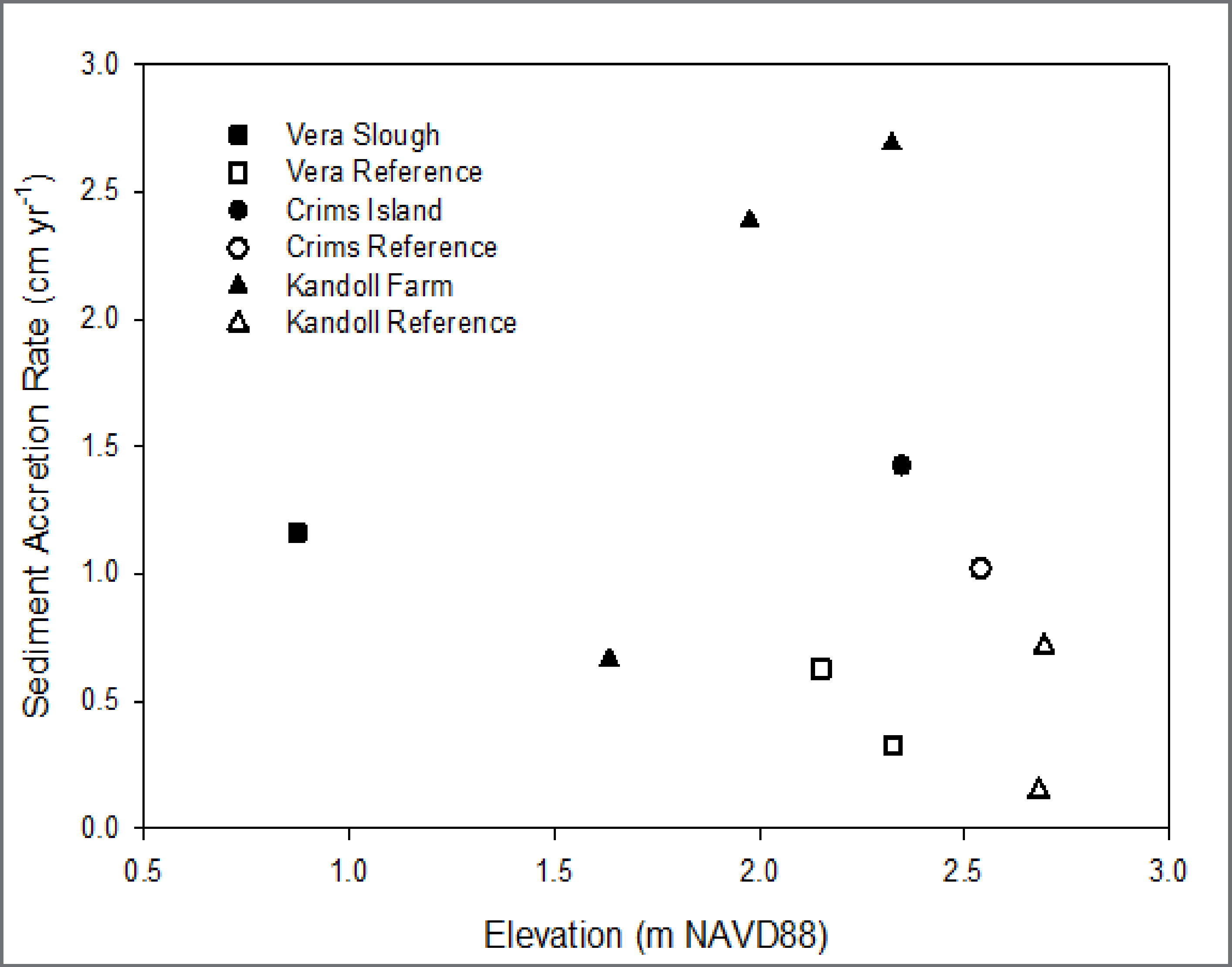
Implications for Physical Processes



Example Paired Sites: Maximum Inundation Perimeter, Area-Time Inundation Index, & Maximum Frequency Inundation Perimeter Vary Greatly Between Restoration and Reference Sites

See Coleman et al. In Preparation. "A Spatially Based Area-Time Inundation Index Model for Tidal Wetlands and Restoration Sites of the Lower Columbia River Floodplain and Estuary"

Topographic Change: Sediment Accretion



Findings:
(4-year rates, 2005-2009, with annual records)
1. In all cases, accretion rate at restoration site is greater than at paired reference site.
2. Highest rate at dike breach, followed by channel excavation, and lowest at tide-gate replacement.

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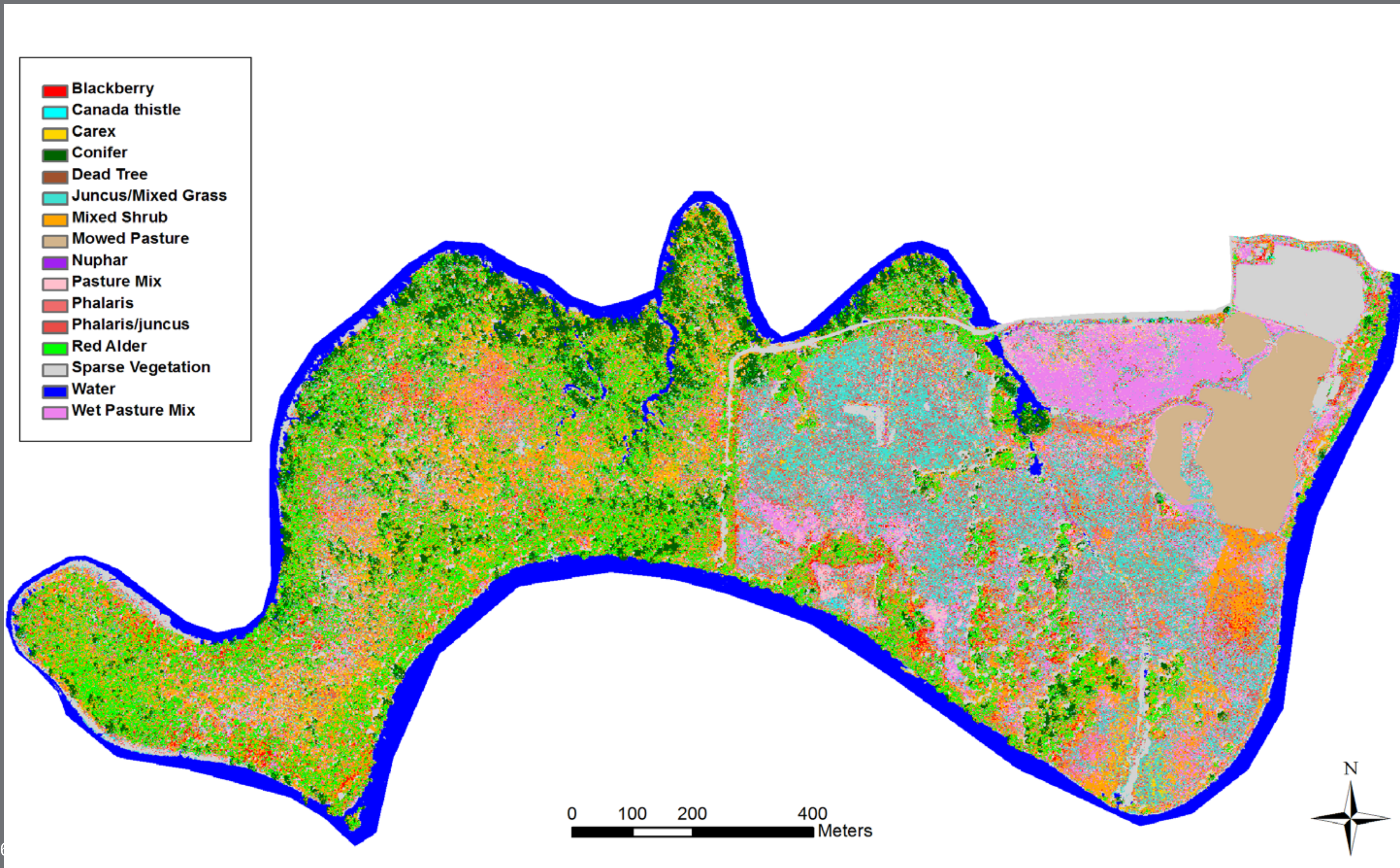
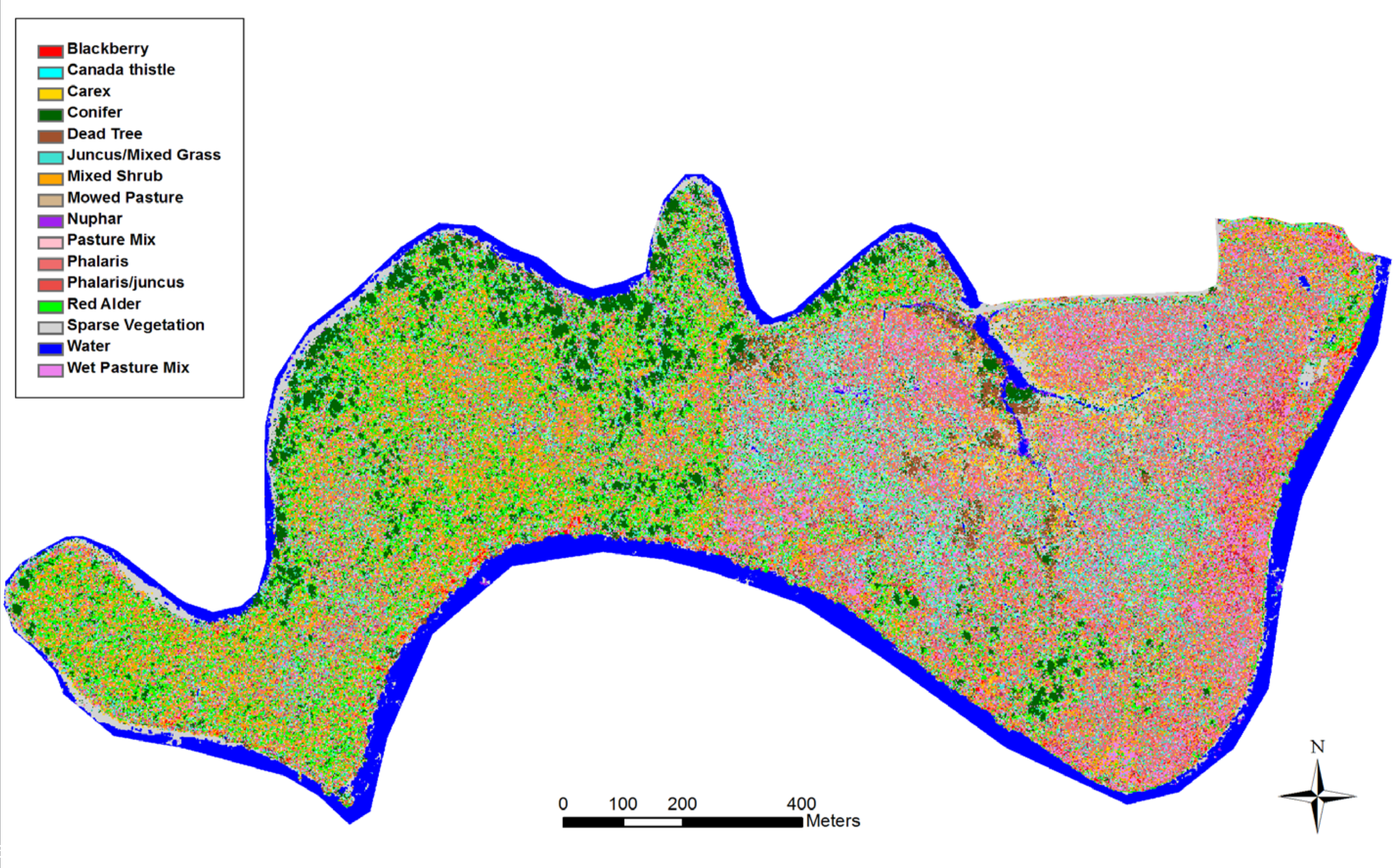
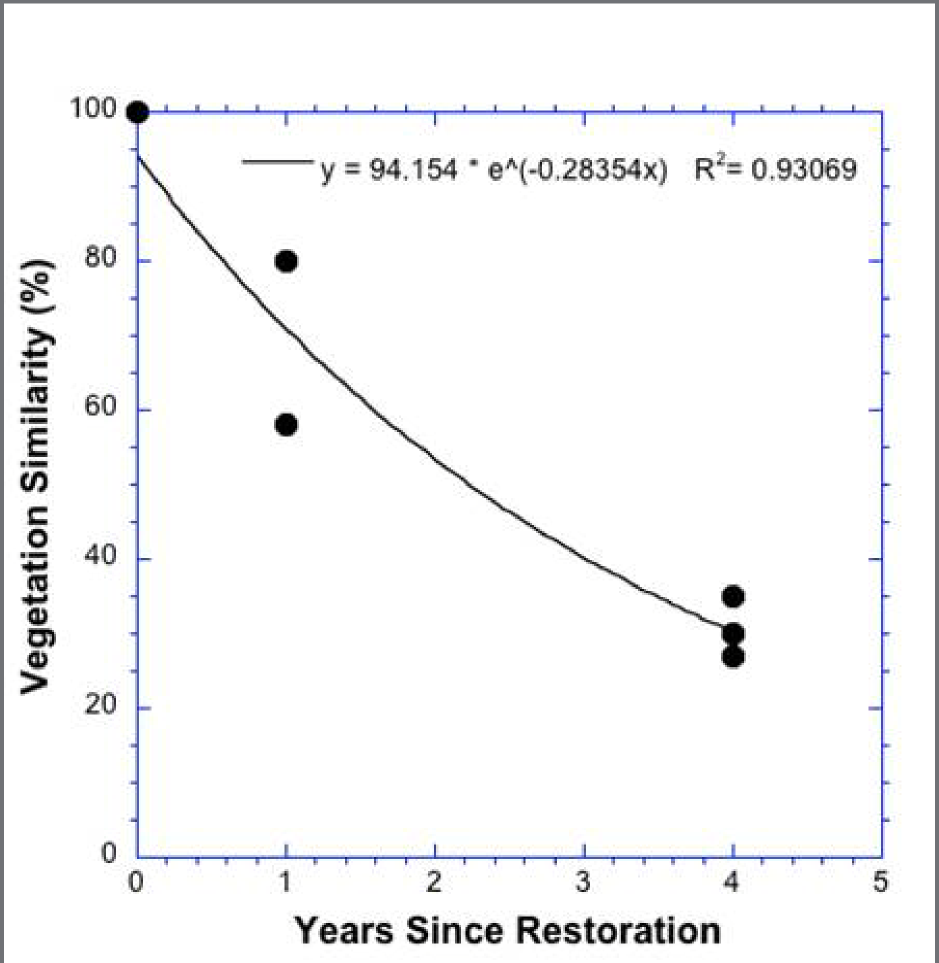
Biotic Change: Landscape Scale (Before, 2005) Satellite Imagery Analysis for Monitoring Design



Biotic Change: Landscape Scale (After, 2009) Changes are Consistent with Plot-Scale Results

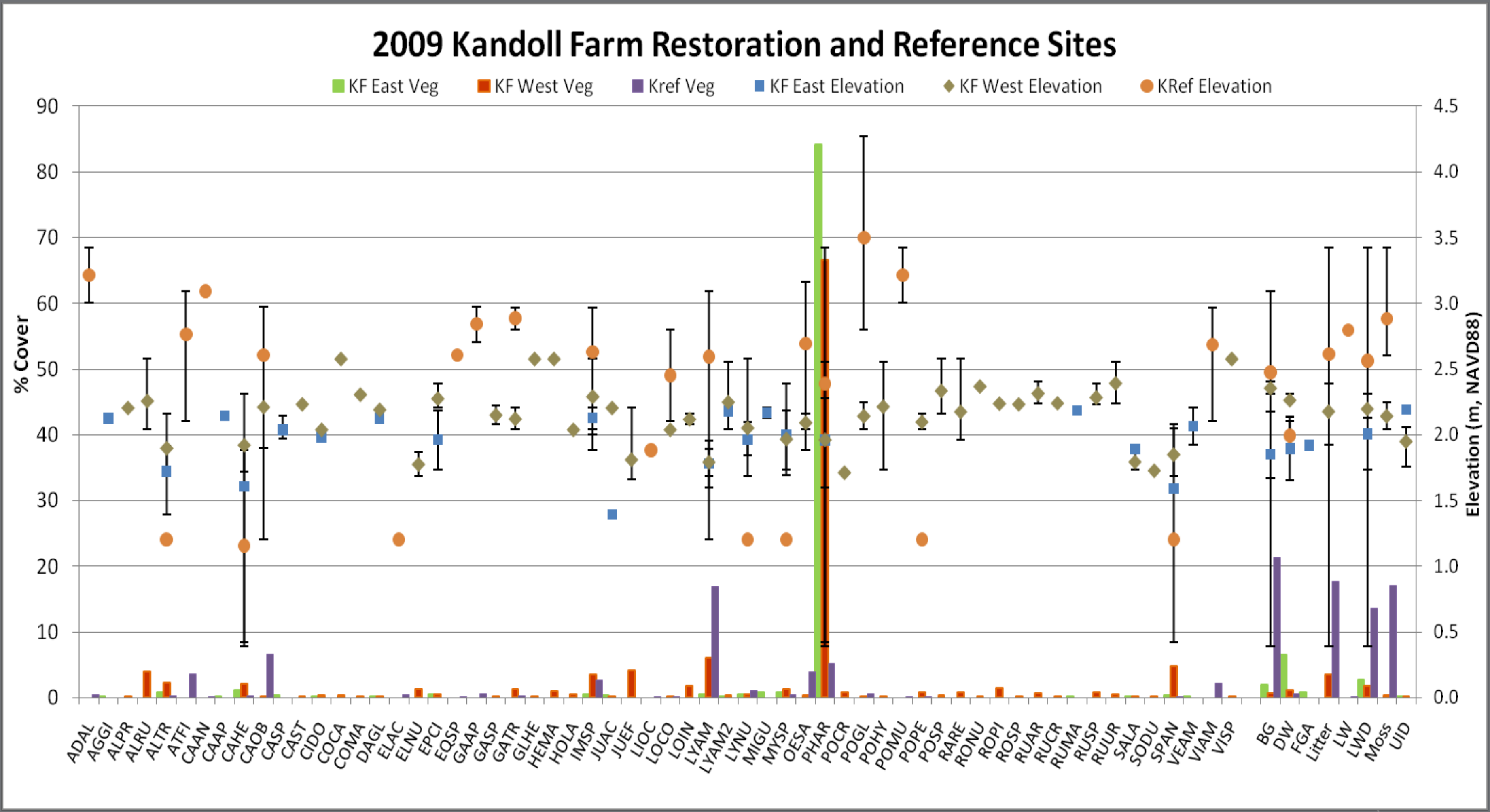


Biotic Change: Plot-Scale Similarity Indices



At Columbia River restoration sites, the plant community has changed dramatically from its original composition after 4 years. However, it has not begun to trend toward paired reference sites. This is consistent with Thom et al. (2002, *Rest. Ecol.* 10:487-496), which showed that conversion to salt marsh plants took a full 5 years, change began to slow after 6 years, and full recovery was not predicted for 75-150 years.

Biotic Change: Plant Species-Elevation Relationships for Restoration Design/Planning



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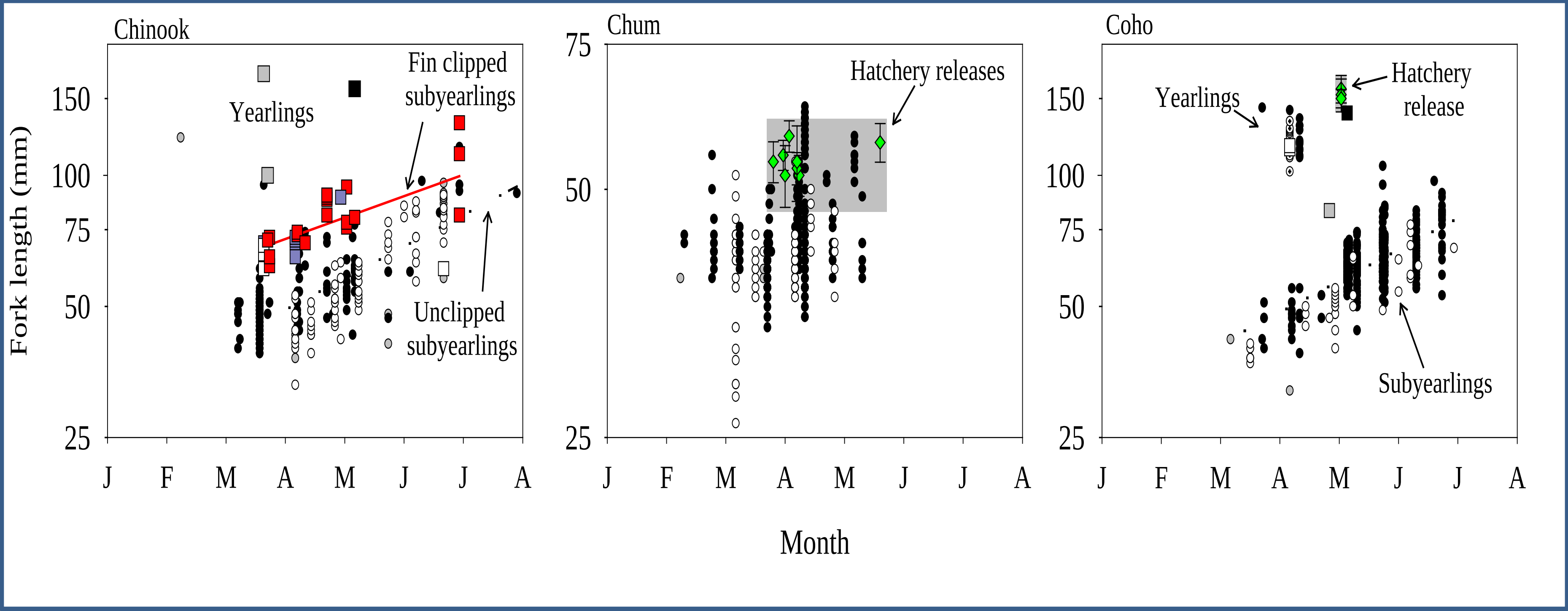
Biotic Change: Salmon Fork Length



<u>Evidence for out-of-basin habitat use</u>

•No hatchery subyearling Chinook released into GR, but larger clipped fish found in restoration wetlands – likely from other watersheds.

•Hatchery chum salmon released in GR and found in TN sites; based on size, most were wild.

•Both wild and hatchery yearling coho found in restoration sites, but most were wild subyearlings.

Roegner et al. 2010, Transs of the Am. Fish. Soc. 139:1211-1232.

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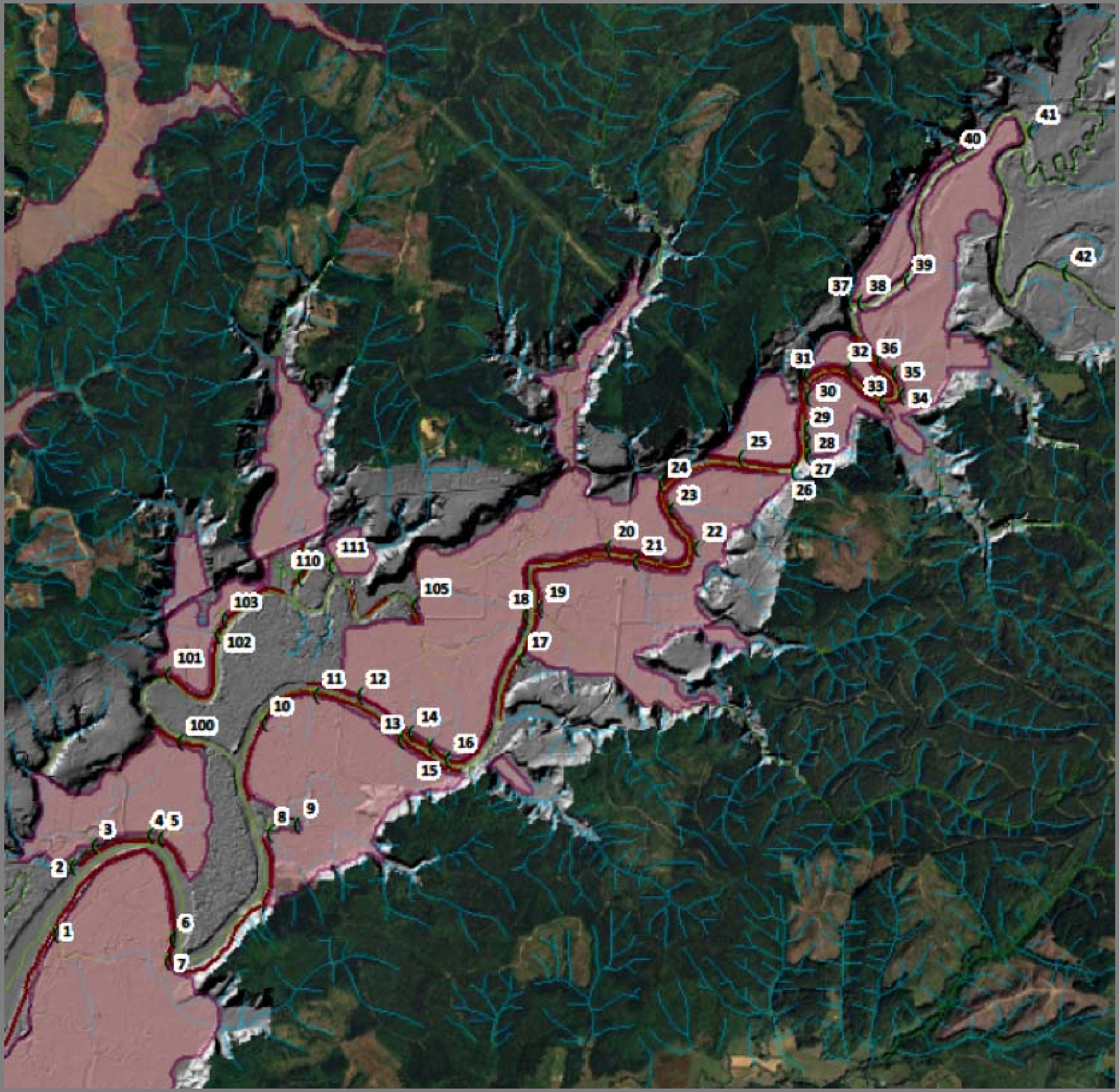
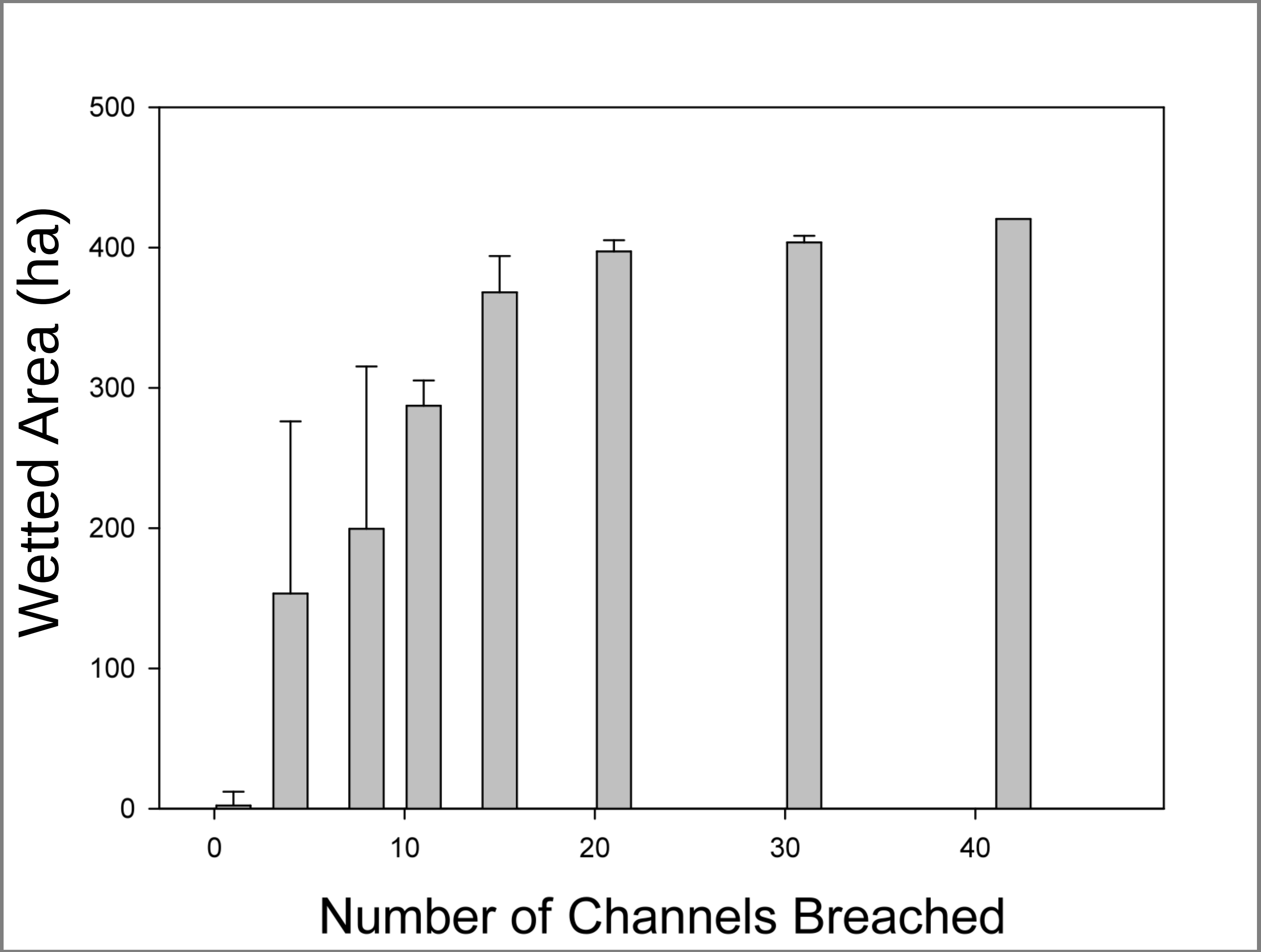
Study Design for Hydrologic Effects Accumulation



Statistical Model: Randomly selected subsets of 42 total available channels. Grays River, WA.

Hydrodynamic Model:
2-D, depth-averaged finite element RMA2.

Results: Hydrologic Effects Accumulation



See: Diefenderfer et al. In Preparation.“Diminishing Returns In Hydroecologic Restoration.”

Predicting Restoration Outcomes for Fish and Habitat Capacity: Historical Dike Breaches

Karlson Island, prior to 1981

Fort Clatsop, ~1960

Trestle Bay, 1995

Breached & Created, 1960s forward

Field Sampling Dates: 2008-2009

Rapid Assessment Indicators:

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

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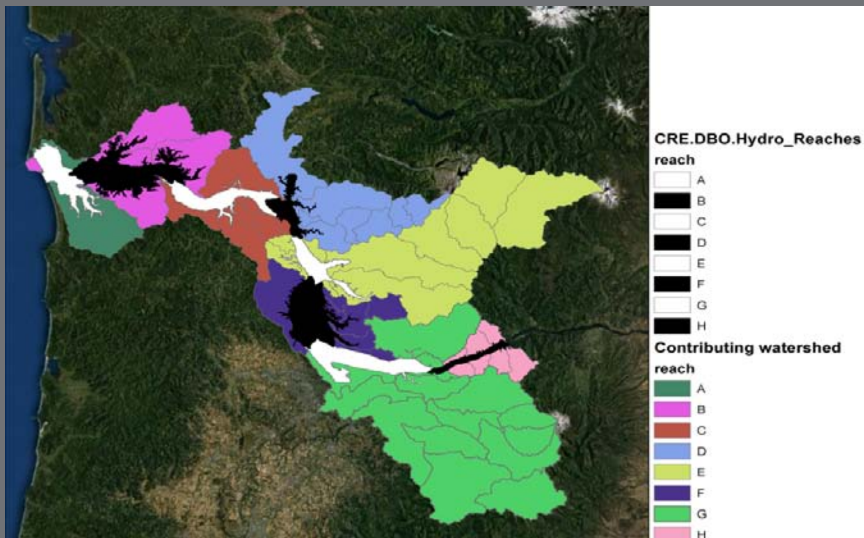
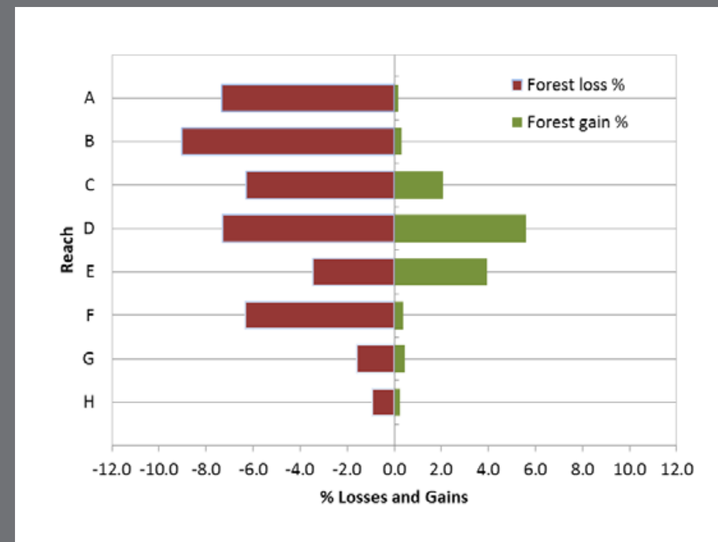
Net Ecosystem Improvement

Temporal Land Cover Analysis of the Contributing Watersheds





- ►Forest land dominated the landscape of the LCRE , with more than 8,000 km^2 (over 60% of the land area) covered by evergreen, mixed, deciduous forest, and forested wetland.
- ►Between 2001 and 2006, a net loss of 190 km^2 of forest area occurred in the primary contributing watersheds. Both losses and gains occurred.
- ► Forest cover declined in the contributing watersheds of all reaches, with the exception of reach E, which saw a 10-km^2 increase.

Ancillary Hypothesis Testing

Would the Preponderance of Evidence from base, synergy, and predictive lines of evidence…convince a reasonable person that the combined restoration projects and programs achieve measurable change toward the restoration goal in the Columbia Estuary?

- Proof of frequent and prolonged salmon use of restored sites
- Proof of prey production and use in restored systems
- Evidence of improved WQ conditions for salmon
- Initial quantification of export of macro-detritus to ecosystem
- Evidence of initiation of sediment accretion, channel formation, wetland vegetation, nutrient processing and OM export
- Evidence of initial rates of recovery
- Evidence that the greater the tidal reconnection the faster the recovery
- Evidence of potential synergism and optimization of projects
- Continuing land degradation in contributing watersheds
- Development of an AM plan to accumulate learning and improve results

Key Management Questions and Expected Outcomes

Do multiple restoration actions collectively result in an improvement of the ecosystem that supports natural salmon stocks?

- Quantitative estimates of cumulative effects of existing salmon habitat restoration projects in the estuary, including additive, synergistic and antagonistic effects.

What project actions optimize benefit to the ecosystem and salmon?

- Understanding of juvenile salmon use of restored floodplain habitats.
- Projections of cumulative effects of potential salmon habitat restoration projects, e.g., return of marsh macrodetritis, increase in connectivity, for planning purposes.

How should project design and implementation be changed to improve outcomes?

- Comparisons of the effects of different restoration actions (e.g., dike breaches vs. tide gates) and active versus passive approaches (e.g., whether to excavate/fill).
- Knowledge of fundamental processes affecting restoration trajectories (e.g. sedimentation rates).

How will action plans and project designs be assessed and improved?

- Adaptive management framework bringing project monitoring data into program planning processes.

Acknowledgements

U.S. Army Corps of Engineers, Portland District, Columbia River Fish Mitigation Program, supported this research.

Contributors: Amy Borde, Andre Coleman, Earl Dawley, Gary Johnson, Dave Montgomery, Curtis Roegner, John Skalski, Ian Sinks, Kristiina Vogt, Stephen Breithaupt, Amanda Bryson, April Cameron, Catherine Corbett, Val Cullinan, Erin Donley, Kern Ewing, Kate Hall, Nathan Johnson, Ron Kauffman, Yinghai Ke, Scott McEwen, Lee Miller, Doug Putman, Micah Russell, Kathryn Sobocinski, Cindy Studebaker, Jerry Tagestad, Allan Whiting, Dana Woodruff, Shon Zimmerman