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An Evidence-Based Assessment of the Cumulative Effects of Tidal Freshwater and Estuarine Ecosystem Restoration

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2012 Anadromous Fish Evaluation Program Annual Review
Portland, Oregon

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US Army Corps of Engineers ®
Portland District

Research Objective

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Evaluate the effect of the federal Columbia Estuary Ecosystem Restoration Program (CEERP) on ESA-listed salmon and steelhead stocks.

Status: Approach Published 2011
Early-Stage Assessment in SRWG Review 2012

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SPECIAL THEME: PROTECTION AND RESTORATION—ARE WE HAVING AN EFFECT?

A Levels-of-Evidence Approach for Assessing Cumulative Ecosystem Response to Estuary and River Restoration Programs

Heida L. Diefenderfer, Ronald M. Thom, Gary E. Johnson, John R. Skalski, Kristiina A. Vogt, Blaine D. Ebberts, G. Curtis Roegner and Earl M. Dawley

ABSTRACT

Large-scale ecological restoration programs are beginning to supplement isolated projects implemented on rivers and tidal waterways. Nevertheless, the effects of estuary and river restoration often continue to be evaluated at local project scales or by integration in an additive manner. Today, we have sufficient scientific understanding to apply knowledge gained from measuring cumulative impacts of anthropogenic stressors on ecosystems to assessment of ecological restoration. Integration of this knowledge has potential to increase the efficacy of restoration projects that are conducted at several locations but comanaged within the confines of a larger integrative program. We introduce a framework based on a levels-of-evidence approach that facilitates assessment of the cumulative landscape effects of individual restoration actions taken at many different locations. It incorporates data collection at restoration and reference sites, hydrodynamic modeling, geographic information systems, and meta-analyses in a five-stage process: design, data development, analysis, synthesis and evaluation, and application. This framework evolved from the need to evaluate the efficacy of restoration projects that are being implemented in numerous wetlands on the 235 km tidal portion of the Columbia River, USA, which are intended to increase rearing habitat for out-migrating juvenile salmonid fishes.

Keywords: Columbia River, cumulative effects, estuary restoration, levels of evidence, salmon recovery

The structure and function of coastal and riverine ecosystems are affected by the cumulative impacts of multiple anthropogenic stressors. Globally, such human land-use activities are one of the primary causes of declining health of most coastal and large river systems (Nilsson et al. 2005, Halpern, Walbridge et al. 2008). Commonly, these stressors decrease system resilience to additional disturbances by altering components of the stability regime, such as species composition (Gunderson 2000) and nutrient composition (Kemp et al. 2005). Many of the terrestrial and marine systems flanking the world's coasts and rivers are being degraded by multiple stressors that are interacting in synergistic, additive, and antagonistic ways to alter the functioning of these ecosystems (Darling and Côté 2008, Halpern, McLeod et al. 2008, Crain et al. 2008). Recently, a meta-analysis of the depletion of species and habitats in estuaries and coastal seas and the factors that contributed to these changes summarized information dating back to the time of human settlement on three continents. This analysis provided evidence that 78% of recoveries in coastal and riverine ecosystems were driven by reducing the expression of two or more anthropogenic stressors, for instance, by restricting resource exploitation and pollution (Lotze et al. 2006).

The urgency for restoring coastal and riverine ecosystems significantly altered by anthropogenic activities has stimulated the implementation of large ecological restoration programs at scales not previously imagined (Steyer et al. 2003, Manning et al. 2006). These programs are attempting to leverage the research previously conducted on individual projects to increase the success of restoration at landscape scales. Both the size of the investments needed and the potential for substantial environmental and ecosystem services benefits, highlight the importance of validating the efficacy of restoration at the ecosystem level and at the landscape scale. Therefore, any assessment protocol will need to integrate the cumulative effects resulting from the implementation of multiple restoration projects across larger landscapes. This methodology needs to be able to predict outcomes, provide a means of identifying the projects likely to have the strongest effect on ecosystems for prioritization, and function as a guide for the efficient expenditure of restoration funding.

Ecological Restoration Vol. 29, Nos. 1-2, 2011
ISSN 1522-4740 E-ISSN 1543-4079
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U.S. DEPARTMENT OF ENERGY

PNNL-XXXXX

Prepared for the U.S. Department of Energy
under Contract DE-AC05-76RL01830

An Evidence-Based Assessment of the Cumulative Effects of Tidal Freshwater and Estuarine Ecosystem Restoration: Early Life-Stage Habitat Functions for Endangered Salmonids

DRAFT REPORT

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November 2012

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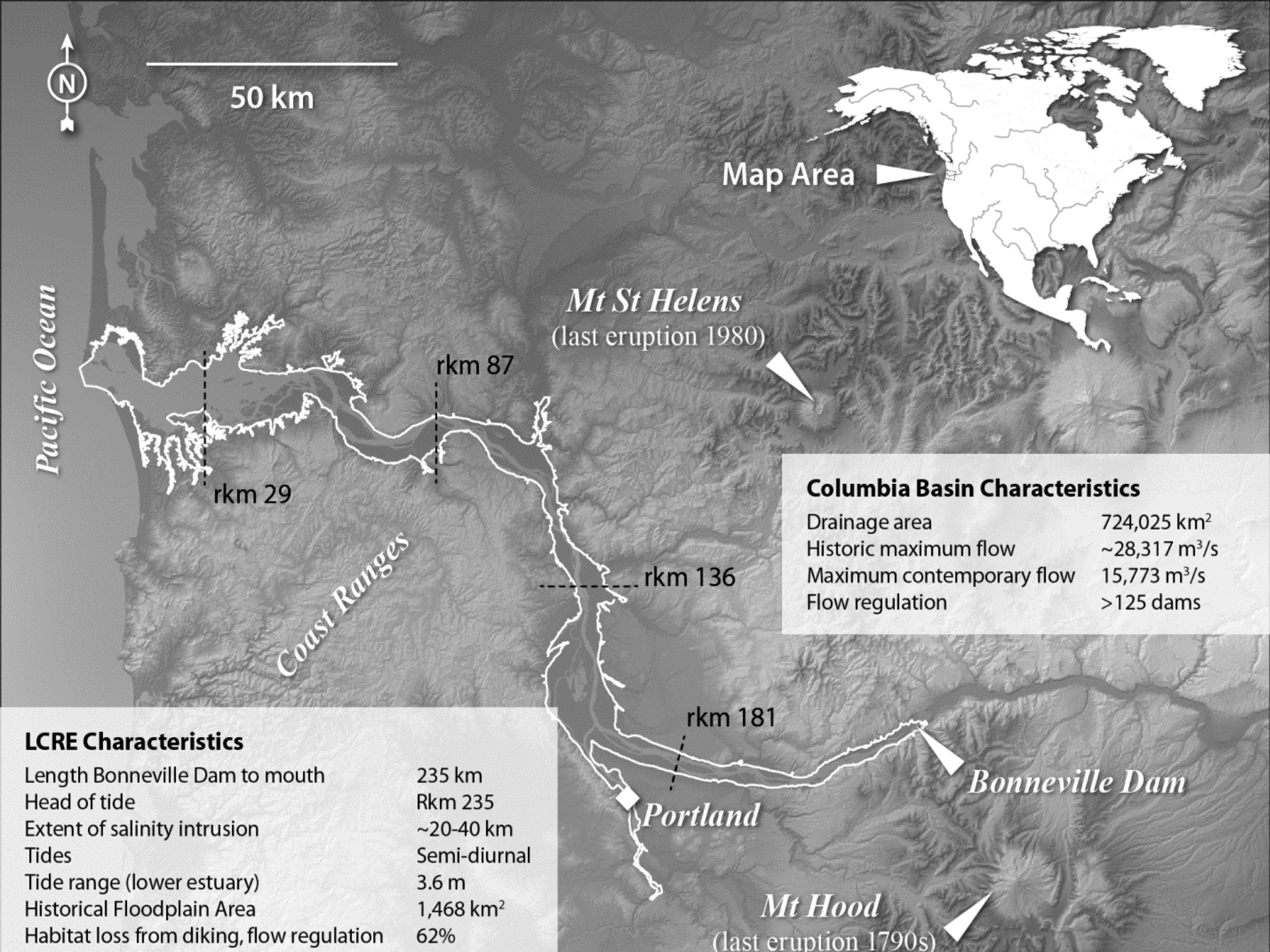

Columbia Basin Characteristics

Drainage area	724,025 km^2
Historic maximum flow	~28,317 m^3/s
Maximum contemporary flow	15,773 m^3/s
Flow regulation	>125 dams

LCRE Characteristics

Length Bonneville Dam to mouth	235 km
Head of tide	Rkm 235
Extent of salinity intrusion	~20-40 km
Tides	Semi-diurnal
Tide range (lower estuary)	3.6 m
Historical Floodplain Area	1,468 km^2
Habitat loss from diking, flow regulation	62%

Background

It is a **complex problem** to link changes in the quality and landscape pattern of tidal wetlands in the lower Columbia River and estuary (LCRE) to salmon recovery.

Factors:

- The ecosystem
- The salmonids
- The restoration actions
- Cumulative effects
- Current sampling technologies

Why Cumulative Effects?

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Restoration is occurring at multiple sites yet the collective effect is important to salmon recovery. **Documented interactions of juvenile salmon** with restored tidal wetlands include cumulative effects:

- Multiple visits to a restored site
- Visits to more than one restored site
- Offsite (indirect) effects of multiple restored sites on the food web in the main stem river
- Effects of a restored site on other restored sites

Conservation and restoration planning on the Grays R., courtesy of Columbia Land Trust, 2006.

General Research Approach

Designed a formal approach to develop and evaluate evidence of CEERP early-stage outcomes.

Working hypothesis: Habitat restoration activities in the LCRE have a cumulative beneficial effect on juvenile salmon.

Two necessary conditions:

1) Habitat-based indicators of ecosystem controlling factors and structures show positive effects from restoration actions.

2) fish-based indicators of ecosystem processes and functions show positive effects from habitats undergoing restoration.

Definitions – Evidence-Based Evaluation

Working Hypothesis: Guides research but is not directly testable.

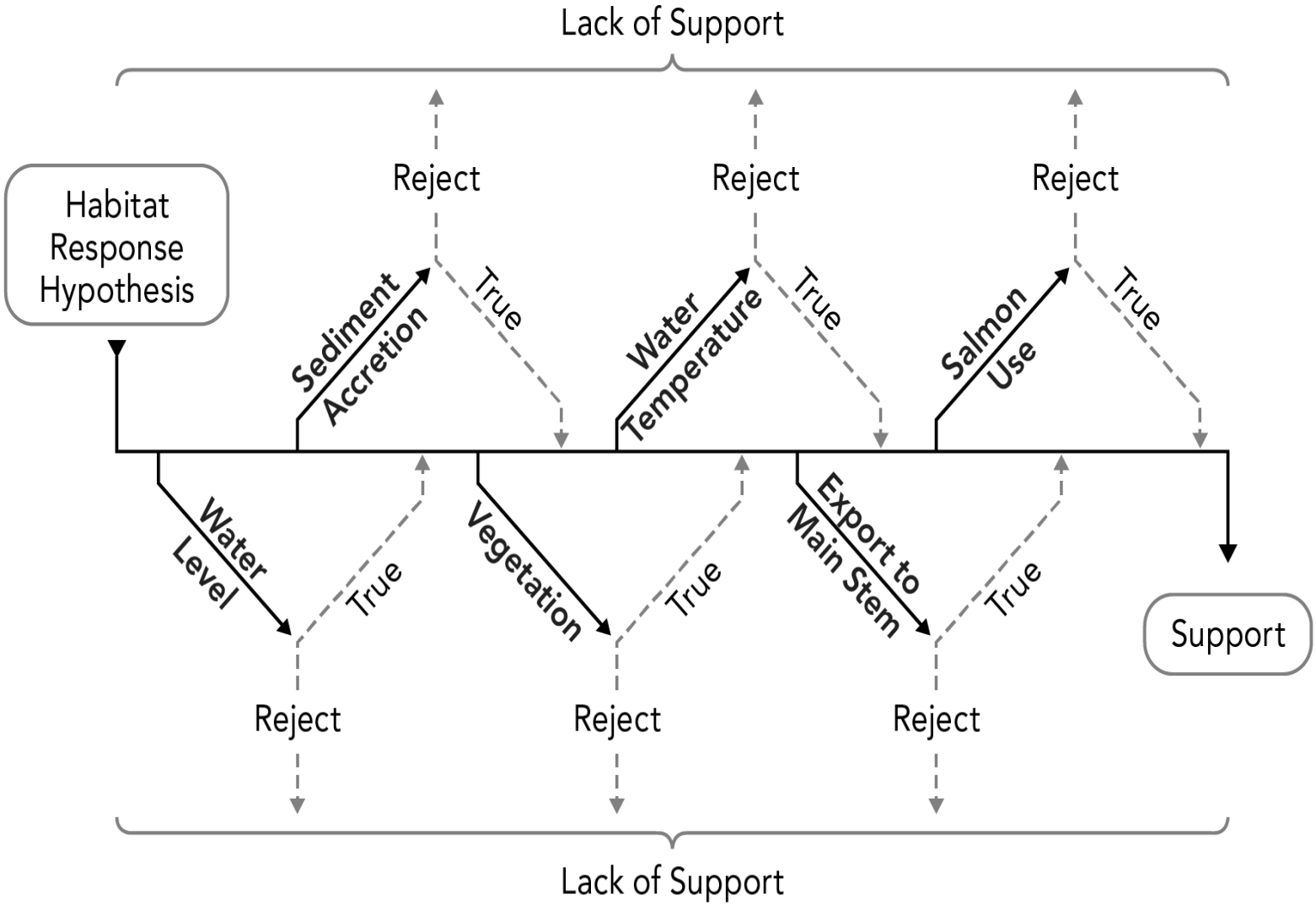
Necessary Condition: Element of the working hypothesis that must be true to conclude the working hypothesis is not refuted by the evidence.

Ancillary Hypothesis: Testable hypothesis related to the working hypothesis through the conceptual model. Testing can show support or lack of support for the working hypothesis.

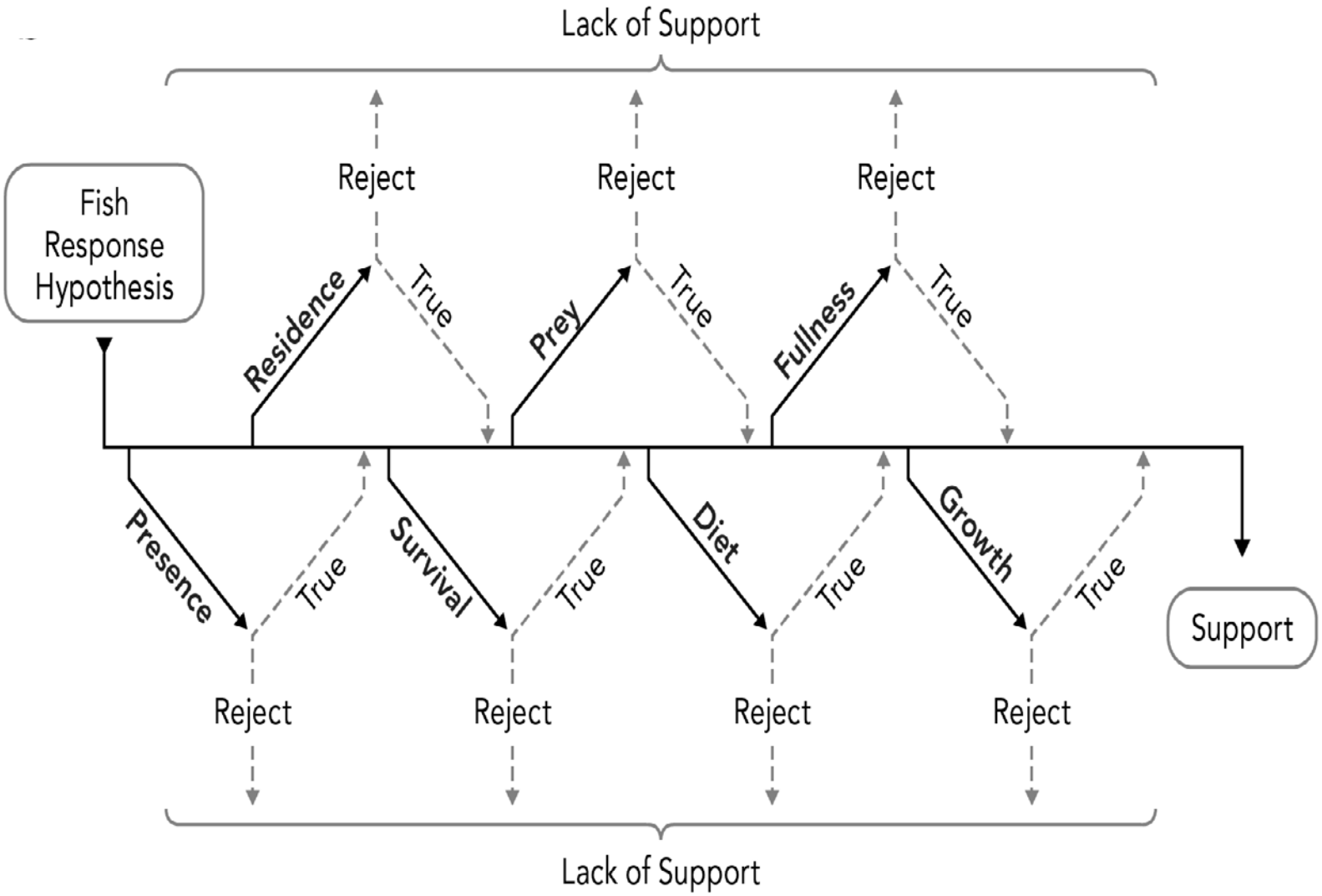
Line of Evidence: Area of inquiry related to the working hypothesis through the conceptual model, for which analysis and/or synthesis of data can provide evidence for or against the working hypothesis.

Causal Criteria: Aspects of association that require study before causation can be claimed; none can prove the case alone and none is indispensable (Hill 1965).

First Condition: Habitat Response Metrics



Second Condition: Fish Response Metrics



Seven Lines of Evidence

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Two lines of evidence from outside the LCRE:

1) Systematic review/scoring of global literature
2) Trends in landscape condition[1]

Five lines of evidence from the LCRE:

1) Analysis of spatial[2] and temporal synergies
2) Net ecosystem improvement model
3) Qualitative meta-analysis of restoration projects
4) Identification of site-scale ecological relationships[3]
5) Assessment of offsite benefits to juvenile salmon

[1]Ke et al. 2012, in the Final Annual Report of the "Cumulative Effects Study" EST-P-02-04 (Johnson et al. 2012, Report No. PNNL-20296)
[2]Diefenderfer et al. 2012, *Landscape Ecology* 27:671–682
[3]Roegner et al. 2010, *Trans Am Fish Soc* 139:1211–1232
[3]Thom et al. 2012, Chapter 2 in PNNL-20296.

Methods for Data Development

- Field measurements and analysis
- Hydrodynamic Modeling
- Meta-analysis of existing restoration data
- Other reanalysis of existing data sets
- Remote sensing data analysis

The approach for this study is available in:
Diefenderfer et al. (2011) "A levels-of-evidence approach for assessing cumulative ecosystem response to estuary and river restoration programs. *Ecological Restoration* 29:111-132.

Ten Causal Criteria Used to Assess Evidence For and Against the Two Conditions

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1) Strength
2) Consistency
3) Specificity
4) Temporality
5) Biological gradient
6) Plausibility
7) Coherence
8) Experiment
9) Analogy
10) Complete exposure pathway

Adapted from Hill (1965)
"The environment and disease: association or causation?"
Proceedings of the Royal Society of Medicine 58:295-300

Results

Qualitative Meta-analysis of Restoration Projects

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Restoration Site	Water Level	Sediment Accretion	Water Temperature	Vegetation Similarity	Salmon Presence
Crims Island	Haskell and Tiffan 2011	Thom et al. 2012	Haskell and Tiffan 2011	Thom et al. 2012	Haskell and Tiffan 2011
Johnson Farm					Eaton 2010
Julia Butler Hanson NWR	Johnson J et al. 2009, 2011		Johnson J et al. 2009, 2011		Johnson J et al. 2009, 2011
Kandoll Farm	Roegner et al. 2010	Thom et al. 2012, In Prep.	Roegner et al. 2010, Thom et al. 2012	Thom et al. 2012	Roegner et al. 2010
South Slough	CREST 2012		CREST 2012		CREST 2012
Tenasillahe Island	Johnson J et al. 2008		Johnson J et al. 2008		Johnson J et al. 2008
Vera Slough	Thom et al. 2012	Thom et al. 2012, In Prep.	Thom et al. 2012	Thom et al. 2012	Thom et al. 2012

Restoration Project Performance on Ancillary Hypotheses of Habitat Response:
Green=Support (13)
Red=Lack of Support (7)
Yellow=Inconclusive (5)

Note Role of Post-Restoration Lag Times in Slow-Response Variables; This is Early-Stage Assessment

Analysis of Temporal Synergies—Results

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Karlson Island, ~60 years since breaching

2008-09 Rapid Assessment of Historically Breached Sites

Fort Clatsop, ~50 years since breaching

Haven Island, ~10 years since breaching

Net Ecosystem Improvement Model Results: Primary Productivity

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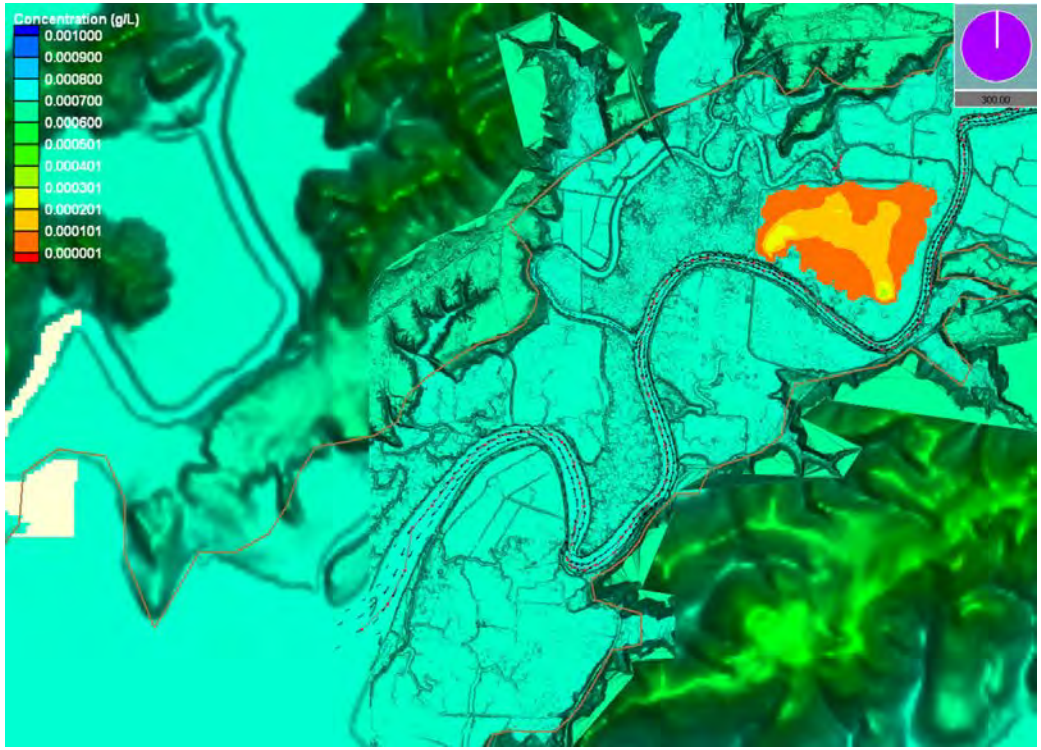
River Position (Rkm)	Plant Community Land Cover	No. site/yr samples	Dry Weight (S.D.)
0 - 30	Marsh	16 - 147	1125 (465)
0 - 30	Restored	2 - 14	849 (613)
31-87	Marsh	16 - 131	866 (415)
31-87	Restored	2 - 16	909 (387)
88-136	Marsh	2 – 16	600 (36)
88-136	Restored	3 – 24	445 (196)



<u>Aboveground Herbaceous Plant Biomass Summary</u>:
Mean values of 600-1125 g dry/m^2 for reference marshes and 850-909 g dry/m^2 for recently reconnected marshes.
Offsite Benefits: Particulate organic matter transport model shows organic matter from restoration sites can be exported at least 7 km to the main-stem river (Thom et al. 2012)

Net Ecosystem Improvement Model Results: Secondary Productivity

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Study Characteristics			Prey Resources (#/m^2)				
River Position (Rkm)	Plant Community Land Cover	No. studies-samples	Chiron-omidae	Other Diptera	Hemip-tera	Arach-nida	Amphi-poda
0 - 30	Marsh	1 - 15	141 (NA)	275 (NA)	61 (NA)	104 (NA)	–
0 - 30	Restored	1 - 15	192 (NA)	42 (NA)	7 (NA)	12 (NA)	–
31-87	Marsh	5 - 75	1113 (713)	288 (114)	18 (8)	19 (6)	–
31-87	Marsh	3 - 45	139 (28)	898 (289)	–	–	148 (116)
31-87	Shrub	1 - 15	170 (NA)	77 (NA)	12 (NA)	17 (NA)	–
31-87	Forested	3 - 45	76 (19)	140 (48)	16 (10)	21 (11)	–
31-87	Forested	1 - 15	56 (NA)	556 (NA)	–	–	583 (NA)
31-87	Restored	2 - 34	454 (522)	284 (205)	10 (7)	8 (8)	–
31-87	Marsh	2 - 69	25 (2)	31 (23)	2 (1)	–	–
31-87	Forested	1 - 15	20 (NA)	16 (NA)	1 (NA)	–	–

Prey Summary:

Estimated 4.2 Km^2 of restoring area in Rkm 0-30 produce about 1.7 billion adult dipteran insects/48 h in April-June.

3.8 Km^2 restoring area in Rkm 31-87 produce about 5.3 billion.

Some additional data for benthic & emergent insects.

Data gaps above Rkm 88.

Offsite Benefits to Juvenile Salmon—Results

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Analysis of 2,247 stomachs for active feeding (AF). AF = >24% full of identifiable prey (no digested material or non food):

	John Day % (n)	Bonneville % (n)	CR Mouth % (n)	CR Mouth Average stomach fullness (% body weight)
Subyearling Chinook Salmon	27 (441)	7 (292)	52 (193)	0.63 (0.83)
Yearling Chinook Salmon	11 (626)	5 (456)	56 (107)	0.83 (0.97)
Yearling Coho	ND	ND	51 (171)	0.68 (0.72)
Juvenile Steelhead	12 (600)	5 (406)	68 (109)	0.19 (0.37)

Out-migration Summary:

Rkm 349 John Day Dam
Active Feeding by 12% of juvenile steelhead and yearling Chinook.

Rkm 235 Bonneville Dam
5% of steelhead & Chinook

Rkm 15
68% juv. steelhead
56% yrl. Chinook
52% subyr. Chinook
51% yrl. coho

Systematic Literature Review and Scoring Results

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Global search identified 709 papers; 15 met the criteria (tidal, hydrologic restoration and original salmon data).

River	Study Weight	Presence		Residence		Survival		Prey		Diet		Fullness		Growth	
		Y	N	Y	N	Y	N	Y	N	Y	N	Y	N	Y	N
Chehalis	4			1						1			1	1	
Duwamish	8	1	1							1		1		1	
Duwamish	10							1							
Fraser	7			1				1		1					
Fraser	7	1													
Grays/ Columbia	3	1								1					
Puyallup	1			1										1	
Puyallup	1	1						1		1					
Sacramento	1	1													
Sacramento	3					1		1		1				1	
Sacramento	1	1		1										1	
Salmon	9	1		1											
Salmon	7	1						1		1		1			
Skjern	2						1								
Snohomish	6	1						1		1					
		Y	N	Y	N	Y	N	Y	N	Y	N	Y	N	Y	N
		43	8	22	0	3	2	34	0	39	0	15	7	17	0
		Support		Support		Insuff.		Support		Support		Insuff.		Insuff.	

Summary Results

Data from the lower CR and estuary confirm evidence in the literature that restored tidal habitats provide forage for juvenile salmon:

1) global literature strongly supports benefits to salmon from tidal wetland reconnection: presence, residence, prey, and diet;

2) historically reconnected sites in the LCRE are emergent marshes with high potential fish access;

3) salmonid response at recent LCRE restoration sites is mixed; fast-response variables show restorative ecosystem processes;

4) net ecosystem improvement in prey and plant biomass indicates wetlands support salmonid foraging;

5) a particulate organic transport model indicates matter produced at restoration sites can be exported >7 km to the main-stem river;

6) stomachs of Chinook salmon and steelhead near rkm 15 are substantially fuller than fish exiting the hydropower system and guts contain large quantities of marsh-produced dipteran insects.

Limitations and Future Research Needs

- Evidence from restoration sites in the LCRE is limited, thus, assessment of global literature was critical to concluding the potential for success.
- Adaptive learning from LCRE restoration monitoring is needed to both demonstrate and improve benefits over time.
- The use of reference sites to assess trends in the spatially complex and dynamic LCRE must be done carefully.
- Several remaining uncertainties *that can inform decision making* are identified in the report: juvenile salmon growth; spatial dynamics of prey and biomass flux (e,g., role of reed canarygrass), trends in early life history diversity and unmarked fish density; maximum potential function of tide gates in typical channel types; gaps in reference sites network; experimental assessment of project effectiveness.

Conclusions

- All lines of evidence from the LCRE indicate positive habitat-based and salmonid-based responses (**two "necessary conditions"**), except in cases of tide gate installation on small sloughs.
- On this basis, habitat restoration activities in the LCRE are likely having a cumulative beneficial effect (**the "working hypothesis"**) on juvenile salmonids that access restored shallow-water areas *or* actively transit main-stem river habitats between the hydrosystem and lower-river tributaries and the ocean.
- Tidal wetlands in the LCRE currently support juvenile salmonids, including interior basin salmonids, and this effect would be expected to increase over time as existing restoration projects mature and new ones are implemented.

Acknowledgements

This research was supported by the U.S. Army Corps of Engineers Columbia River Fish Mitigation Program, Portland District, “Cumulative Effects” study code EST-P-02-04. Data collection by L Weitkamp was funded by the NOAA Fisheries, Northwest Fisheries Science Center. Special thanks to Ron Thom, for his vision, to assess the cumulative effects of restoration, and to Blaine Ebberts, for supporting that vision.

HLD thanks her doctoral committee chair, Kristiina Vogt, U of Washington.

Many Thanks to Other Contributors:

André Coleman, Val Cullinan, Earl Dawley, Lyndal Johnson, Yinghai Ke, Keith Marcoe, Regan McNatt, Doug Putman, Curtis Roegner, Nikki Sather, John Skalski, Cindy Studebaker, and numerous field technicians.

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The final report is currently undergoing review by the SRWG.