How Do We Measure Positive Change in Urban Seas?

An Example Using Cumulative Effects Evaluation from Washington, USA

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PICES Annual Science Meeting
27 October 2026
Nanaimo, BC, Canada

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SKAGIT RIVER SYSTEM COOPERATIVE

Pacific Northwest NATIONAL LABORATORY

School of Oceanography
College of the Environment

WESTERN WASHINGTON UNIVERSITY
MAKE WAVES.

TULALIP TRIBES

NOAA FISHERIES

CRAMER FISH SCIENCES
An Employee Owned Consulting Company

SALISH SEA INSTITUTE
WESTERN WASHINGTON UNIVERSITY


SALISH SEA
A transboundary bioregion encompassing the inland marine waterways of British Columbia and Washington and their watersheds
Coast Mountains
Campbell River
Strait of Georgia
Saturna Island
N. Gulf Islands
Vancouver Island
Vancouver
Fraser River
Nooksack River
MOUNT BAKER
S. Gulf Islands
San Juan Islands
Skagit River
Victoria
Strait of Juan de Fuca
Cascade Range
Olympic Peninsula
Puget Sound
Snohomish River
Seattle
Puyallup River
Olympia
MOUNT RAINIER
CANADA
USA
Map created by Aquila Flower, 2020. Data from USGS, NOAA, NASA, Natural Resources Canada, and Natural Earth.



2022

COMMENTARY | DECEMBER 16 2022

Urban seas as hotspots of stress in the Anthropocene ocean: The Salish Sea example

Collections: Knowledge Domain: Ocean Science

Kathryn L. Sobocinski, C. Drew Harvell, Natalie J. K. Baloy, Ginny Broadhurst, Megan N. Dethier, Aquila Flower, John R. Delaney

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Elementa: Science of the Anthropocene (2022) 10 (1): 00055.

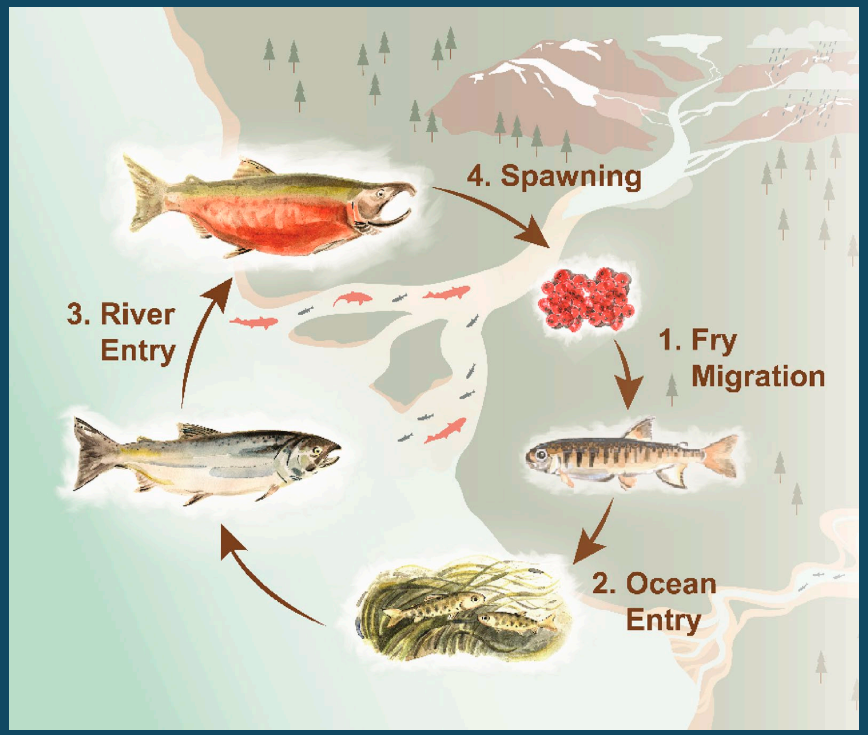
https://doi.org/10.1525/elementa.2022.00055 **Article history**

1. Engage in data collection, curation, and integration using a systems approach in science and management

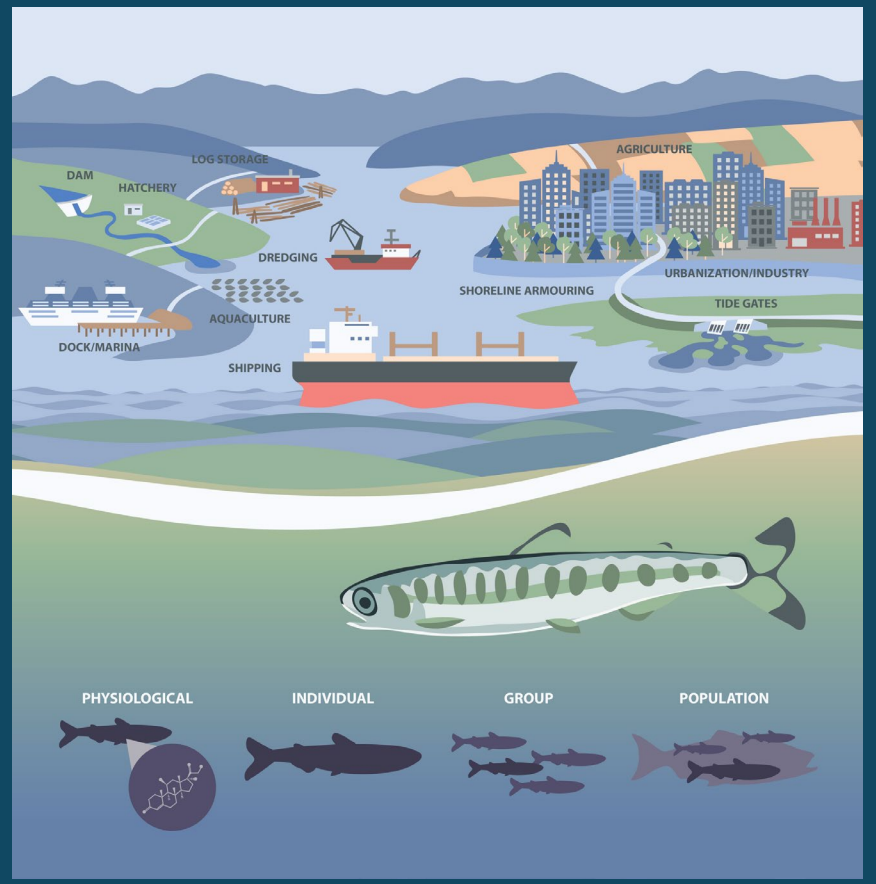
2. **Leverage place-based knowledge to sustain community-based action**

3. Align science and policy with ecosystem boundaries

Salmon Migrate Through an Urban Gauntlet



From Wilson and Peacock 2025



From Hodgson et al. 2020

Cumulative Impacts

Problem: Extensive Estuarine Habitat Loss





Photo: TNC

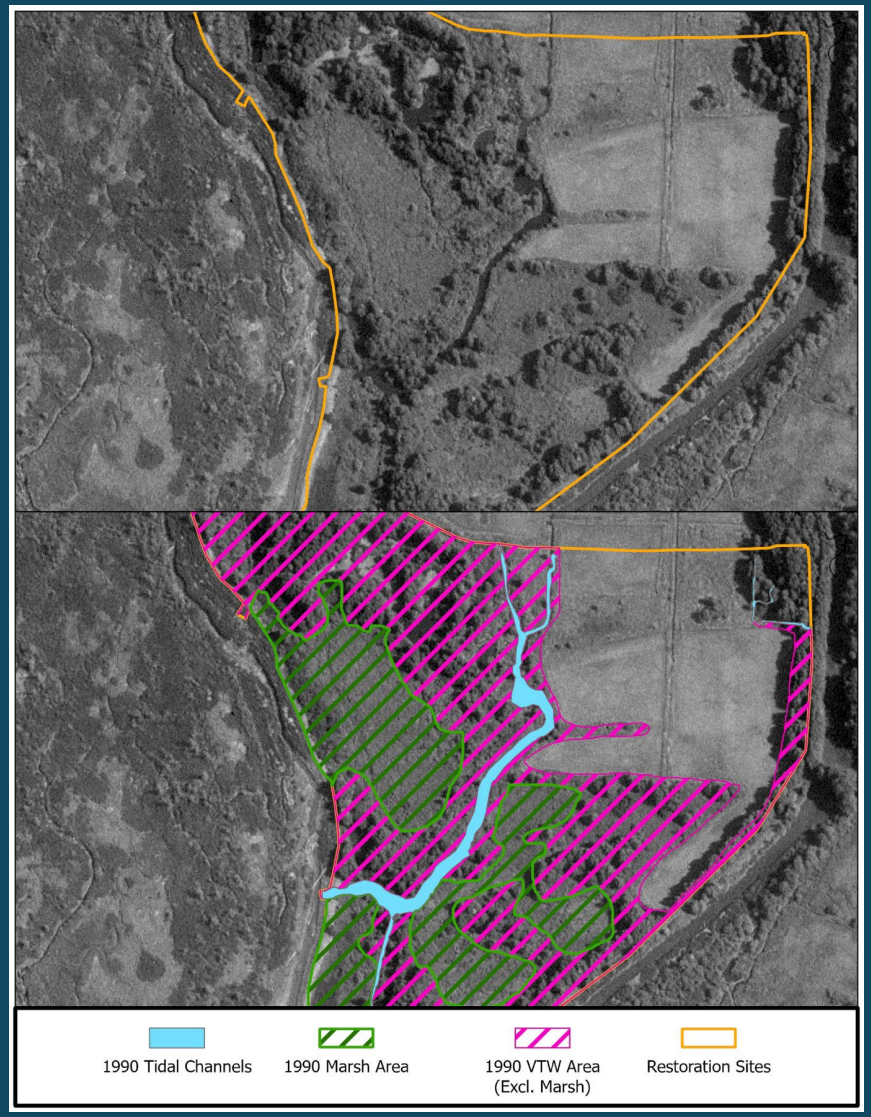
Solution: Habitat Restoration

Salmon Estuarine Habitat Restoration

Open up impounded habitat for outmigrating juvenile salmon access

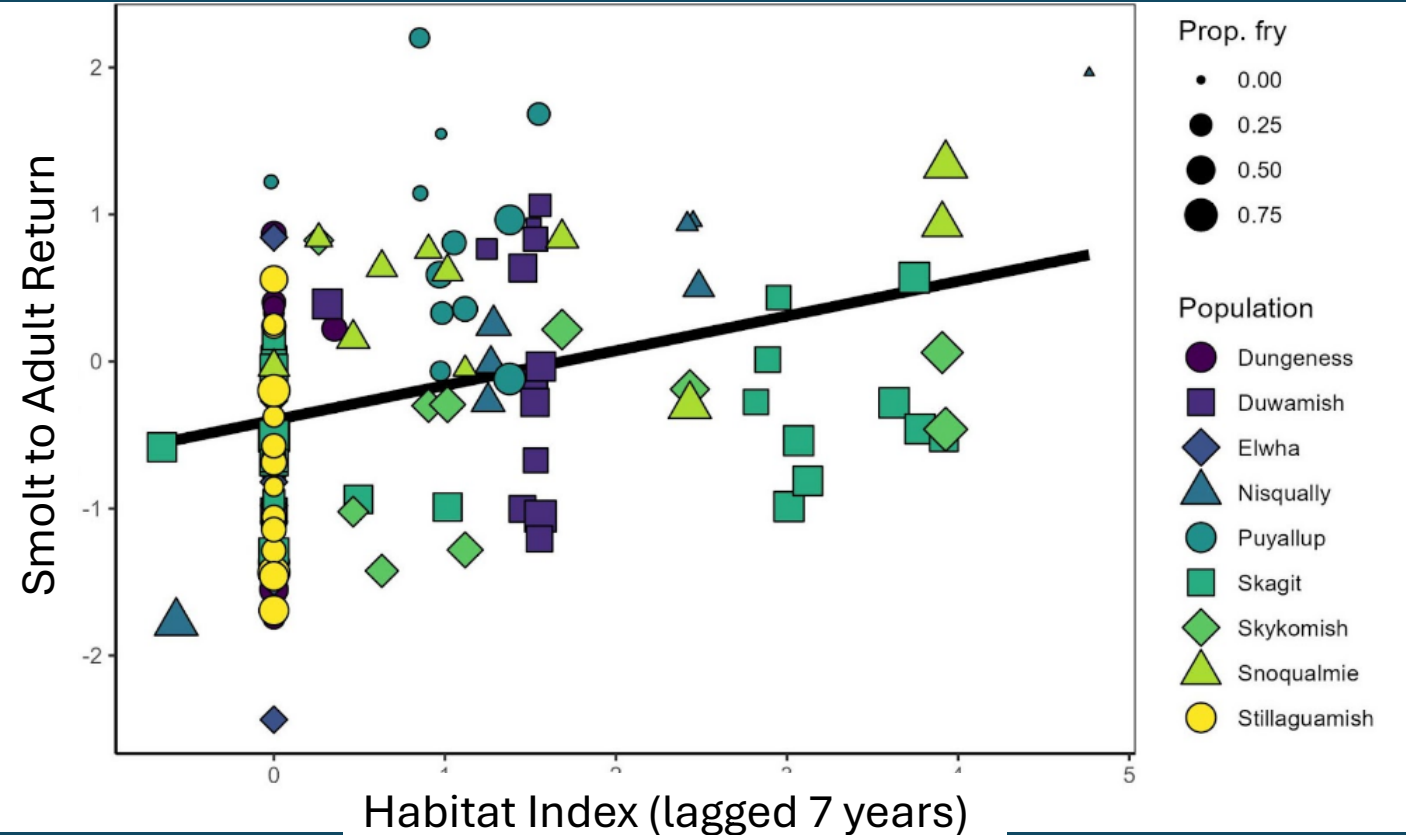
Target restoration of areas with characteristics of success but history of impacts

Sobocinski et al. 2022



A. Tulloch

Increased Chinook Salmon Survival with Increasing Rearing Habitat



ORIGINAL RESEARCH article

Front. Mar. Sci., 02 June 2025

Sec. Marine Ecosystem Ecology

Volume 12 - 2025 | https://doi.org/10.3389/fmars.2025.1584913

This article is part of the Research Topic

Turning with the Tide and Time in the Salish Sea: Change in Estuary and Nearshore Habitats and Species Dependent on Them

View all 14 articles

Population responses of Chinook salmon to two decades of restoration of estuary nursery habitat

Correigh M. Greene[1*†] Eric M. Beamer[2] Stuart H. Munsch[1] Joshua W. Chamberlin[1]

Michael T. LeMoine[2] Joseph H. Anderson[3]

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[2] Skagit River System Cooperative, LaConner, WA, United States
[3] Washington Department of Fish and Wildlife, Fish Program, Science Division, Olympia, WA, United States

C. Greene, Chamberlin, Beamer, LeMoine, Munsch, Anderson, Lisi, Hood+ many others

https://salishsearestoration.org/wiki/Chinook_Response_to_Estuary_Restoration

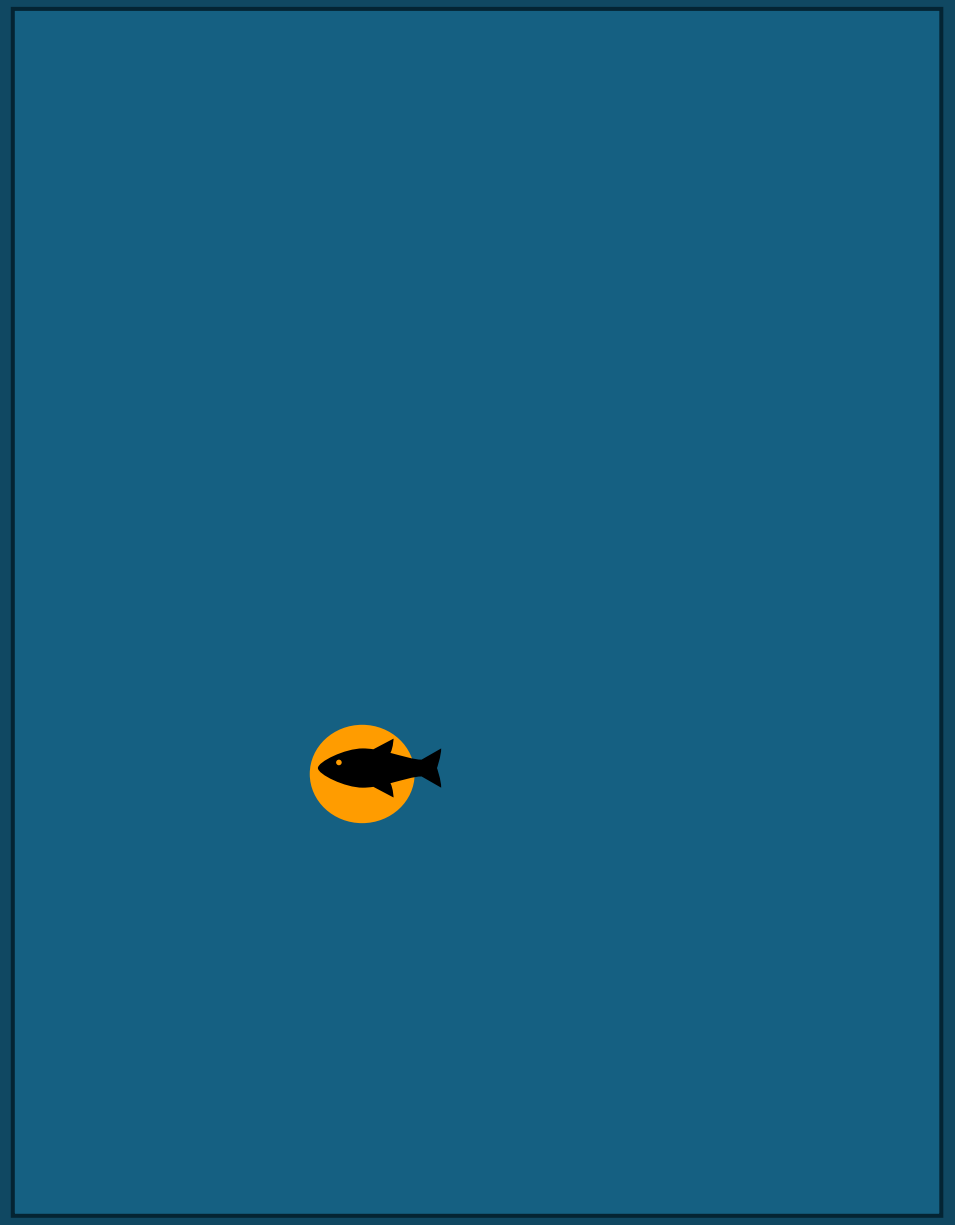
Problem: Restoration is at the site scale, fish pass through the landscape



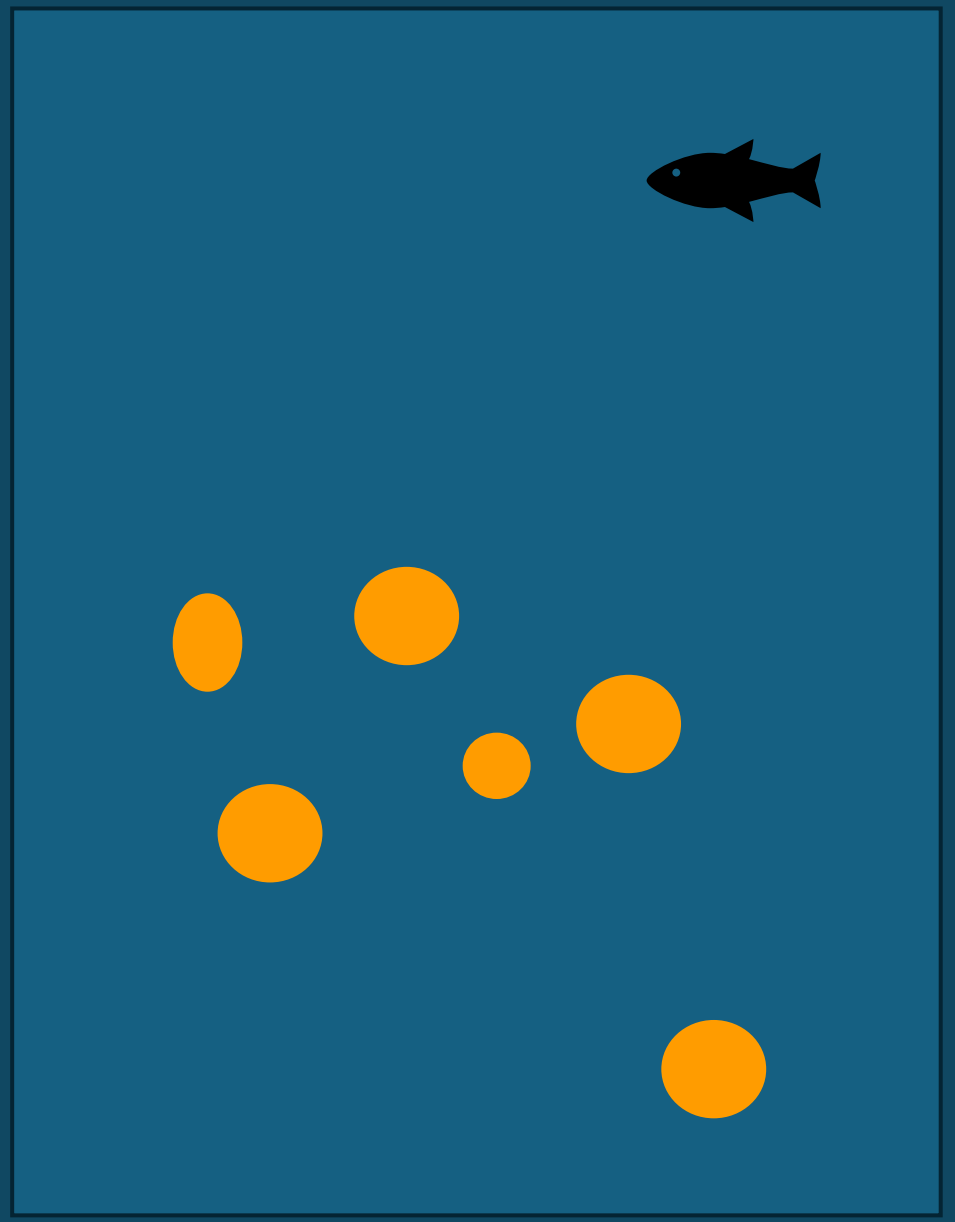
Map: TNC



Photo: Seattle Times



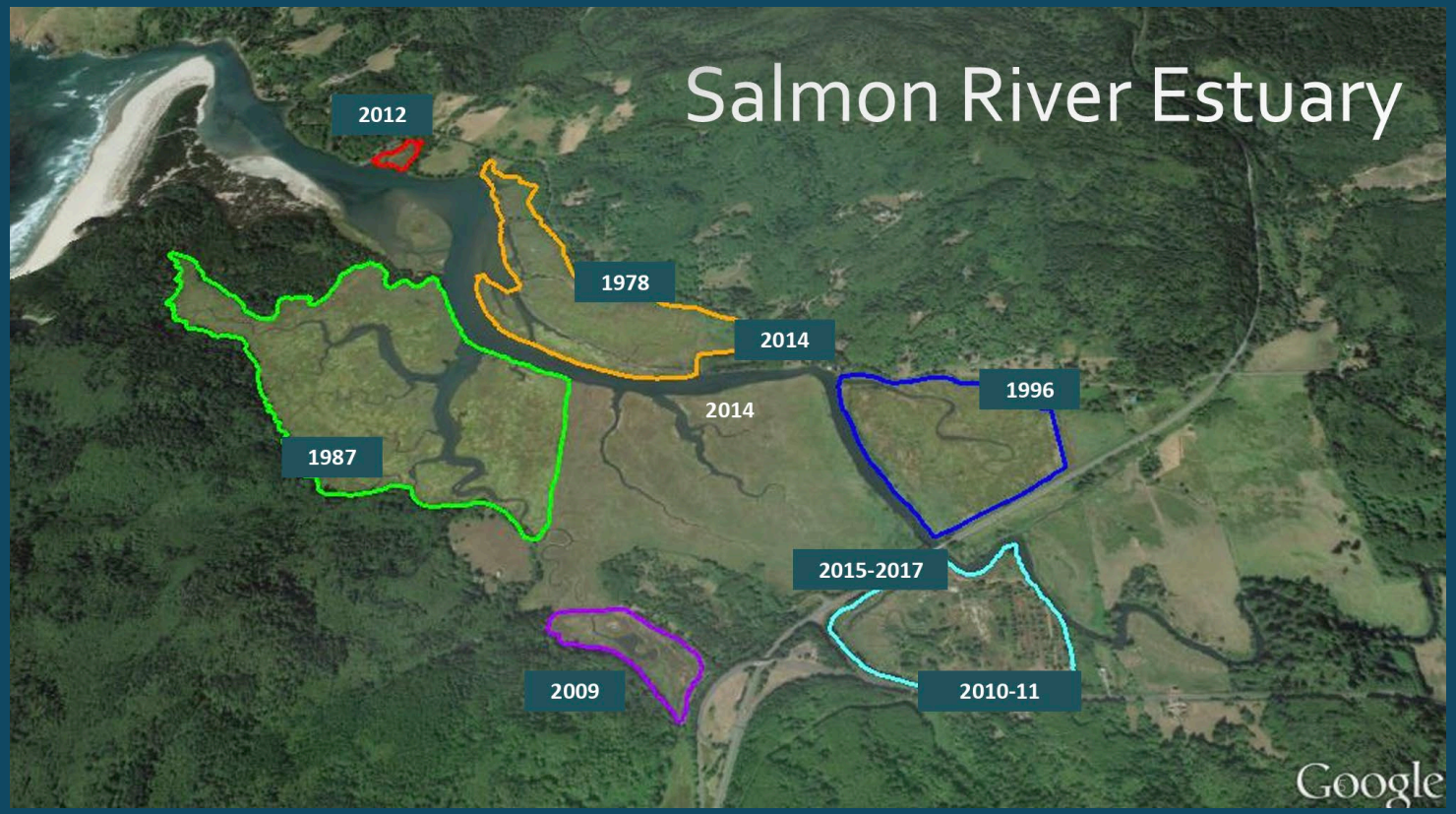
Site Scale: How do salmon use a site?



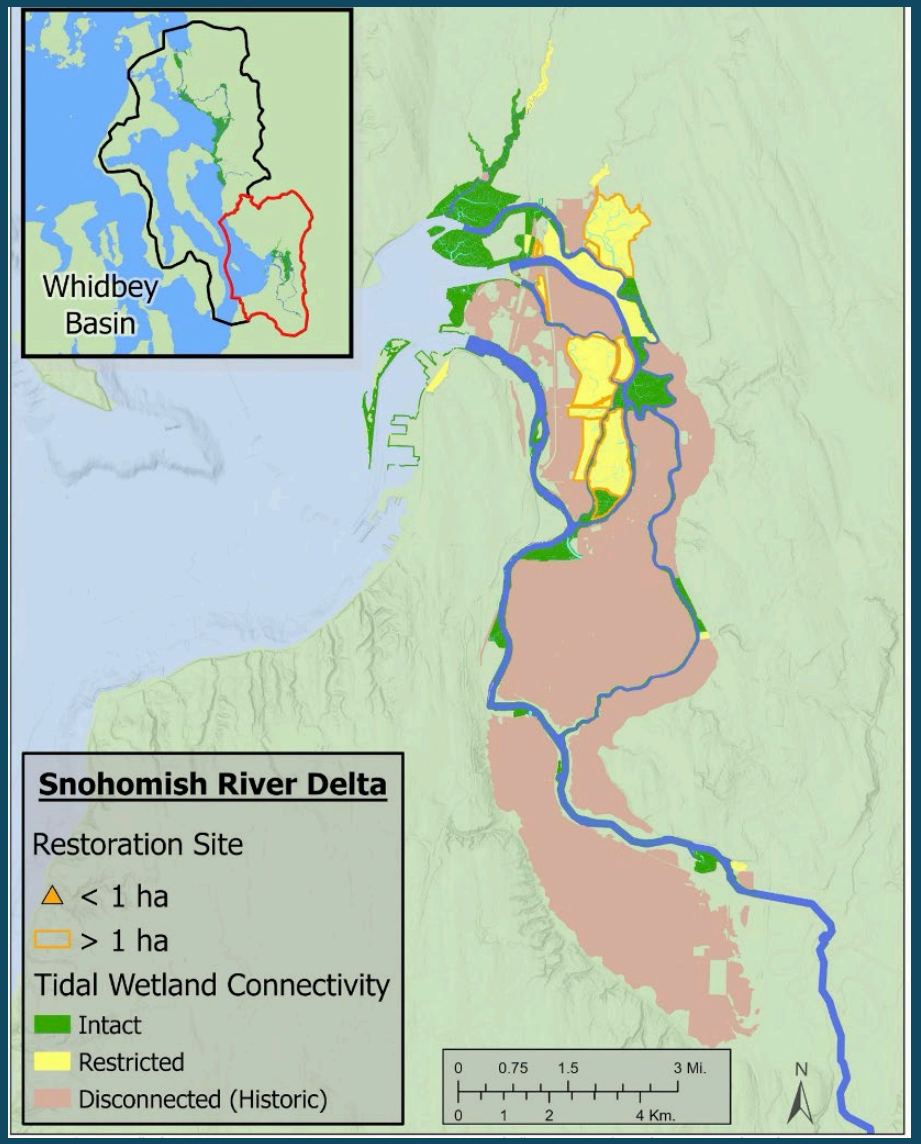
Landscape Scale: How do the cumulative effects of restoration benefit salmon?

Habitat Restoration

Ecosystem Restoration



K. Ellingson



A. Tulloch

Research Objective:

Measure the cumulative effects (benefits) for juvenile salmon from multiple restoration projects

Cumulative effects in the context of ecosystem restoration "…**are the collective additive, synergistic, and antagonistic effects of all restoration activities** that occur within a setting defined by common or connected characteristics of hydrology, geomorphology, ecology, ecological function, and biodiversity" (NASEM 2022, p.61).

Framework: Cumulative Effects Evaluation (CEE)

frontiers | Frontiers in Marine Science

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Check for updates

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Sobocinski KL, LeMoine M, Chamberlin JW, Conway-Cranos L, Del Rio A, Diefenderfer HL, Greene CM, Hall J,

Assessing the cumulative effects of nearshore habitat restoration actions for multiple populations of juvenile salmon in Whidbey Basin, Washington: foundation and approach for synthesis and evaluation

Kathryn L. Sobocinski[1]*, Michael LeMoine[2], Joshua W. Chamberlin[3], Letitia Conway-Cranos[4], Annelise Del Rio[5], Heida L. Diefenderfer[6,7], Correigh M. Greene[3], Jason Hall[8], Gary E. Johnson[6], Ronald M. Thom[5], Elene Trujillo[5] and Todd Zackey[9]

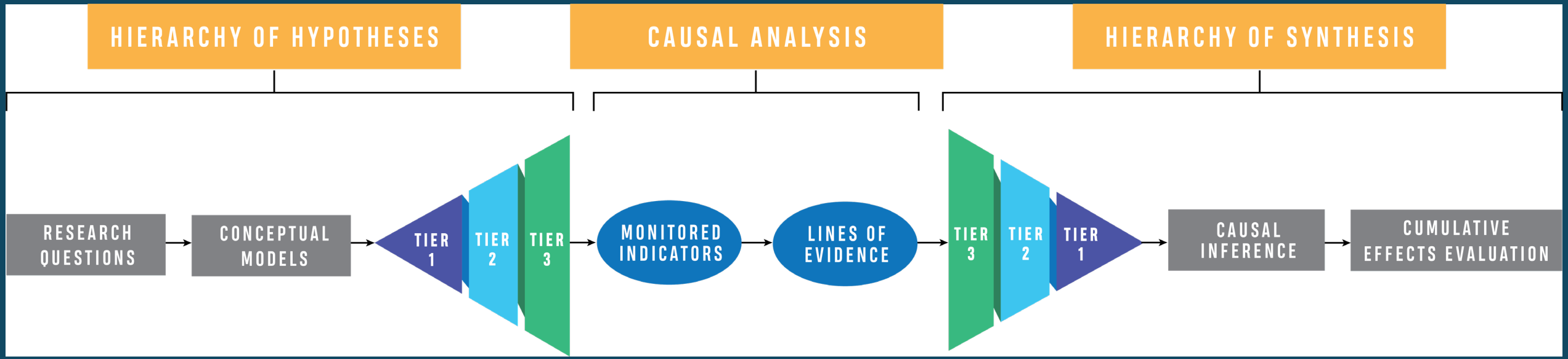
Sobocinski et al. 2025, Frontiers in Marine Science

The Challenges:

- Relatively small portion of salmon habitat is restored in some systems
- Trying to detect a restoration signal in a sea of noise
- Measuring success in a small portion of an organism's life history



Cumulative Effects Evaluation Framework



Sobocinski et al. 2025

esa ECOSPHERE

Evidence-based evaluation of the cumulative effects of ecosystem restoration

Heida L. Diefenderfer,[1,]† Gary E. Johnson,[1] Ronald M. Thom,[1] Kate E. Buenau,[1] Laurie A. Weitkamp,[2] Christa M. Woodley,[1,3] Amy B. Borde,[1] and Roy K. Kropp[1]

[1]*Marine Sciences Laboratory, Pacific Northwest National Laboratory, 1529 West Sequim Bay Road, Sequim, Washington 98382 USA*
[2]*Northwest Fisheries Science Center, National Oceanic and Atmospheric Administration, Newport, Oregon 97365 USA*

JOURNAL ARTICLE

The Hierarchy-of-Hypotheses Approach: A Synthesis Method for Enhancing Theory Development in Ecology and Evolution

Tina Heger ✉, Carlos A Aguilar-Trigueros, Isabelle Bartram, Raul Rennó Braga, Gregory P Dietl, Martin Enders, David J Gibson, Lorena Gómez-Aparicio, Pierre Gras, Kurt Jax ...
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BioScience, Volume 71, Issue 4, April 2021, Pages 337–349,

Tier 1:

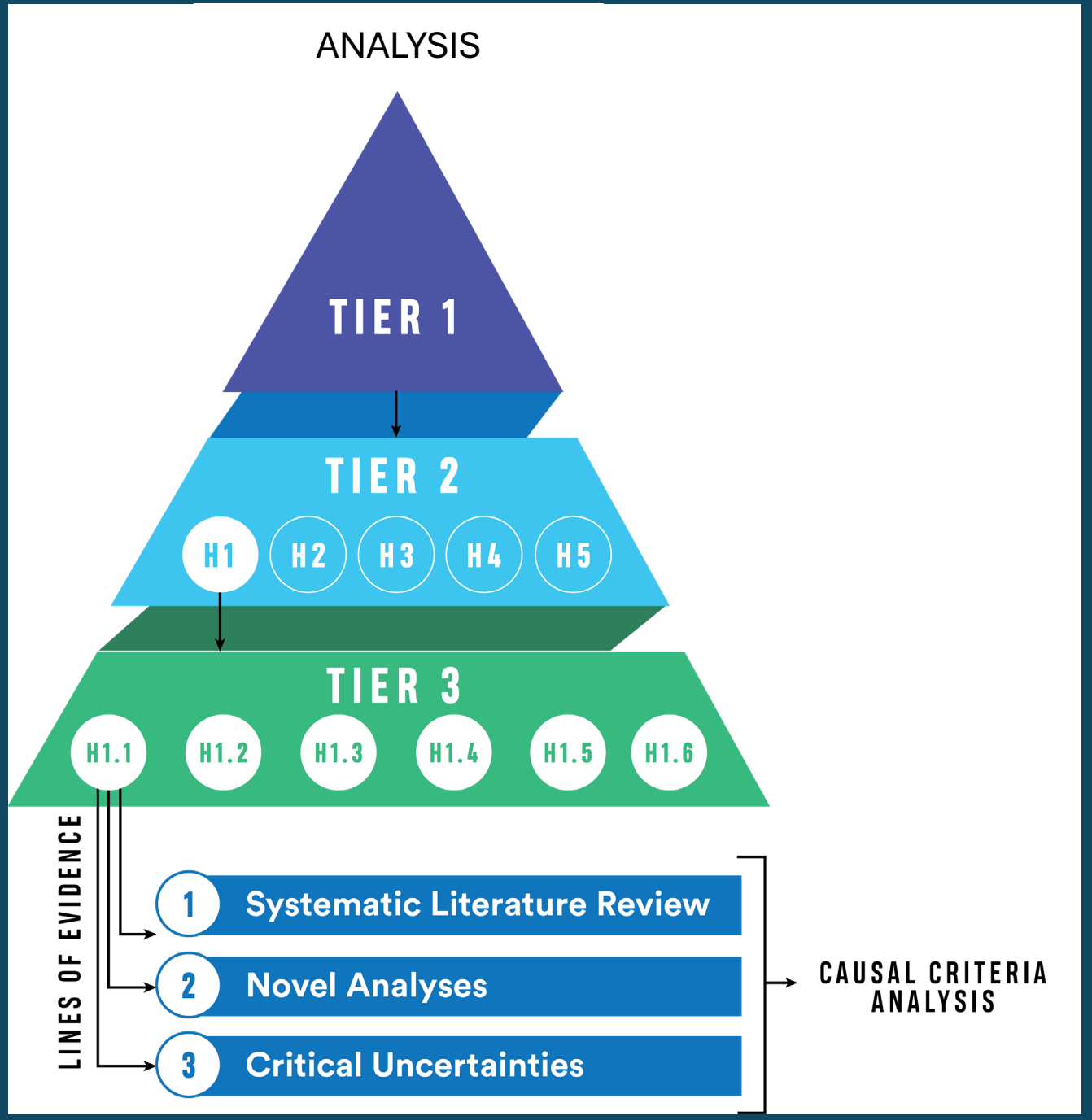
Restoration actions benefit juvenile Chinook salmon

Tier 2:

Habitat Structure
Habitat Function
Salmon Growth
Salmon Distribution and Movement
Salmon Abundance and Survival

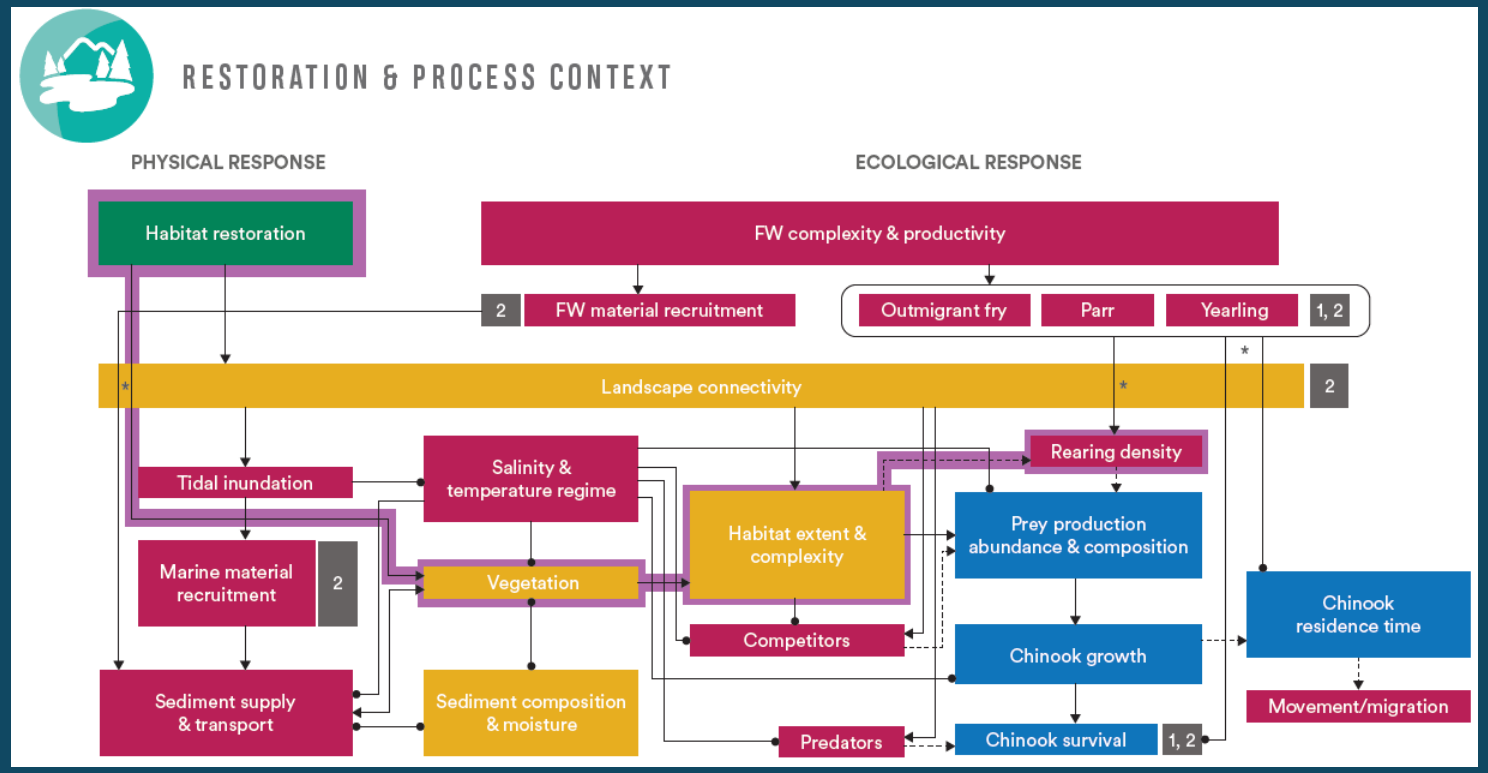
Tier 3:

4-6 testable sub-hypotheses within each Tier 2 domain



Cumulative Effects Evaluation: Causal Pathways and Hypotheses

Hypothesis 4.6: *Increases in habitat availability from restoration improve total capacity to support salmon*



Habitat restoration

↓

Channel and Vegetation Structure, Habitat Extent & Complexity

↓

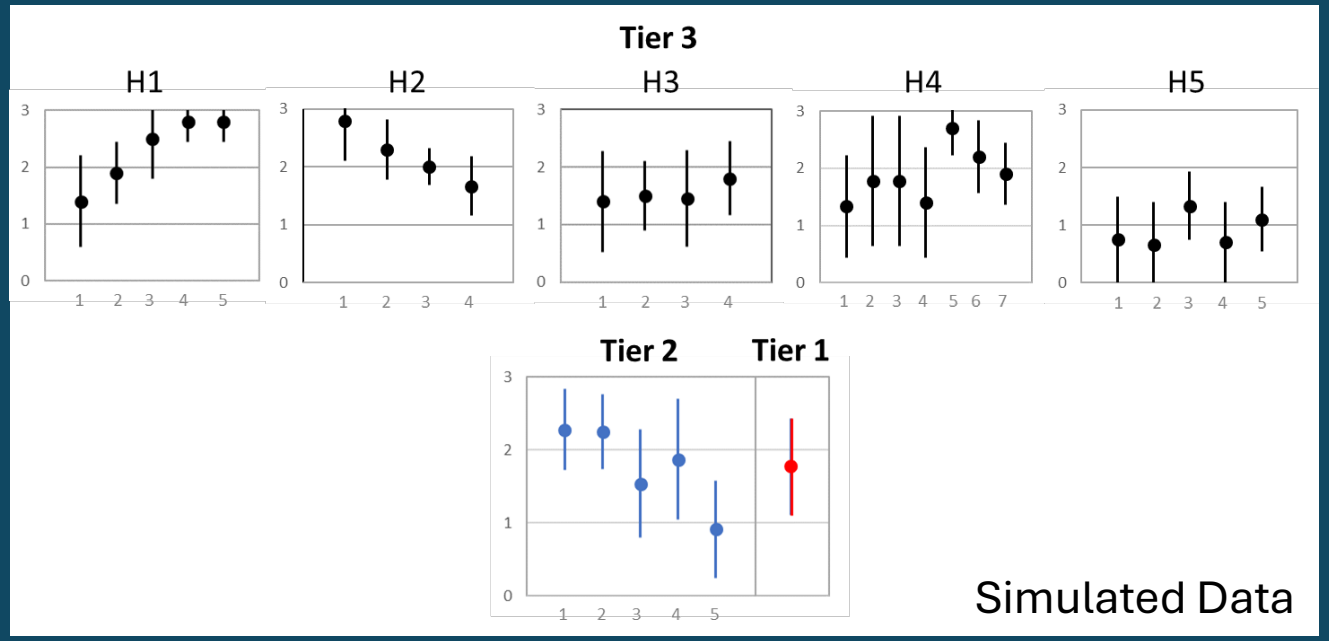
Juvenile Chinook Density

Hypothesis “Testing” Using Causal Analysis

1. Use available evidence (empirical data, literature, and novel analyses where needed) to assess each hypothesis with causal criteria
2. Score each hypothesis for strength of support based upon causal criteria (e.g., strength of association, consistency, plausibility, etc.)
3. Synthesize scores and provide overall support for higher order hypotheses using causal inference

Work is ongoing: 2/5 Tier 2 hypotheses are complete; novel analyses (IBM for salmon movement and growth) to Hyp. 5; extensive literature review.

SYNTHESIS OF KNOWLEDGE



The evaluation uses local data about salmon use of estuaries to understand cumulative effects of restoration actions

Cumulative Effects Evaluation is fundamentally a science synthesis analysis

*Synthesis: The inferential process whereby **new models** are developed from analysis of multiple data sets to explain observed patterns across a range of time and space scales*

- Taking disparate streams of data and unifying them in a framework where they can be collectively analyzed
- Using multiple lines of evidence and causal inference to draw conclusions about cumulative effects of restoration for salmon



Photo: Frank James, Nooksack River Delta

Causal Criterion	Description
Strength of association	Magnitude of the effect
Consistency of association	Consistent direction of the effect documented by multiple observers
Biological Plausibility	Knowledge of the mechanism
Biological gradient	Gradient in the cause and response level
Experimentation	Manipulation of the cause
Specificity of association	Limited to specific sites and effects
Temporality	Effect follows the cause
Analogy	Comparison to similar systems
Coherence	Lack of conflict between cause-and-effect interpretation and known facts
Complete exposure pathway	Cause can reach the receptor
Predictive performance	Prediction of restoration outcome

