How do we measure positive change in urban seas?

An example using cumulative effects evaluation for salmon habitat restoration from Washington, USA

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PICES Annual Meeting 2025
Yokohama, Japan

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TULALIP TRIBES

NOAA FISHERIES

CRAMER FISH SCIENCES
An Employee Owned Consulting Company

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Science of the Anthropocene

2022

COMMENTARY | DECEMBER 16 2022

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

Collections: Knowledge Domain: Ocean Science

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Split-Screen Views

Sobocinski et al. 2025

frontiers | Frontiers in Marine Science

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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]

Urban Seas

Urban Seas are coastal estuaries and marginal seas with drainage basins that are extensively developed and populated by humans…Urban seas are a nexus of anthropogenic change, where global climate change intersects with urbanization, as well as ***being living laboratories for generating solutions for decelerating the Anthropocene.***

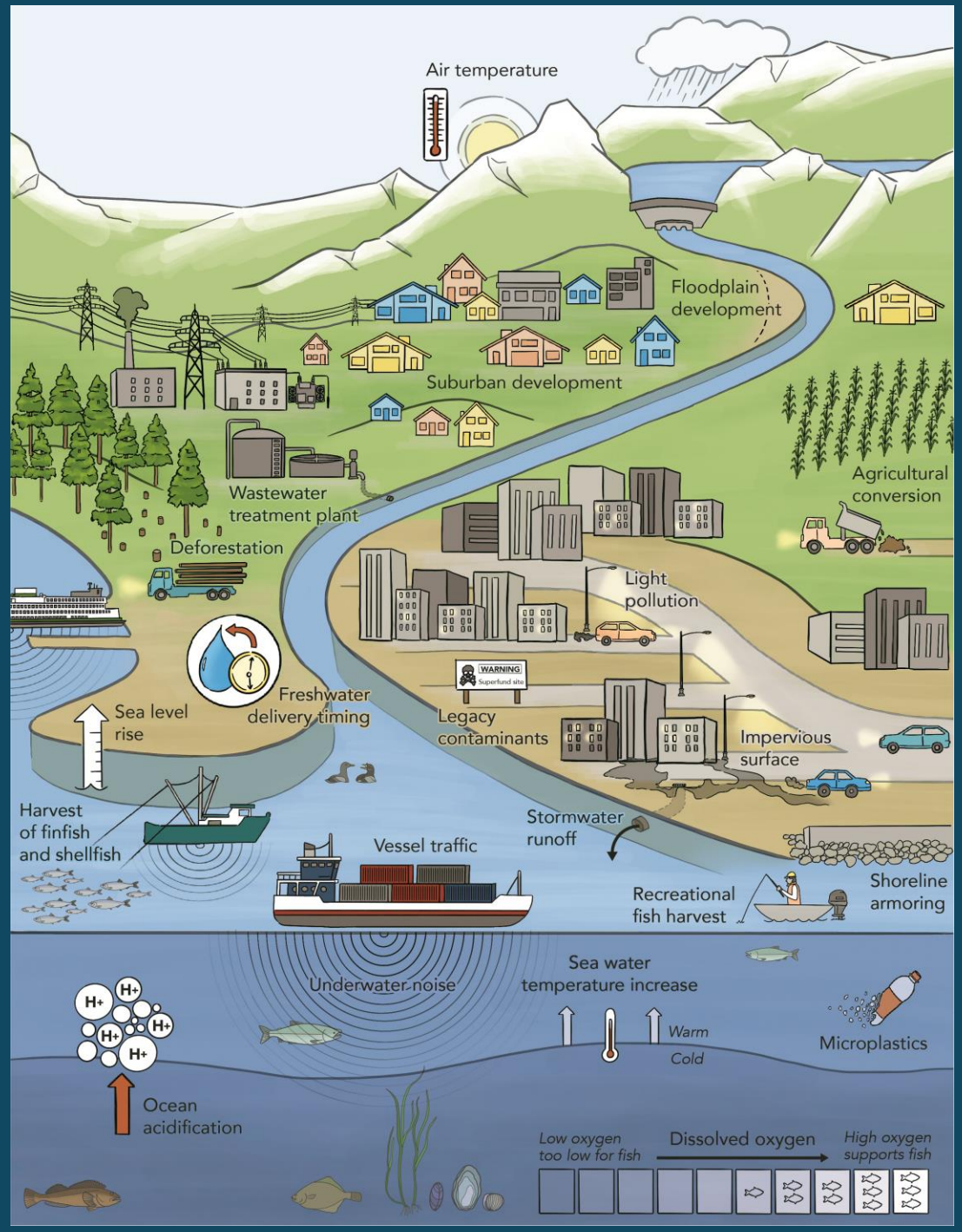
Sobocinski et. al. 2022

From Hodgson et al. 2020


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
N. Gulf Islands
Vancouver Island
Vancouver
Fraser River
Nooksack River
MOUNT BAKER
S. Gulf Islands
San Juan Islands
Victoria
Skagit River
Strait of Juan de Fuca
Cascade Range
Olympic Peninsula
Seattle
Sound
Puyallup River
Olympia
MOUNT RAINIER
CANADA
USA
Map created by Aquila Flower, 2020. Data from USGS, NOAA, NASA, Natural Resources Canada, and Natural Earth.

Salish Sea: Unique in Oceanography, But Not in Stressors and Impacts

Pressures are Relentless and Growing as Legacy, Continuing, and Emerging Impacts Converge



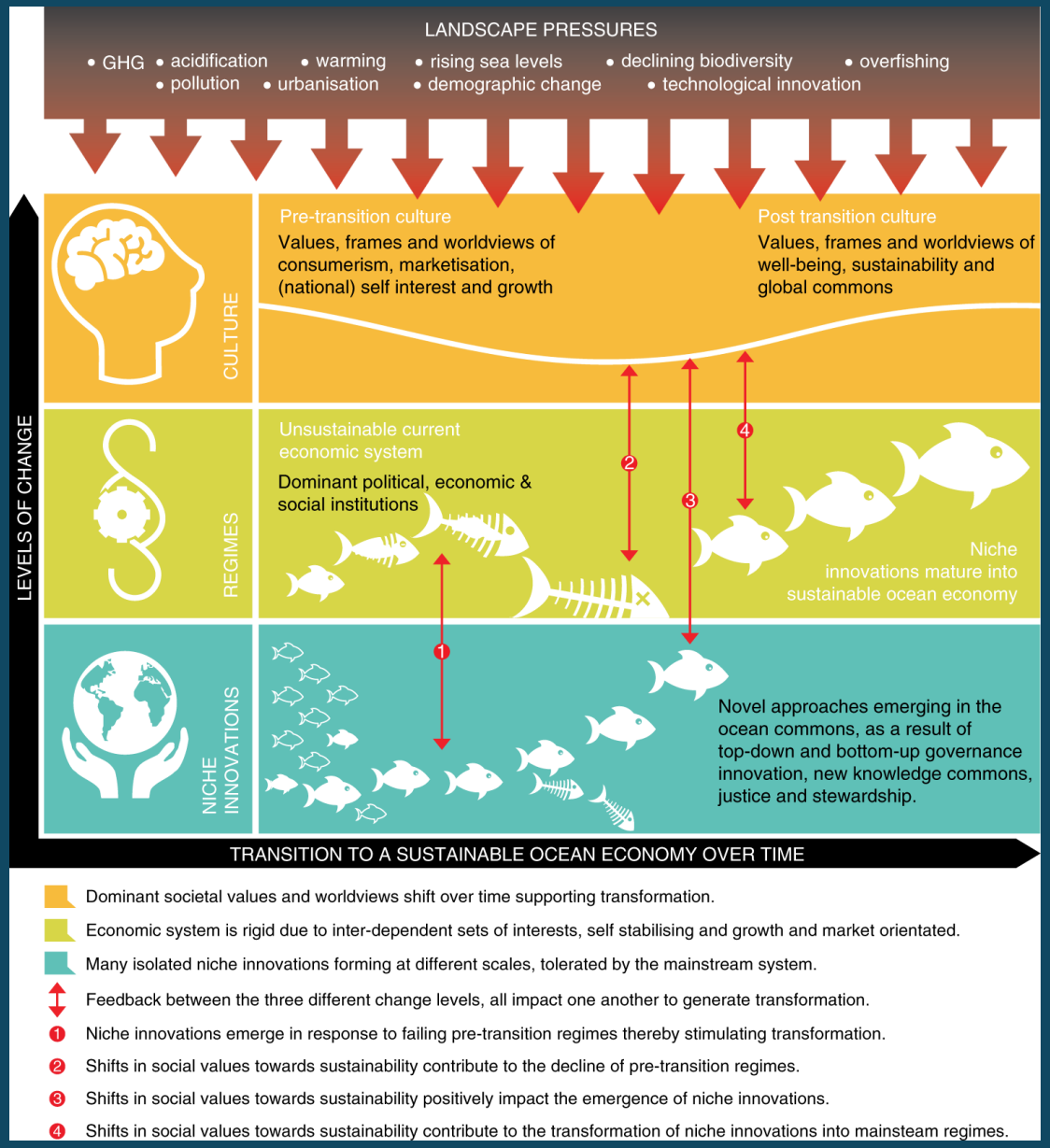
Environmental Scientists: Very Good at Problem Identification

But to change the trajectory, we need solutions.
In open systems, “solutions” are challenging.

Solution: Systems Thinking

Data collection, curation, and integration using a systems approach in science and management

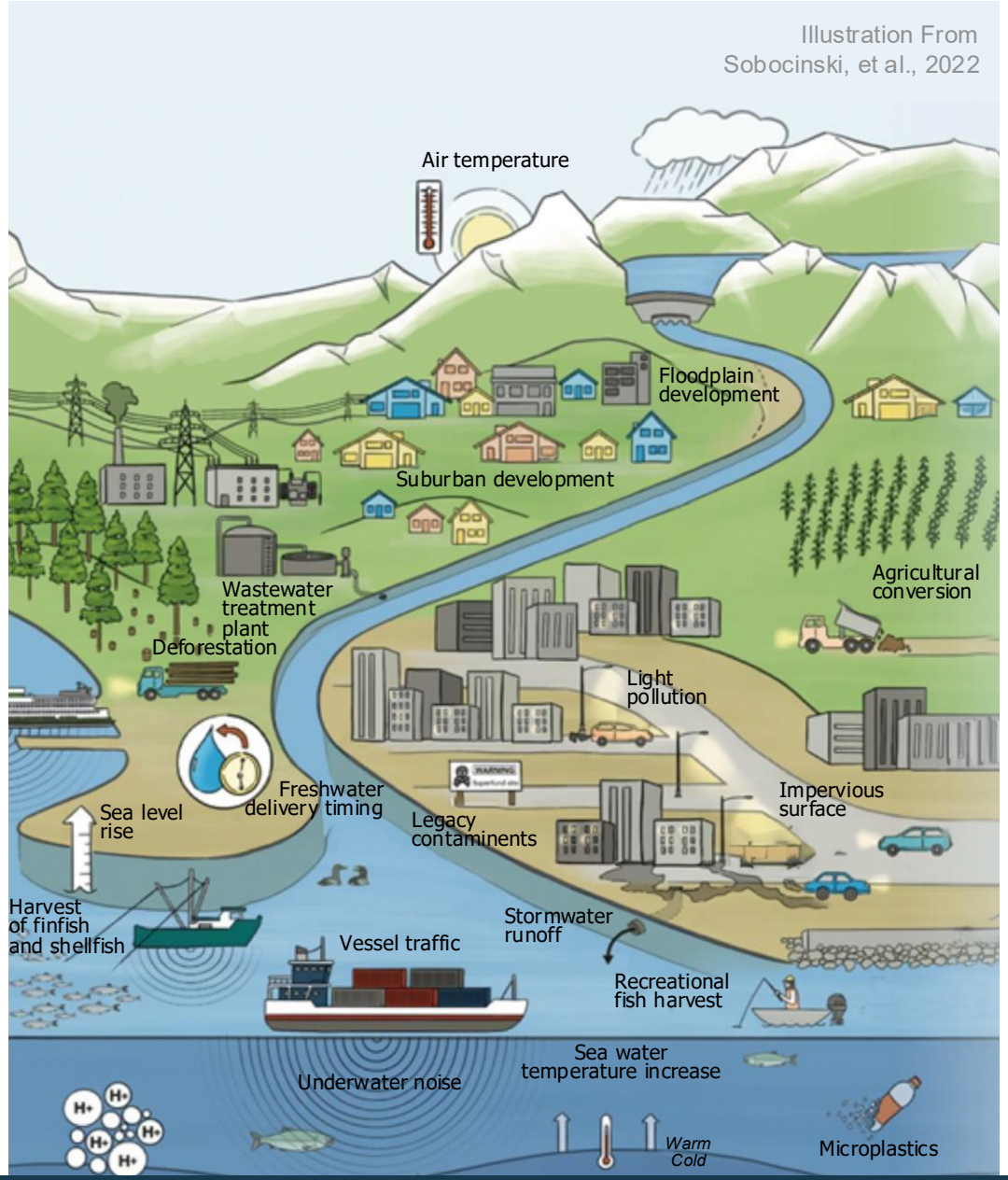
Sobocinski et al. 2022



Rudolph et al. 2020, Nature Communications

EACH PROCESS CAN BE CHARACTERIZED

- WEATHER CLIMATE
- SEA LEVEL STORM FLOODING
- STORM & WASTE H2O' MANAGEMENT
- PORT OPERATIONS SUPPLY CHAIN
- POLLUTION ALL FORMS
- "REAL-TIME" DATA FLOW
- CIRCULATION OF MARINE SECTOR
- EDUCATION OUTREACH



BY A DIGITAL TWIN MODULE

- HAZARDS NATURAL MAN MADE
- POWER GENERATION: C-NEUTRAL
- FISHING INDUSTRY & RECREATION
- MANUFACTURING INPUT OUTPUT
- AGRICULTURE AQUACULTURE
- BUILT ENVIRONMENT SMART CITY
- COMMUNITY OWNERSHIP POPULATION HEALTH
- FOREST MANAGEMENT

FULL URBAN SEA SYSTEM DIGITAL TWINS WILL COMPRISE ALL INTERACTING MODULES

Solution: Ecosystem Restoration

Restoration of areas with characteristics of success but history of impacts

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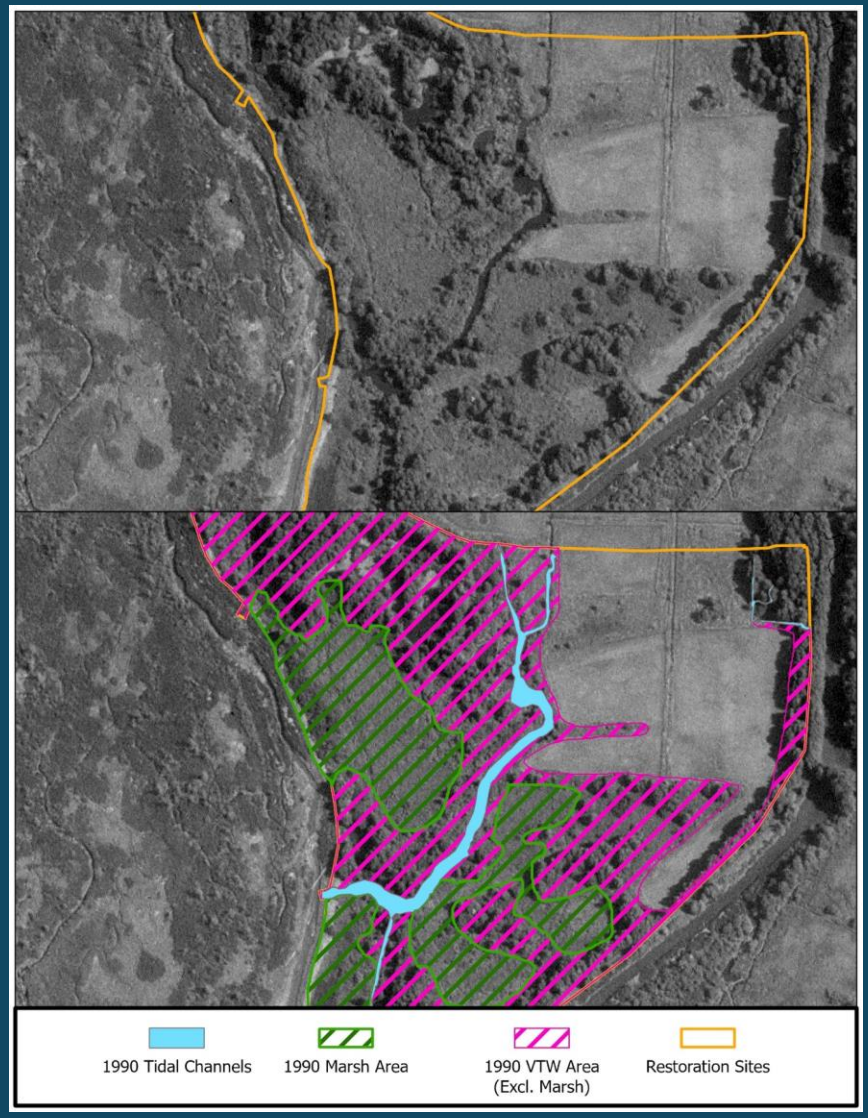
Opening habitat access for outmigrating juvenile salmon

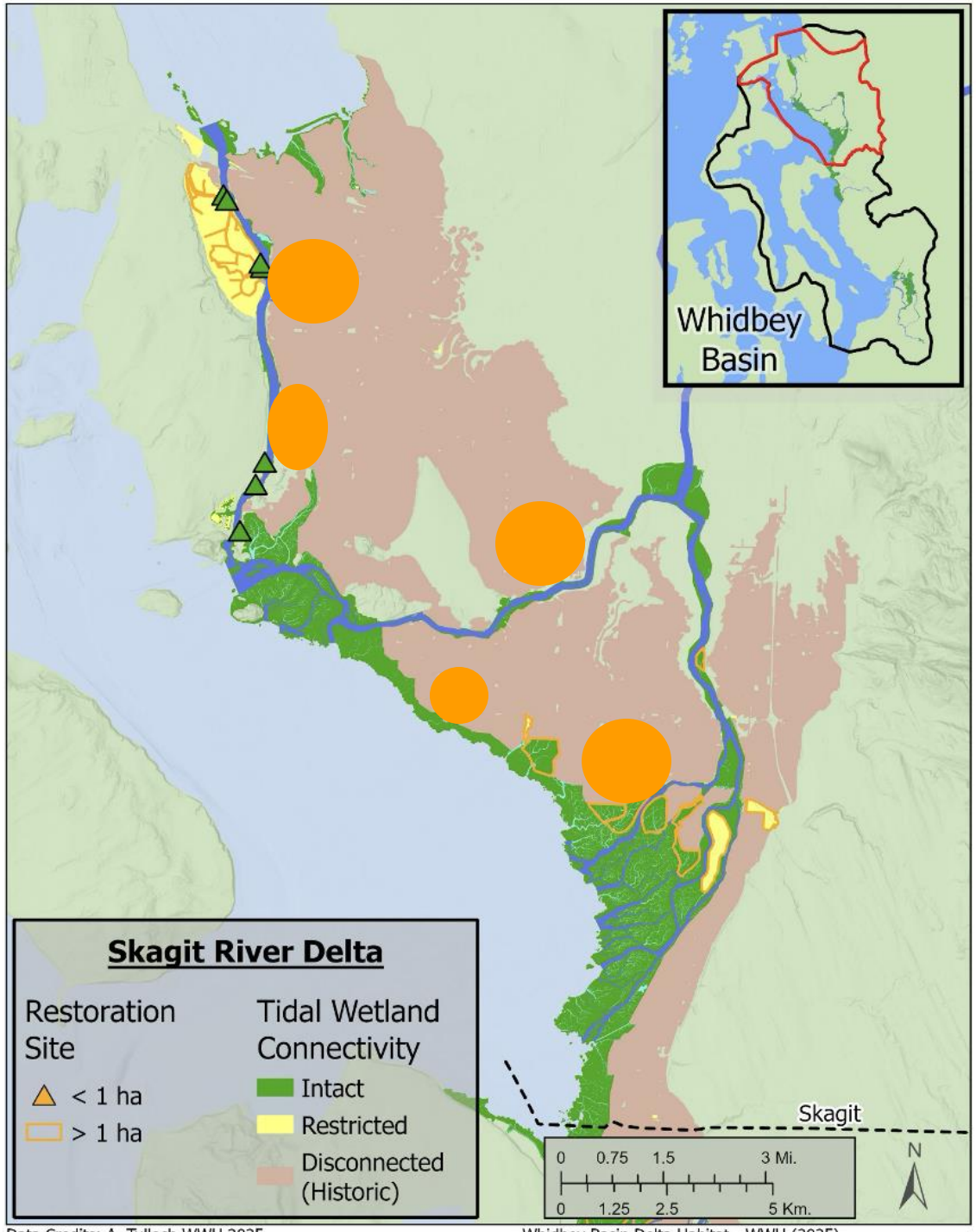


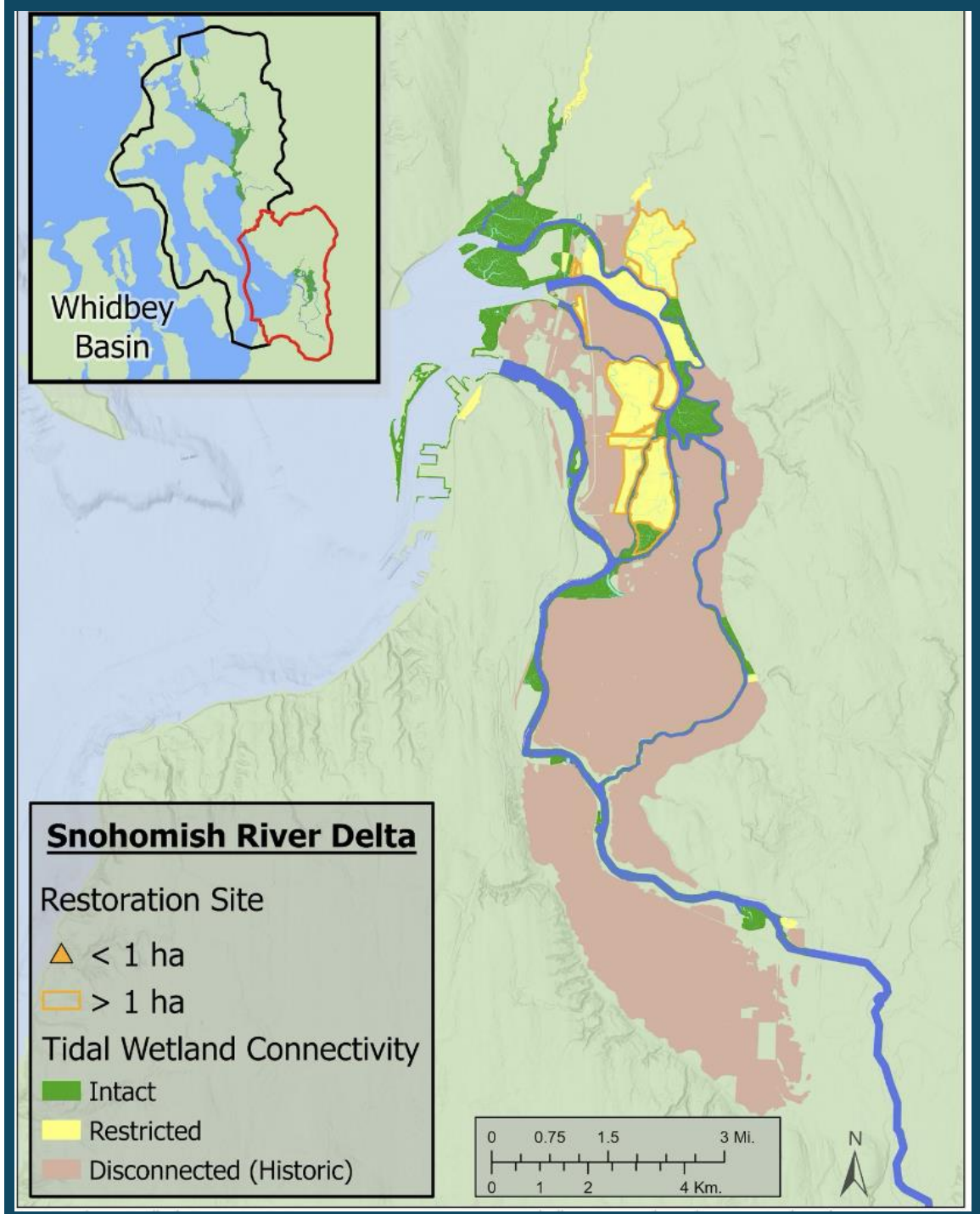
Restoration is Opportunistic and Piecemeal

Map: TNC


Photo: Seattle Times

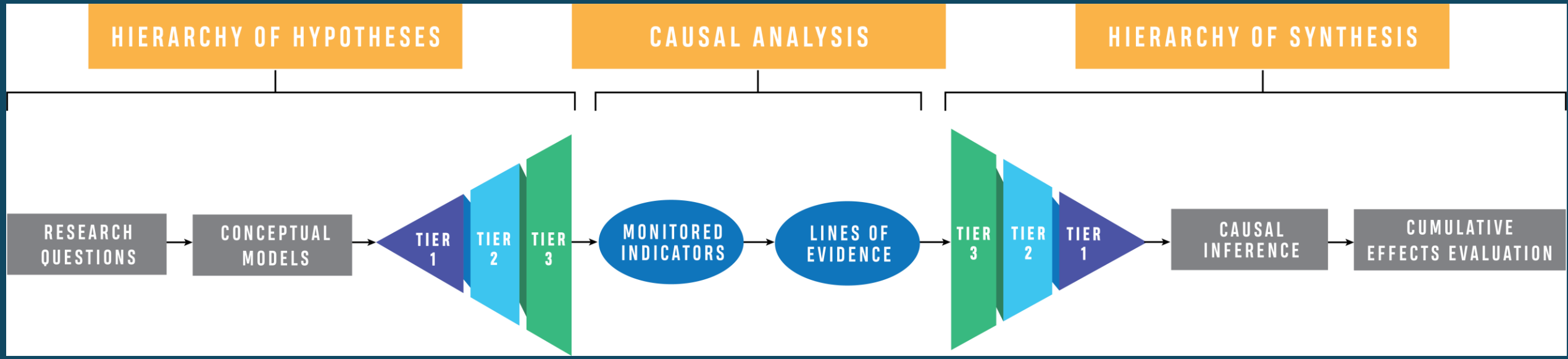
Calls for an Integrated Approach to Assessment


Whidbey Basin
Skagit River Delta
Restoration Site
< 1 ha
> 1 ha
Tidal Wetland Connectivity
Intact
Restricted
Disconnected (Historic)
Skagit
0 0.75 1.5 3 Mi.
0 1.25 2.5 5 Km.
N


Whidbey Basin
Snohomish River Delta
Restoration Site
< 1 ha
> 1 ha
Tidal Wetland Connectivity
Intact
Restricted
Disconnected (Historic)
0 0.75 1.5 3 Mi.
0 1 2 4 Km.
N

The Problem:
Detecting a restoration signal in a sea of noise

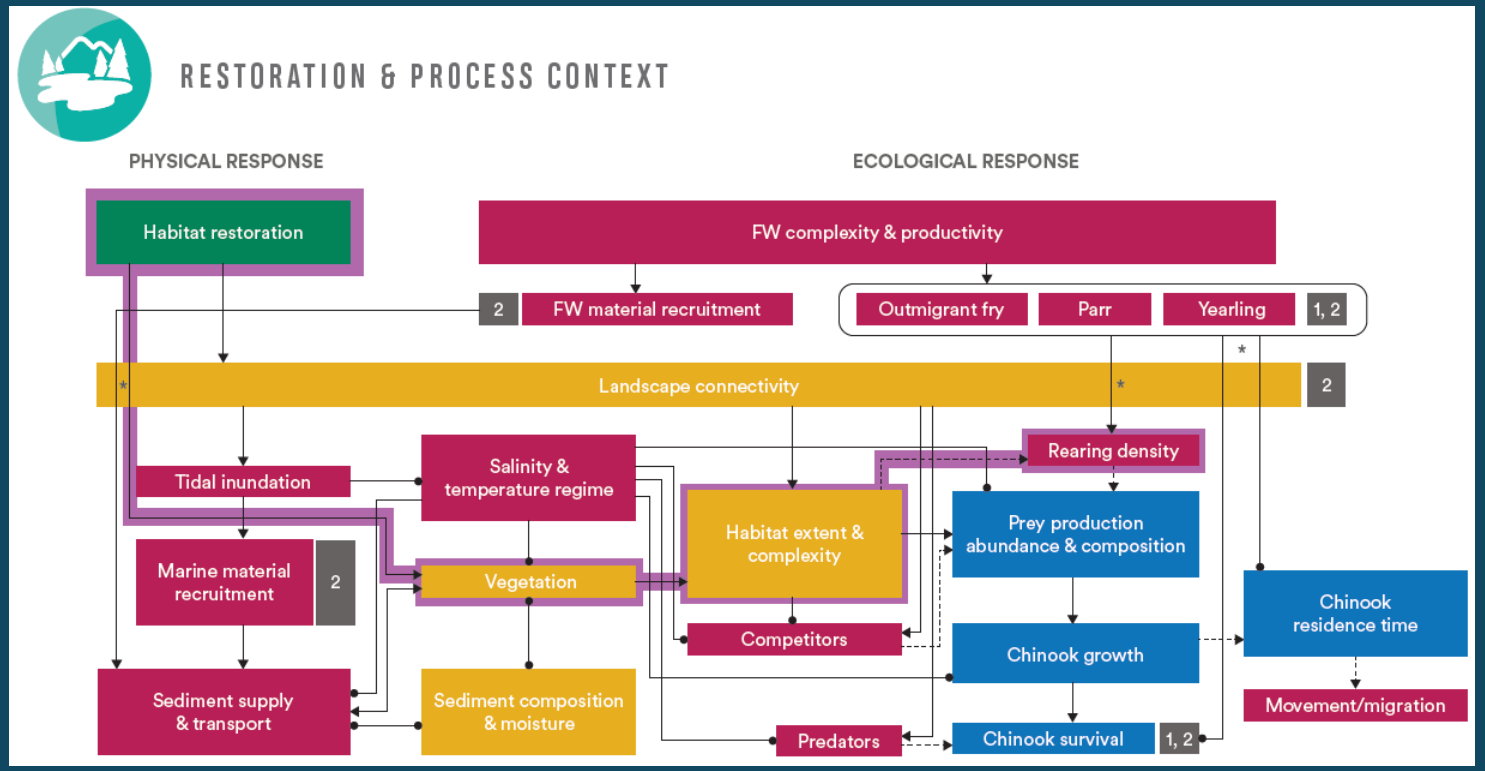
Cumulative Effects Evaluation Framework



Sobocinski et al. 2025

Hierarchy of Hypothesis: A Bottom-Up Approach

Hypothesis: *Restoration creates reference-condition-like habitat structure that increases juvenile Chinook salmon rearing density.*



Habitat restoration

↓

Vegetation Structure, Habitat Extent & Complexity

↓

Juvenile Chinook Rearing Density

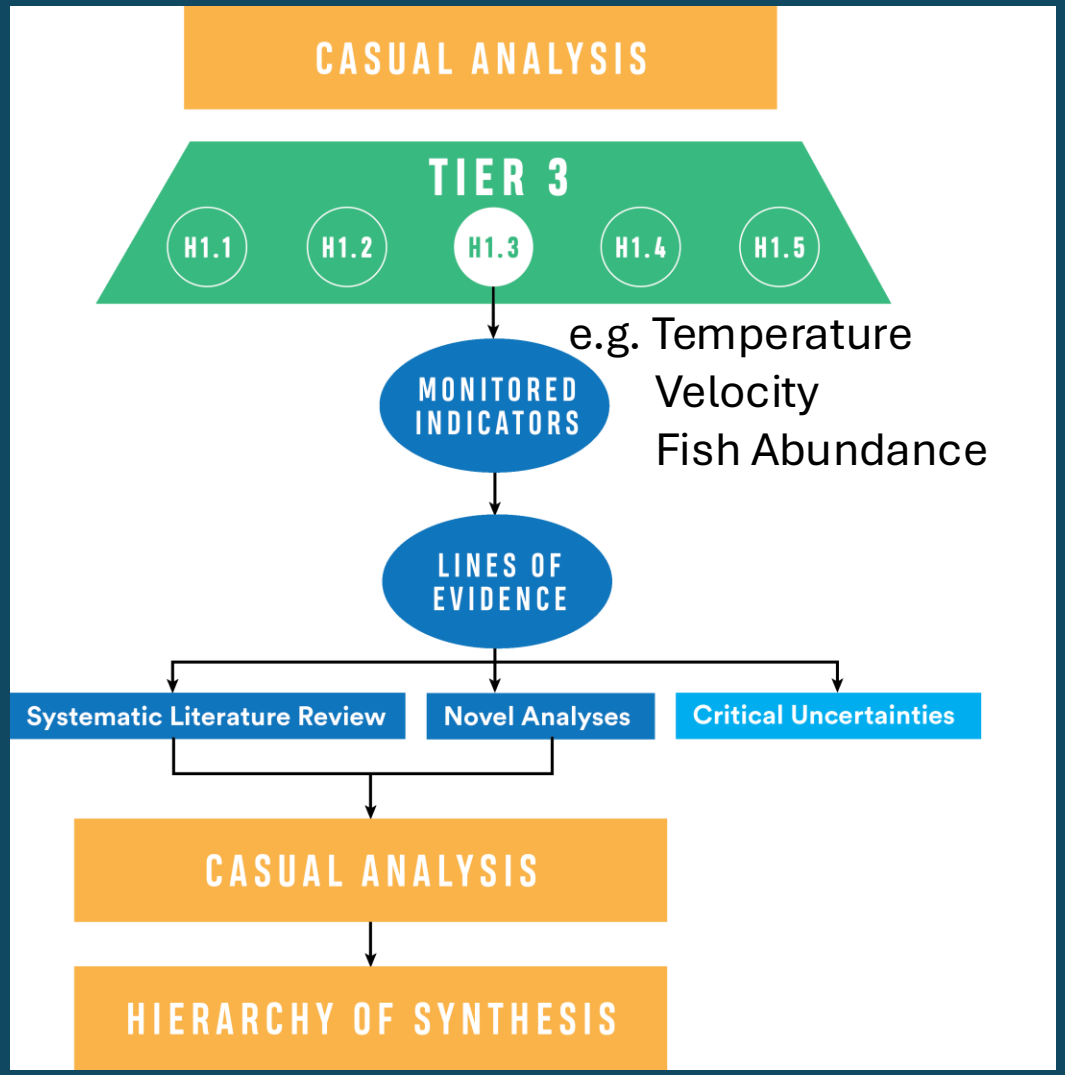
Hypothesis “Testing” Using Causal Analysis

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
3. Synthesize scores and provide overall support for higher order hypotheses using causal inference

Causal Analysis

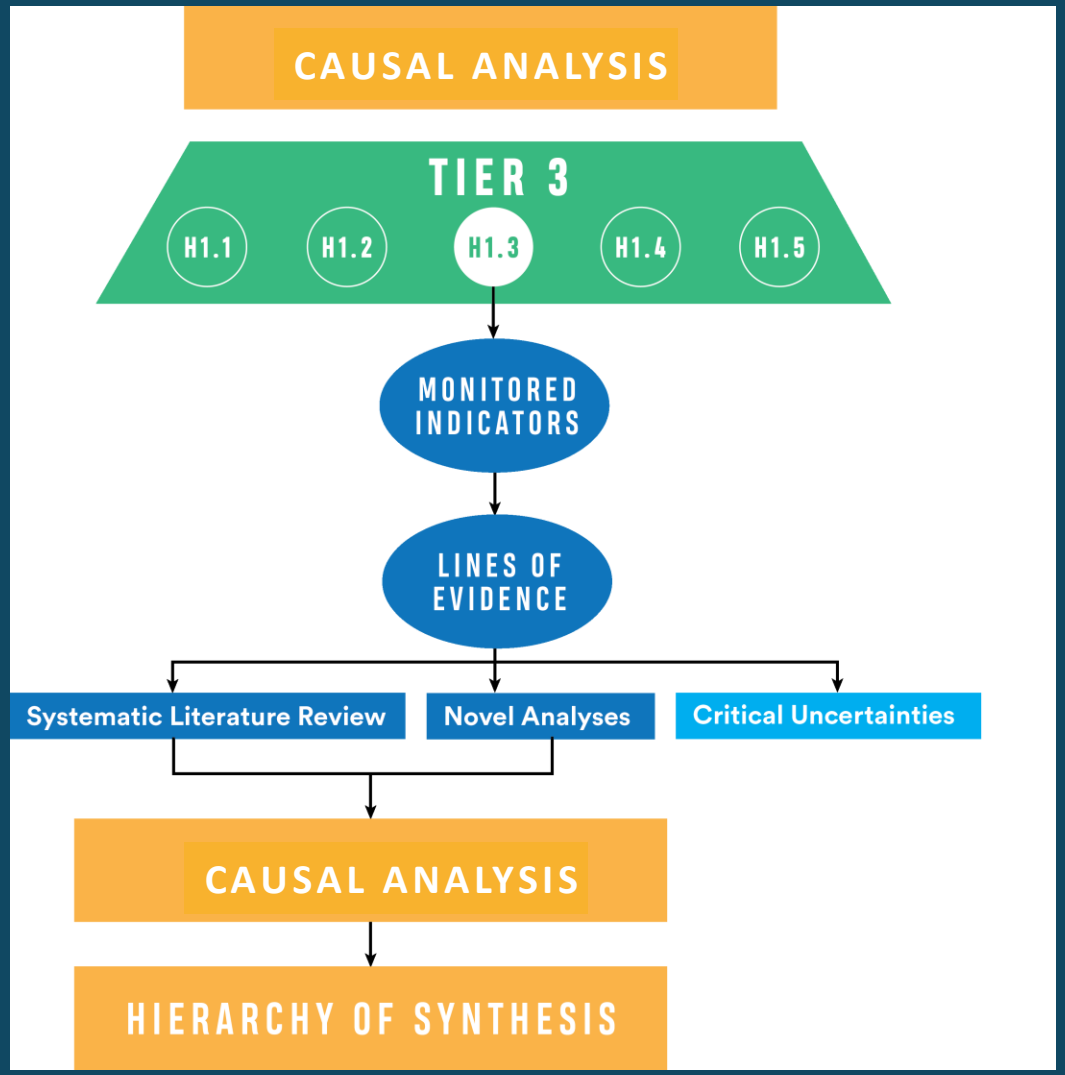
Breaks down cause-and-effect relationships into relatable things

- If X causes Y, then:
  - X is known to influence Y
  - X and Y must co-occur in space
  - X must precede Y
  - If X is removed, Y does not occur



Causal Criteria

- Strength and consistency of association
- Biological plausibility
- Biological gradient
- Experimentation
- Specificity of association
- Temporality
- Analogy
- Coherence
- Complete exposure pathway
- Predictive performance



From Diefenderfer et al. 2016, Adapted from Hill 1965

ID	Hypotheses	Evidence Based Literature Review	Meta Analysis	Empirical Analysis	Spatial Analysis	Modeling
H1.0 Habitat Structure: Restoration increases available habitat and improves habitat structure.						
1.1	Restoration increases available rearing habitat.	2 (NA) n=1	2 (NA) n=1	NA	2.86 (0.38) n=7	NA
1.2	Restoration increases habitat availability unevenly among habitat types and/or watersheds.	NA	NA	NA	2.5 (0.58) n=4	NA
1.3	The effect of restoration on habitat structure is contingent upon a site's location in the Whidbey Basin.	NA	NA	NA	2 (0.63) n=6	NA
1.4	Restoration creates reference-condition-like habitat structure.	1 (NA) n=1	1 (NA) n=1	NA	NA	NA
1.5	Restoration-related effects on habitat structure change over time, trending toward a reference condition.	2 (NA) n=1	1 (NA) n=1	1.67 (0.94) n=3	1.25 (0.43) n=4	NA

Lines of Evidence

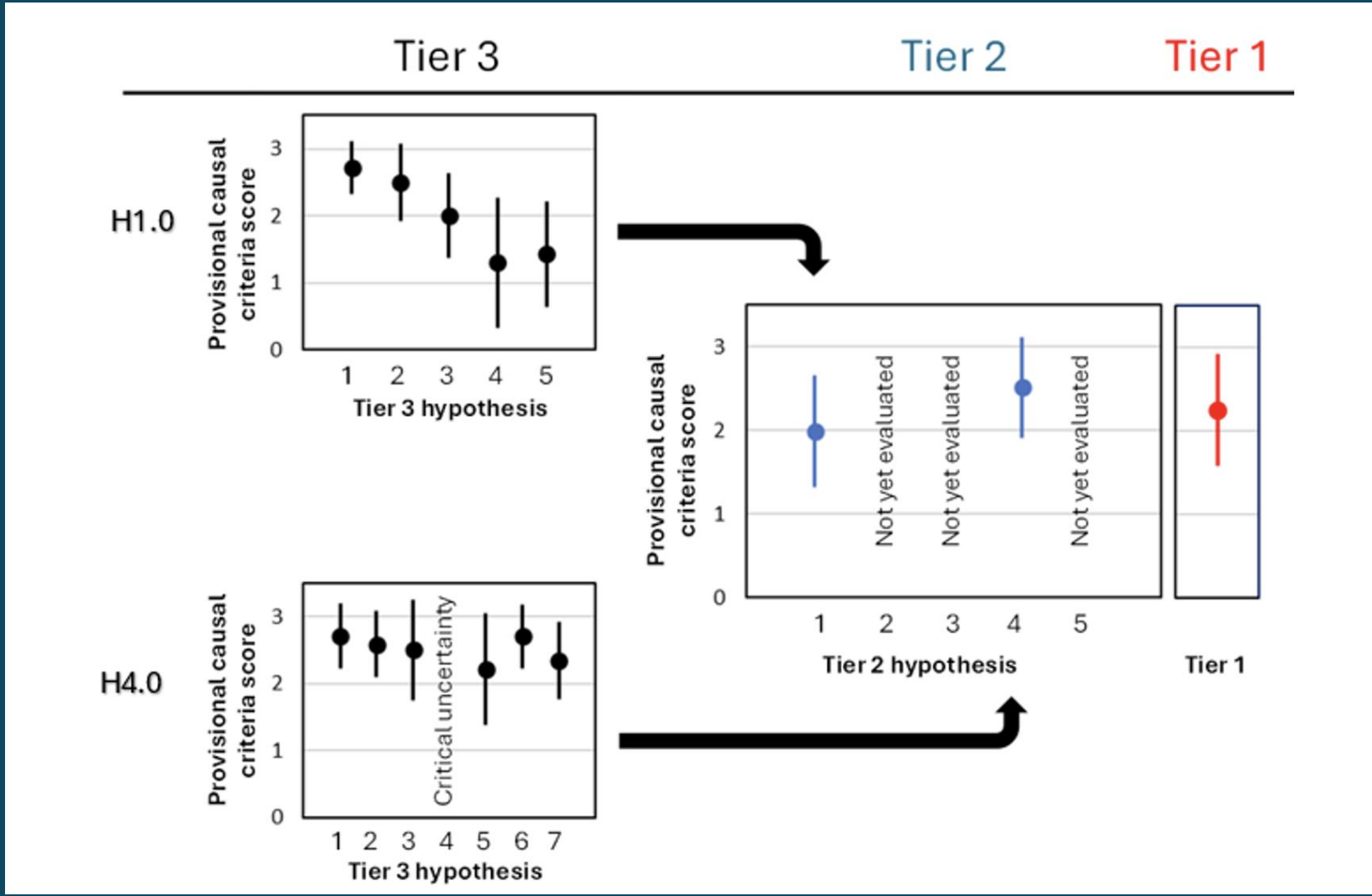
Assessment for Each Hypothesis

Scores from 0-3, with 3 being strong support

Causal Criteria Assessed Across all Lines of Evidence for Each Hypothesis

ID	Hypotheses	Strength of Assocation	Consitency	Biological Plausibility	Biological Gradient	Experimen-tation	Specificity of Association	Temporality	Analogy
1	Restoration increases available habitat and improves habitat structure.								
1.1	Restoration increases available rearing habitat.	2.5	2.5	3	3	NA	3	2	3
1.2	Restoration increases habitat availability unevenly among habitat types and/or watersheds.	3	2	3	NA	NA	2	NA	NA
1.3	The effect of restoration on habitat structure is contingent upon a site's location in the Whidbey basin.	2	2	3	1	NA	2	2	NA
1.4	Restoration creates reference-condition-like habitat structure.	1	0.5	3	NA	NA	1	NA	1
1.5	Restoration-related effects on habitat structure change over time, trending toward a reference condition.	1	1	3	NA	NA	1	2	1

Hierarchy of Synthesis



Synthesis in Ecology and Environmental Science

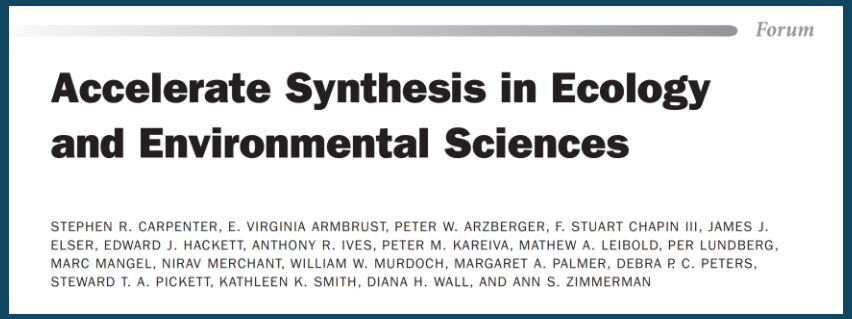
CEE is fundamentally a science synthesis analysis:

- 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

Solutions: Systems Thinking

Data collection, curation, and integration using a systems approach in science and management

Sobocinski et al. 2022


Forum

Accelerate Synthesis in Ecology and Environmental Sciences

STEPHEN R. CARPENTER, E. VIRGINIA ARMBRUST, PETER W. ARZBERGER, F. STUART CHAPIN III, JAMES J. ELSER, EDWARD J. HACKETT, ANTHONY R. IVES, PETER M. KAREIVA, MATHEW A. LEIBOLD, PER LUNDBERG, MARC MANGEL, NIRAV MERCHANT, WILLIAM W. MURDOCH, MARGARET A. PALMER, DEBRA P C. PETERS, STEWARD T. A. PICKETT, KATHLEEN K. SMITH, DIANA H. WALL, AND ANN S. ZIMMERMAN

Carpenter et al. 2009,
BioScience

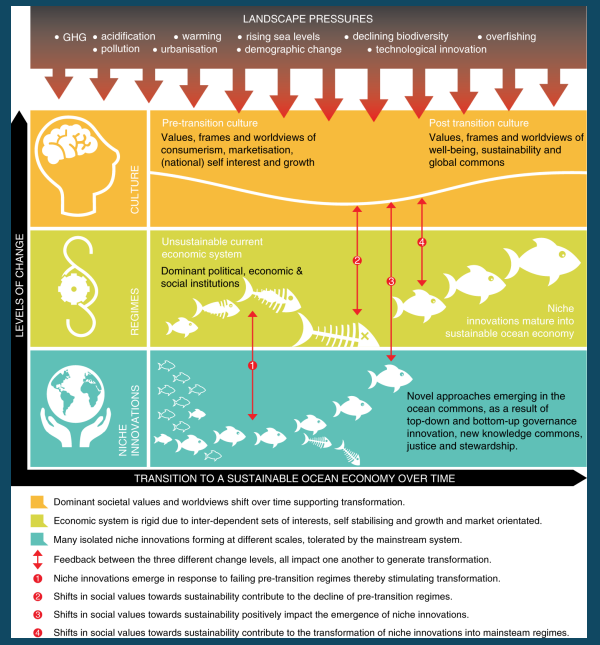

Estuaries and Coasts (2012) 35:1–22
DOI 10.1007/s12237-011-9464-9

THE H.T. ODUM SYNTHESIS ESSAY

Synthesis in Estuarine and Coastal Ecological Research: What Is It, Why Is It Important, and How Do We Teach It?

W. Michael Kemp · Walter R. Boynton

Kemp and Boynton 2012
Estuaries & Coasts



Rudolph et al. 2020
Nature Communications

Photo: Frank James, Nooksack River Delta

Science Synthesis

Synthesis in estuarine and coastal science:

*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*