

# Ecosystem Indicators Across the Seascape: Integrating Estuarine and Marine Processes to Understand Salmon Survival

KATHRYN L. SOBOCINSKI

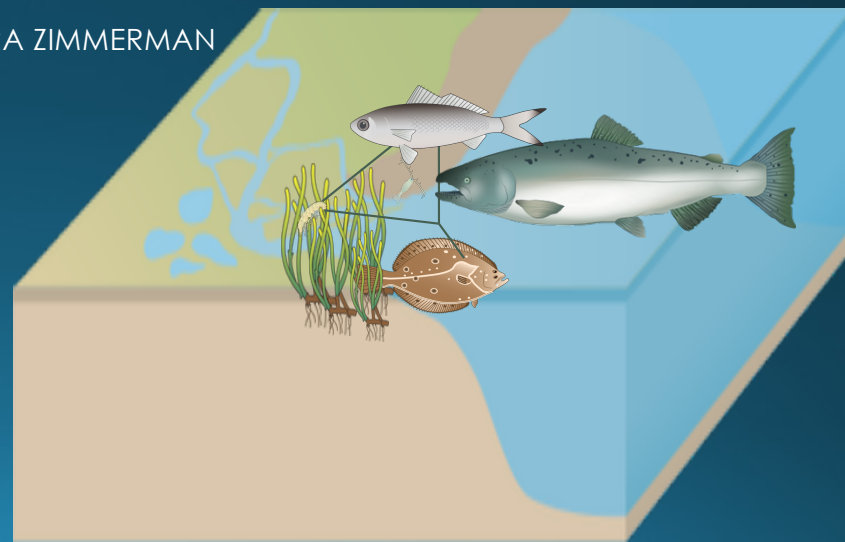


CORREIGH GREENE, MICHAEL SCHMIDT, NEALA KENDALL, JOE ANDERSON, MARA ZIMMERMAN



PSC

Introduction to Using Environmental Indicators  
May 11, 2021

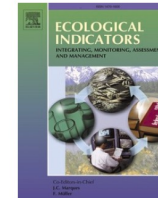




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## Ecological Indicators

journal homepage: [www.elsevier.com/locate/ecolind](https://www.elsevier.com/locate/ecolind)



### A hypothesis-driven statistical approach for identifying ecosystem indicators of coho and Chinook salmon marine survival

Kathryn L. Sobocinski<sup>a,b,\*</sup>, Correigh M. Greene<sup>a</sup>, Joseph H. Anderson<sup>c</sup>, Neala W. Kendall<sup>c</sup>, Michael W. Schmidt<sup>b</sup>, Mara S. Zimmerman<sup>c,d</sup>, Iris M. Kemp<sup>b</sup>, Su Kim<sup>a</sup>, Casey P. Ruff<sup>e</sup>

<sup>a</sup> National Oceanic and Atmospheric Administration, United States

<sup>b</sup> Long Live the Kings, 1326 5th Ave, #450, Seattle, WA 98101

<sup>c</sup> Washington Department of Fish and Wildlife, PO Box 40100, Olympia, WA 98512

<sup>d</sup> Coast Salmon Partnership, 100 South "I" Street, Everett, WA 98201

<sup>e</sup> Skagit River System Cooperative, 11426 Moorag Road, Skagit County, WA 98280

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## Progress in Oceanography

journal homepage: [www.elsevier.com/locate/pocean](https://www.elsevier.com/locate/pocean)



### Ecosystem indicators of marine survival in Puget Sound steelhead trout

Kathryn L. Sobocinski<sup>a,b,\*</sup>, Neala W. Kendall<sup>c</sup>, Correigh M. Greene<sup>a</sup>, Michael W. Schmidt<sup>b</sup>

# DECLINE IN MARINE SURVIVAL

Received: 31 August 2016 | Accepted: 29 March 2017  
DOI: 10.1111/fog.12222

## ORIGINAL ARTICLE

WILEY FISHERIES

### Salish Sea Chinook salmon exhibit weaker coherence in early marine survival trends than coastal populations

Casey P. Ruff<sup>1</sup> | Joseph H. Anderson<sup>2</sup> | Iris M. Kemp<sup>3</sup> | Neala W. Kendall<sup>2</sup> | Peter A. Mchugh<sup>2,4</sup> | Antonio Velez-Espino<sup>5</sup> | Correigh M. Greene<sup>6</sup> | Marc Trudel<sup>5,7</sup> | Carrie A. Holt<sup>5</sup> | Kristen E. Ryding<sup>2</sup> | Kit Rawson<sup>8</sup>

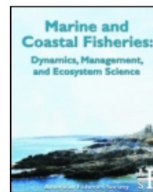


1275

## ARTICLE

### Declining patterns of Pacific Northwest steelhead trout (*Oncorhynchus mykiss*) adult abundance and smolt survival in the ocean

Neala W. Kendall, Gary W. Marston, and Matthew M. Klungle



## Marine and Coastal Fisheries

Dynamics, Management, and Ecosystem Science

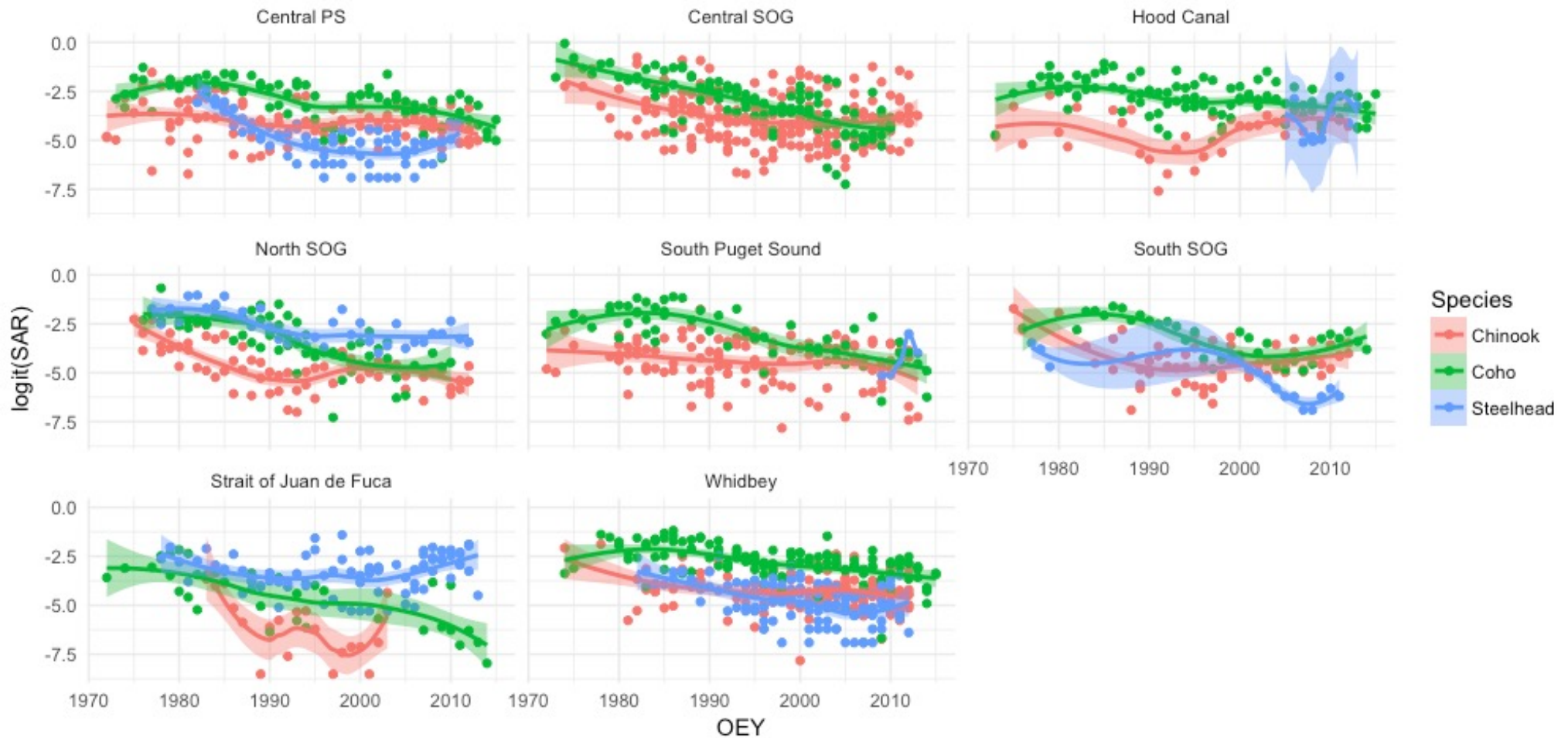


ISSN: (Print) 1942-5120 (Online) Journal homepage: <http://www.tandfonline.com/loi/umcf20>

### Spatial and Temporal Patterns in Smolt Survival of Wild and Hatchery Coho Salmon in the Salish Sea

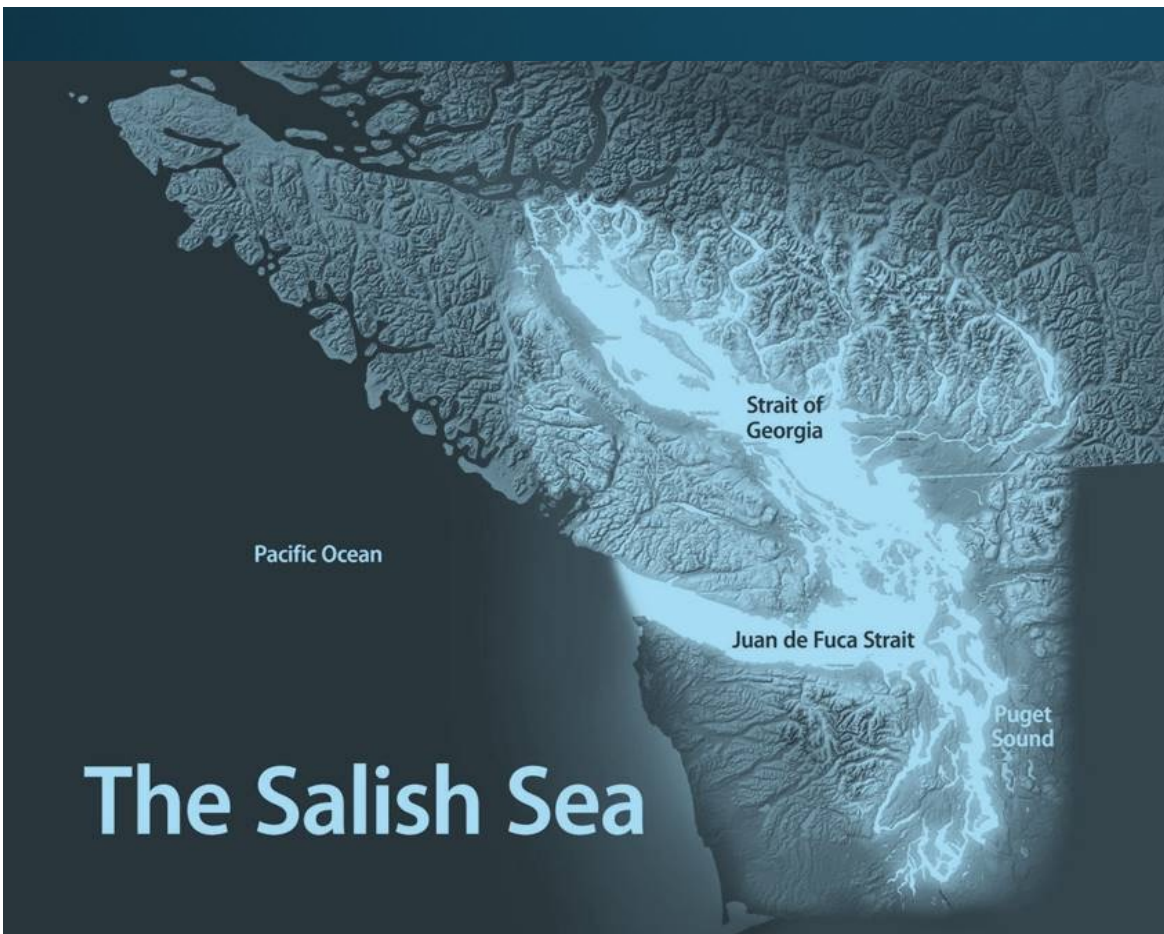
Mara S. Zimmerman, James R. Irvine, Meghan O'Neill, Joseph H. Anderson, Correigh M. Greene, Joshua Weinheimer, Marc Trudel & Kit Rawson

# DOWNWARD TRENDS WITH HIGH VARIATION



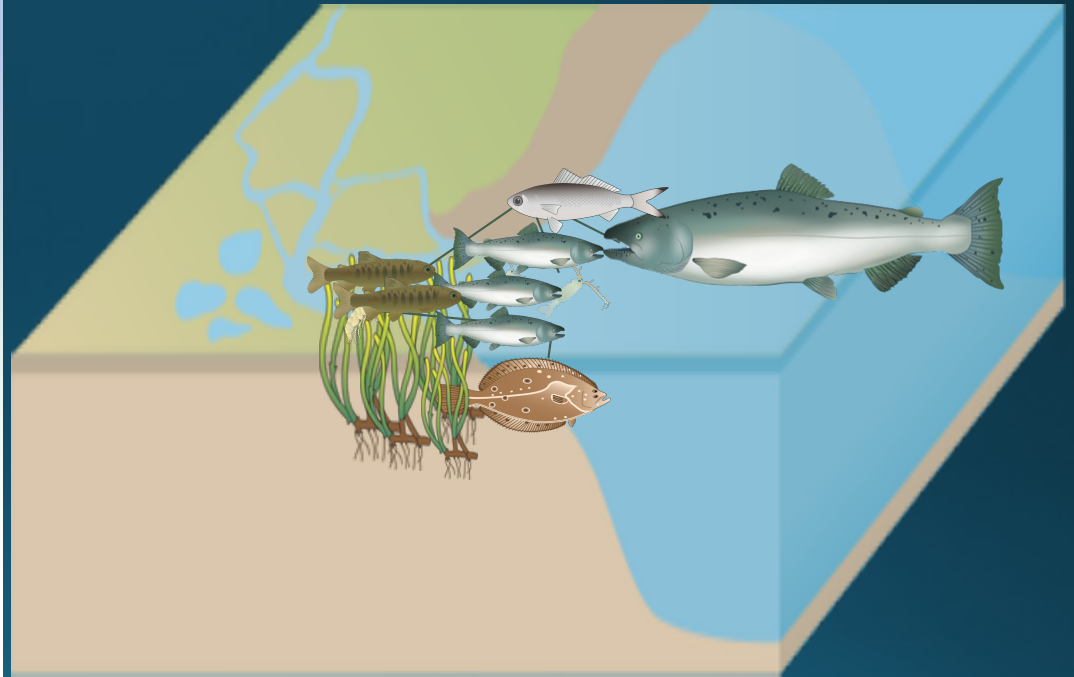
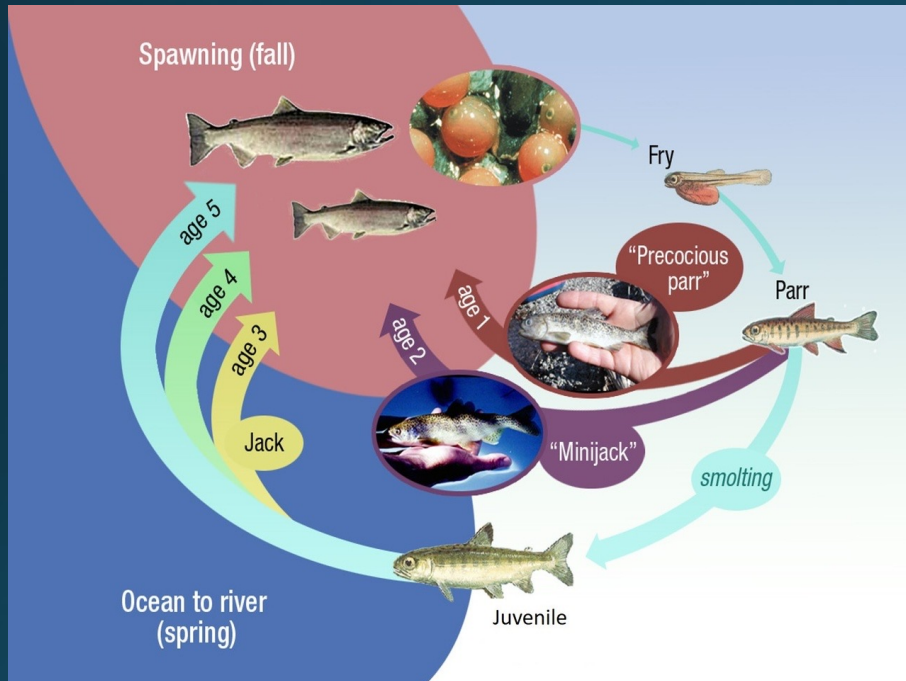


# ECOSYSTEM INDICATORS ACROSS THE SEASCAPE



What factors influence marine survival in coho and Chinook salmon and steelhead trout?

# SALMON AS ECOSYSTEM INTEGRATORS



<https://www.fisheries.noaa.gov/west-coast/science-data/pacific-salmon-life-history-research>

# OVERARCHING HYPOTHESES ABOUT SALMON SURVIVAL

1. Bottom-Up
2. Top-Down
3. Anthropogenic and Cumulative Effects



THE PROJECT

RESEARCH ACTIVITIES

RESOURCES

PARTNERS

NEWS

DONATE

## KEY HYPOTHESES

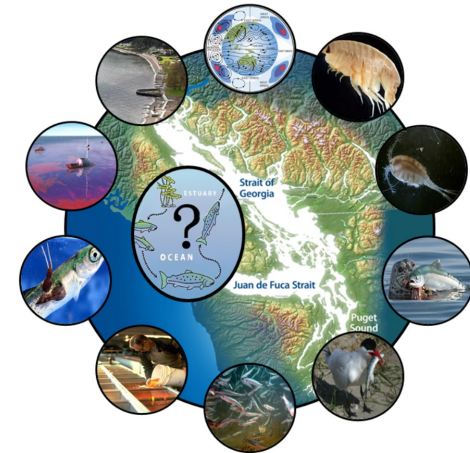
What do we think is going on?

We appreciate the complexity of ecosystems: how multiple factors may be interacting and contributing to the fate of juvenile salmon and steelhead in the Salish Sea. To address this, we convened scientists from U.S. and Canada to develop a comprehensive, multi-disciplinary, and highly coordinated research program at an ecologically relevant scale – [the entire Salish Sea](#).

### The scientists concluded the key hypotheses are, in order:

1. Bottom-up processes—including weather, water, and plankton—that drive juvenile Chinook, coho and forage fish prey availability have changed, and salmon aren't able to compensate. This is limiting salmon growth and survival.
2. Top-down processes have also changed. Primarily, there are more predators eating steelhead, resident salmon and larger forage fish.
3. Additional factors are exacerbating these ecological shifts, including toxics, disease, competition, and the cumulative effect of significant top-down and bottom-up shifts occurring simultaneously.

[Click here for a comprehensive list of hypotheses and their assessment status](#)



# POTENTIAL INDICATORS

## Boundary Conditions

- Freshwater (e.g., spring river discharge, timing of max flow, day of year of cumulative flow at 25/50/75%)
- Ocean (e.g., temperature, upwelling index, sea level)
- Atmosphere/Climate (e.g., multivariate ENSO index, NPGO, PDO, NPI)

## Salish Sea Conditions

- Temperature, salinity, primary production, stratification, zooplankton

## Predators and Competitors

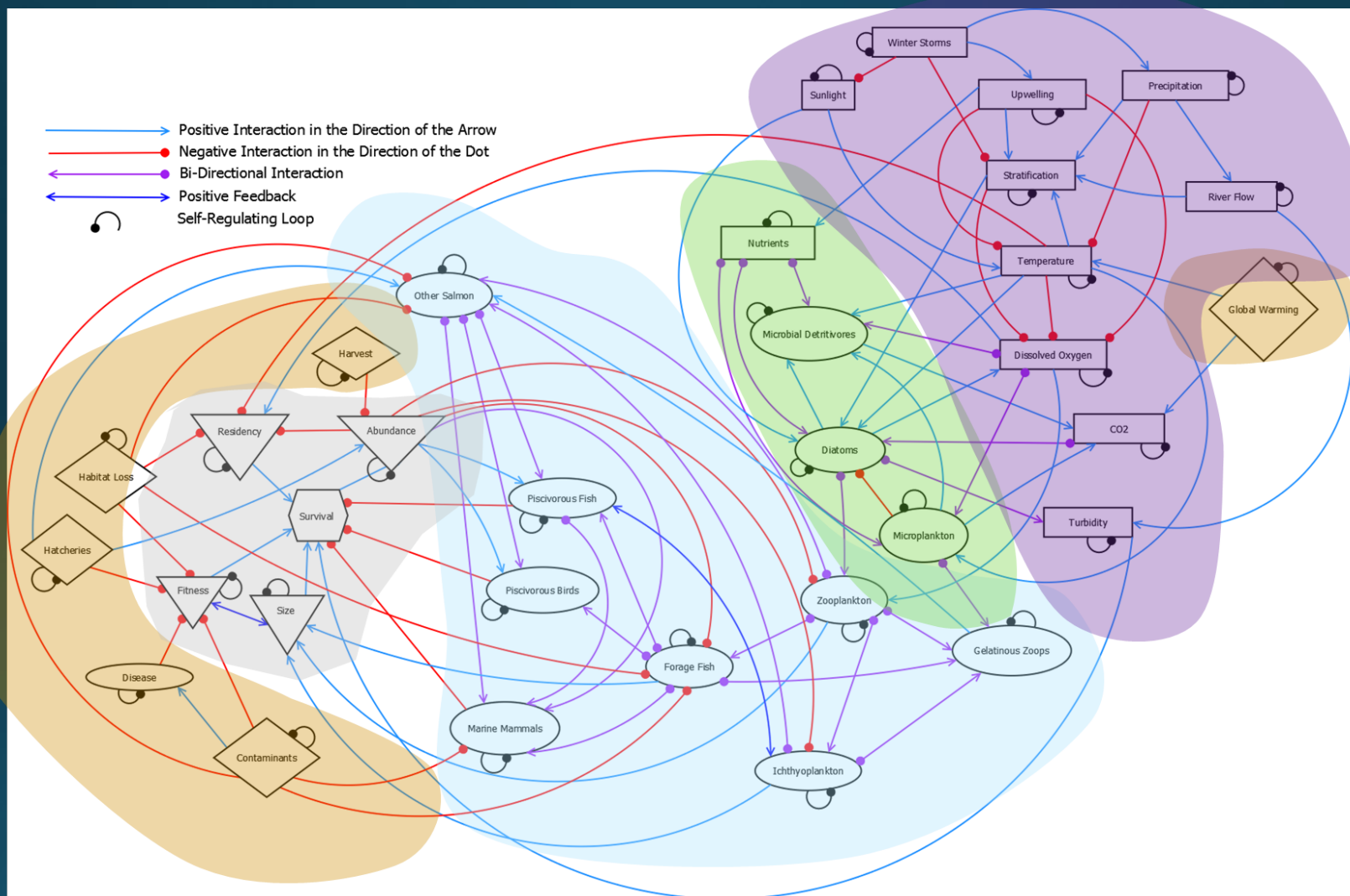
- Forage fish abundance, birds, finfishes, pinnipeds, other mammals

## Anthropogenic Impacts

- Harvest, Contaminants, Habitat Loss

## Salmon Characteristics

- Abundance of outmigrants in the system, including hatchery releases
- Timing of outmigration
- Size/Growth





# INDICATORS

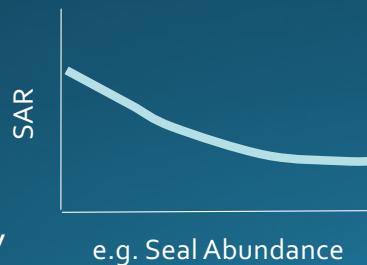
Indicators should be:

- Theoretically sound
- Respond predictably to ecosystem change
- Integrative
- Relevant to management concerns

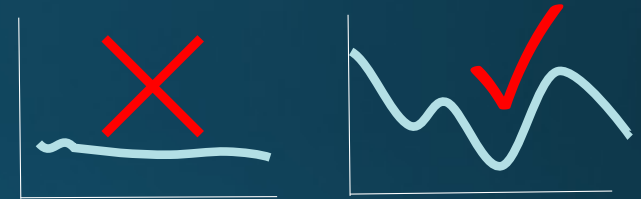
## Hypothesis-driven

H<sub>1</sub>: Predation

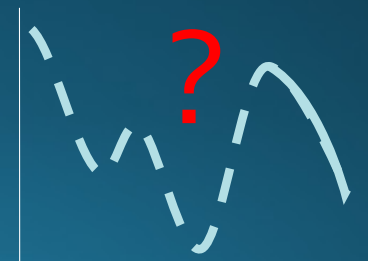
-Increases in marine mammals increase early marine mortality



Changing over time

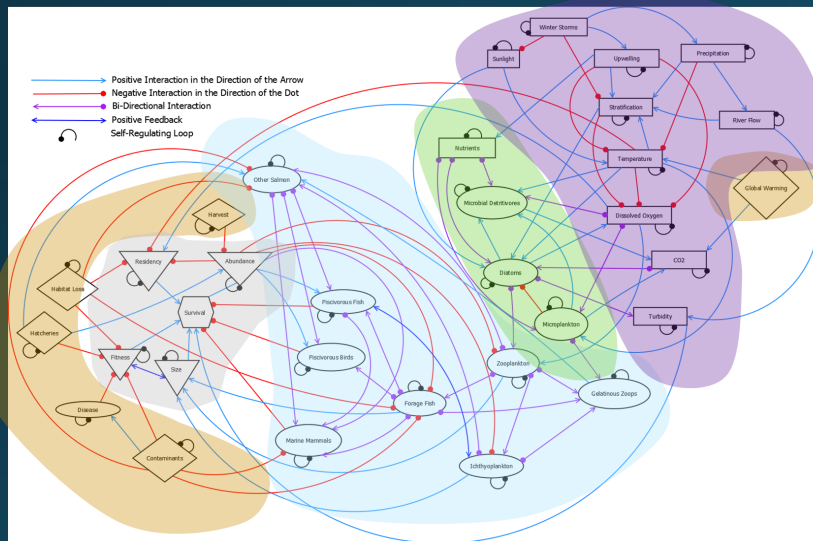


Available



(Niemeijer and de Groot 2008, O'Neill et al. 2008, Kershner et al. 2011)

# CONCEPTUAL FRAMEWORK AND HYPOTHESES



$$Y = \theta_0 + \theta_1 X_1 + \theta_2 X_2 + \dots + \theta_n X_n + \varepsilon$$

# RELEVANT SCALES FOR POTENTIAL INDICATORS

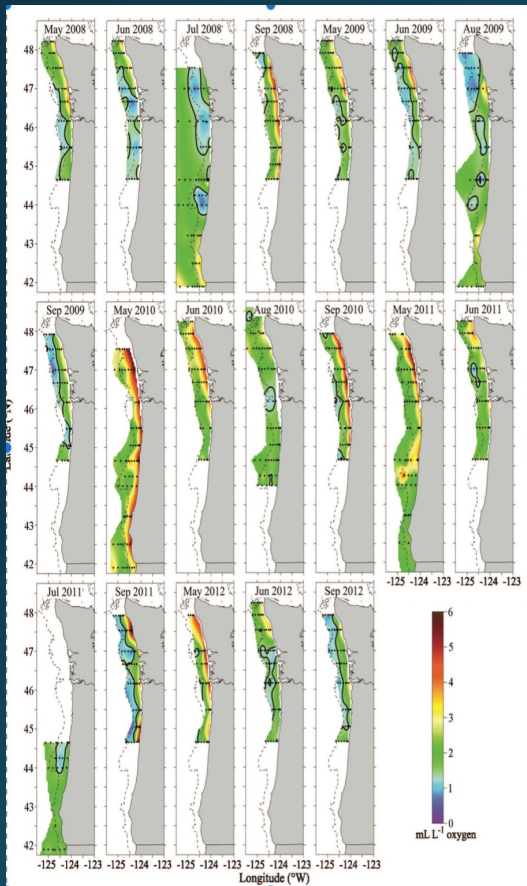
Local, Regional, and Global\* Indicators

\*Global=N. Pacific Ocean



<https://faculty.washington.edu/pmacc/LO/LiveOcean.html>

# GLOBAL AND REGIONAL CONDITIONS INFLUENCE LOCAL CONDITIONS



Estuaries and inland waters, like the Salish Sea, are influenced by larger scale ocean processes that are continually changing

Anthropogenic impacts locally can impact fish beyond the inland waters

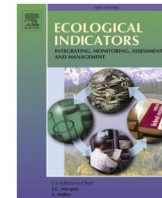
From Peterson et al. 2013



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<sup>a</sup> National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112, United States

<sup>b</sup> Long Live the Kings, 1326 5th Ave, #450, Seattle, WA 98101, United States

<sup>c</sup> Washington Department of Fish and Wildlife, PO Box 43200, Olympia, WA 98504-3200, United States

<sup>d</sup> Coast Salmon Partnership, 100 South "I" Street, Suite 103, Aberdeen, WA 98520, United States

<sup>e</sup> Skagit River System Cooperative, 11426 Moorage Way, La Conner, WA 98257-0368, United States



## COHO AND CHINOOK HYPOTHESES

### **H1: Predator Buffering (Abundance)**

-Abundance of fish in the system mitigates predation

### **H2: Predator Buffering (Timing)**

-Release timing of hatchery fish determines relative mortality

### **H3: Food Availability and Competition (Density-dependent)**

-A scarcity of prey and an abundance of predators (salmon and forage fishes) results in low SAR

### **H4: Food Availability Timing (Density-independent)**

-Production of prey is driven by physical conditions and a mismatch in timing of production and outmigration leads to low SAR

### **H5: Water Quality**

-Salish Sea and ocean conditions may be unfavorable

### **H6: Water Delivery Timing**

-The timing of FW delivery to the nearshore and the spring transition on the coast determine year class success

### **H7: Anthropogenic Impacts**

- Impacts of human population, including harvest, negatively impact survival

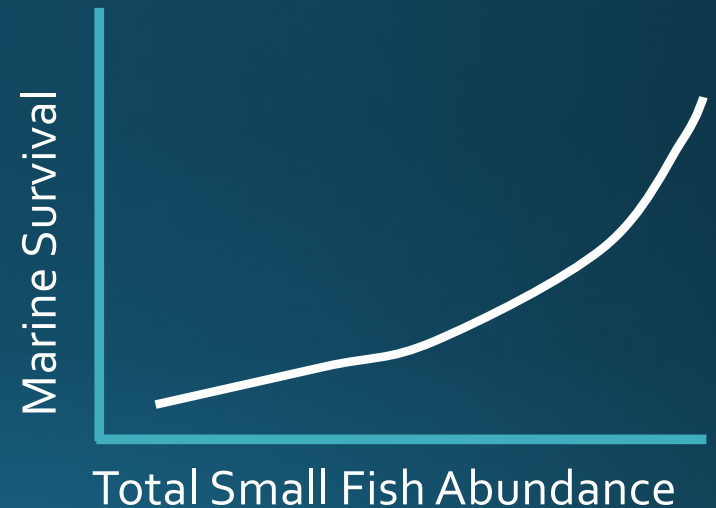
## Example

### H1: Predator Buffering (Abundance)

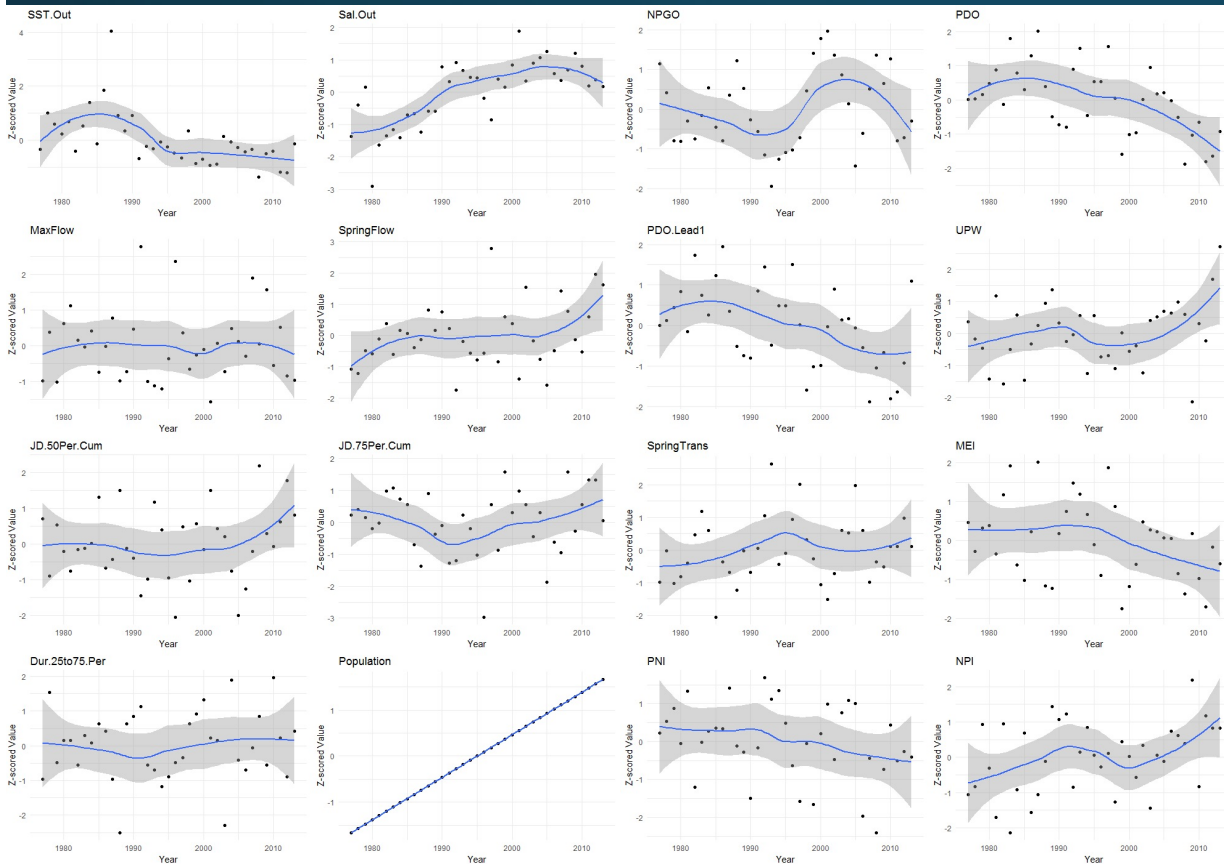
Abundance of fish in the system mitigates predation on any individual salmon

#### H1: Indicators

- Seals Abundance
- Orca Abundance
- SOG Herring Abundance
- PS Herring Spawning Stock Biomass
- PS Pink Salmon Abundance (Outmigrating)
- Fraser Pink Salmon Abundance (Outmigrating)
- Yearling Chinook Hatchery Release Abundance
- Subyearling Chinook Hatchery Release Abundance
- Yearling Coho Hatchery Release Abundance
- Index of Ocean Salmon



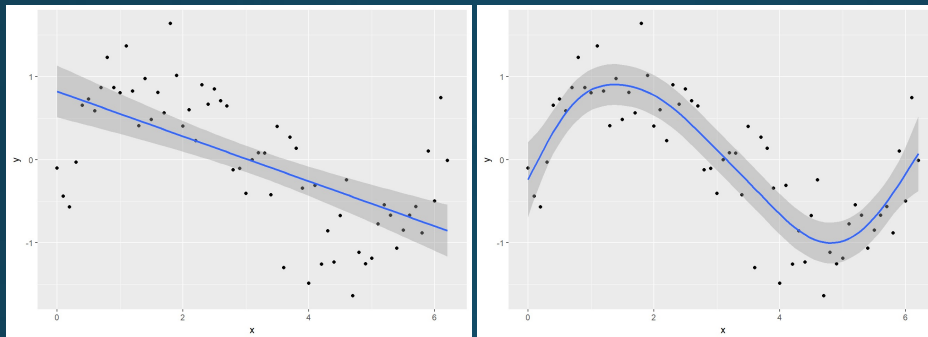
# TIME SERIES OF POTENTIAL INDICATORS



**Evaluate Candidate Indicators:**  
Correlations with SAR  
Collinearity with other covars.  
Lags  
Time period of aggregation





















# GENERALIZED ADDITIVE MODELING

































- Flexible GLM, allows for non-linear relationships by use of a smoothing term



- More parameters to estimate
- Survival datasets are not giant: need to limit maximum # of explanatory variables (5) and wiggleness of smoothed term ( $k=4$ )
- Used best subsets selection within a hypothesis, selection by AICc
- Generated a composite best model with variables appearing most often in models for each hypothesis

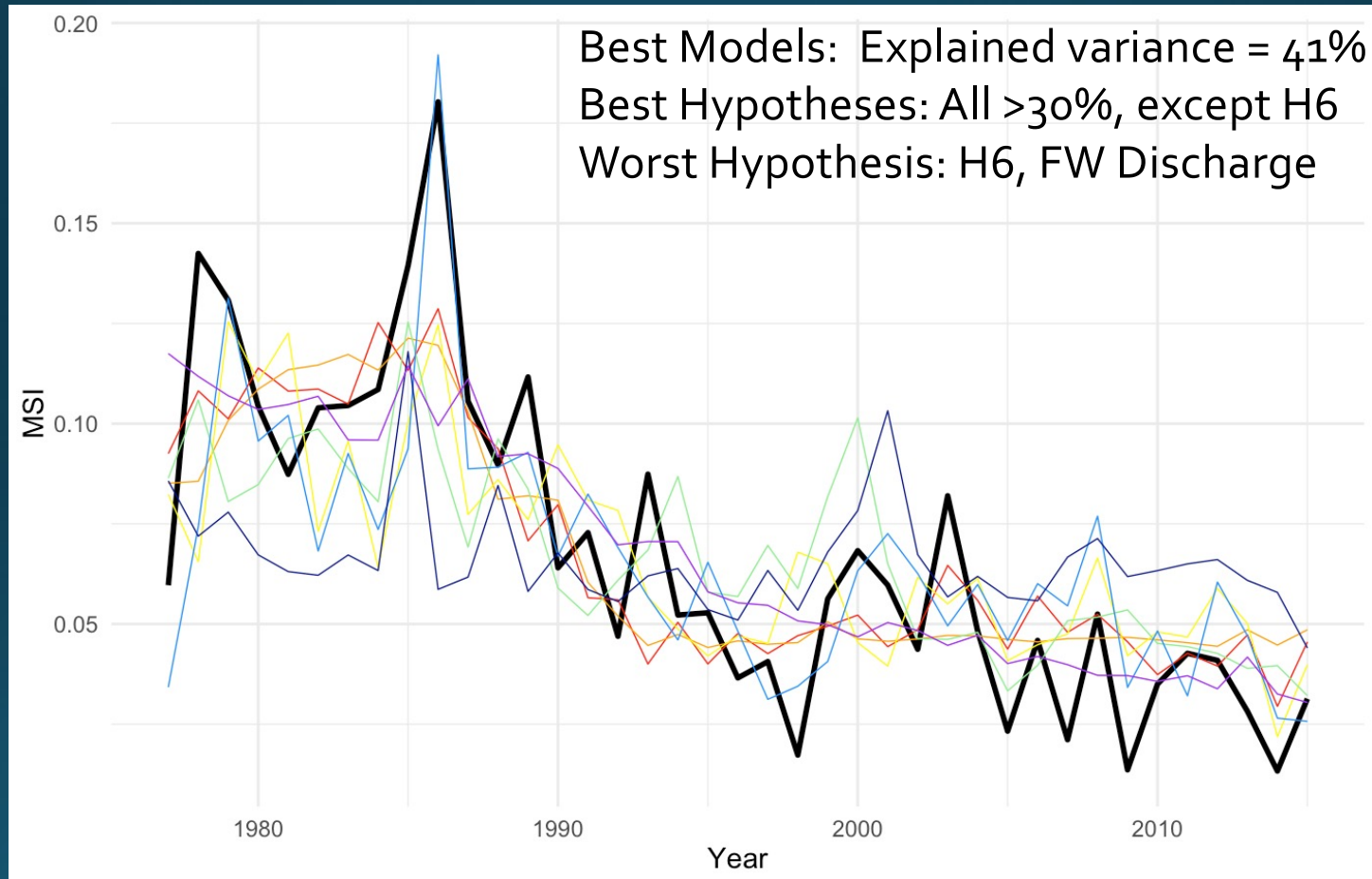
## H1: Predator Buffering (Abundance)

Indicators	VIW	Direction of Rel.
 Seal Abundance	0.82	
 SOG Herring Abundance	0.57	
 PS Pink Abundance (outmigrating)	0.49	
 Y Chinook Hatch Release Abundance	0.32	
 Fraser Pink Abundance (outmigrating)	0.25	
 PS Herring Abundance (total)	0.23	
 PS Herring Abundance (by subbasin)	0.09	
 Orcas Abundance	0.09	
 SY Chinook Hatch Release Abundance	0.08	
 Y Coho Hatch Release Abundance	0.00	
 Ocean Salmon Abundance	0.00	

Best Models	$\Delta AICc$	$\omega AICc$	$r^2$
  	0	0.142	0.353
 	0.500	0.111	0.340
    	1.212	0.077	0.342
	1.436	0.069	0.339
   	1.726	0.060	0.355
   	1.784	0.058	0.359
 	1.989	0.052	0.349
 	2.349	0.044	0.345
  	2.388	0.043	0.345
  	2.513	0.040	0.357
  	2.591	0.039	0.341
 	2.804	0.035	0.342












# COHO RESULTS

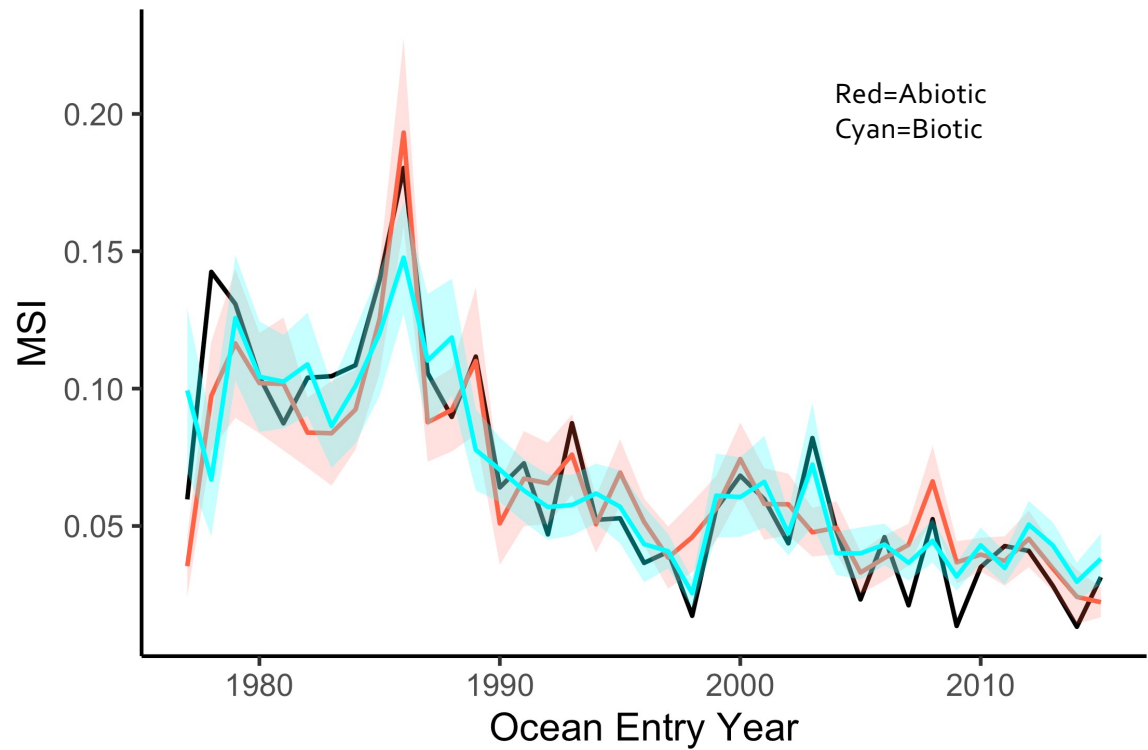


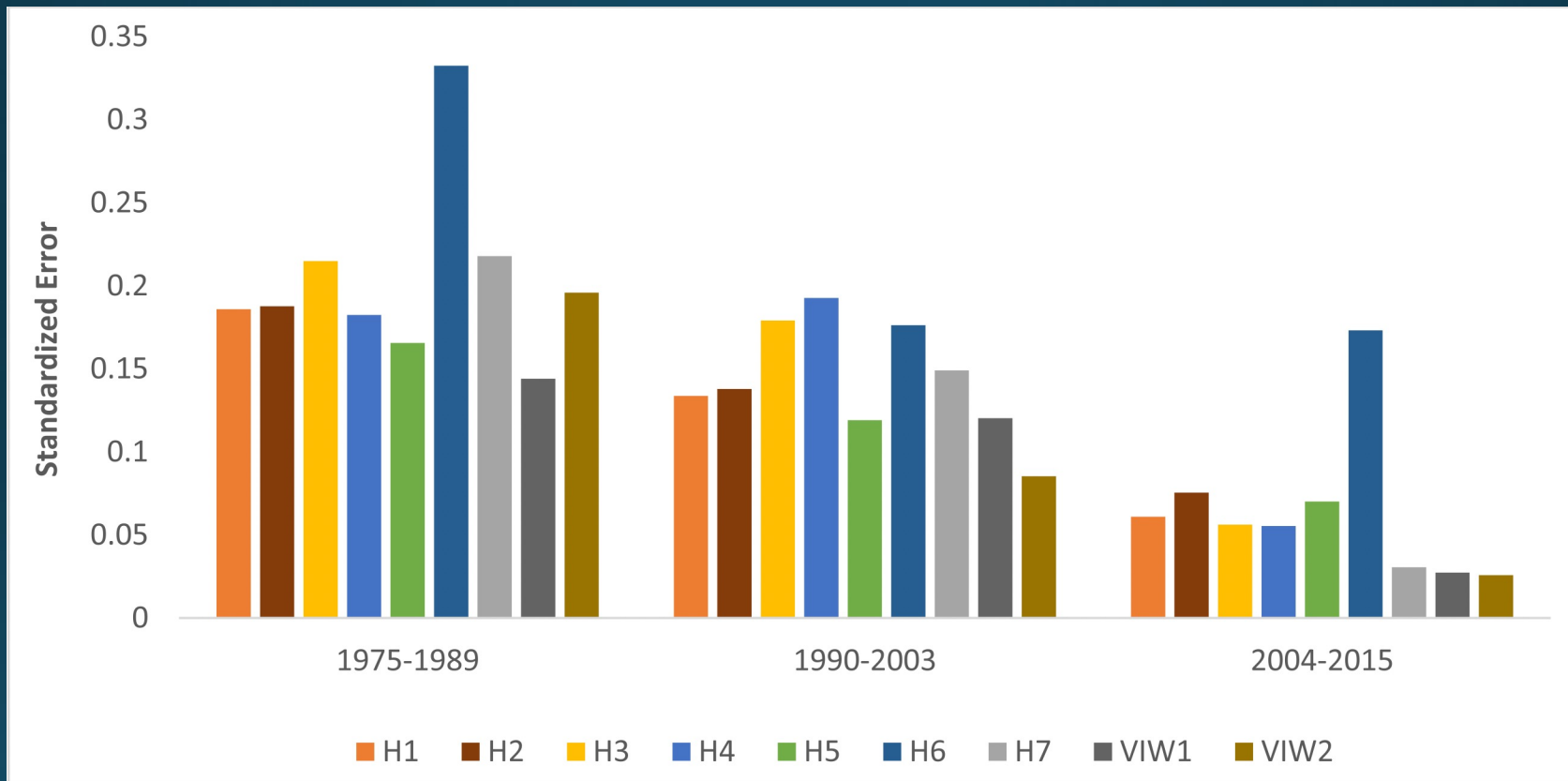
## Best VIW

Indicators	VIW	Direction of Rel.
 NPI	0.74	
 Precipitation (Spring)	0.66	
 Stratification Index at RR	0.66	
 CV of SY Chk Hatch Rel Date	0.66	
 Max Air Temp (Spring)	0.53	
 Total Salmon Harvest	0.39	
 Seal Abundance	0.34	
 NPGO.Out	0.34	
 SOG Herring Abundance	0.34	
 Y Coho Hatch Rel Date	0.09	
 Date of 75% Cumulative Flow	0.05	
 PS Pink Abundance (outmigrating)	0.04	
 Salinity	0.0	
 Chl $a$ (JDF Strait)	0.0	
 Spring Transition Date	0.0	
 Population	0.0	

Best Models					$\Delta AICc$	$\omega AICc$	$r^2$
					0	0.524	0.417
					2.613	0.142	0.411

## Ocean Entry Year





## SUMMARY

- All best performing models explained 30-40% of variation in dataset
- FW input indicators typically did the worst at explaining variance
- Seal abundance was supported (correlates with time series, also mechanistic work supporting predation hypotheses)
- Hatchery release timing and abundance should be considered more fully—some negative relationships with survival; protracted release timing indicated higher survival
- Same suite of indicators may not perform well over entire time series
- Forecasting models might be able to take into account newer data streams (zooplankton, ocean sampling)

## CHALLENGES

- Indicators are based on hypotheses, but there are limitations to a purely statistical approach
- Correlated variables can explain variance, but may not be the most important factors to consider—mechanisms are not articulated
- Indirect and interaction effects are not captured well
- Potentially important data streams don't exist (e.g. forage fish, zooplankton, fish predators) limiting model quality



# Thank You!

[kathryn.sobocinski@wwu.edu](mailto:kathryn.sobocinski@wwu.edu)

- Data providers: WDFW, NOAA, UW, WA Dept. of Ecology, USGS, and others
- SAR datasets developers
- SSMSP Technical Team and Collaborators

