Salish Sea Marine Survival Project: Ecosystem Indicators Development

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Photo Credit: Tavish Campbell

Decline in Marine Survival

1275

NRC Research Press

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

Abstract: Examination of population abundance and survival trends over space and time can guide management and conservation actions with information about the spatial and temporal scale of factors affecting them. Here, we analyzed steelhead trout (anadromous *Oncorhynchus mykiss*) adult abundance time series from 35 coastal British Columbia and Washington populations along with smolt-to-adult return (smolt survival) time series from 48 populations from Washington, Oregon, and the Keogh River

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ORIGINAL ARTICLE

WILEY FISHERIES OCEANOGRAPHY

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

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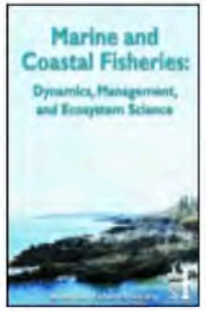
Abstract

Identifying factors that influence anadromous Pacific salmon (*Oncorhynchus* spp.) population dynamics is complicated by their diverse life histories and large geographic range. Over the last several decades, Chinook salmon (*O. tshawytscha*) popu-



Taylor & Francis

Marine and Coastal Fisheries

Dynamics, Management, and Ecosystem Science

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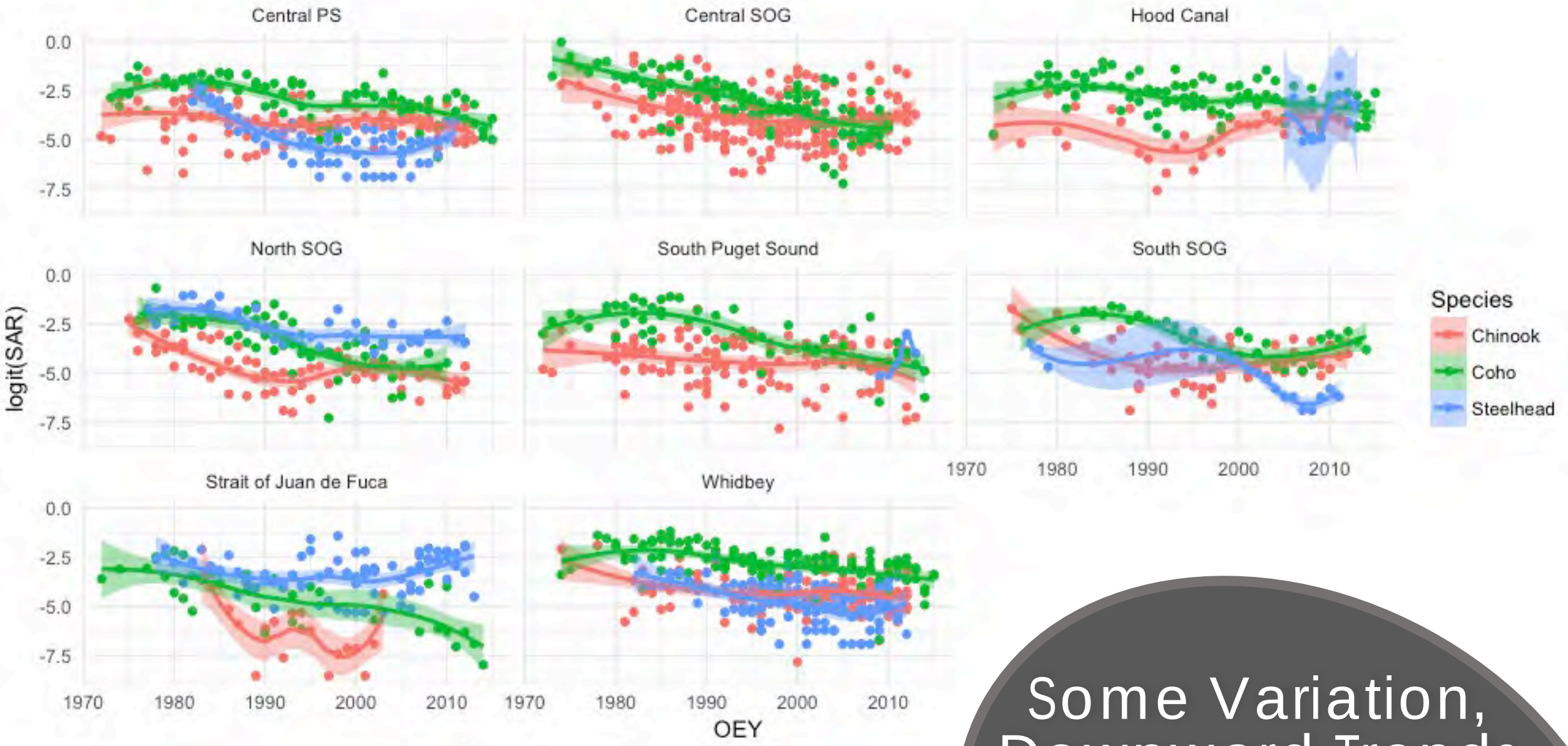
Spatial and Temporal Patterns in Smolt Survival of Wild and Hatchery Coho Salmon in the Salish Sea

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



Some Variation, Downward Trends

Causes of Decline are Unknown

A. **Bottom-Up Processes** that drive prey availability have changed, and salmon aren't able to compensate.

B. **Top-Down Processes**, including increasing abundances predators, may be exacerbating mortality

C. **Multiple Anthropogenic Factors** may compound the problem:
   - Disease
   - Contaminants
   - Hatchery management
   - Habitat loss

D. **Cumulative Effects** are unknown

How do we evaluate contributing factors?

Indicators

Indicators are quantitative measurements that reflect the structure, composition, or functioning of a complex system

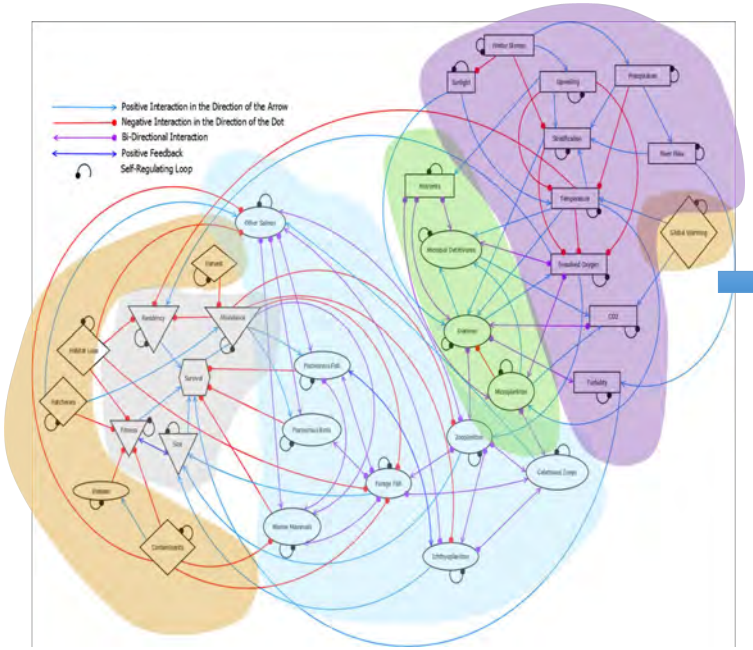
Indicators should be :

- theoretically sound
- respond predictably to ecosystem change
- integrative
- relevant to management concerns (in this case, marine survival in salmon)

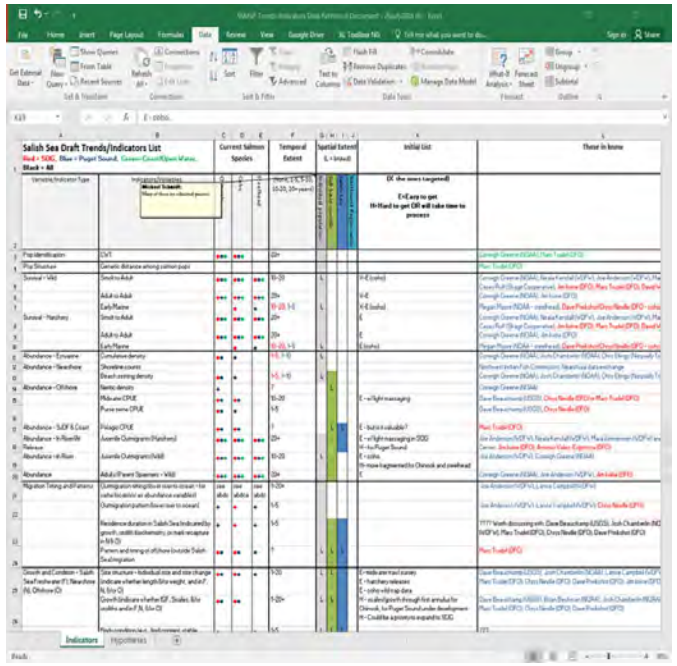
Datasets are a start, but are not in and of themselves indicators

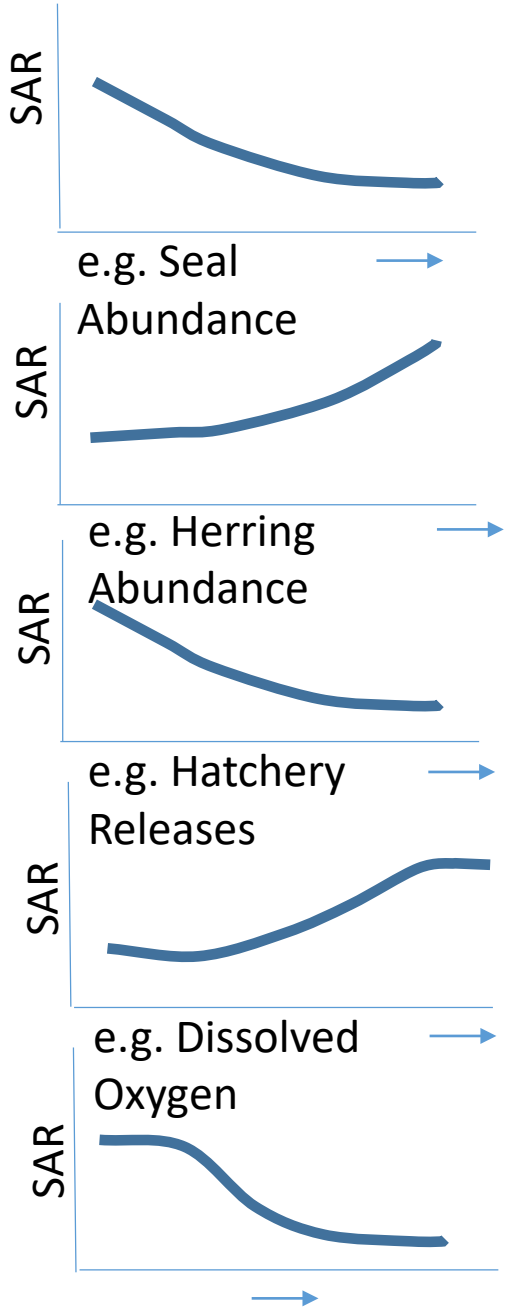
(Niemeijer and de Groot 2008, O'Neill et al. 2008, Kershner et al. 2011)

Conceptual → Statistical



Sobocinski et al. 2017, Env. Conservation





$$Y=\beta_0+\beta_1X_1+\beta_2X_2+\ldots\beta_nX_n+\varepsilon$$

Hypothesis-Driven

Boundary Conditions

- Freshwater (e.g., river discharge, temperature, turbidity)
- Ocean (e.g., temperature, upwelling index, sea level)
- Atmosphere/Climate (multivariate ENSO index, wind speed/direction, PDO)

Salish Sea Conditions

- Temperature, chlorophyll concentrations, turbidity, dissolved oxygen, etc.

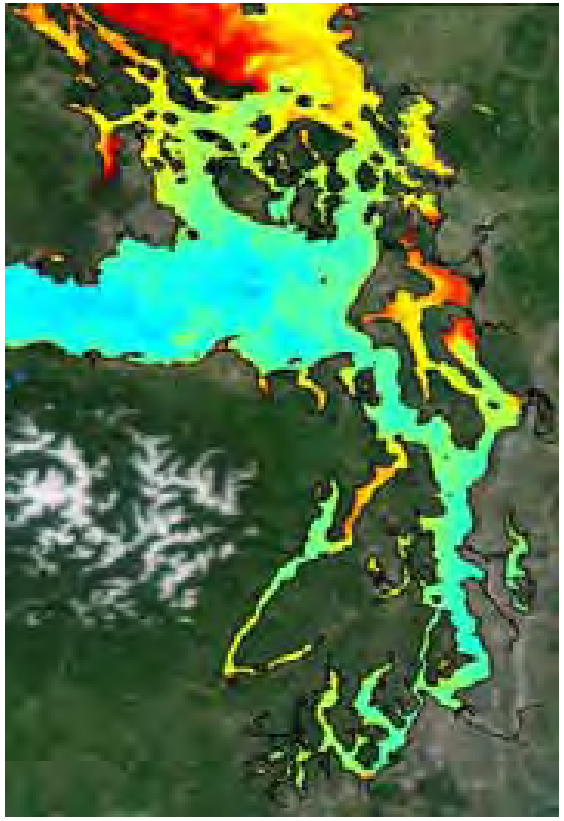
Predators and Competitors

- Forage fish, finfish, pinnipeds, other mammals, birds, other salmon

Salmon Characteristics

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

Anthropogenic Impacts



MODIS-Aqua 500-m Chlorophyll *a*
Developed for Puget Sound, WA
B. Sackmann, Integral

Species-Specific Hypotheses

Steelhead

H1: Predation

-Increases in marine mammals increase mortality

H2: Forage Fish Buffering

-Forage fish may provide a predation buffer

H3: Hatchery Releases

-Predator swamping (decrease SAR) or dinner bell (increase SAR)

H4: Puget Sound Marine Waters Conditions

-Adverse stream flow and water quality at marine entry

H5: Ocean conditions

-Ocean conditions may be unfavorable

- Steelhead spend a short time period in Puget Sound, long migration
- Built on previous work related to survival—including recent acoustic telemetry, work with pinnipeds, etc. (Berejikian, Moore, and others)
- Used mechanistic understanding where possible

Steelhead SAR data from 1977-2013

Species-Specific Hypotheses

Coho and Chinook

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

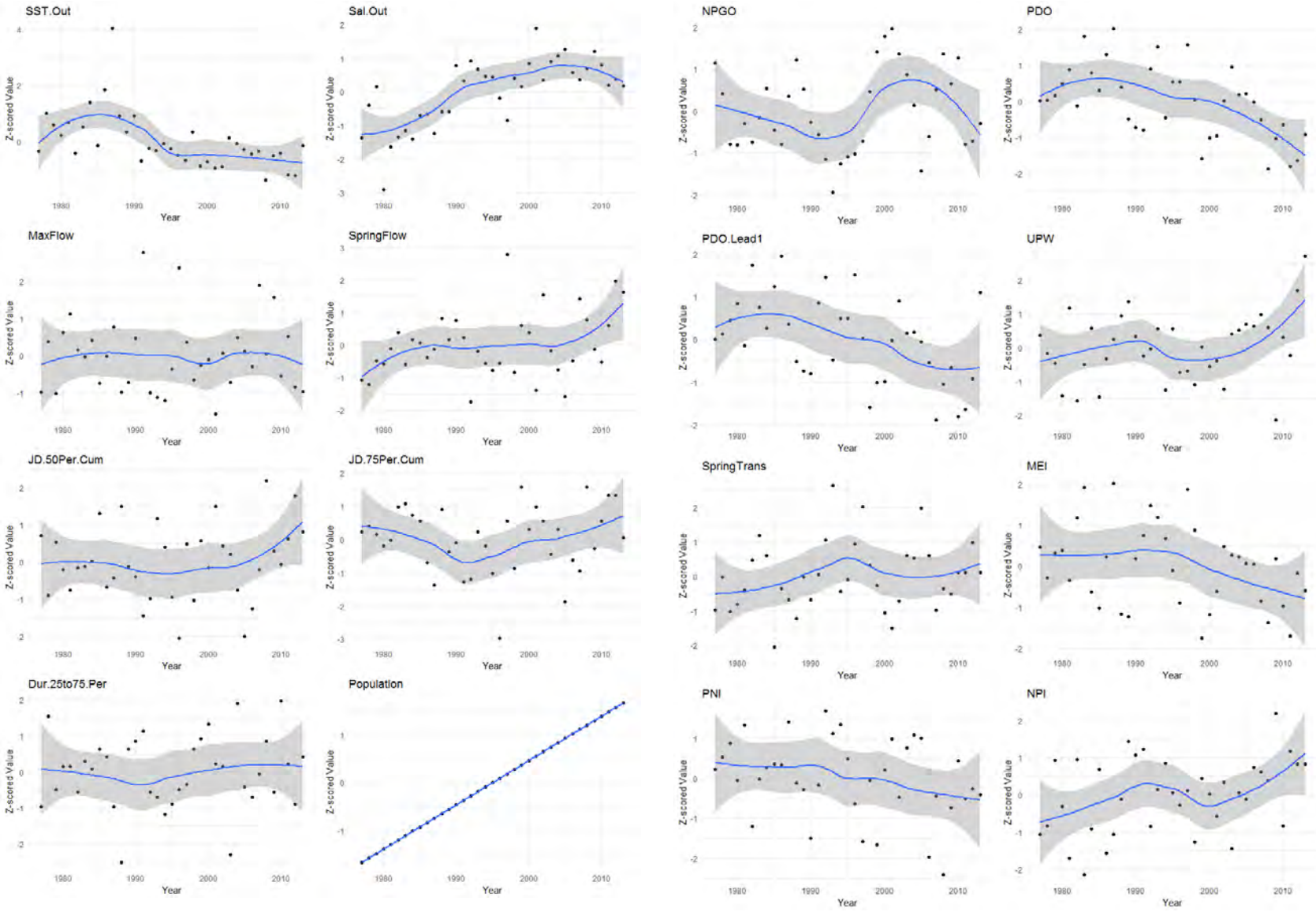
H6: Water Delivery and Spring Bloom Timing

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

H7: Anthropogenic Impacts

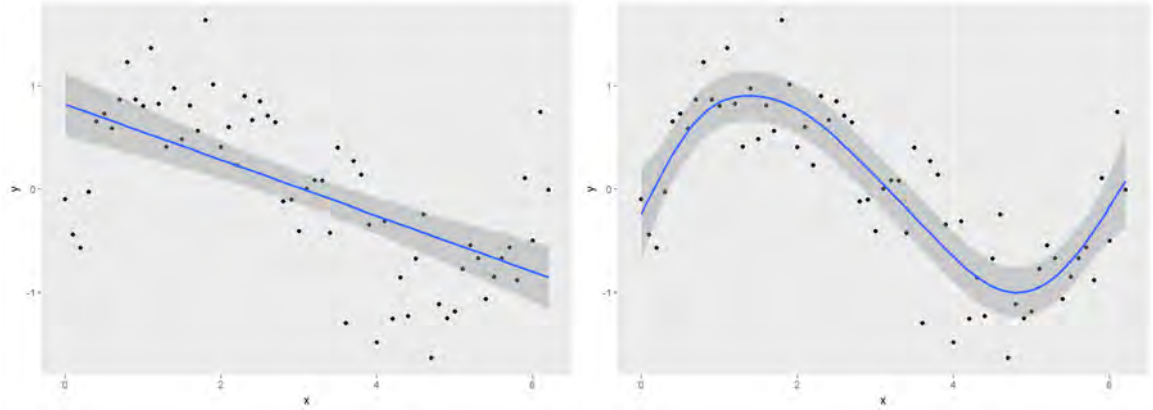
-Human population negatively impacts survival

Time Series of Potential Indicators



Generalized Additive Modeling

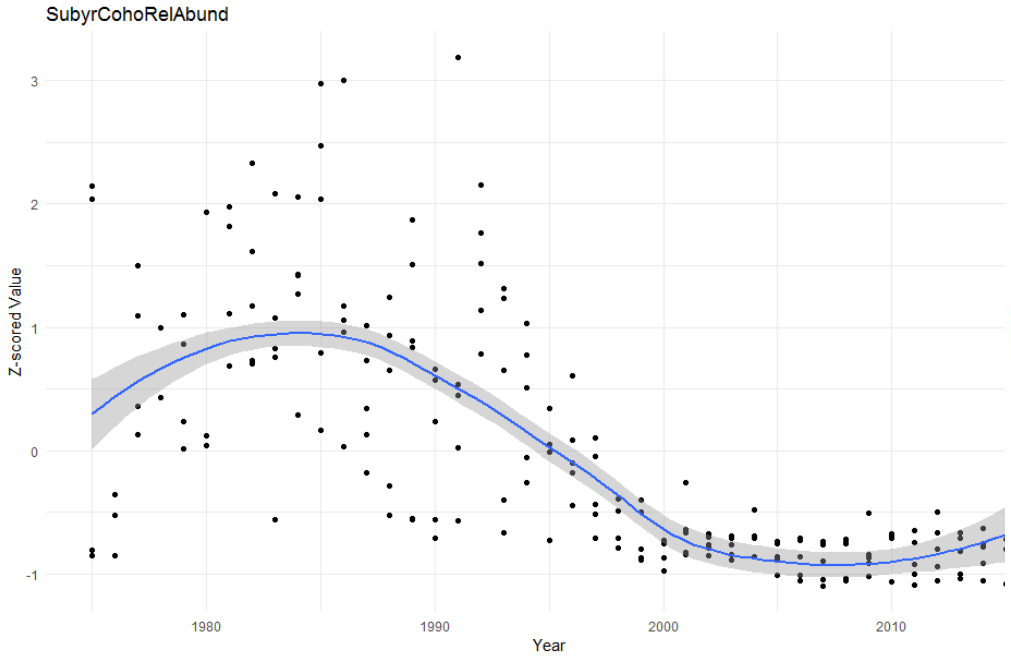
- Flexible GLM that allows for non-linear relationships by use of a smoothing term

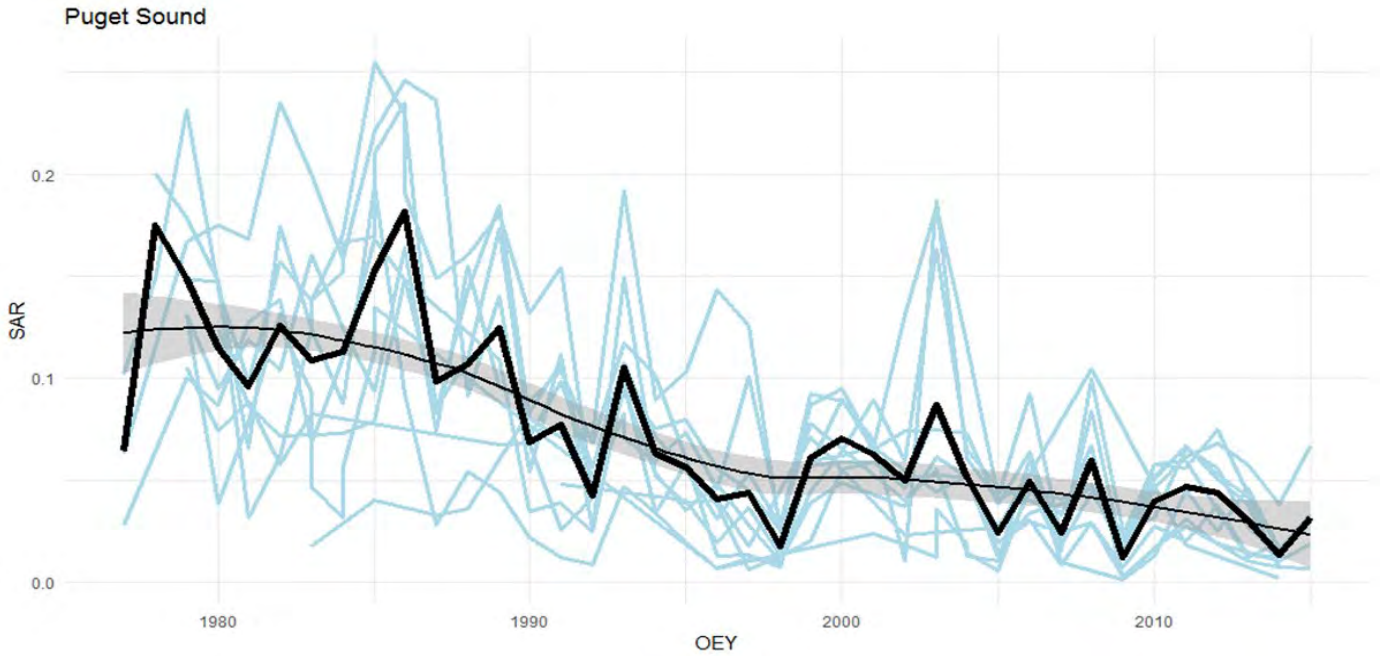


- More parameters to estimate
- Survival datasets are not giant: need to limit maximum # of explanatory variables and wiggliness of smoothed term
- Used a combination of backwards selection and best subsets selection, driven by AIC

Challenges

- Indicators based on hypotheses, but analysis is statistical, not





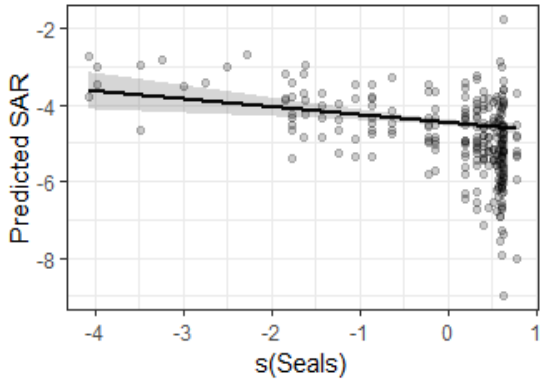
Challenges

- Indicators are based on hypotheses, but analysis is statistical, not mechanistic
- Correlated variables can explain variance, but may not be the most important factors to consider
- Indirect effects are not captured well
- Potentially important data streams don’t exist (e.g. forage fish, zooplankton, fish predators)

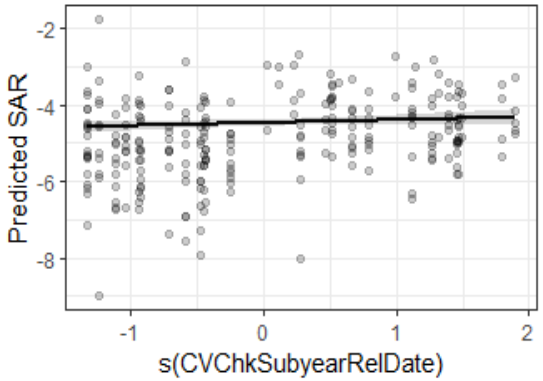
Steelhead Indicators

Increasing SAR

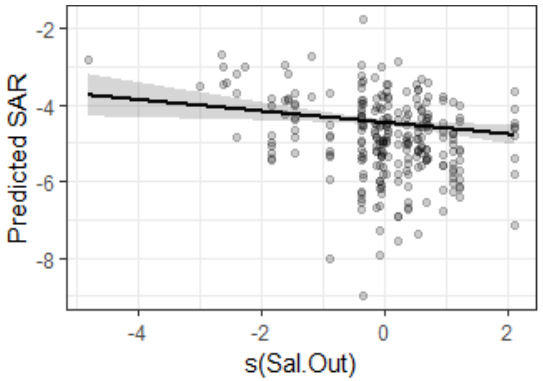
Seal Abundance



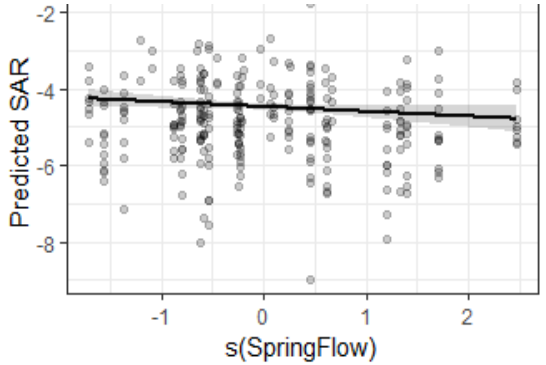
Var. in Hatchery Rel. Timing



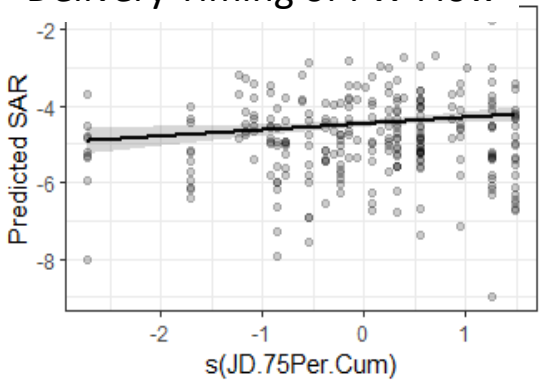
Salinity (Mar.-June)



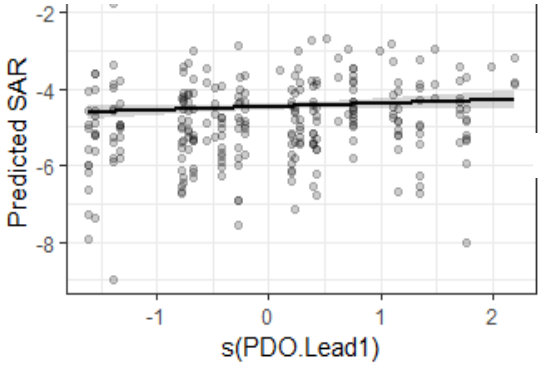
Vol. of FW Flow (Mar.-June)



Delivery Timing of FW Flow

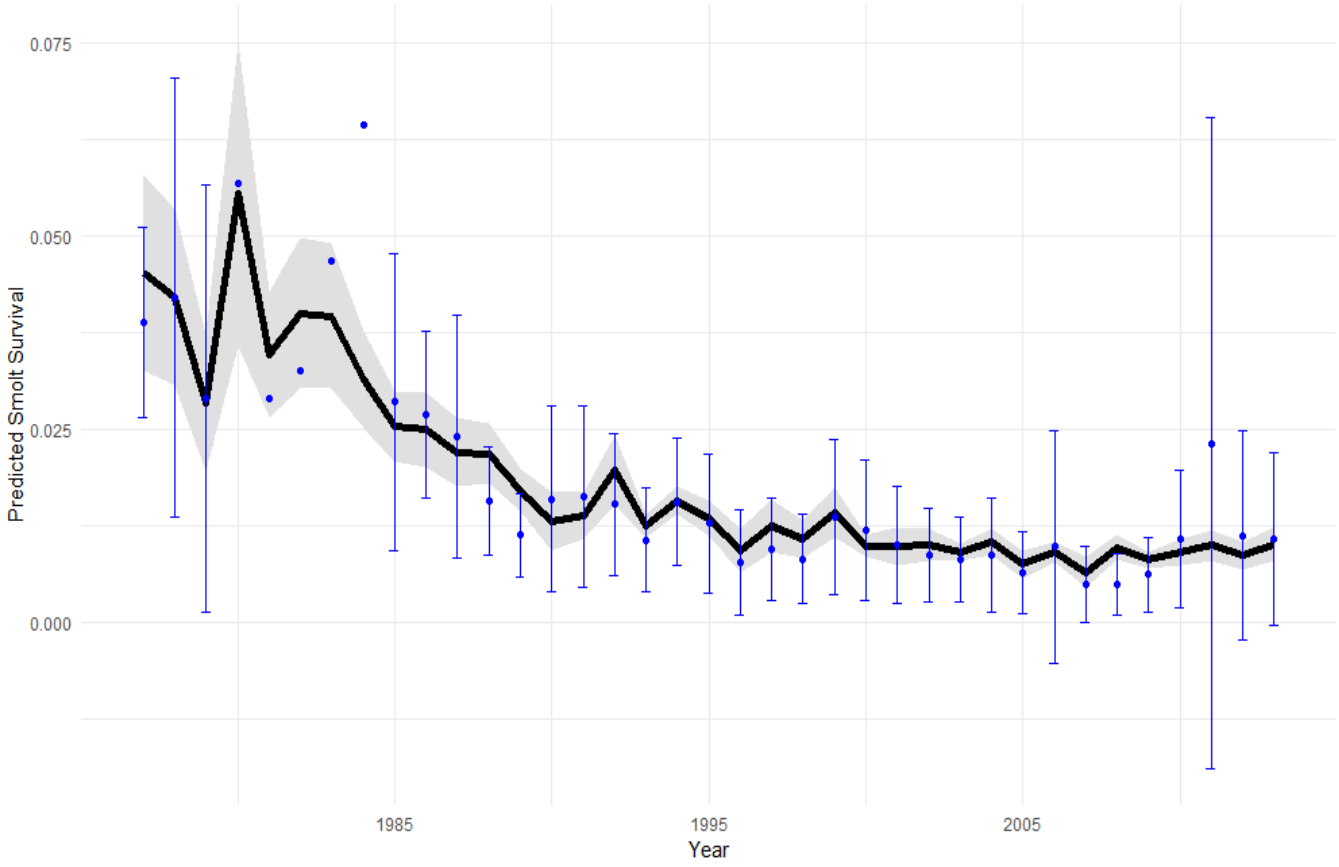


PDO (*t*+1)



	Explanatory Variables																	
Model	Seals	Orcas	Herring	Abundance of Outmigrating Pink Salmon	Chinook Subyearling Hatchery Release Abund.	CV Chinook Subyearling Hatchery Release Date	Chinook Subyearling Hatchery Release Date	SST	Salinity	Spring Flow	Julian Date of 75% Cumul.Flow (Water Year)	Population	PDO	PDO 1 (PDO led 1 yr)	NPI	NPGO	**Dev. Exp. (%)**	**AICc**	**ΔAICc**
Model 1	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	29.2	-1765.7	39.5
Model 2	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	29.2	-1767.7	37.5
Model 3	X	X	X	X		X	X	X	X	X	X		X	X	X	X	29.2	-1769.6	35.6
Model 4	X	X	X			X	X	X	X	X	X		X	X	X	X	31.8	-1793.4	11.8
Model 5	X	X	X			X		X	X	X	X		X	X	X	X	31.8	-1795.1	10.1
Model 6	X	X				X		X	X	X	X		X	X	X	X	31.7	-1796.8	8.4
Model 7	X	X				X		X	X	X	X		X	X		X	31.6	-1798.5	6.7
Model 8	X	X				X		X	X	X	X			X		X	31.5	-1800.1	5.1
Model 9	*X*	*X*				*X*			*X*	*X*	*X*			*X*		*X*	*31.3*	*-1801.6*	*3.6*
Model 10	*X*	*X*				*X*			*X*	*X*	*X*			*X*			*31.2*	*-1803.1*	*2.1*
Model 11	***X***					***X***			***X***	***X***	***X***			***X***			***30.6***	***-1804.7***	***0.5***
Model 12	*X*								*X*	*X*	*X*			*X*			*30.3*	*-1804.4*	*0.8*
Model 13	***X***								***X***	***X***	***X***						***29.9***	***-1804.7***	***0.5***
Model 14	*X*								*X*		*X*						*29.2*	*-1803.4*	*1.8*
Model 15	*X*								*X*								*28.4*	*-1803.3*	*1.9*
Model 16	*X*																*26.8*	*-1801.7*	*3.5*
Auto.	***X***	***X***				***X***											***29.5***	***-1805.2***	-
Auto. Hatch.	*X*	*X*				*X*			*X*								*42.3*		

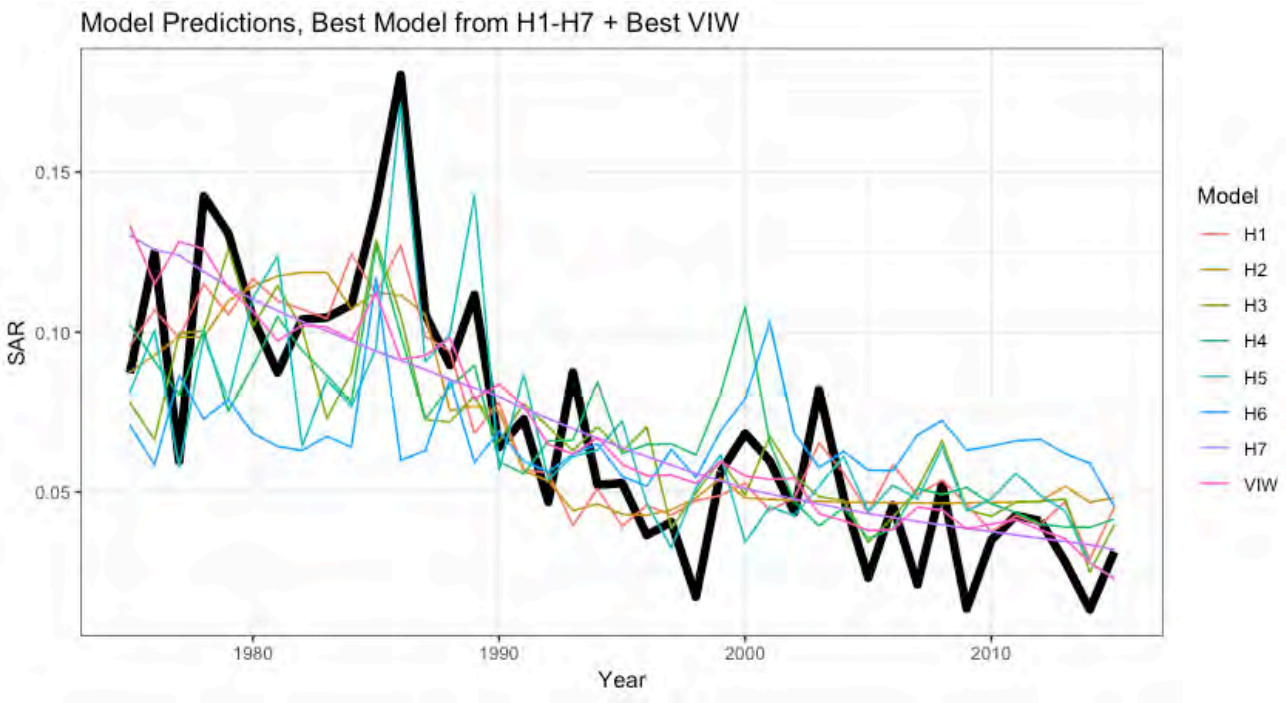
Increasing Value of Indicator



Steelhead Indicators with Strongest Support

Seal Abundance (Neg)
Salinity (Neg)
Delivery Timing of FW Input (Pos)
Orca Abundance (Neg)
Hatchery Rel. Timing (Pos)
Variation in Hatch. Rel. Timing (Pos)

Coho Indicators with Strongest Support



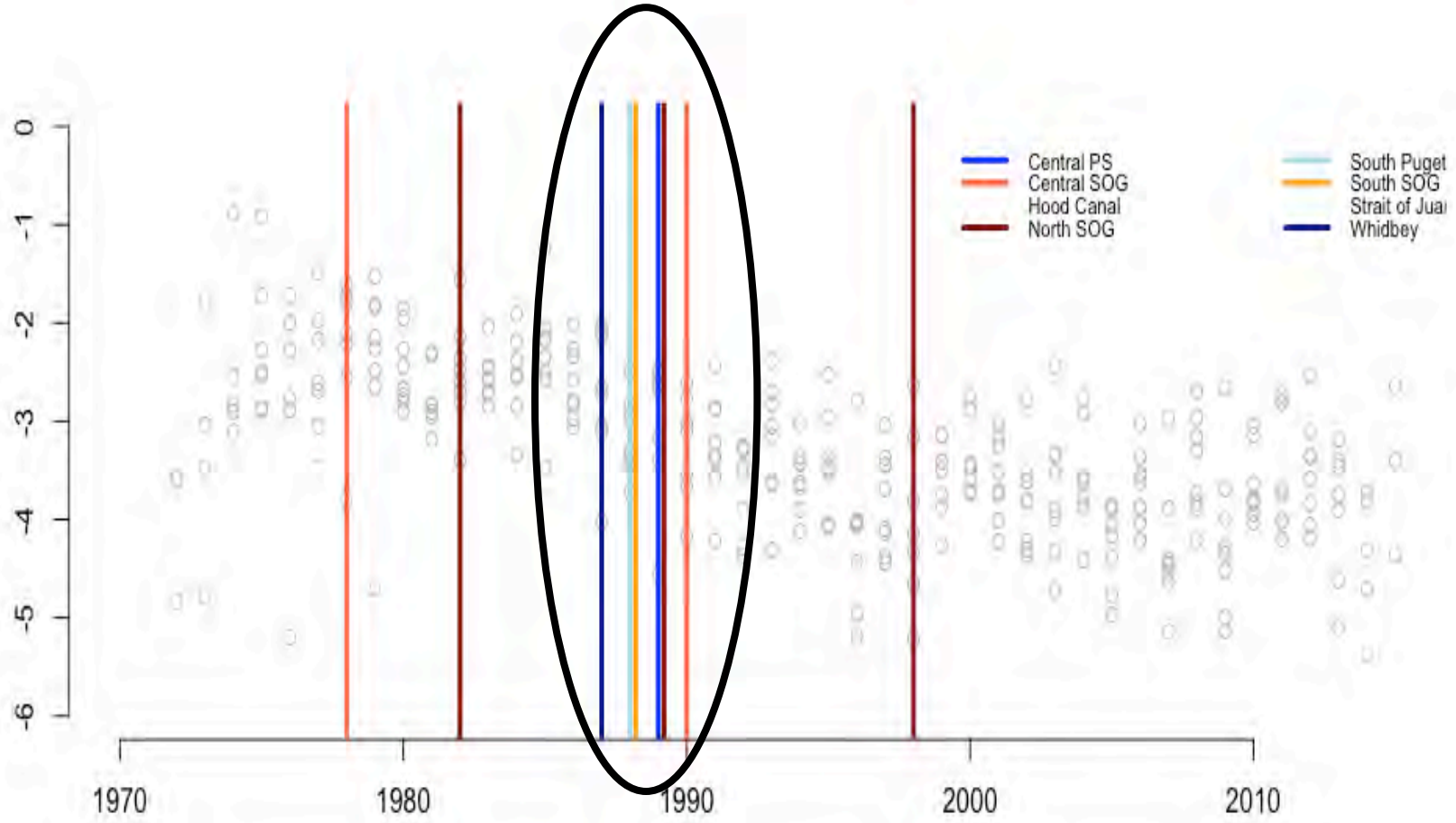
Human Population (Neg)
Salinity (Neg)
Date of Spring Transition (Neg)
Delivery Timing of FW Input (Pos)
Avg. Yr. Coho Hatchery Rel. Date (Pos)
Max. Air Temp. (Mar.-June) (Neg)
Seal Abundance (Neg)
PDO (t-2) (Pos)

Summary

- All best performing models explain 25-35% of variation in dataset
- Models generally show a few strong indicators supported by additional environmental indicators that explain relatively less variation
- Outmigrant response to variation in salinity and freshwater delivery timing should be investigated further; continued mechanistic work on predation would improve understanding of seal predation
- Forecasting models might be able to take into account newer data streams (zooplankton, ocean sampling)

Thanks

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


0
-1
-2
-3
-4
-5
-6
1970
1980
1990
2000
2010
Central PS
Central SOG
Hood Canal
North SOG
South Puget
South SOG
Strait of Jua
Whidbey

Ecosystem Context Matters

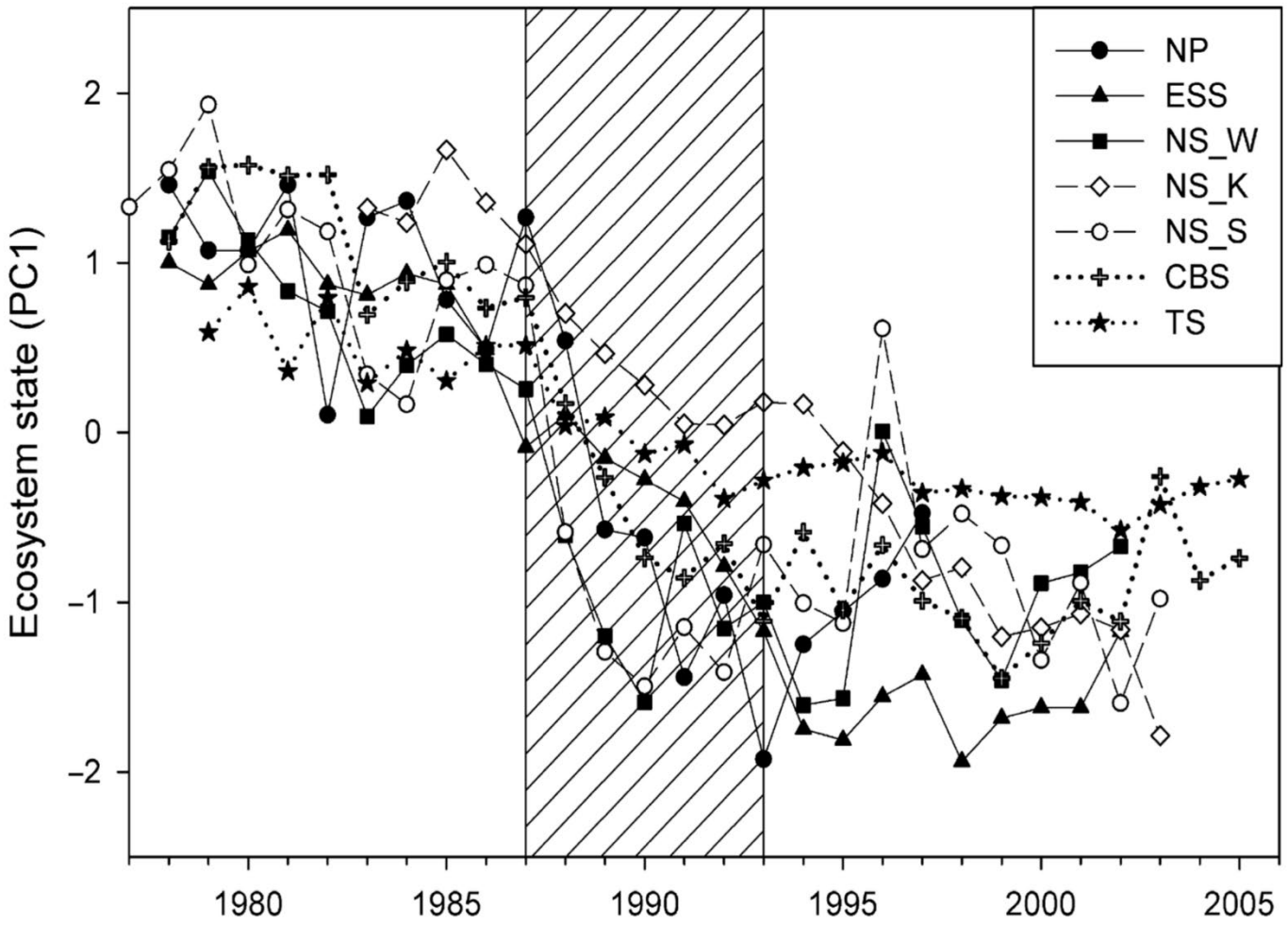


Figure. 9 from Möllmann and Diekmann 2012, *Advances in Ecological Research*