Declining Pacific Northwest steelhead marine survival and associated ecosystem indicators

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SALISH SEA MARINE SURVIVAL PROJECT

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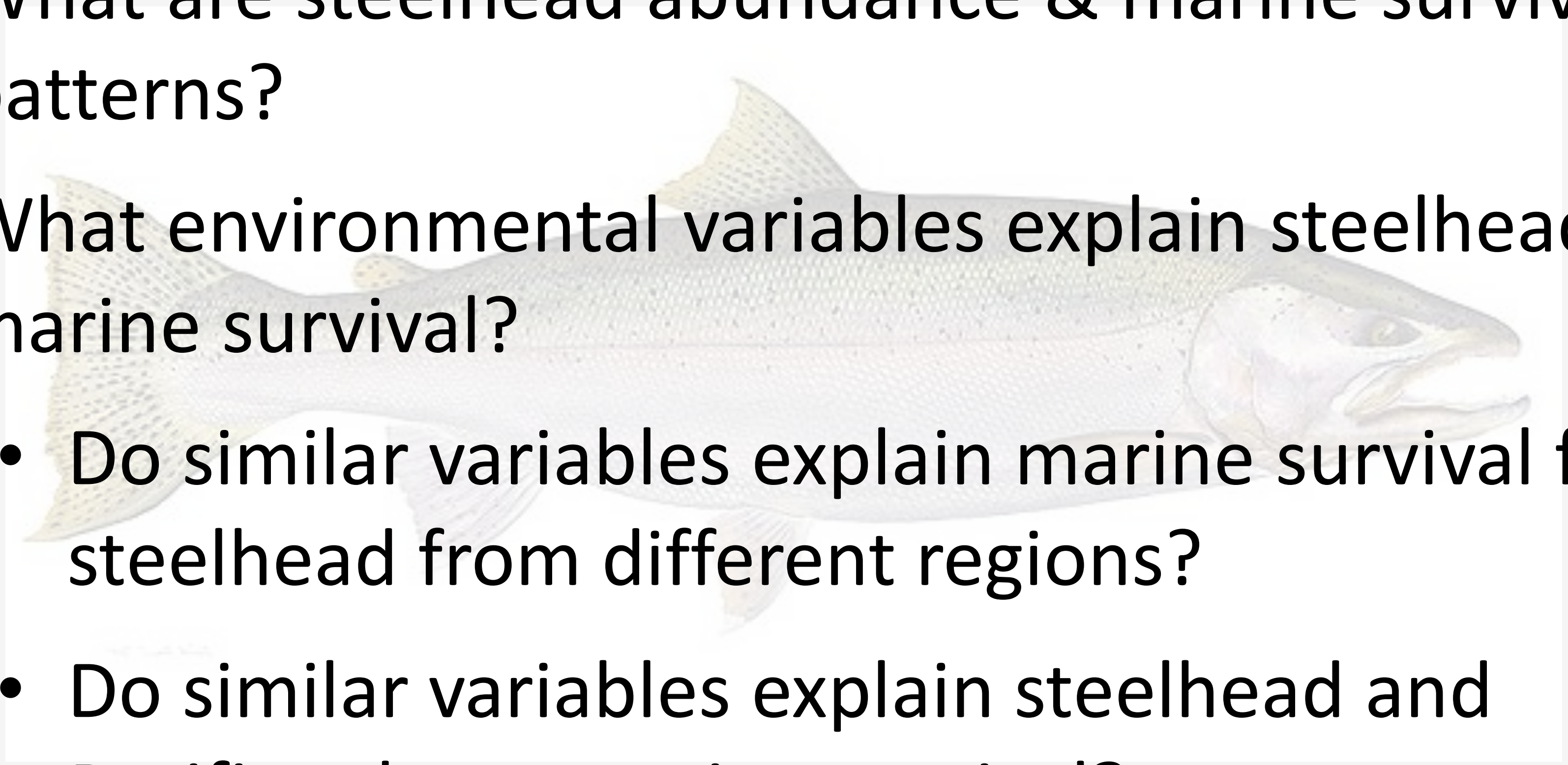
Understanding steelhead marine survival



- What are steelhead abundance & marine survival patterns?
- What environmental variables explain steelhead marine survival?
  - Do similar variables explain marine survival for steelhead from different regions?
  - Do similar variables explain steelhead and Pacific salmon marine survival?

Declining steelhead abundance in Puget Sound

- Are Puget Sound abundance & marine survival trends different than those in other regions?
- How have they changed over time?
- What environmental characteristics are most related to marine survival trends?

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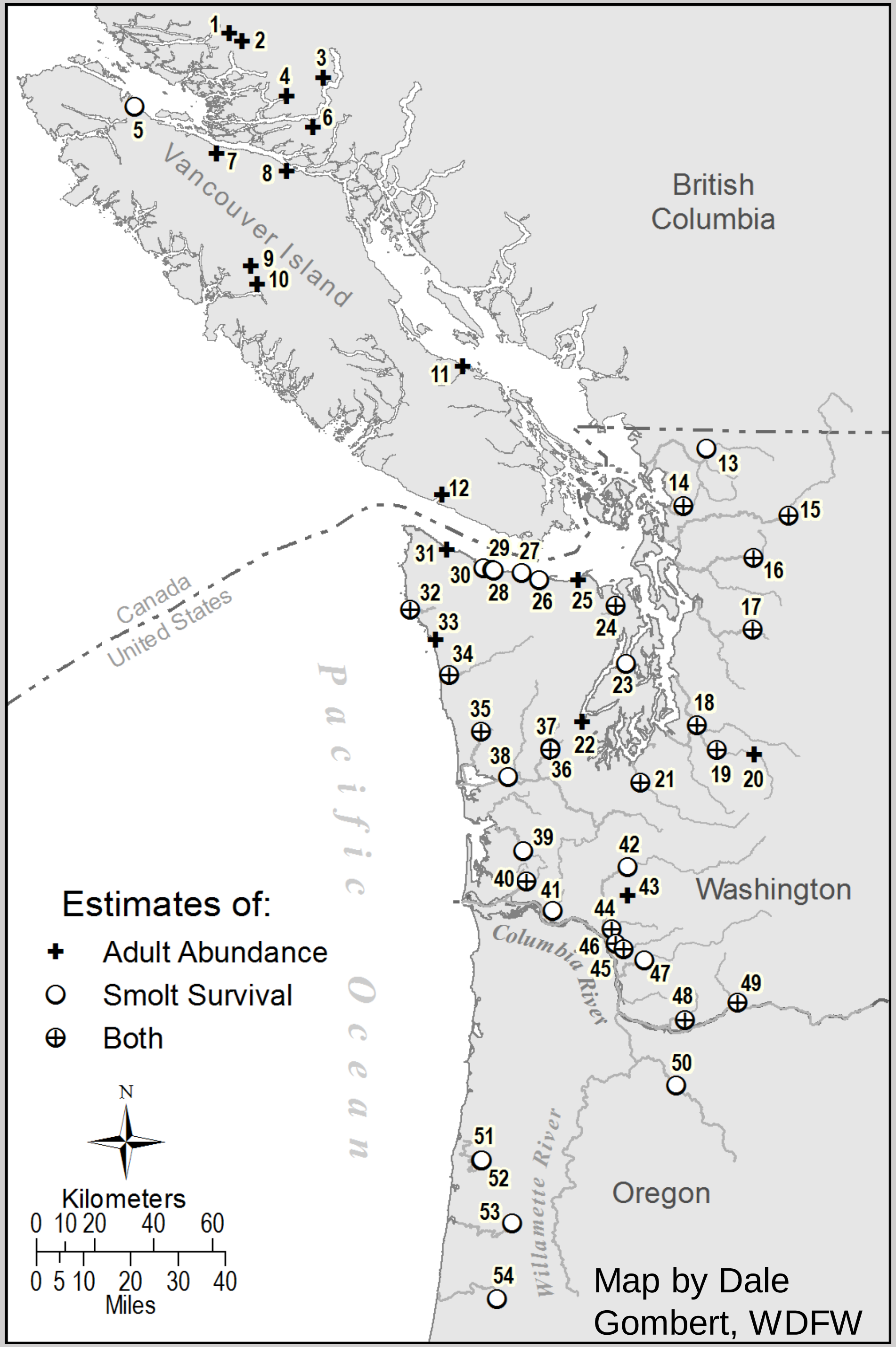
SAR data from 48 stocks/pops:

- **Puget Sound**:
  10 hatchery, 2 wild
- **Strait of Juan de Fuca**:
  1 hatchery, 5 wild
- **Coast**:
  11 hatchery, 2 wild
- **Lower Columbia**:
  12 hatchery, 4 wild
- **Johnstone Strait**:
  1 wild



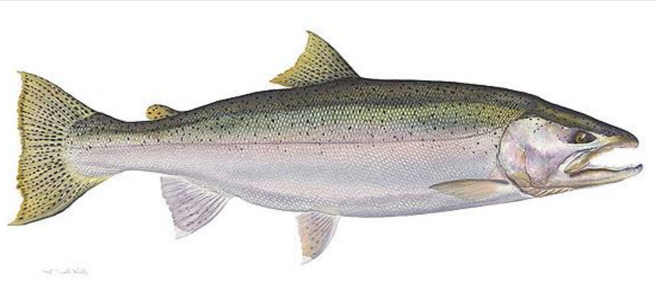
Hatchery & wild marine survival: **smolt-to-adult return rates (SAR)**

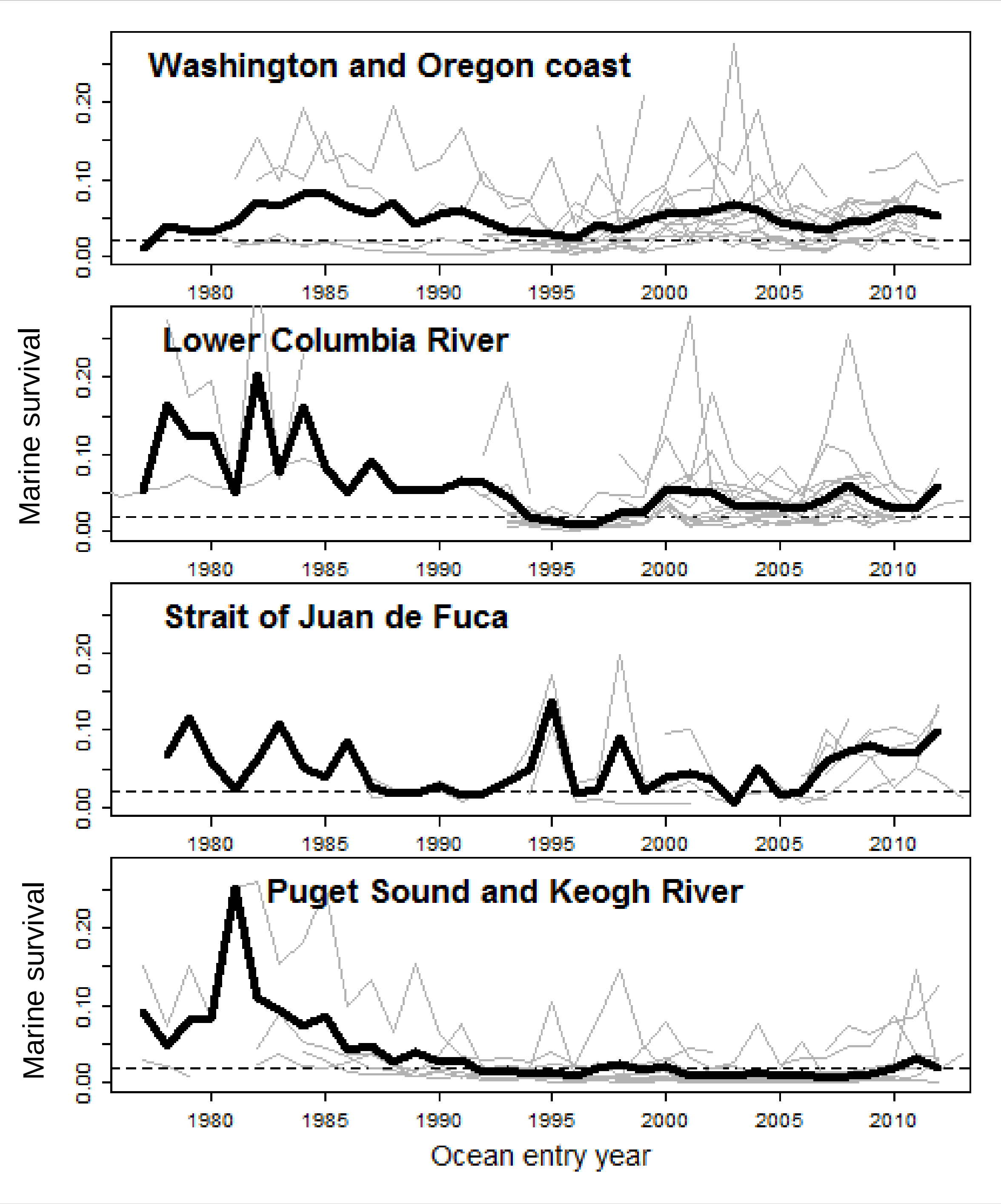
- Percent of smolts leaving freshwater that survival to return as adults

$$\textbf{Smolt survival} = \frac{\textbf{\# spawners/hatchery returns + \# catch}}{\textbf{\# smolts}}$$

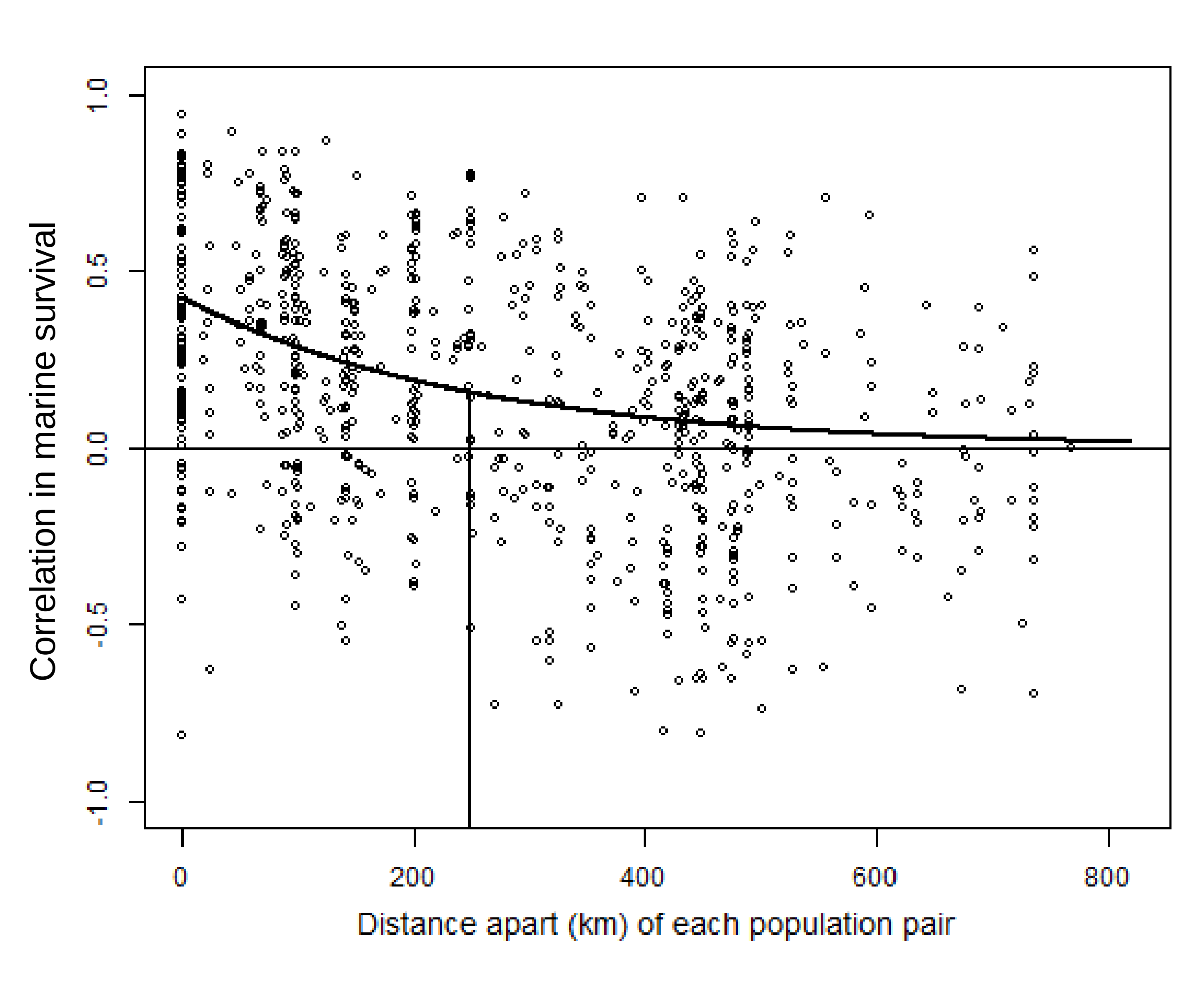

Photo: Morgan Bond

Steelhead marine survival by region





Marine survival correlation by distance



Steelhead marine survival summary

- Puget Sound steelhead marine survival has **declined over time**, especially low since early 1990s
- Puget Sound, Strait of Juan de Fuca, coast, and lower Columbia River steelhead have exhibited **different trends**
- Correlation by distance results support hypothesis that **much of the marine mortality occurs during early marine life**. Environmental conditions influencing marine survival likely have unique smaller-scale characteristics.

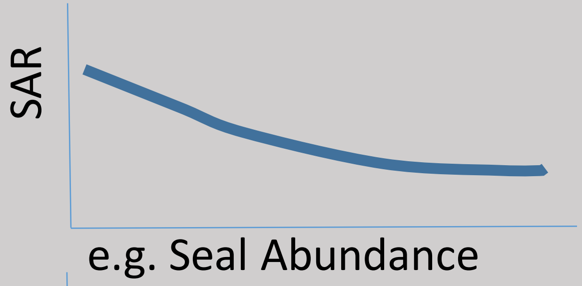
Indicators

On a practical level, indicators should also be:

Hypothesis-driven

H1: Predation

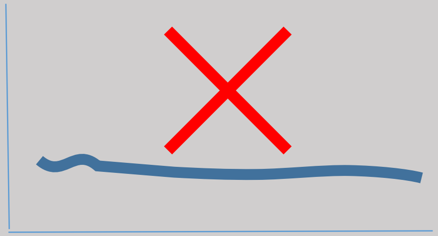
-Increases in marine mammals increase early marine mortality

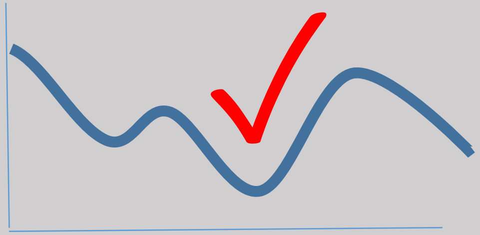


H2: Buffering

-Forage fish provide a predation buffer

Changing over time





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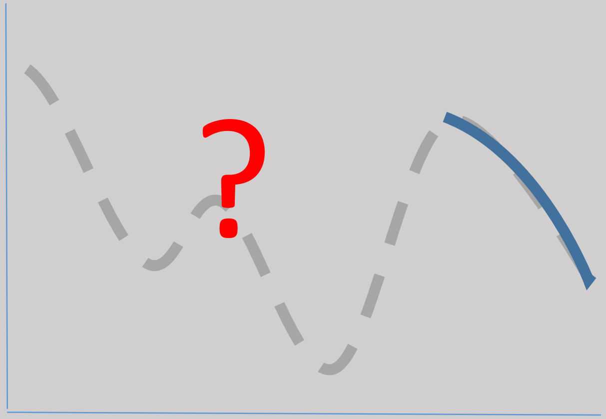
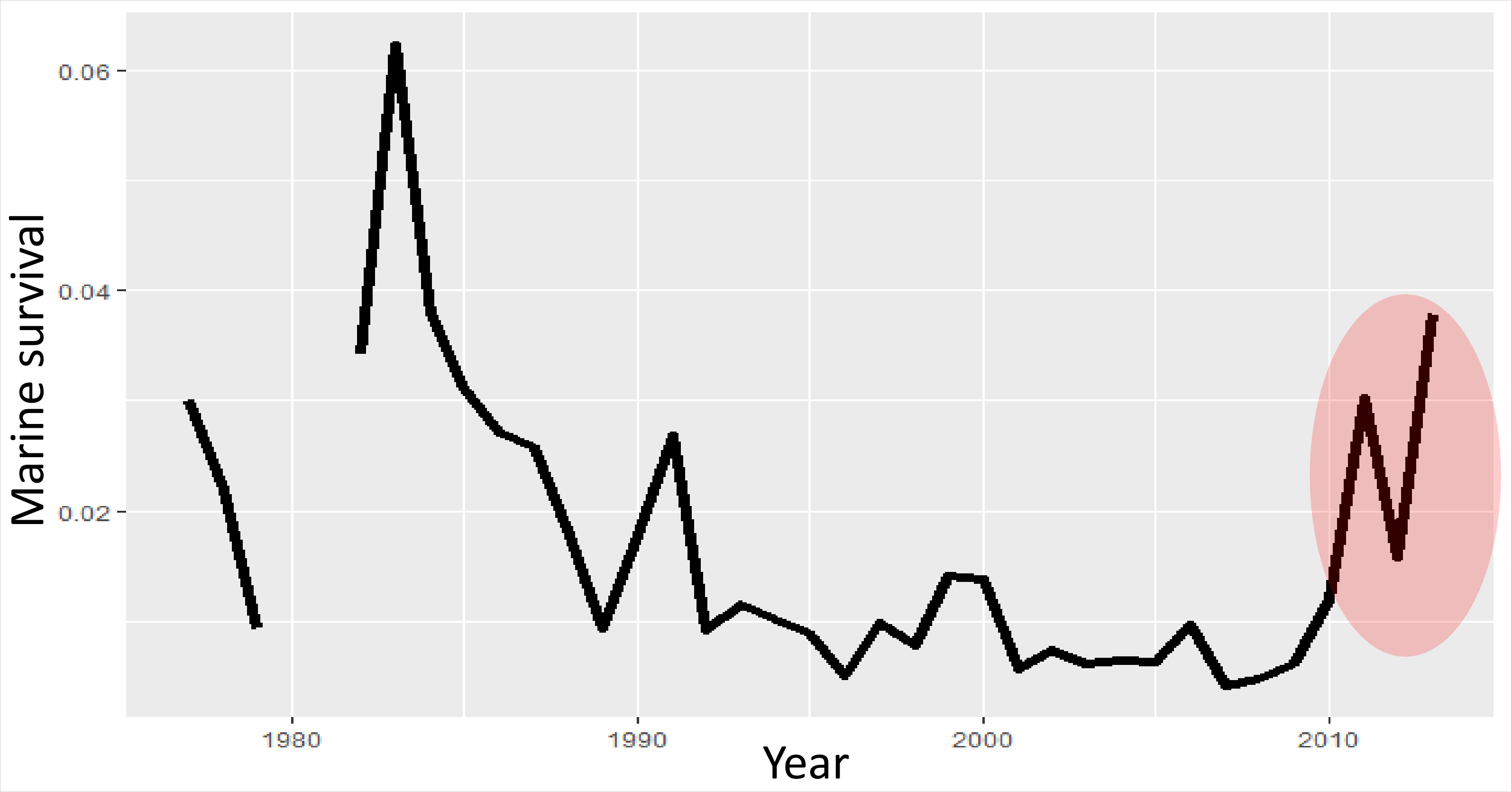


Puget Sound steelhead



Hypotheses

H1: Predation

-Increases in predators increase early marine mortality

H2a: Buffering

-Forage fish or other salmon provide predation buffer

H2b: Competition

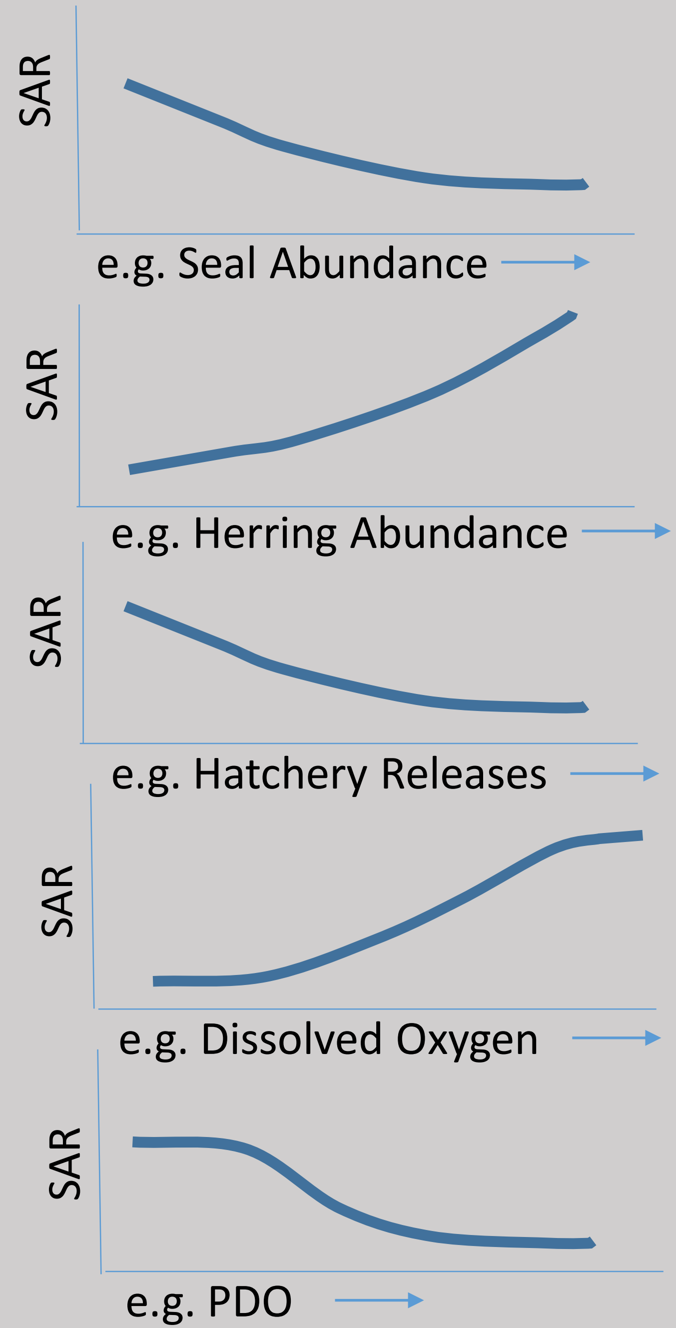
-Other salmonids compete for resources

H4: Rearing Conditions

-Adverse stream flow, env. conditions at marine entry

H5: Ocean conditions

-Ocean conditions may be unfavorable



Indicators

H1: Predation

-Abundance of harbor seals; killer whales (piscivorous fish data not available)

H2a: Buffering

-Herring spawning stock biomass; hatchery Chinook sub-yearling & yearling abundance and release date

H2b: Competition

-hatchery Chinook sub-yearling & yearling abundance and release date; pink salmon outmigration year

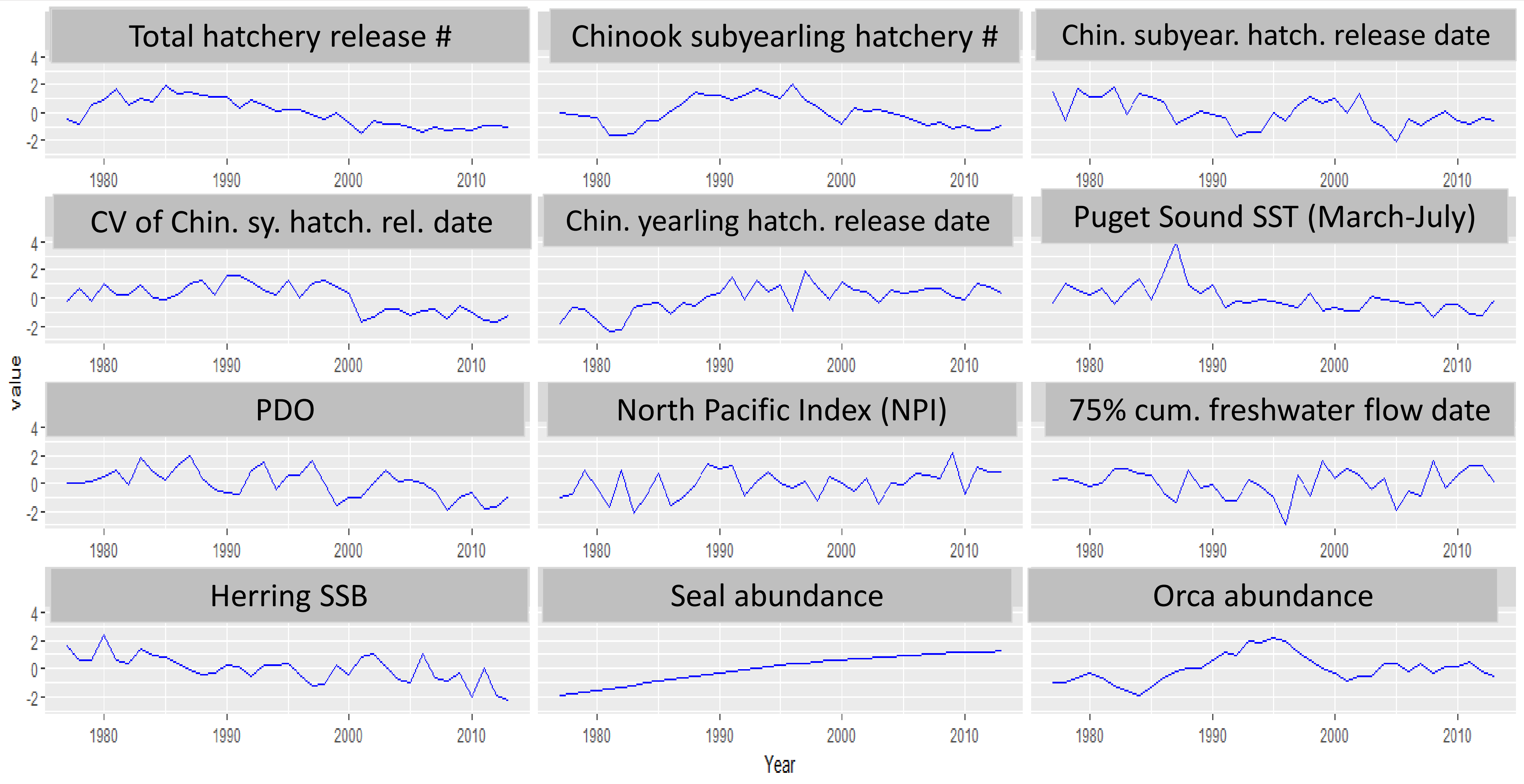
H4: Rearing Conditions

-River flow amounts & dates; Puget Sound SST (salinity, DO, pH, light transmissivity, satellite-derived chlorophyll data not available); human population abundance

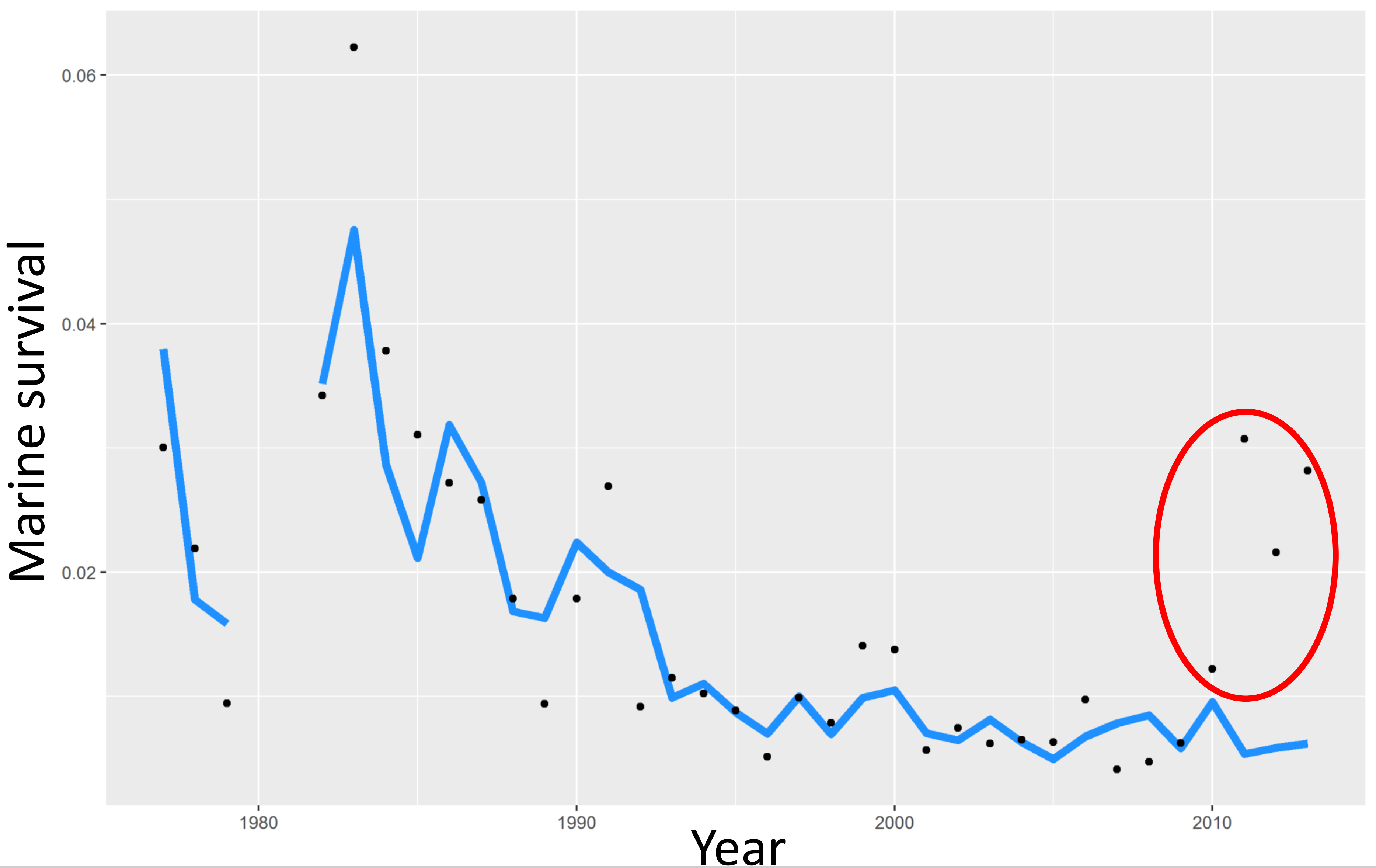
H5: Ocean conditions

-SST, salinity, NPGO, PDO, MEI, PNI, NPI, upwelling index, date of spring transition

Aggregate data and generate time series



Generalized additive models (GAMs)



Best model:

Marine survival **(SAR = run size/smolts) ~**

year +

subyearling Chinook hatchery release abundance +

CV of Chinook subyearling hatchery release date +

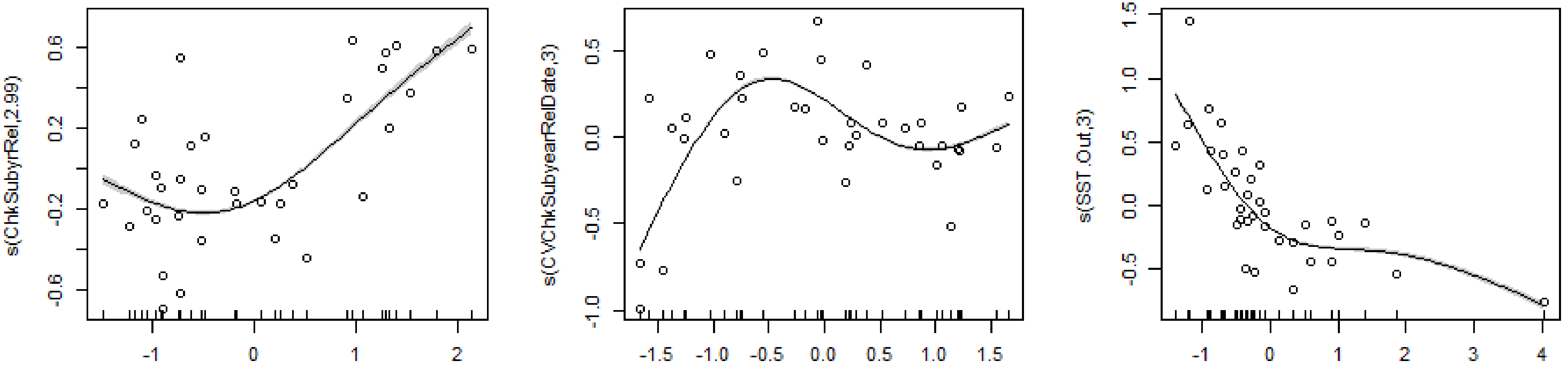
SST in Puget Sound +

NPI +

PDO +

seal abundance

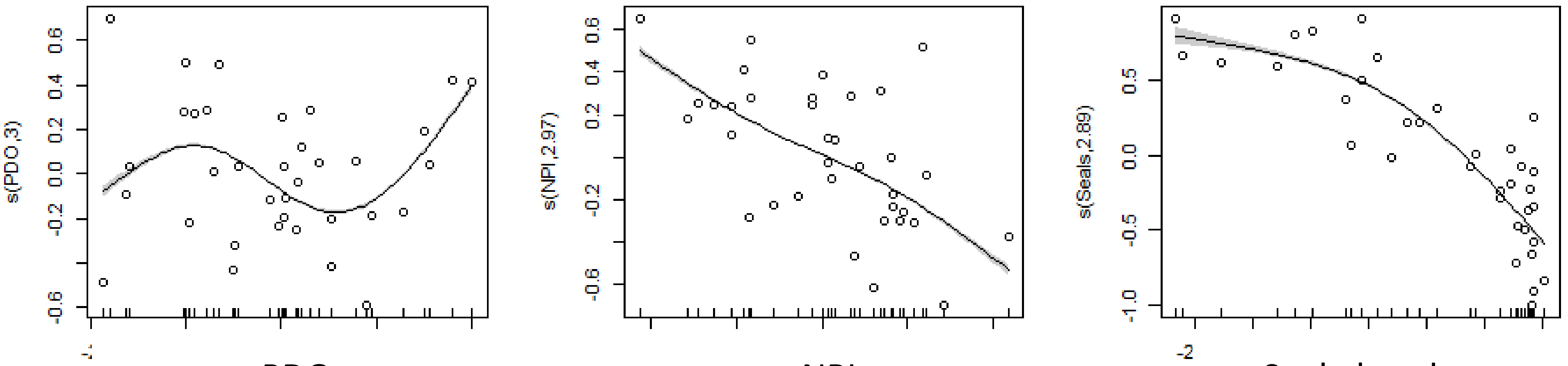
GAM smooth plot for each covariate



Hatchery subyearling Chinook released abundance

CV of date of hatchery sub-yearling Chinook released

SST (March-July in Puget Sound)



PDO

NPI

Seal abundance

Results

- Hatchery release abundance & timing and harbor seal abundance had strongest explanatory power
- SST was the only Puget Sound-specific parameter with explanatory power
- River flows were generally poor predictors of SAR
- Ocean conditions not strong predictors, but did add explanatory power

Steelhead marine survival indicators summary

- Marine survival most related to sub-yearling Chinook hatchery release abundance and timing, harbor seal abundance, and Puget Sound SST
- Better zooplankton and forage fish data would be helpful
- What are we missing???
- Further analyses specifically on early marine survival rates (survival data from acoustically-tagged steelhead—river to Strait of Juan de Fuca)

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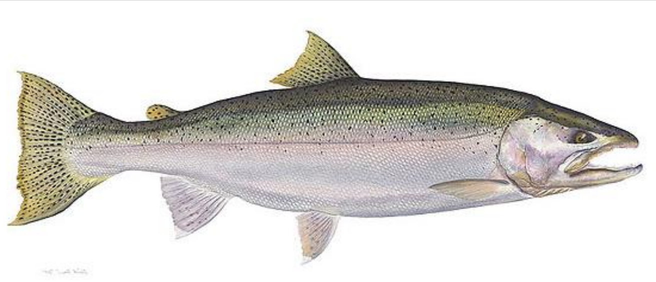
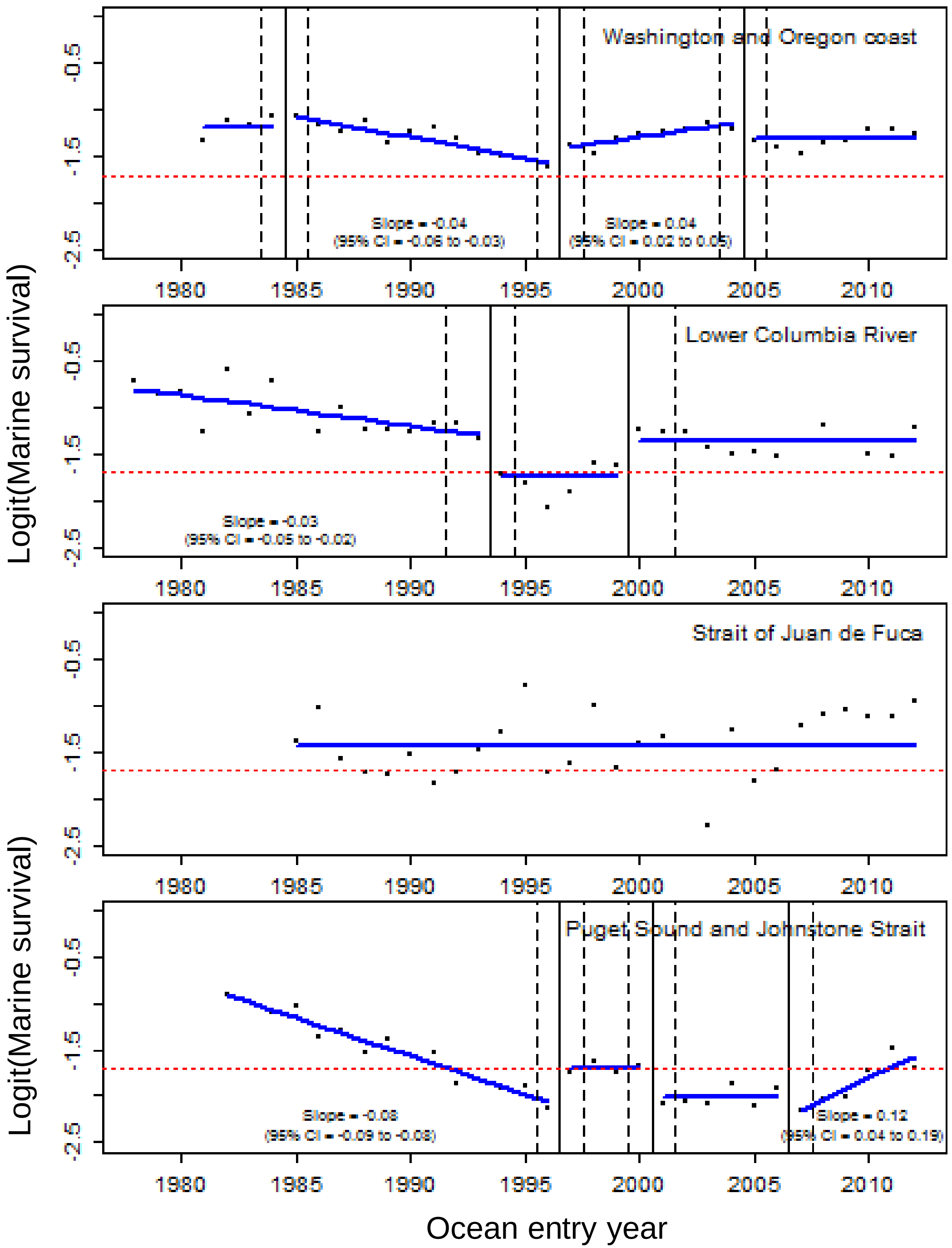
Photo: John McMillan/Trout Unlimited

Range and strength of marine survival spatial synchrony

- Range:
  - Steelhead: 248 km [Kendall et al. 2017]
  - Coho: 294 km [Zimmerman et al. 2015], 217 km [Teo et al. 2009]
  - Chinook: 1019 km [Kilduff et al. 2014], 497 km [Ruff et al. 2017]
  - Pink: 431-678 km, chum: 564-967 km, sockeye: 768-1068
- Strength:
  - Steelhead: 0.42 [Kendall et al. 2017]
  - Coho: 0.84 [Zimmerman et al. 2015
  - Chinook: 0.44 [Kilduff et al. 2014], 0.33 [Ruff et al. 2017]

Steelhead marine survival time series—breakpoints





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, early marine survival of 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)

Objectives:

1.) Develop a list of candidate indicators for salmon marine survival relating to both environmental and anthropogenic factors
2.) Aggregate datasets that might be useful as indicators
3.) **Evaluate candidate indicators for usefulness**
4.) **Use statistical tools and the selected indicators to evaluate retrospective survival and to make predictions**

Evaluate collinearity among potential indicators