

IMPROVED UNDERSTANDING OF FISHERIES & ECOSYSTEMS FROM NOISY & DISPARATE DATA

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Brice Semmens (Scripps)

Acknowledgments

Post-docs

Grad students

Undergrads

Many others





I was trained as a field ecologist



My early research was largely empirical

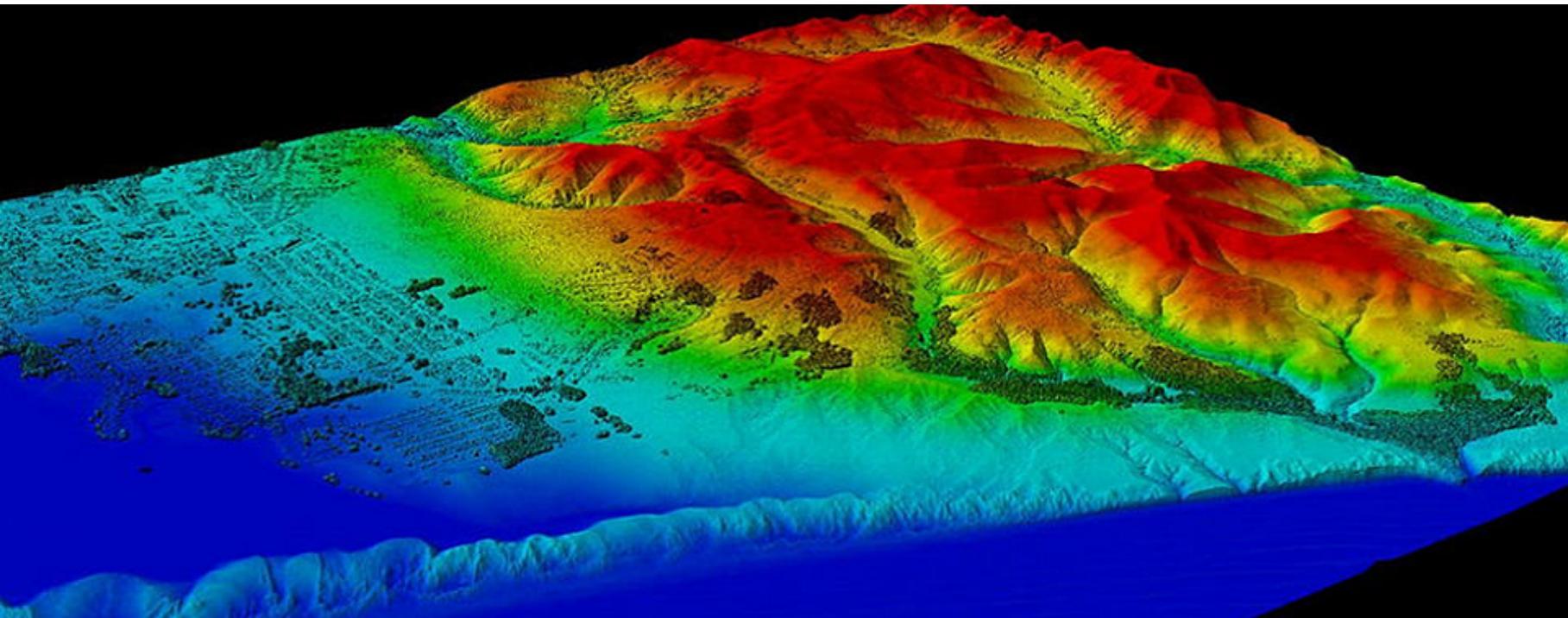
Nutrient limitation of lake productivity

Vertical migration in juvenile sockeye salmon

Trophic interactions among stream fishes

Many scientific advances

Remote sensing



Genetics



Analysis

A word cloud centered around the word "statistical". The words are colored in shades of blue, orange, and red. The size of each word represents its frequency or importance in the context of statistical analysis.

The most prominent words are "statistical" (large, dark blue), "data" (large, orange), "analysis" (large, orange), "models" (medium, blue), "inference" (medium, yellow), and "statistics" (large, teal).

Other visible words include:

- research coefficient
- regression learning
- computing
- generalized linear
- bayesian
- estimation random
- probability modeling
- maximum
- workshops
- simulation
- consulting
- series
- causal equation
- covariate duration
- variance distribution
- graphical standard
- spatial visualization
- methods
- normal
- parameter
- predictive
- time function
- management
- analytics
- expectation
- likelihood
- trend

Current research foci

Models for spatio-temporal data

Integrated population models

Ecological portfolios

How do natural & human forces affect
the structure of aquatic ecosystems &
the services we derive from them?

The forces may be

biological (food web interactions, harvest)

physical (climate, habitat modification)

chemical (ocean acidification, contaminants)

The services can be
provisioning (food production)

supporting (nutrient cycling)

regulating (flood control)

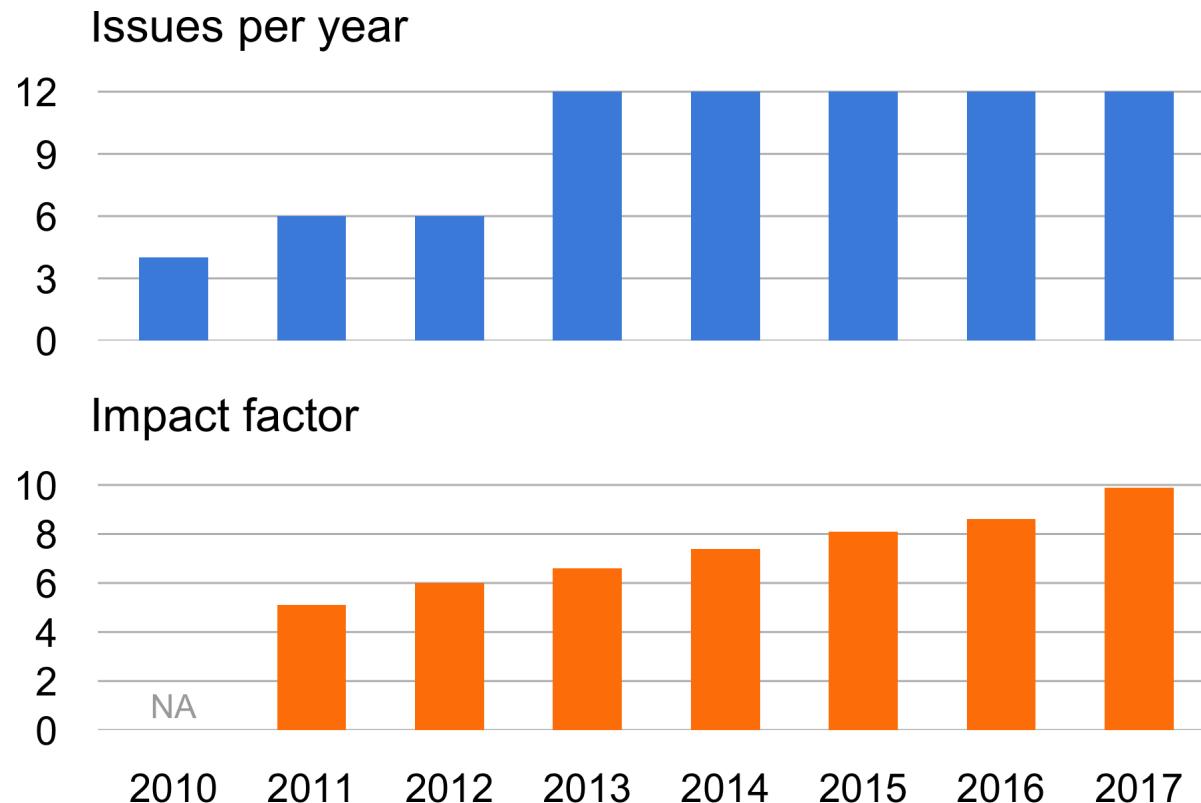
cultural (spiritual benefits)

We love to forecast, but we're not very good at it.

- Nate Silver

The signal and the noise

Methods in Ecology and Evolution



Lots of focus on *hierarchical models*



Hi·er·ar·chi·cal

adjective

1. Arranged in an order

A hierarchical model is simply
a model within a model

Hierarchical models also masquerade as

Nested data models

Mixed models

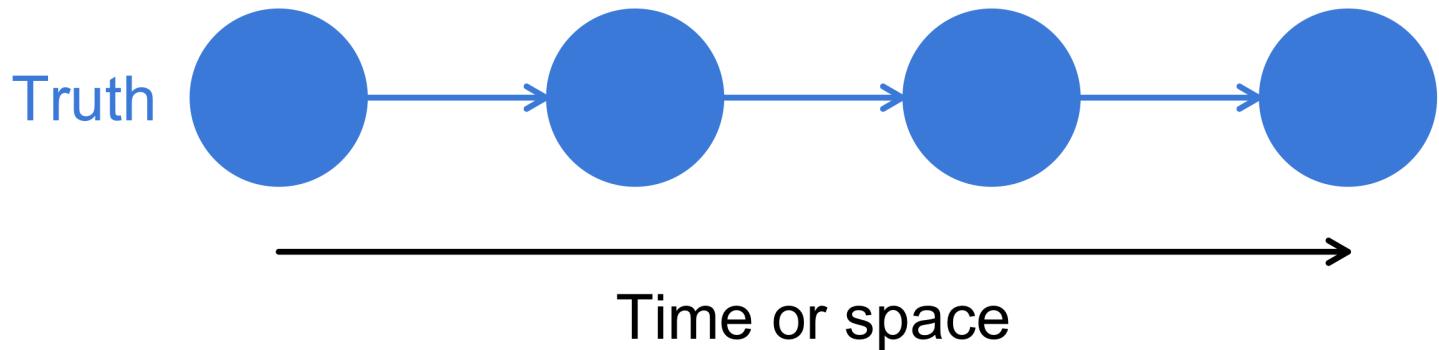
Random-effects models

State-space models

A state-space model has 2 parts

Part 1: State model

Describes the **true state of nature** over time or space



States of nature might be

Animal location

Species density

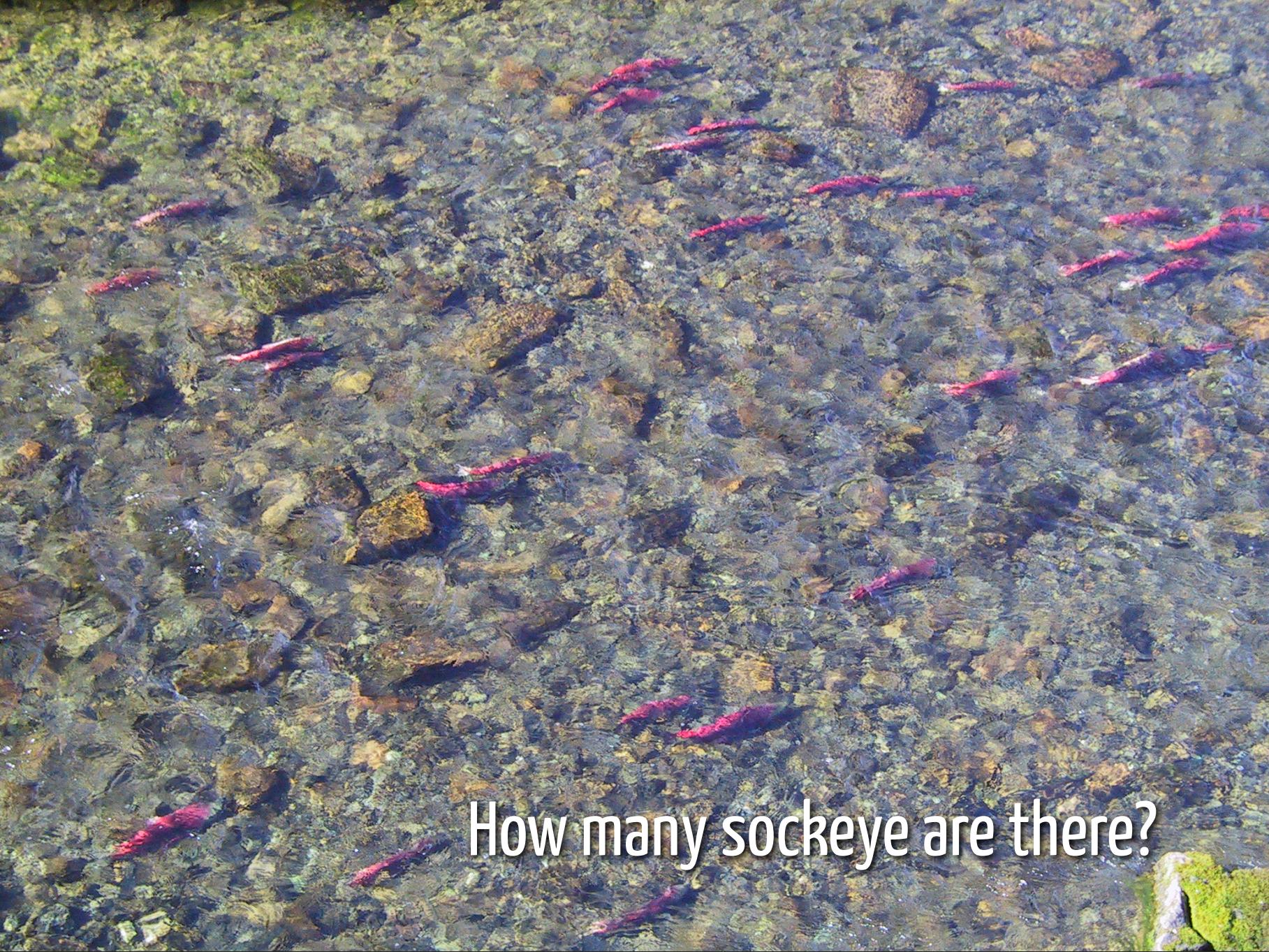
Age structure

Reproductive status

A photograph of two ornate Venetian carnival masks facing each other. The mask on the left is black with gold embroidery and a large orange feathered plume. The mask on the right is gold with red and black patterns and a large green feathered plume. Both masks have decorative elements like beads and sequins.

Revealing the true state requires observations

Observing nature can be easy



How many sockeye are there?

Observing nature can also be hard



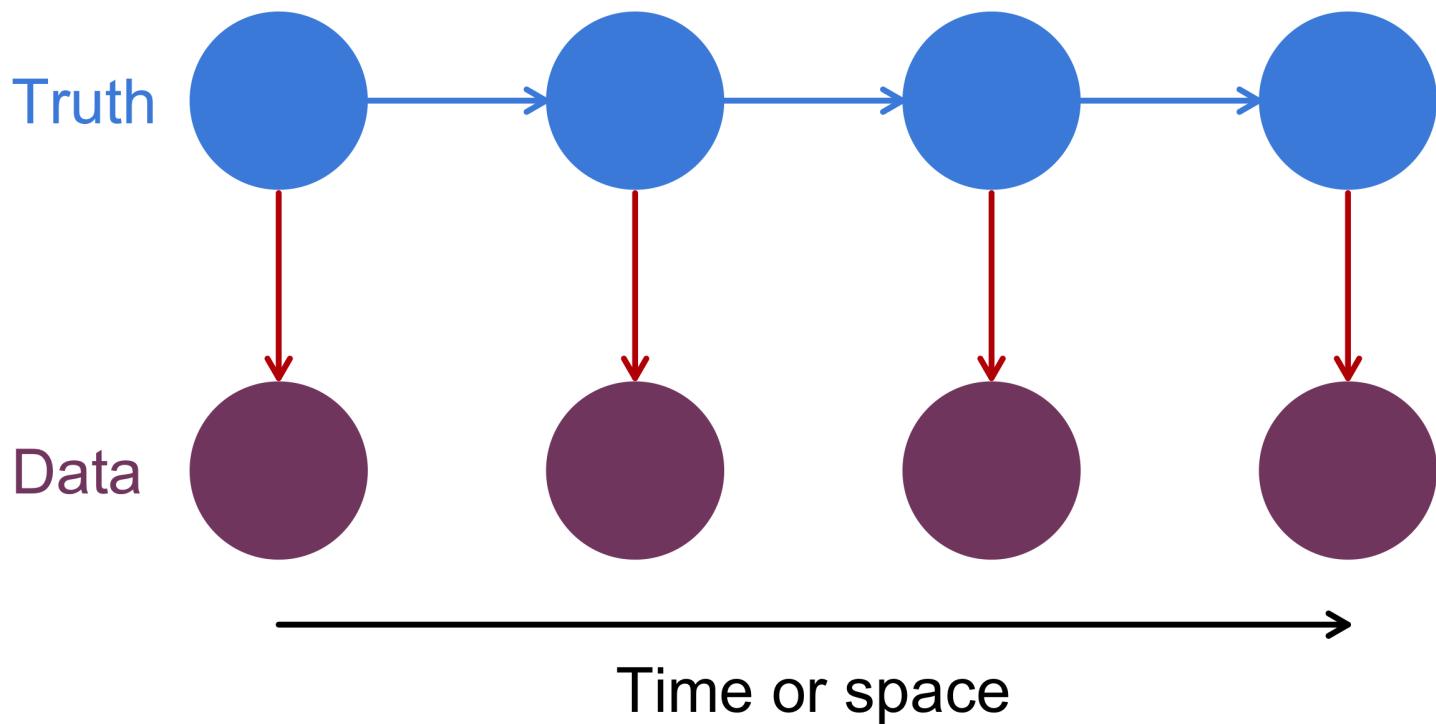
How many mayflies are there?

Part 2: Observation model

Data = Truth \pm Errors

Part 2: Observation model

Data = Truth \pm Errors



OK, but why bother?

Advantages of hierarchical models

1. Can combine many different data types

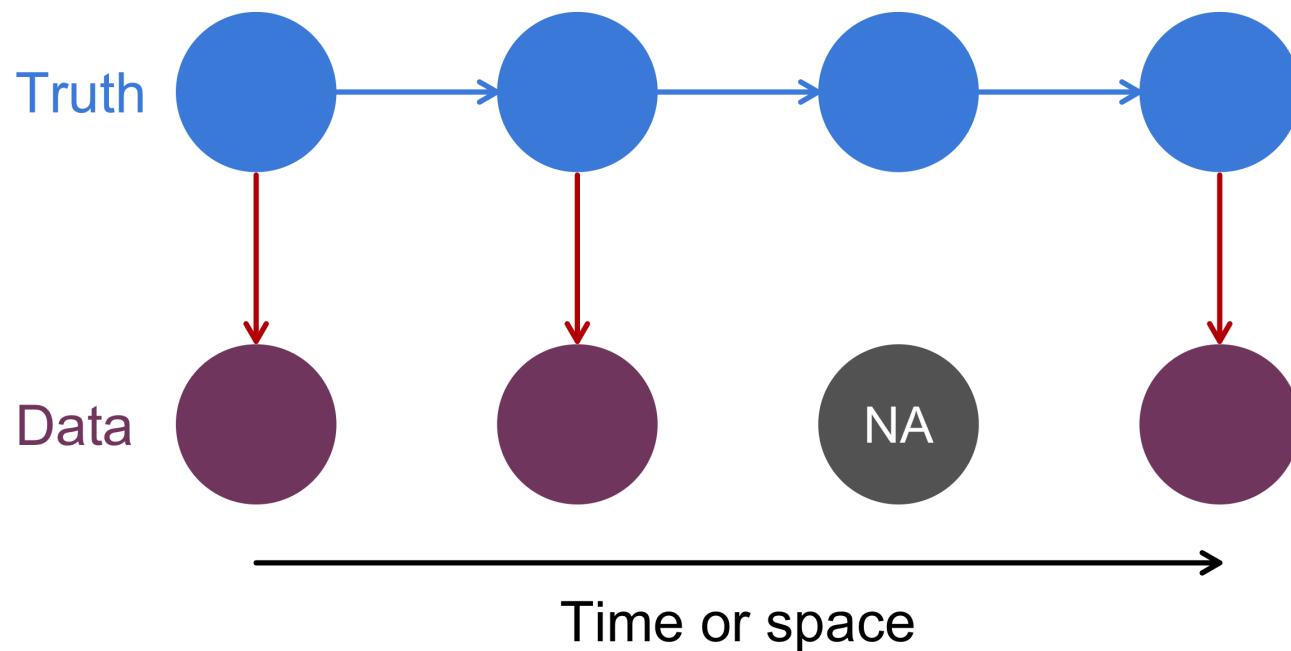
Changes in observers or sensors

Varying survey locations & effort

Direct & remote sampling

Advantages of hierarchical models

2. Missing data are easily accommodated



Advantages of hierarchical models

3. Improved accuracy & precision

Article | **OPEN** | Published: 08 February 2016

Joint estimation over multiple individuals improves behavioural state inference from animal movement data

Ian Jonsen 

Scientific Reports **6**, Article number: 20625 (2016) | Download Citation 

Advantages of hierarchical models

4. Rather flexible

This simple model can be used for 5+ unique applications

$$\mathbf{x}_t = \mathbf{B}\mathbf{x}_{t-1} + \mathbf{w}_t$$

$$\mathbf{y}_t = \mathbf{Z}\mathbf{x}_t + \mathbf{v}_t$$

How do I actually do this?

Many software options

Canned R packages (`dlm`, `vars`, `MARSS`^{*})

Code-your-own (`JAGS`, `Stan`, `greta`)

^{*}Holmes, Ward, Scheuerell (2018) *Analysis of multivariate time-series using the MARSS package*



SNAKE
OIL

For Nervousness
For Weak Stomach
For Tired Legs

DRUGS

Emergence of high-dimension data

Remote sensing

Citizen science

Large-scale surveys

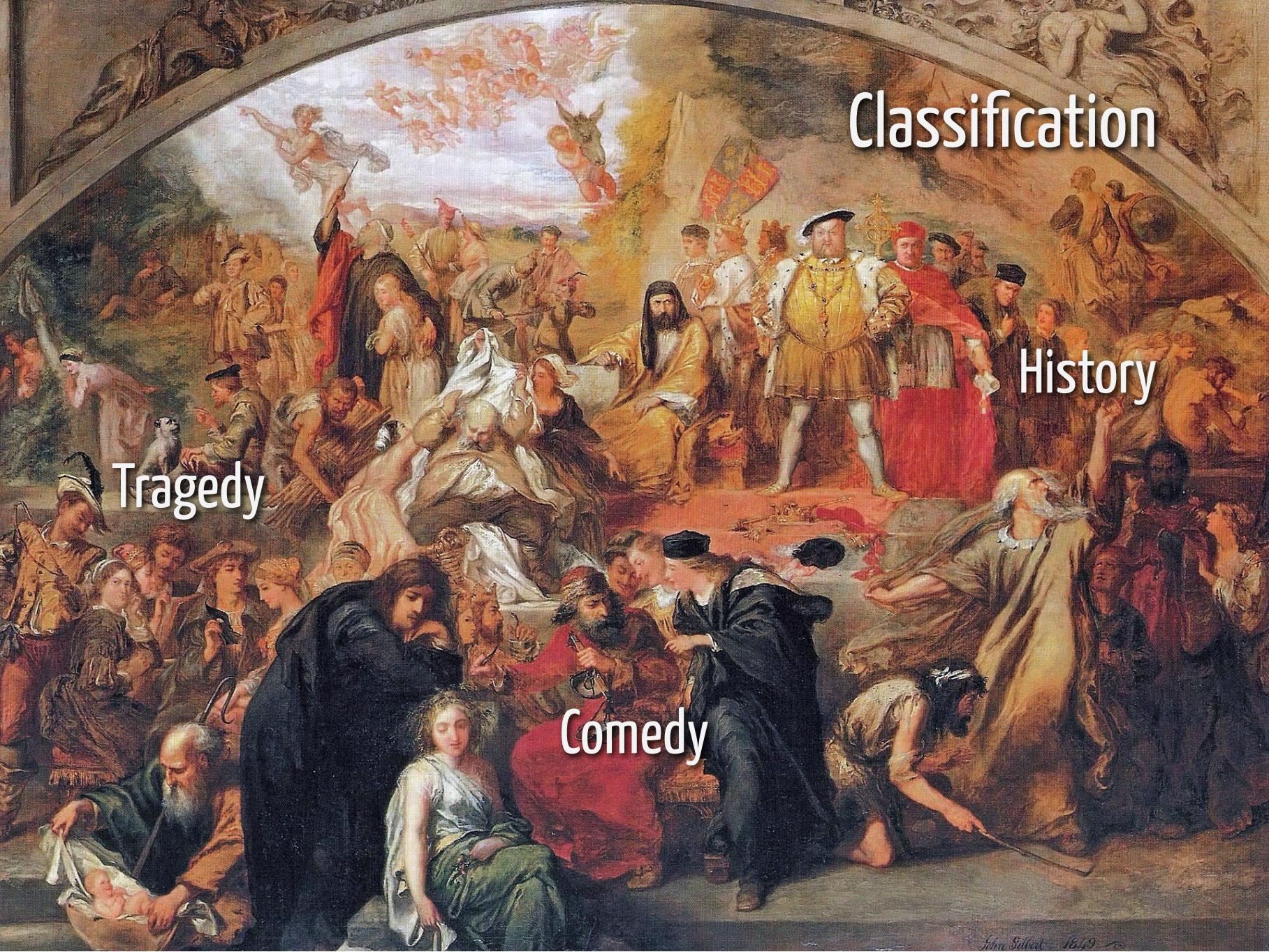
Emergence of high-dimension data

Remote sensing

Citizen science

Large-scale surveys

How can we make sense of all of this?



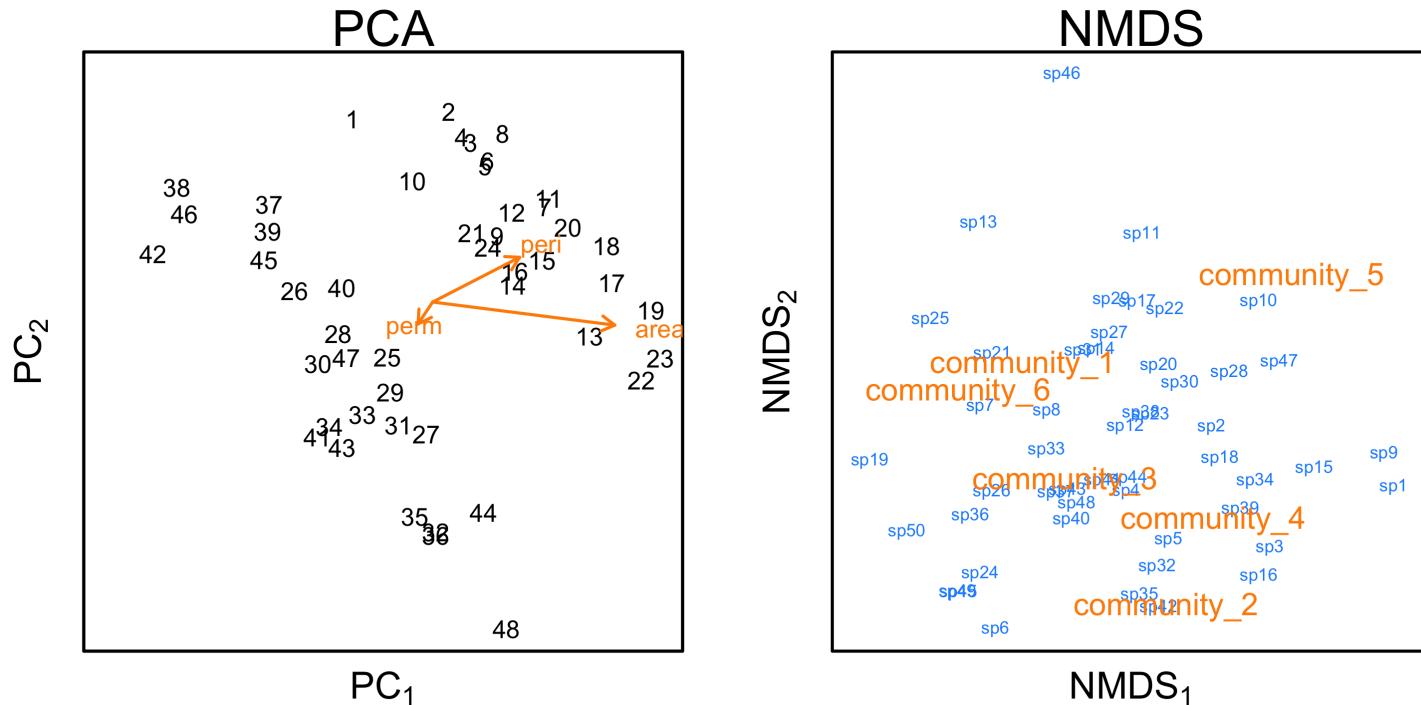
Classification

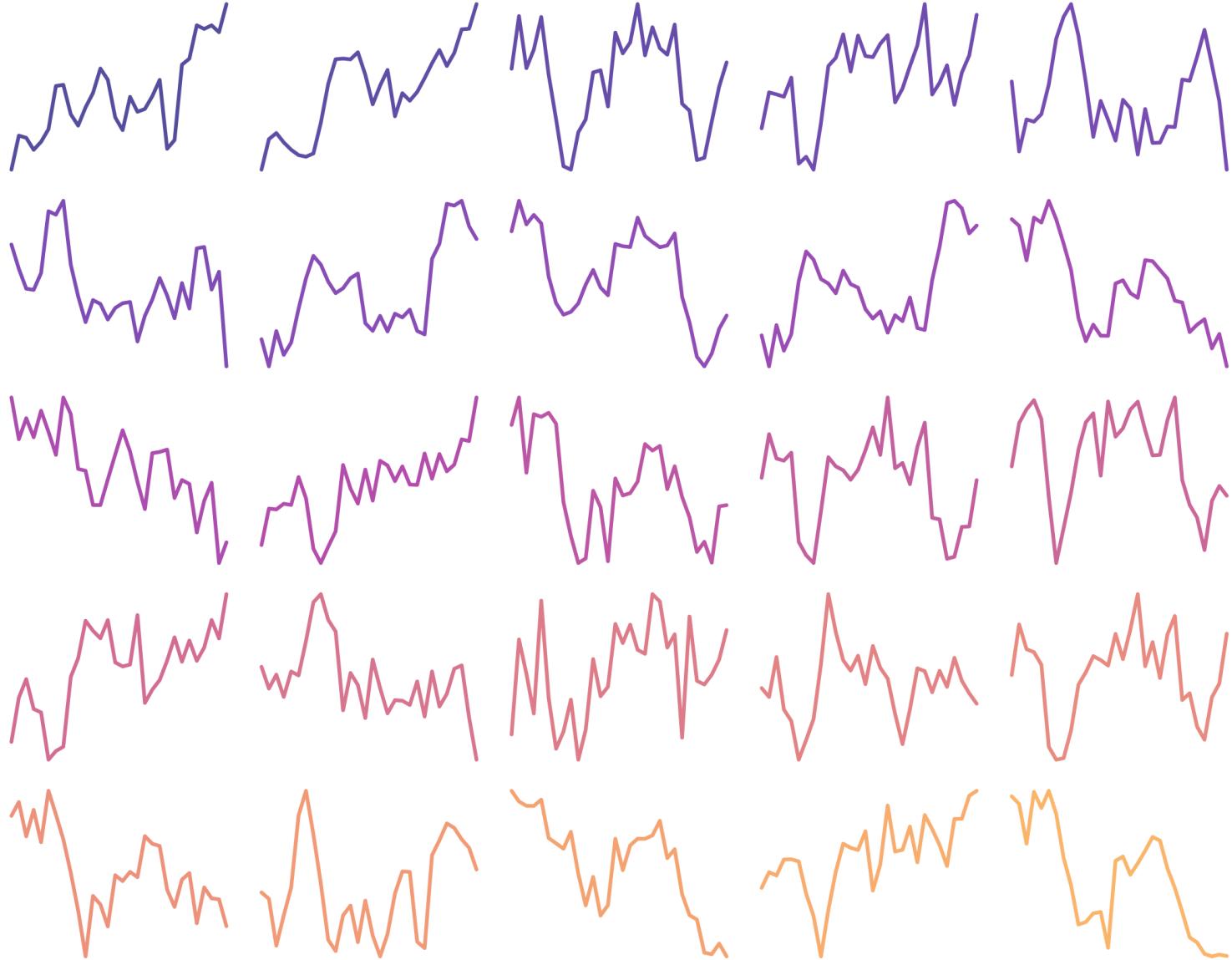
Tragedy

Comedy

History

Ordination





Just some combination of these



Dynamic Factor Analysis

State model

$$\text{Trends}_t = \text{Trends}_{t-1} + \text{error}_t$$

Dynamic Factor Analysis

State model

$$\text{Trends}_t = \text{Trends}_{t-1} + \text{error}_t$$

Observation model

$$\text{Data}_t = \text{Loadings} \times \text{Trends}_t + \text{error}_t$$

Salmon returns & productivity

Trying to understand when & where stocks covary

Mantua et al. (1997)

Mueter et al. (2005)

Stachura et al. (2014)



Arctic-Yukon-Kuskokwim CHINOOK SALMON RESEARCH ACTION PLAN

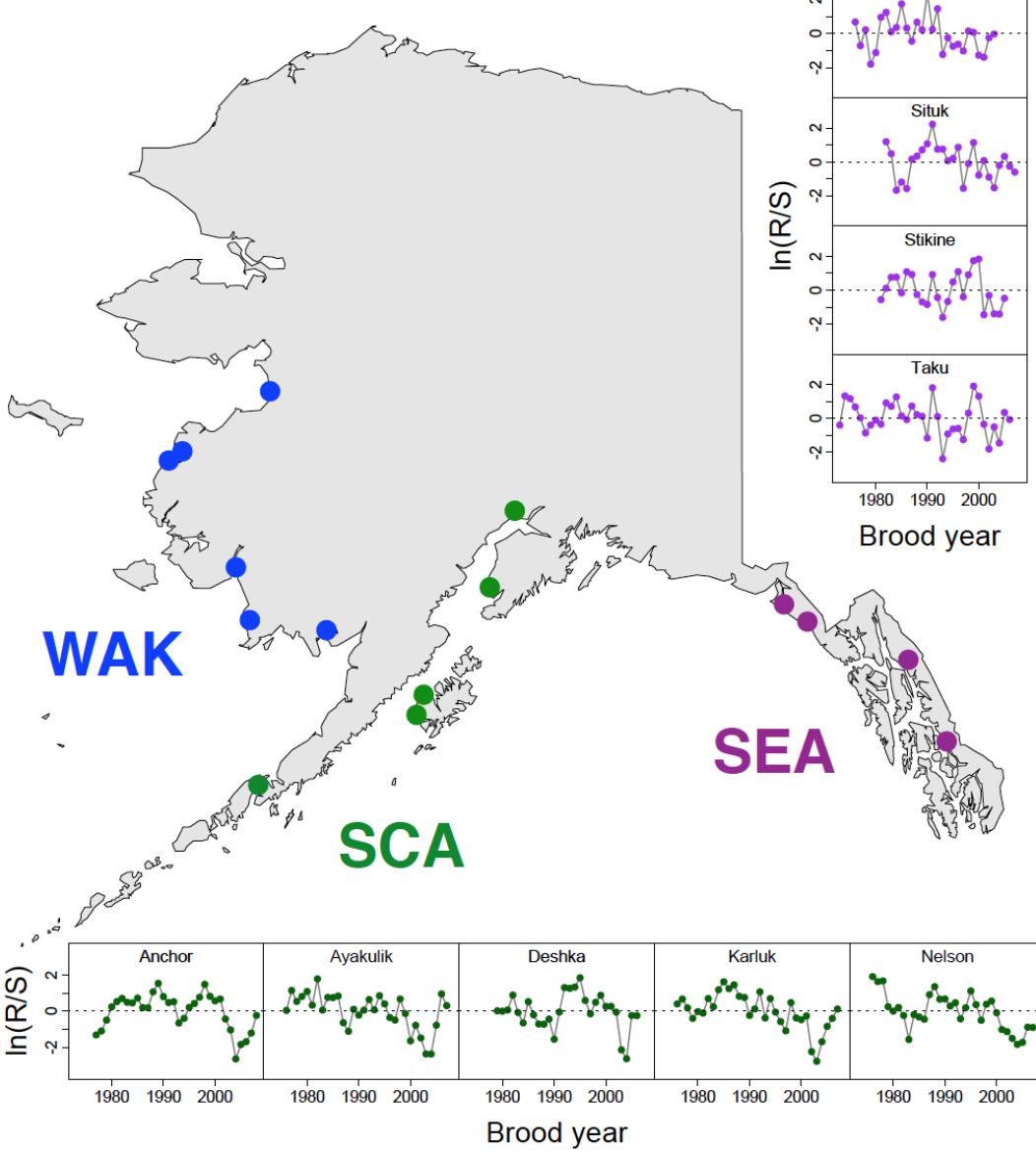
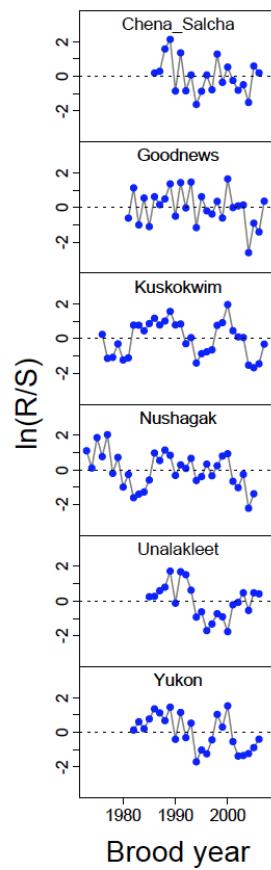
Evidence of Decline of Chinook Salmon Populations
and Recommendations for Future Research

Arctic-Yukon-Kuskokwim Sustainable Salmon Initiative
AYK SSI Chinook Salmon Expert Panel

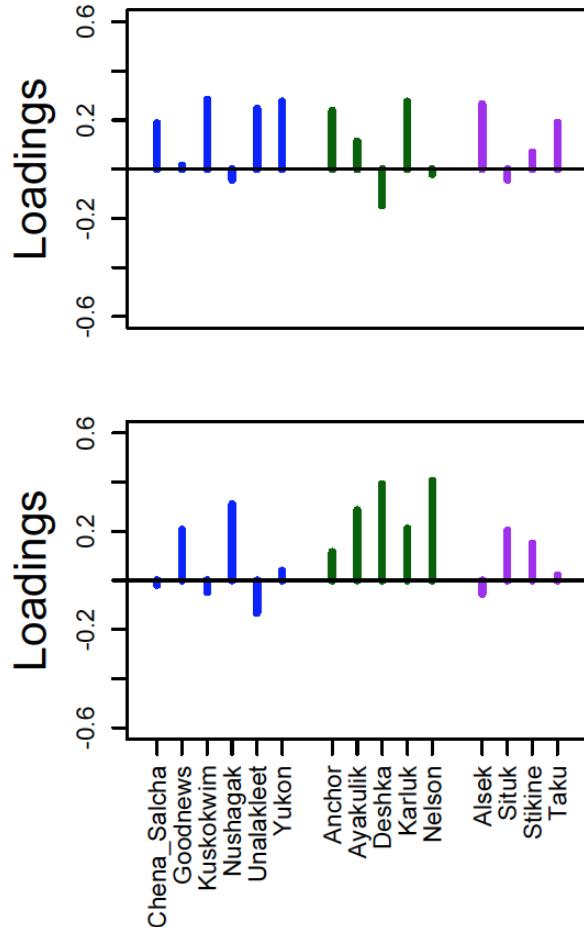
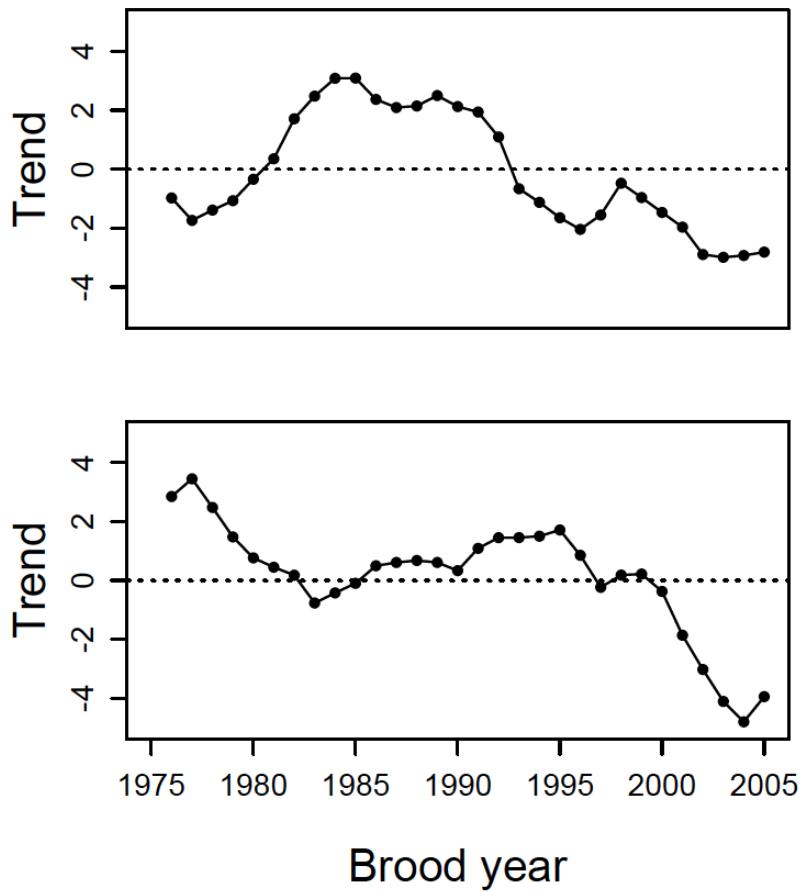
August 2013

Are there common patterns over time?

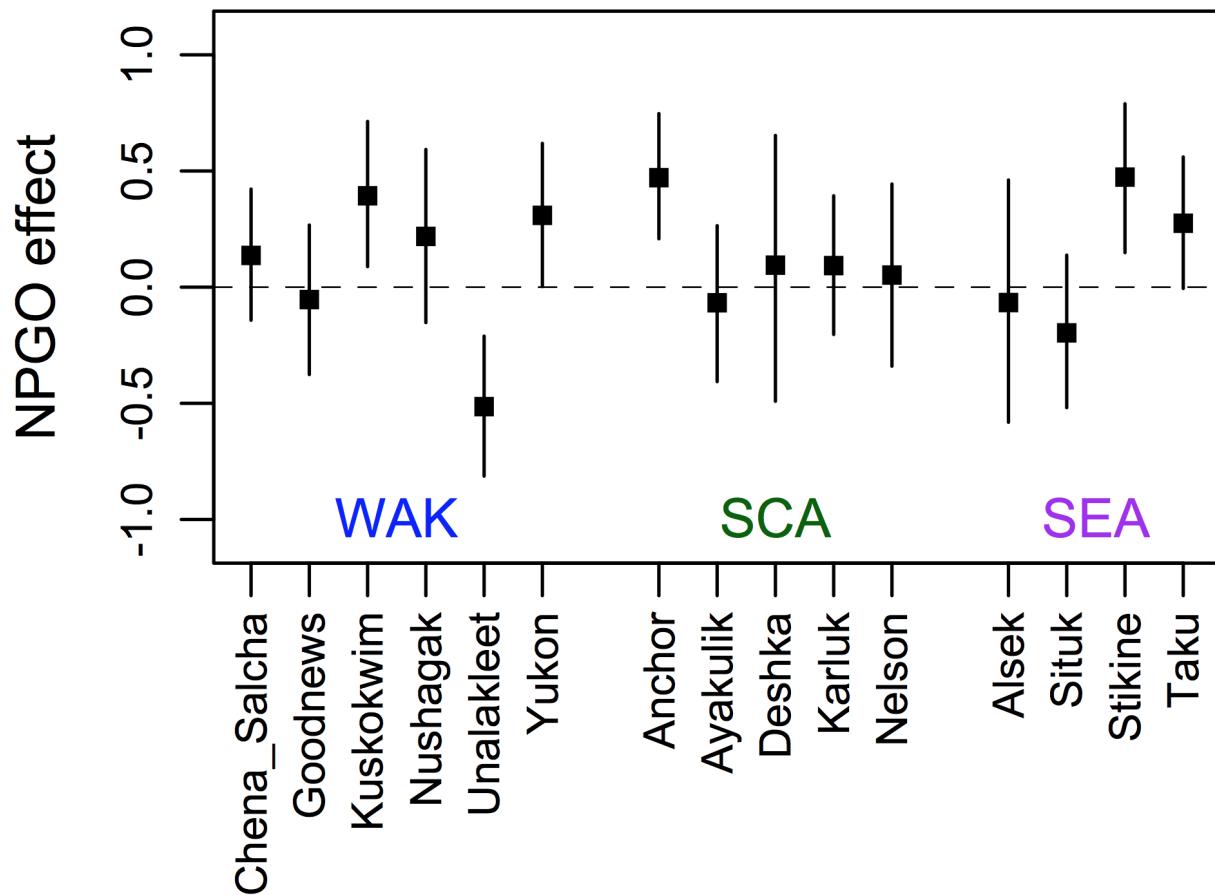
Ex: Alaskan Chinook salmon (15 popns, 25+ years)

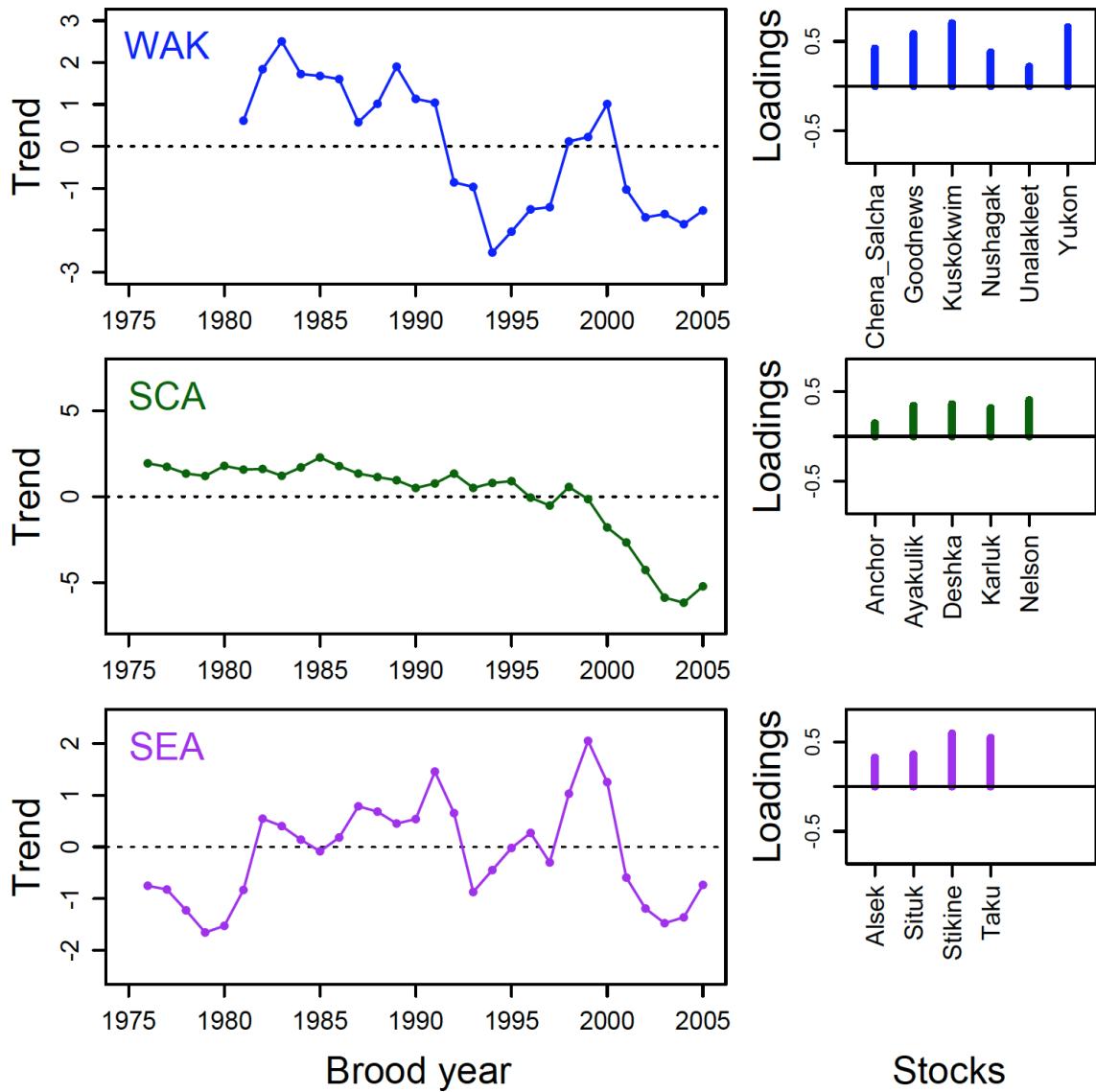


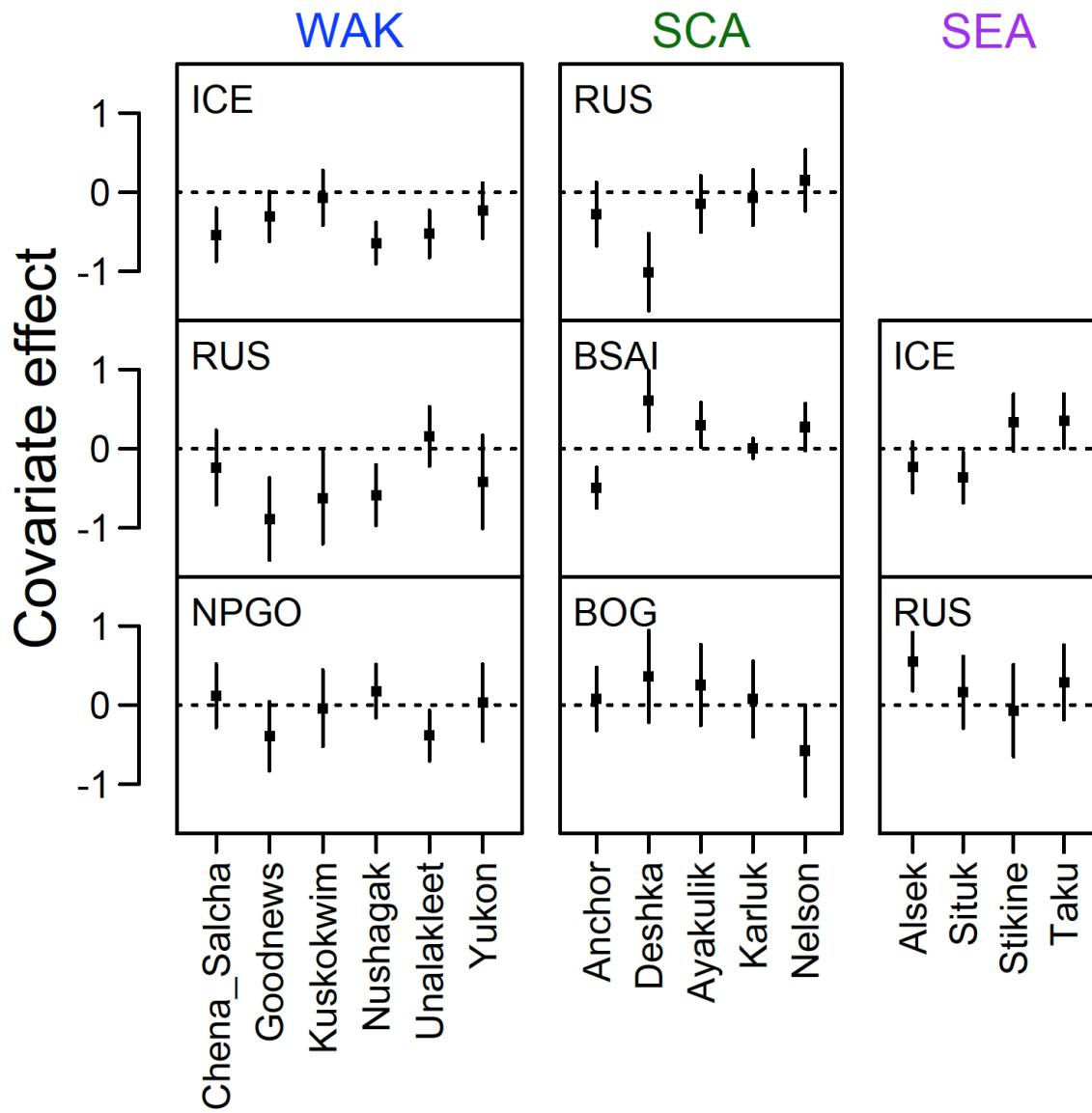
Two declining trends



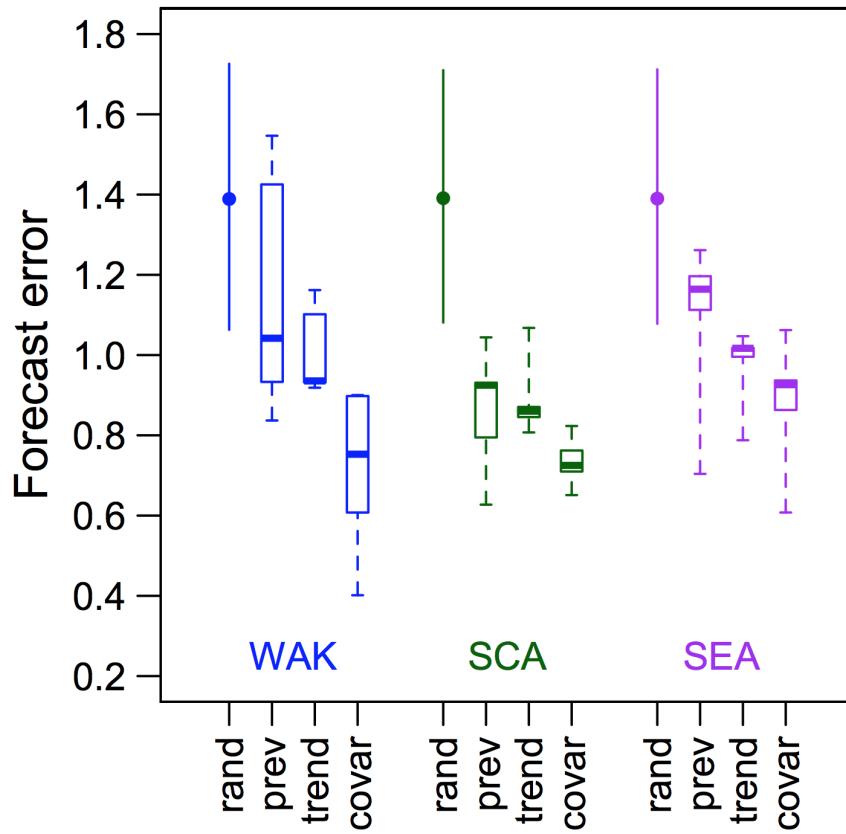
Ocean is part of the story







Environmental effects improve forecasts



Space. The final frontier...

WCGBTs: West Coast Groundfish Bottom Trawl Survey

1998-2018: 20 years of dependability, efficiency & excellence

BIOLOGICAL DATA

- Age structures collected: 360,467
- Diet samples collected: 8,495
- Genetic samples collected
 - fin clip: 15,271
 - coral: 3,000
- Lengths taken: 1,800,324
- Maturity samples collected: 6,729

INTEGRATED ECOSYSTEM ASSESSMENT (IEA)

- Environmental data
- Food web
- Habitat mapping

SURVEY LINKS

- <https://tinyurl.com/surveyleftGF>
- <https://tinyurl.com/WCGBTs>
- <https://tinyurl.com/surveylblogGF>

MANAGEMENT & SCIENTIFIC CONTRIBUTIONS

- MSC certification
- New species: 2
- PFMC assessments: 52 (69% of total)
- Publications: 51
- Species range extensions: 5
- Recovered/rebuilt species: 8

NEAR BOTTOM OXYGEN

- Min O_2 = 0.02 mL/L
- Max O_2 = 5.96 mL/L

TOTAL FISH SALES

- 2017 pounds and dollars delivered:
 - 121,119 lbs
 - \$68,461
- 2016 total revenue of groundfish fishery (not shrimp or crab): \$62,517,873

CATCH DATA

- Fishing time: ~18 million seconds
- Pounds sampled: 9,748,073 lbs
- Sampled fish species: 1,073
- Sampled starfish species: 130

VESSEL DATA

- Boats chartered: 15
- Captains: 26
- Days at sea: 2,727
- Miles traveled per year: ~2,400 per vessel
- Stations sampled: 11,805
- Volunteers: 245



Research

EK-60

- Habitat mapping
- Max depth fished: 4920 ft
- Survey depth range: 180 - 4200 ft

SEAFLOOR TEMPERATURE

- Min Seafloor temp = 2.9 °C
- Max Seafloor temp = 14.7 °C



°C

Westport

Astoria

Newport: homeport F/V Excalibur,
F/V Last Straw

Coos Bay: homeport F/V Ms. Julie

Brookings: homeport F/V Noah's Ark

Eureka

San Francisco

Santa Barbara

Long Beach

San Diego

Are there common patterns over space?

Ex: California Current rockfish (20 spp, 10 years)

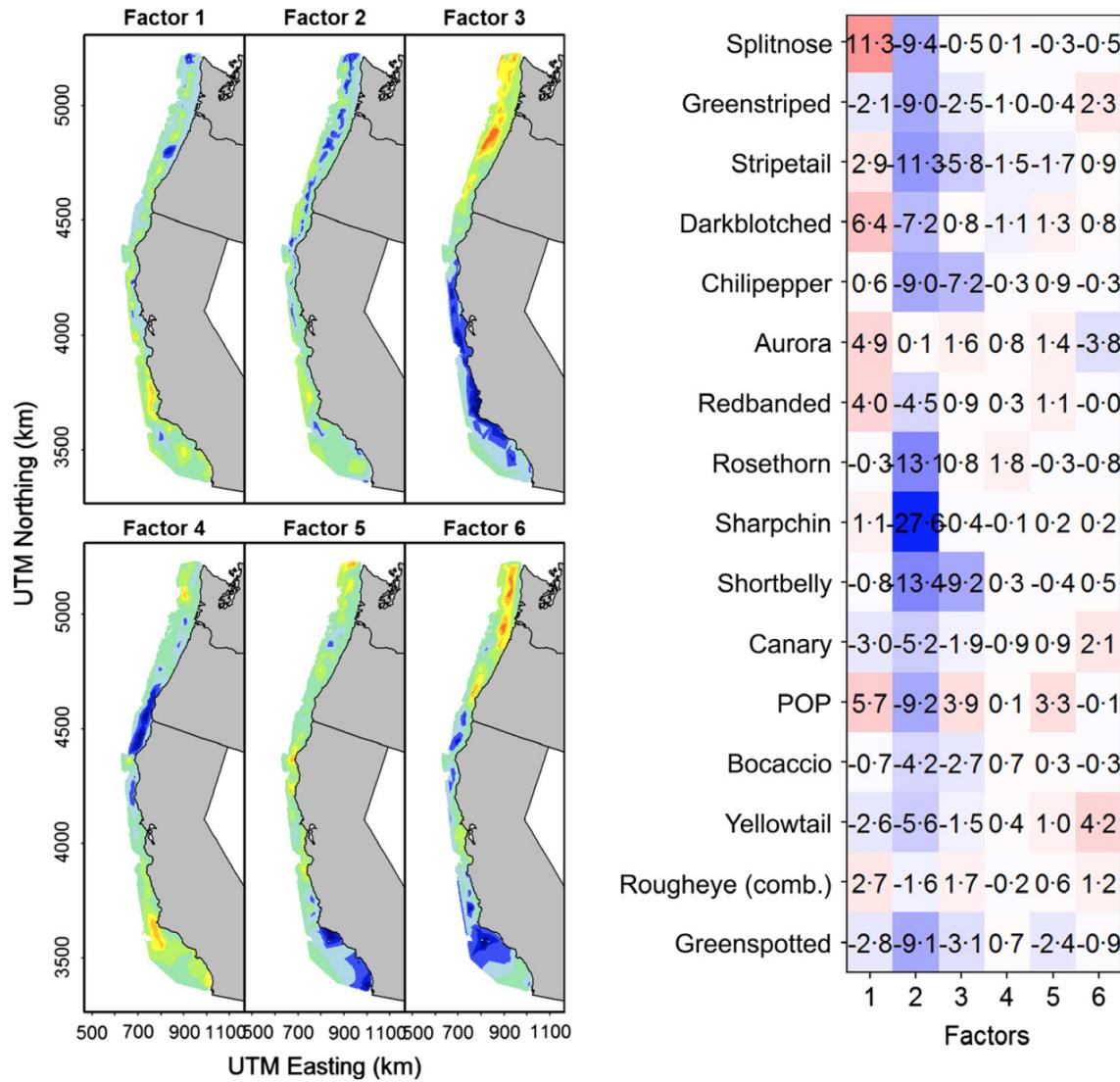
Spatial Factor Analysis

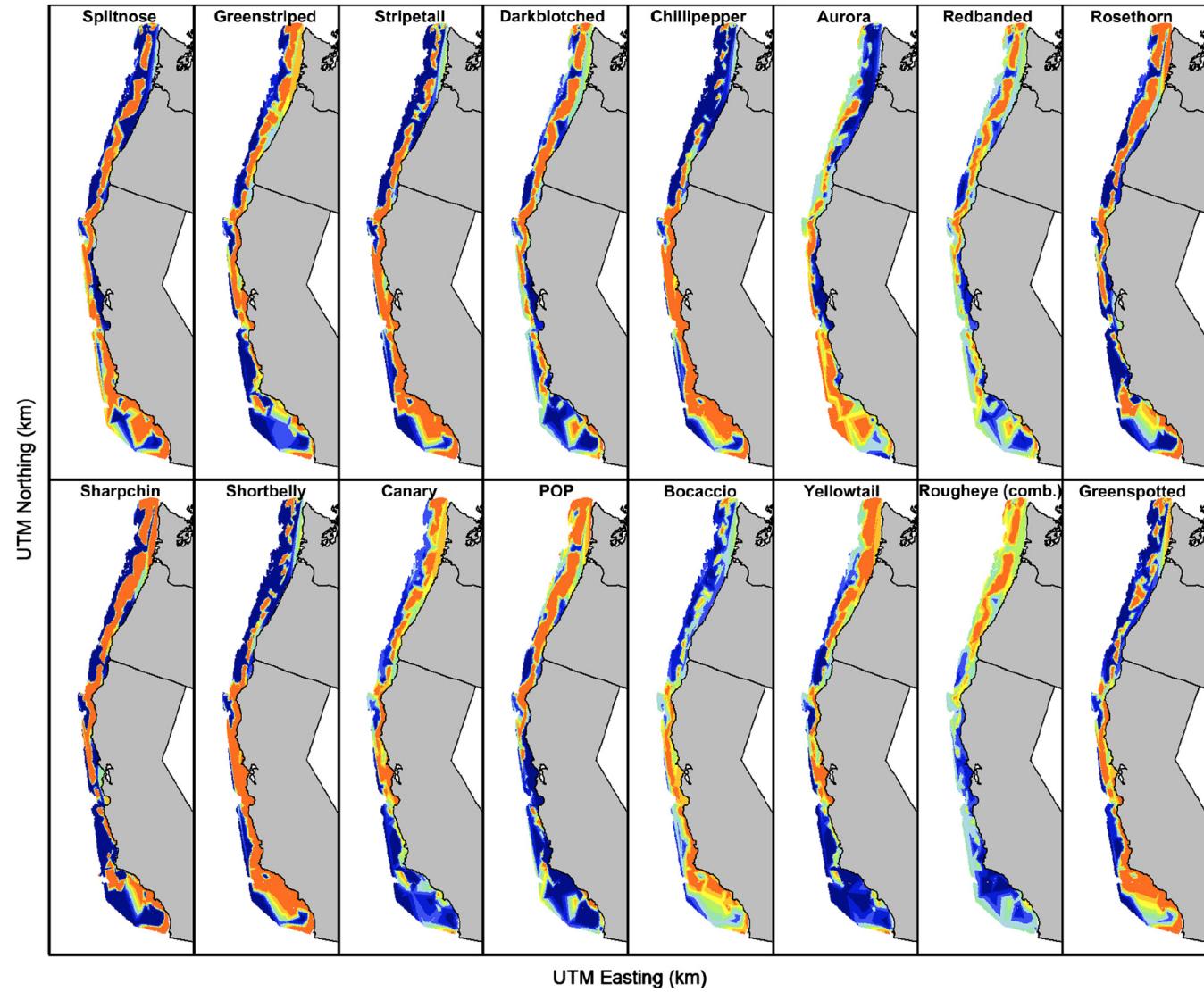
State model

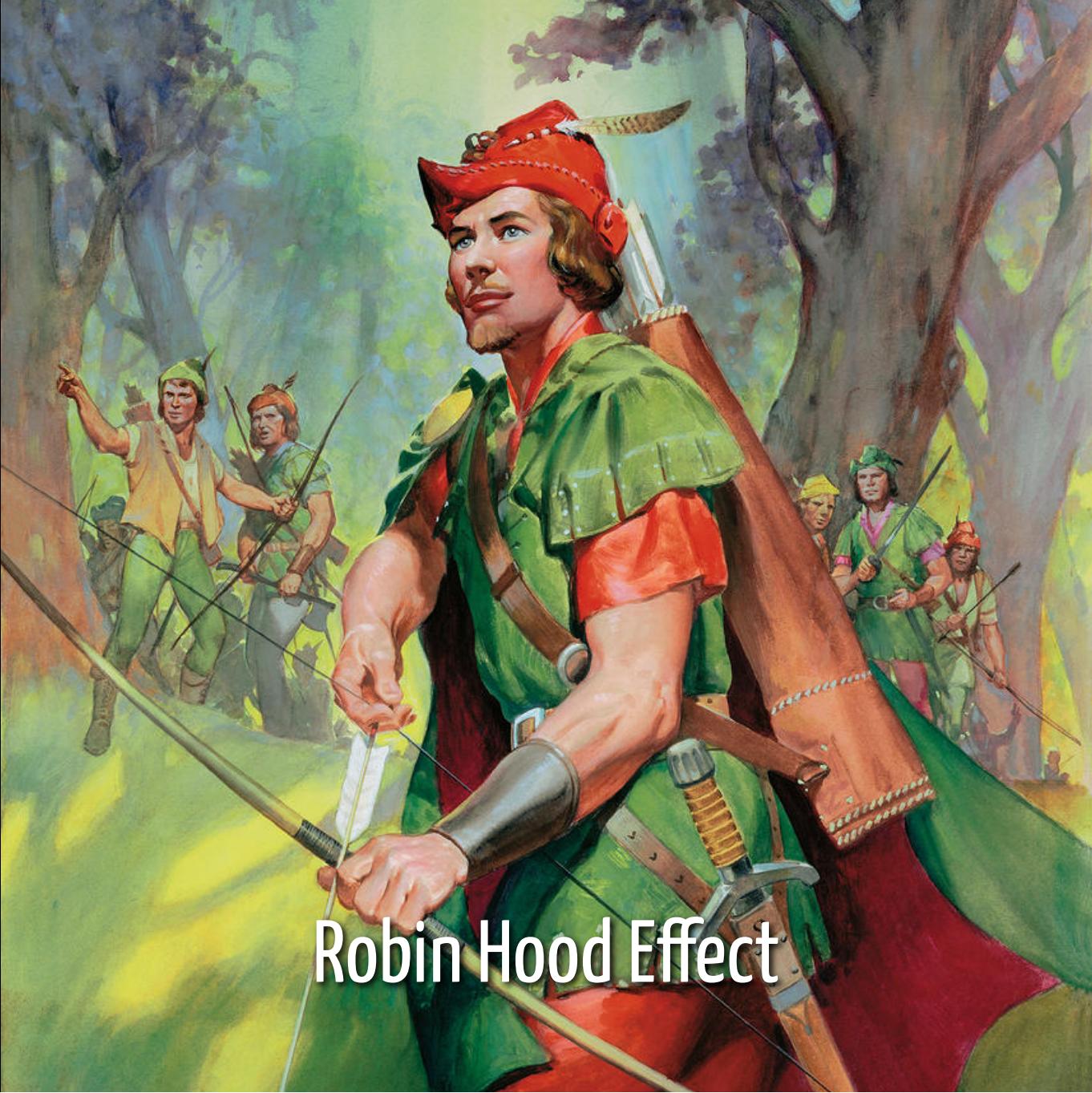
Spatial maps_i

Observation model

Data_i=Loadings × Spatial maps_i+ error_i



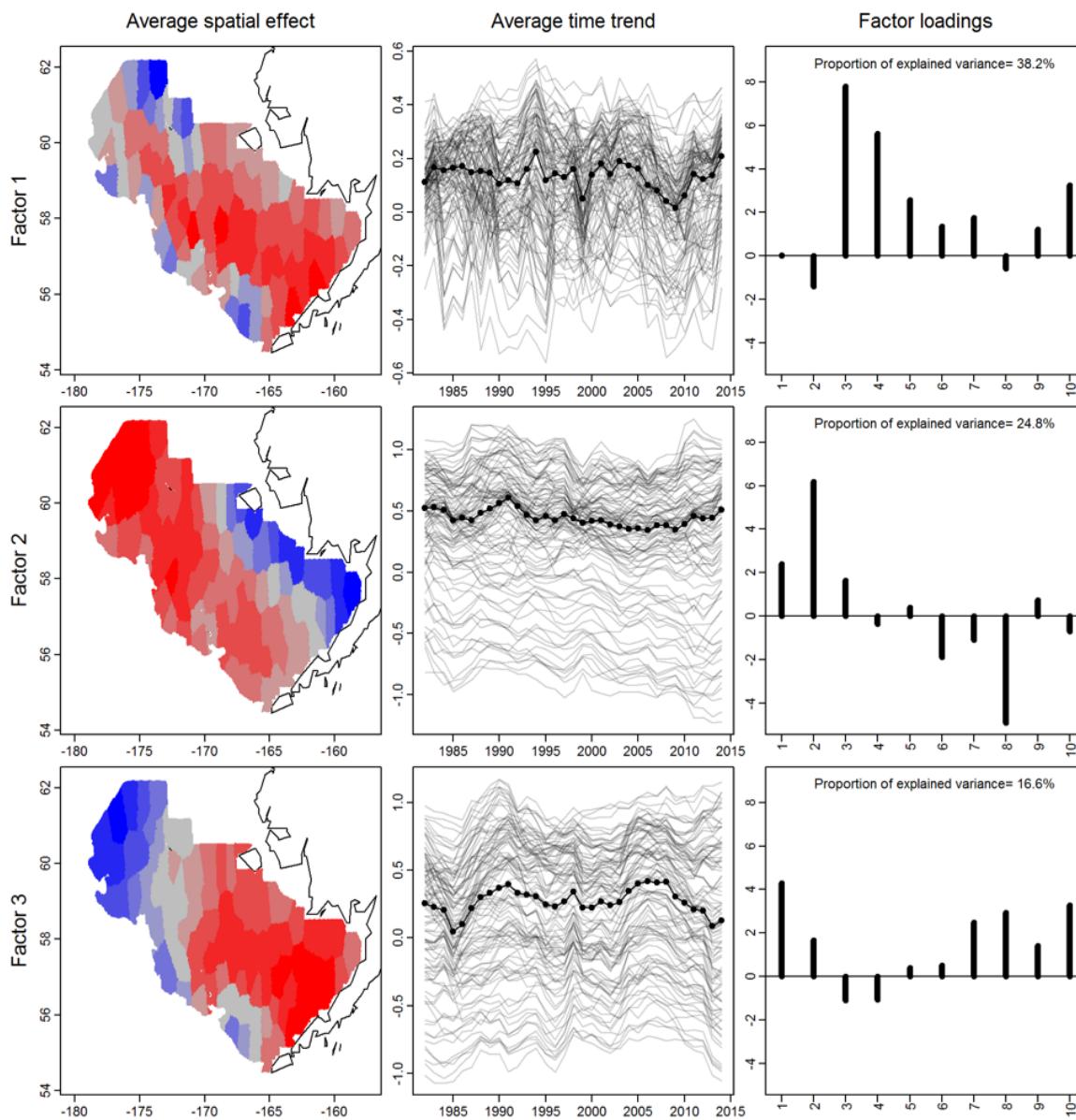




Robin Hood Effect

How do spatial patterns change over time?

Ex: Bering Sea groundfishes (10 spp, 30+ years)



Shifting southward

Conservation of Pacific salmon

More than one-half of the stocks in the lower 48 are listed under the Endangered Species Act

Hydropower

Habitat

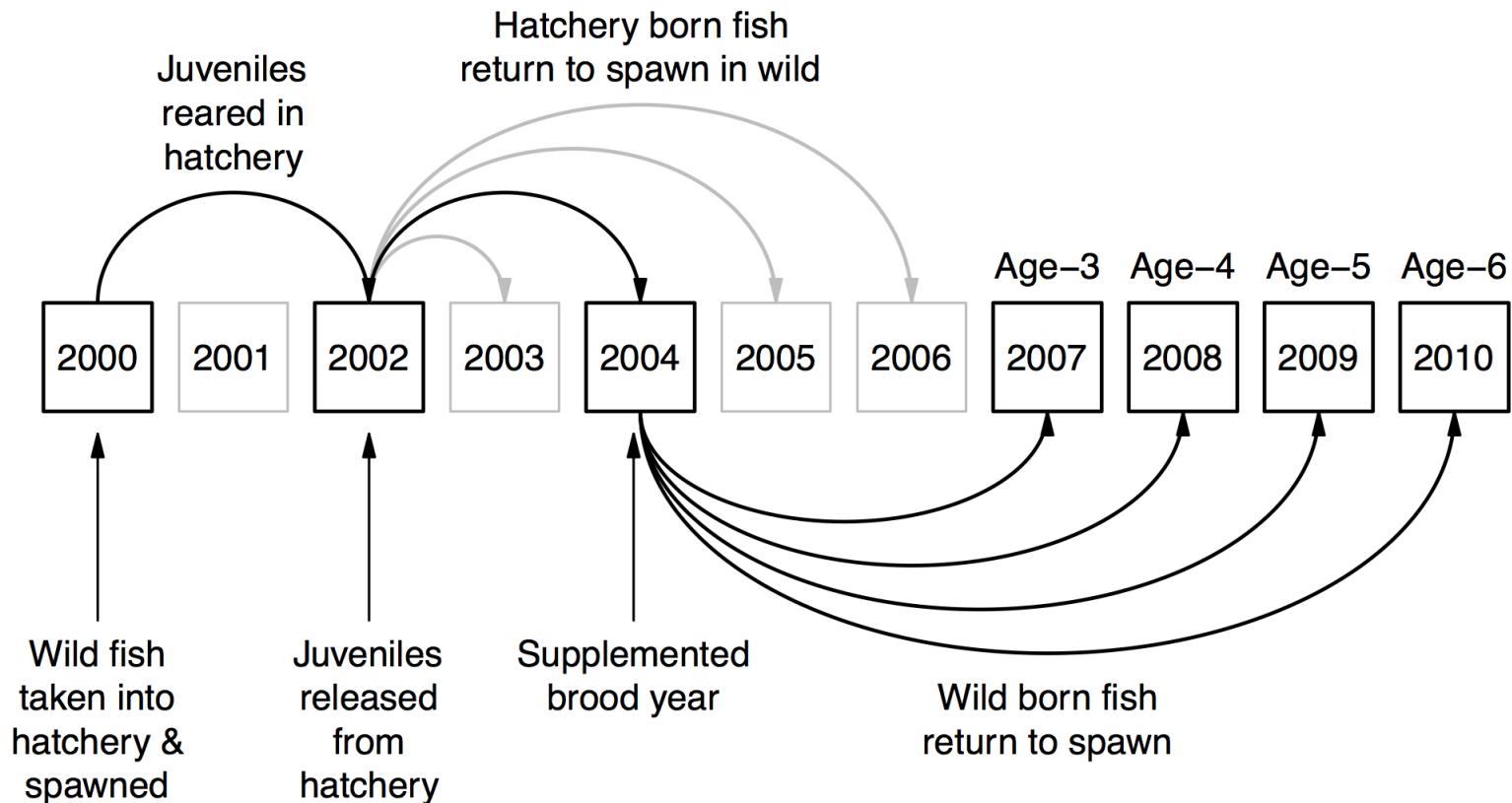
Harvest

Hatcherries

The 4 H's

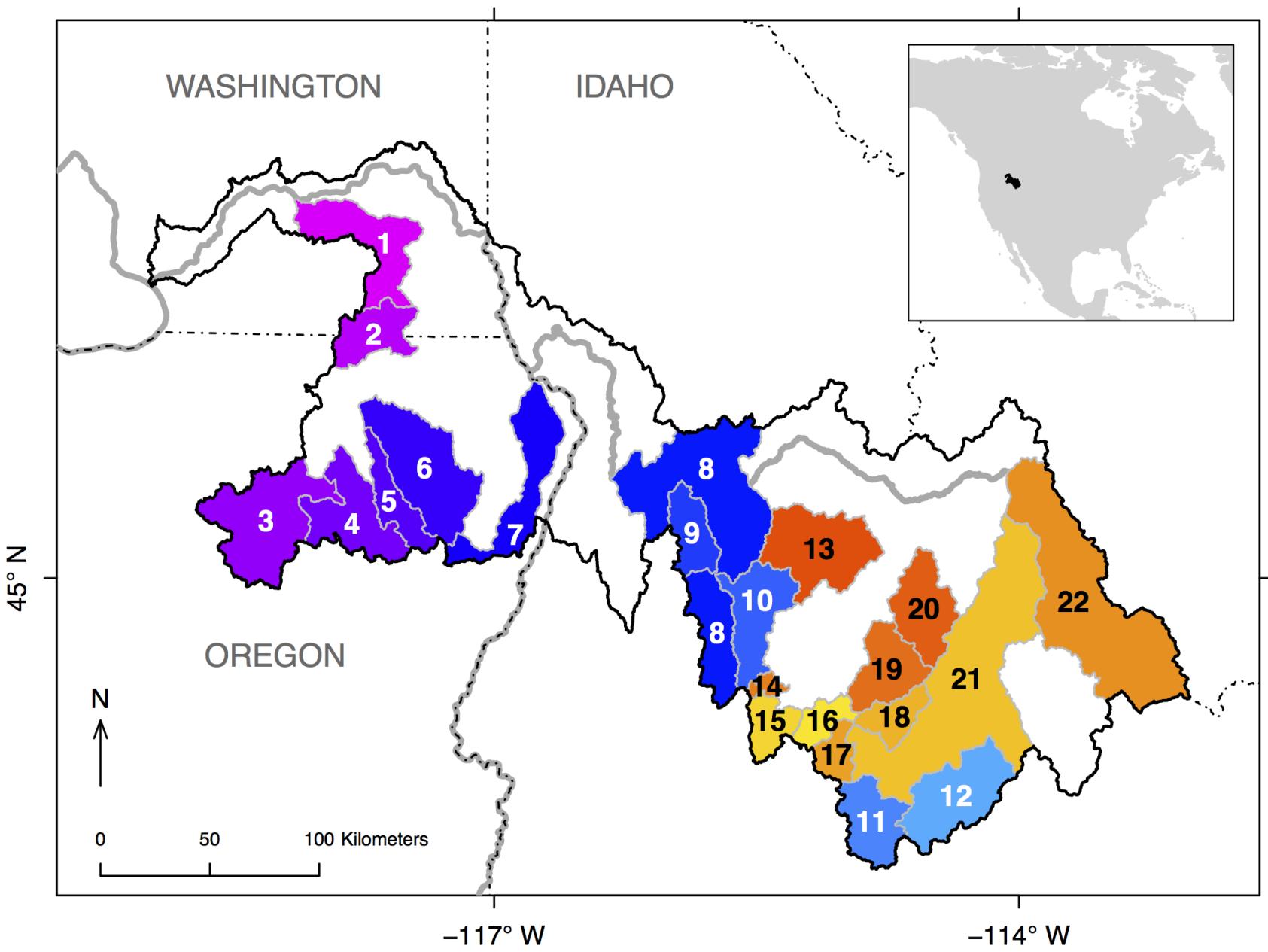
RECOVERY OPTIONS?

One strategy is hatchery supplementation

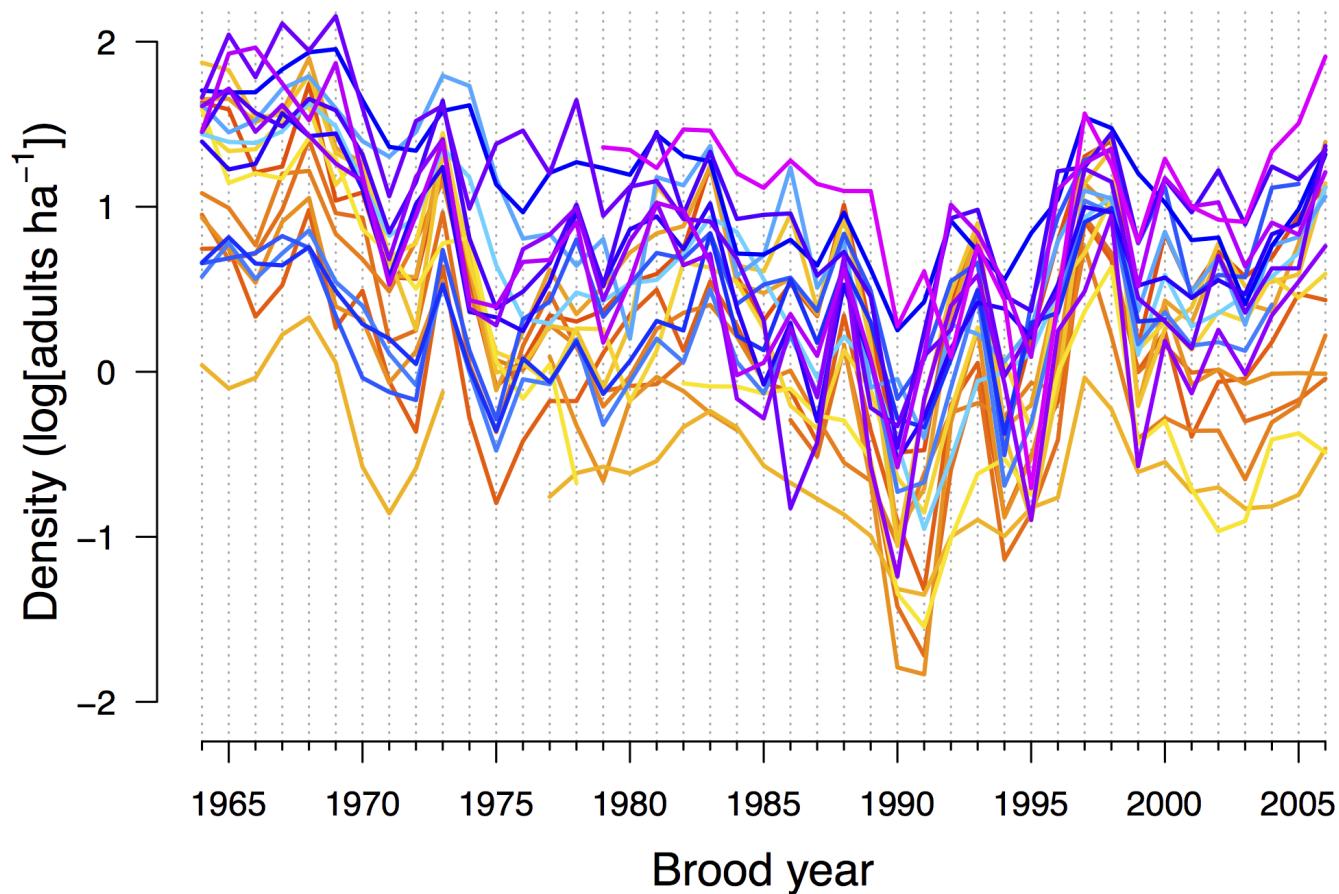


Evaluating conservation interventions

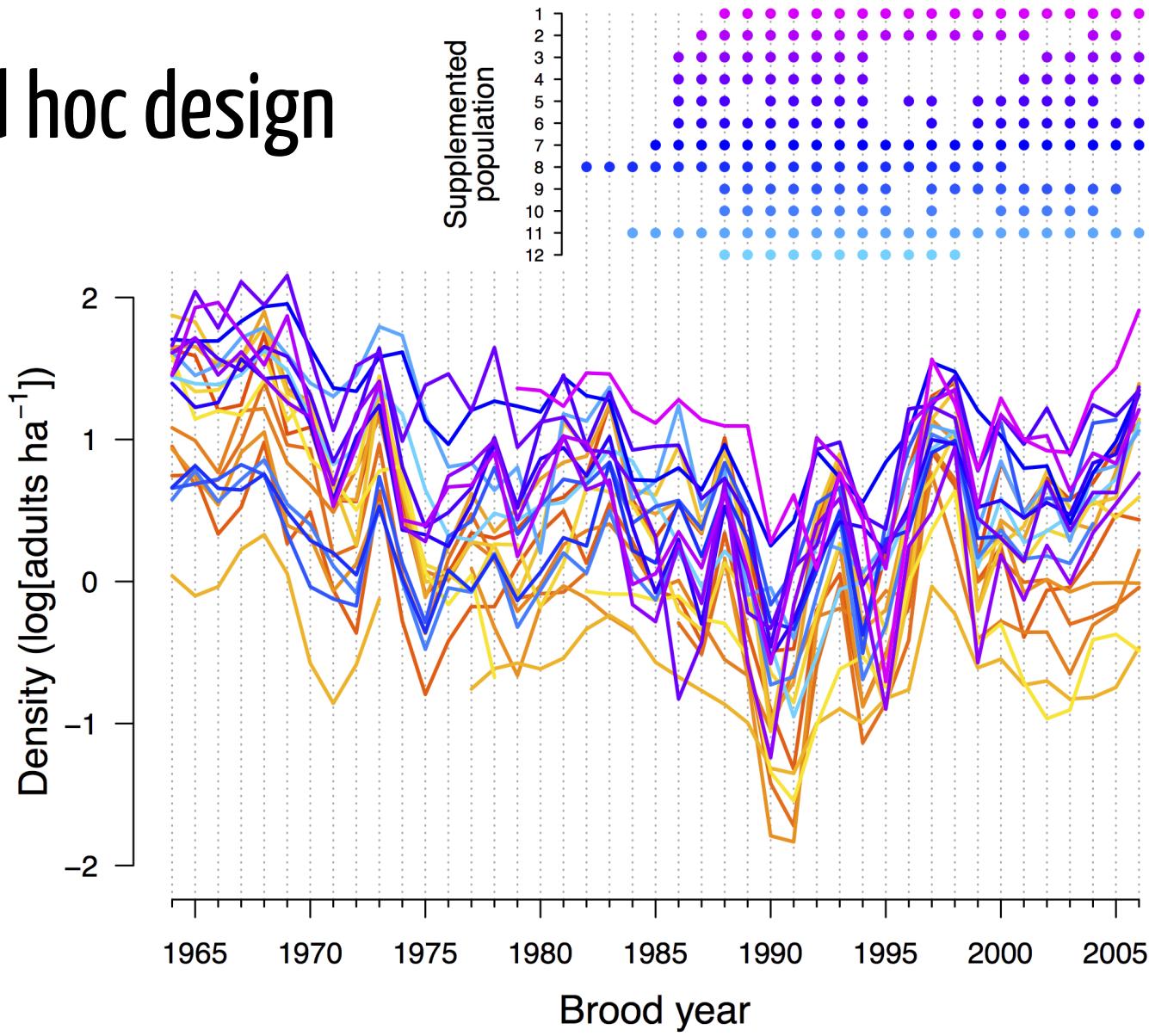
Has 30+ years of hatchery supplementation boosted
the production of wild Chinook in the Snake R?



Density of spawners over time



Ad hoc design



Complications for analysis

No randomized design

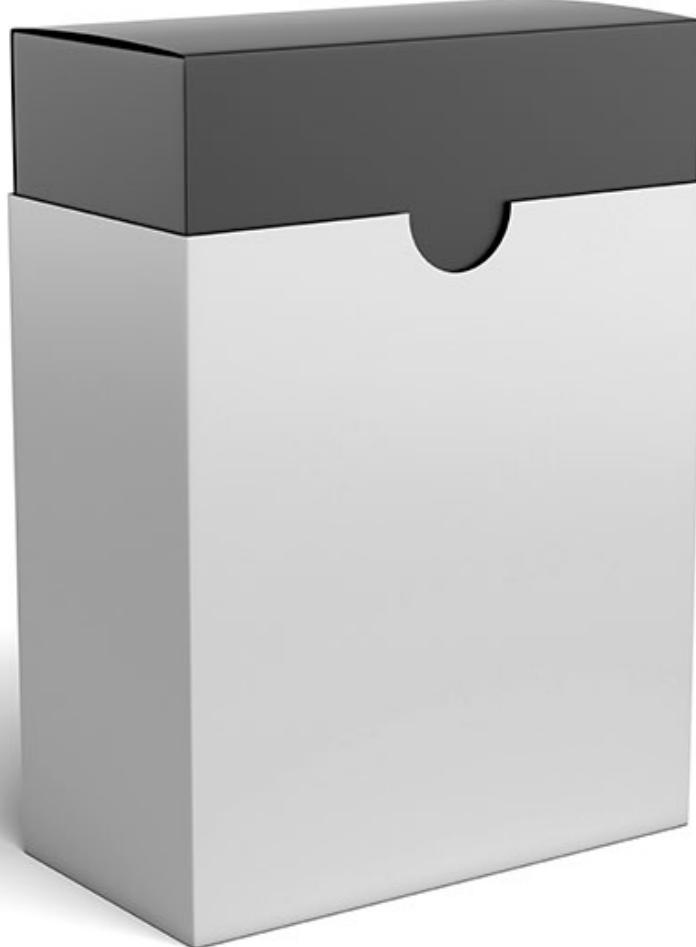
Different start/stop & duration

Changing variance & correlated errors

Multiple agencies & tribes

We need a hierarchical model!

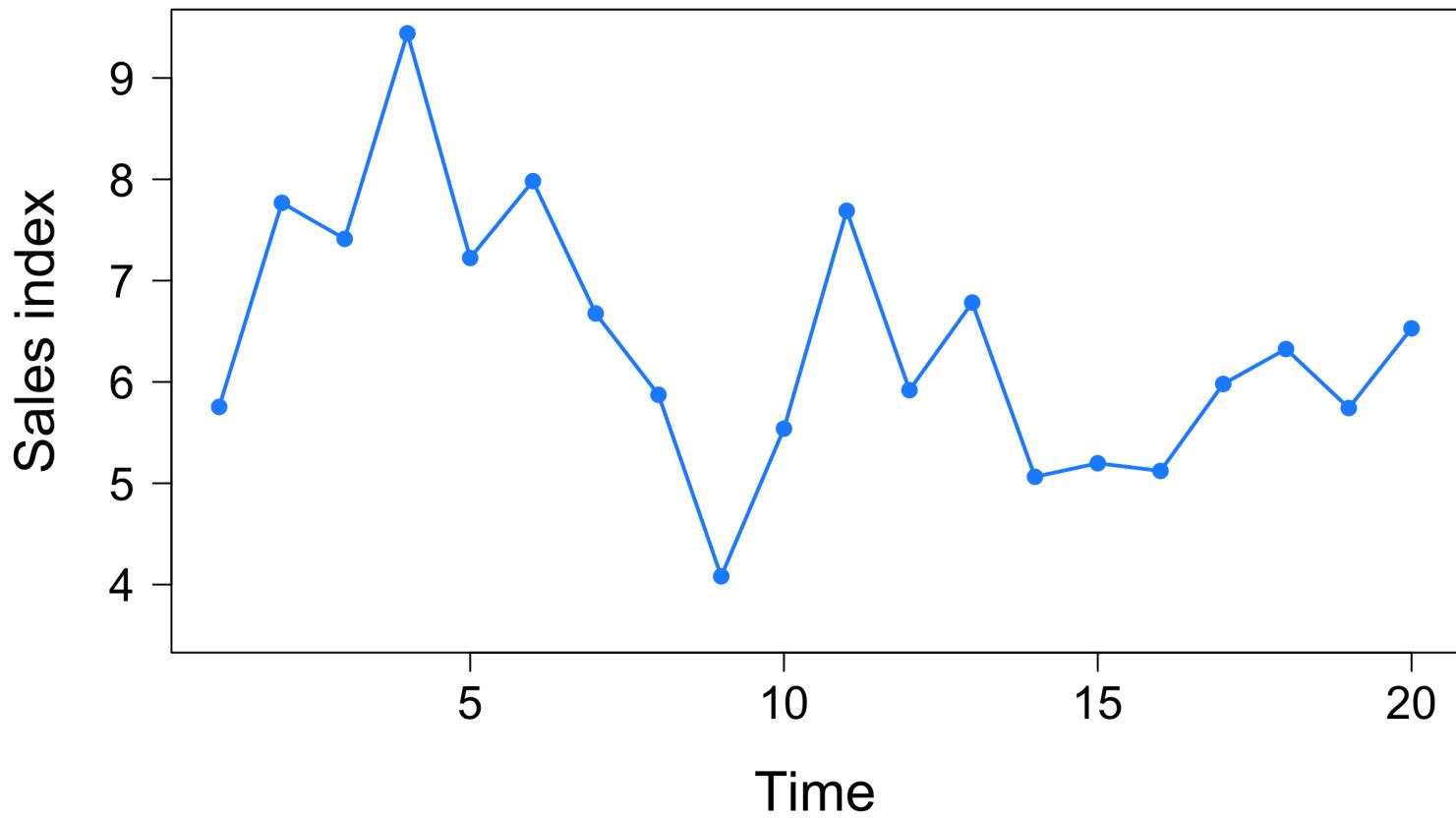
But first, a word from our sponsor...



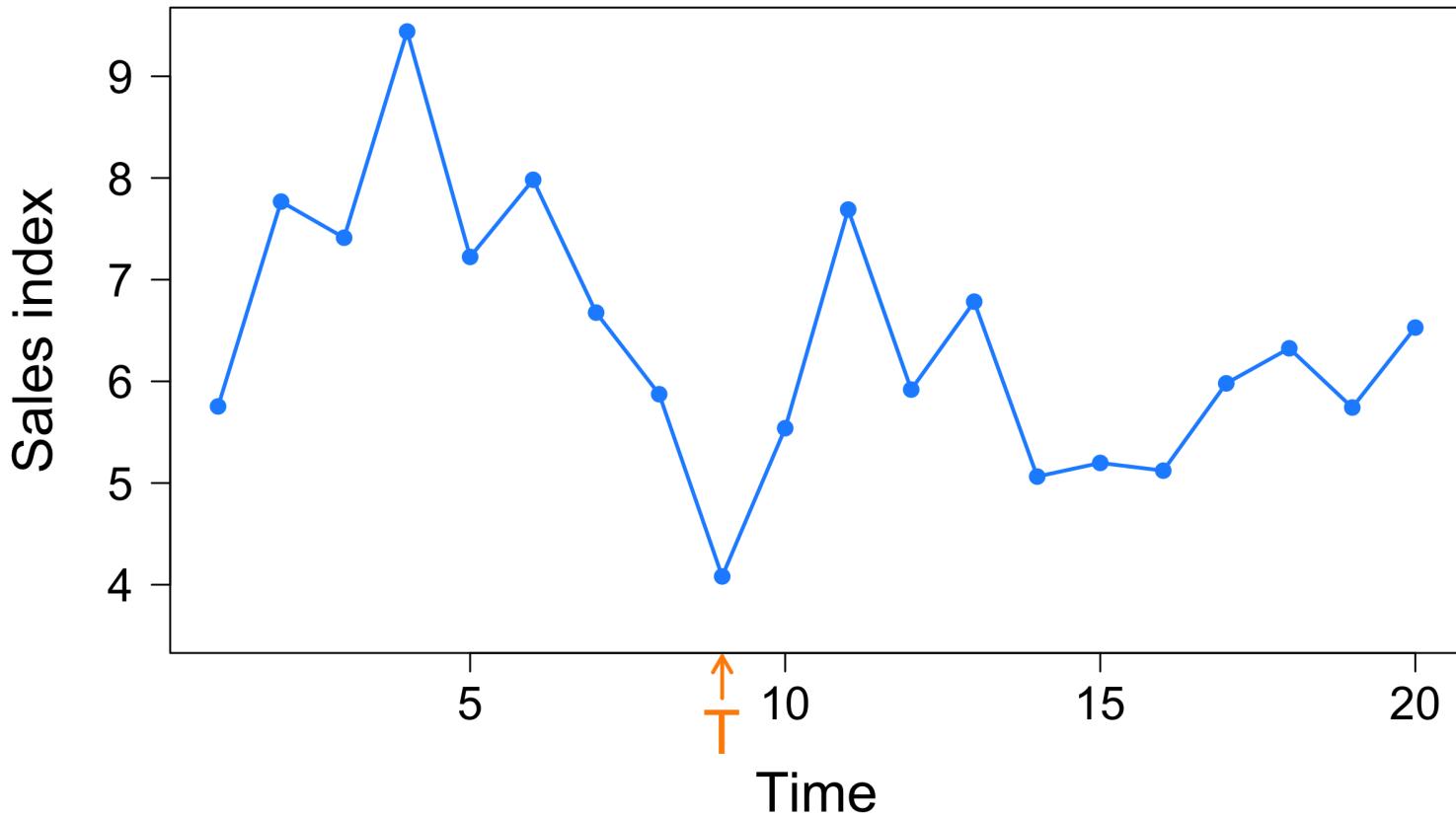
This Product™

Now with a plain gray box!

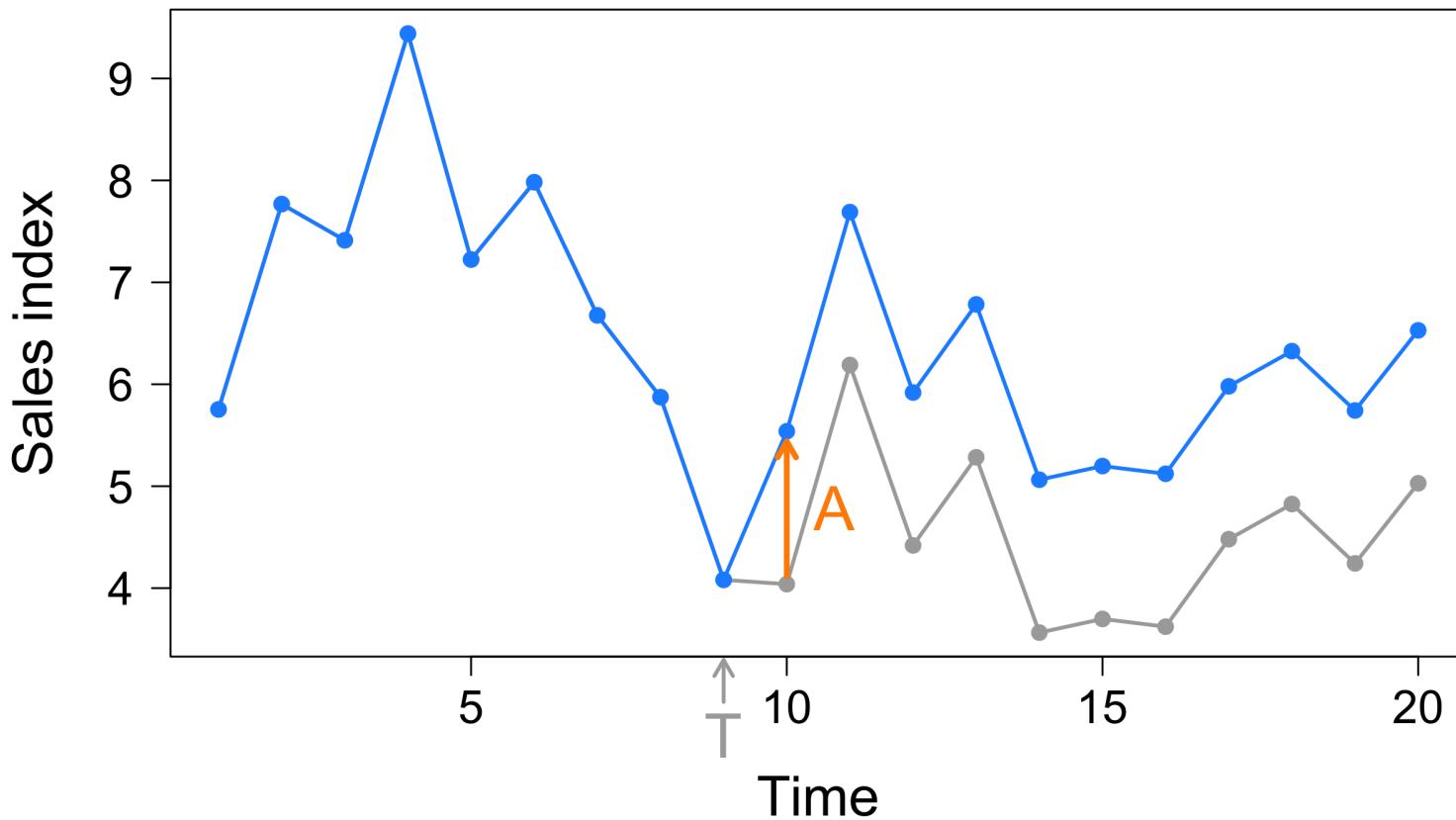
Sales of This Product over time



The company began advertising at Time = 9



How much did advertising increase sales?



A model from advertising

State model

$Sales_t = Sales_{t-1} + Advertising \times I_t + error_t$

A model from advertising

State model

$$\text{Sales}_t = \text{Sales}_{t-1} + \text{Advertising} \times I_t + \text{error}_t$$

Observation model

$$\text{Data}_t = \text{Sales}_t + \text{error}_t$$

Our model for supplementation

State model

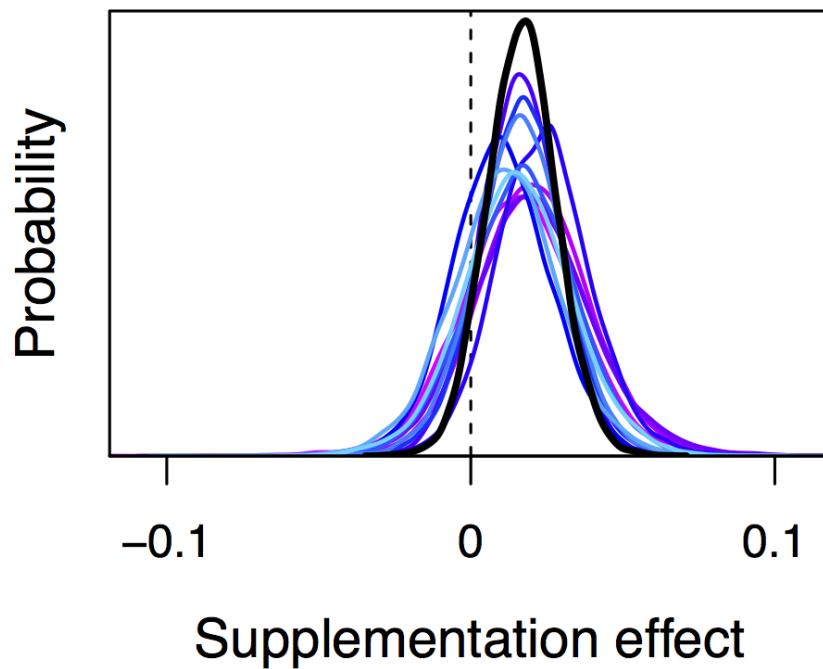
$$\text{Density}_t = \text{Density}_{t-1} + \text{Supplementation} \times I_t + \text{error}_t$$

Observation model

$$\text{Data}_t = \text{Density}_t + \text{error}_t$$

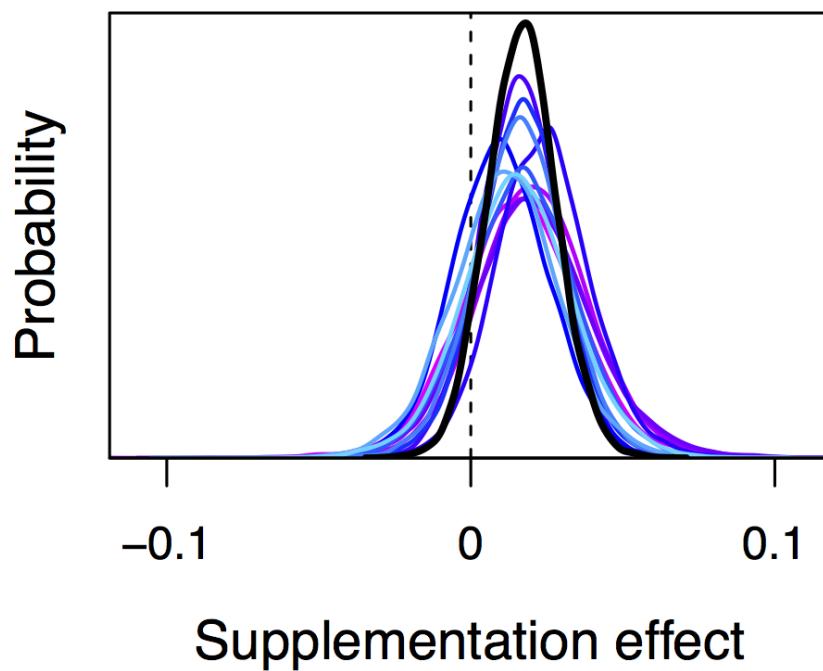
Supplementation effect is rather subtle

Mean increase of only 3.3% over ~25 years

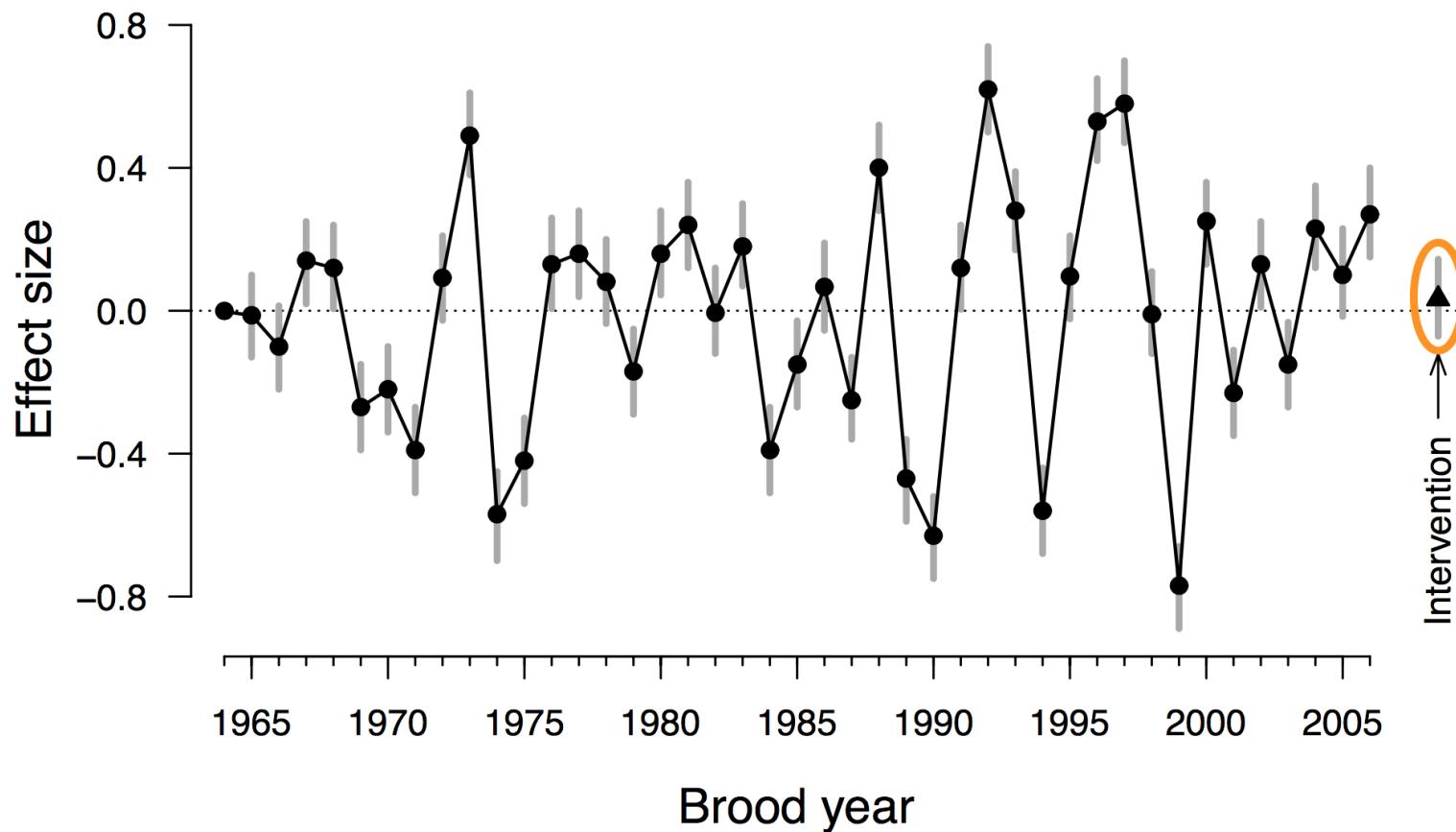


Supplementation effect is rather subtle

Probability of positive effect is ~70%



Common year effects overshadow intervention



Deepwater Horizon oil spill



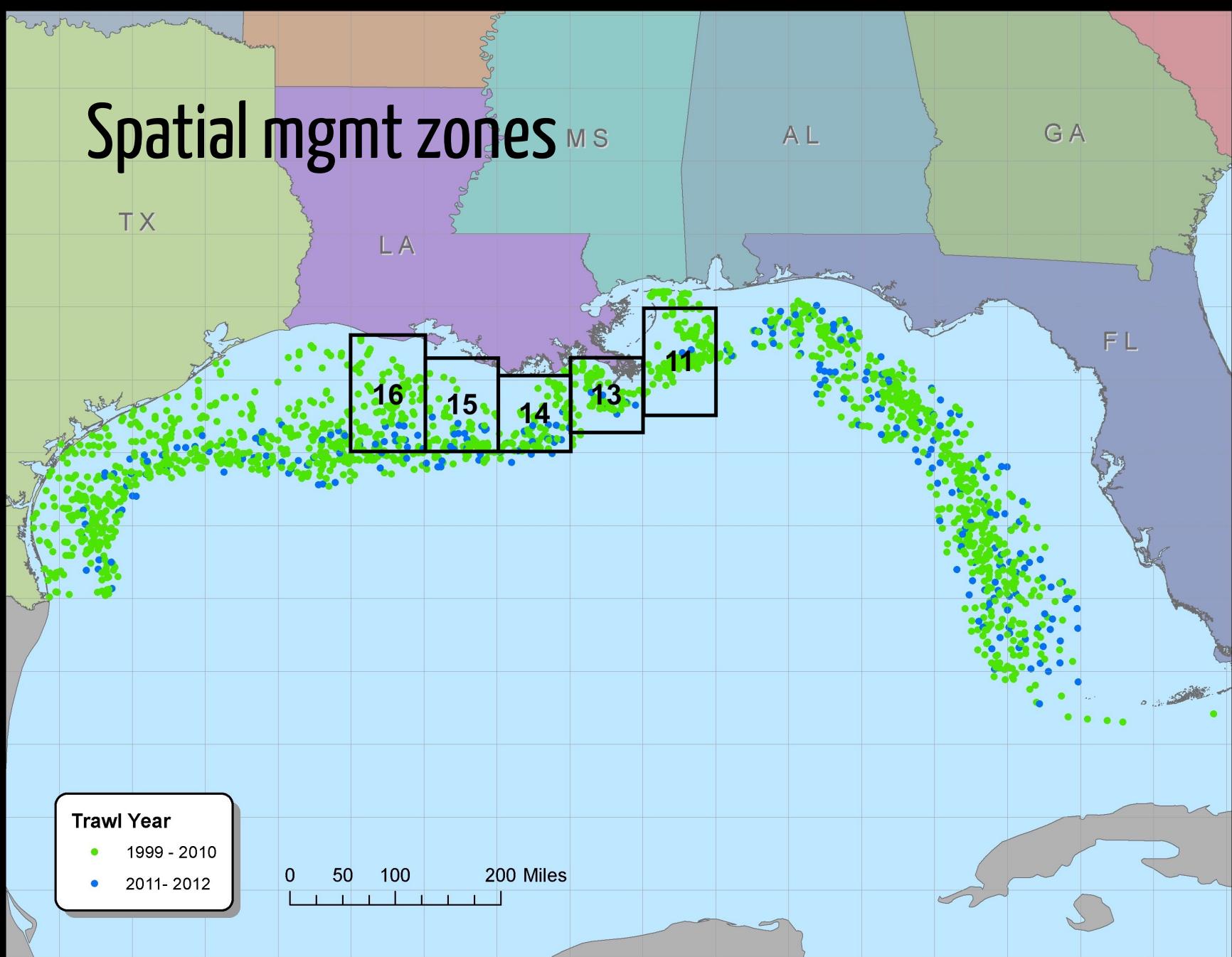
20 April 2010

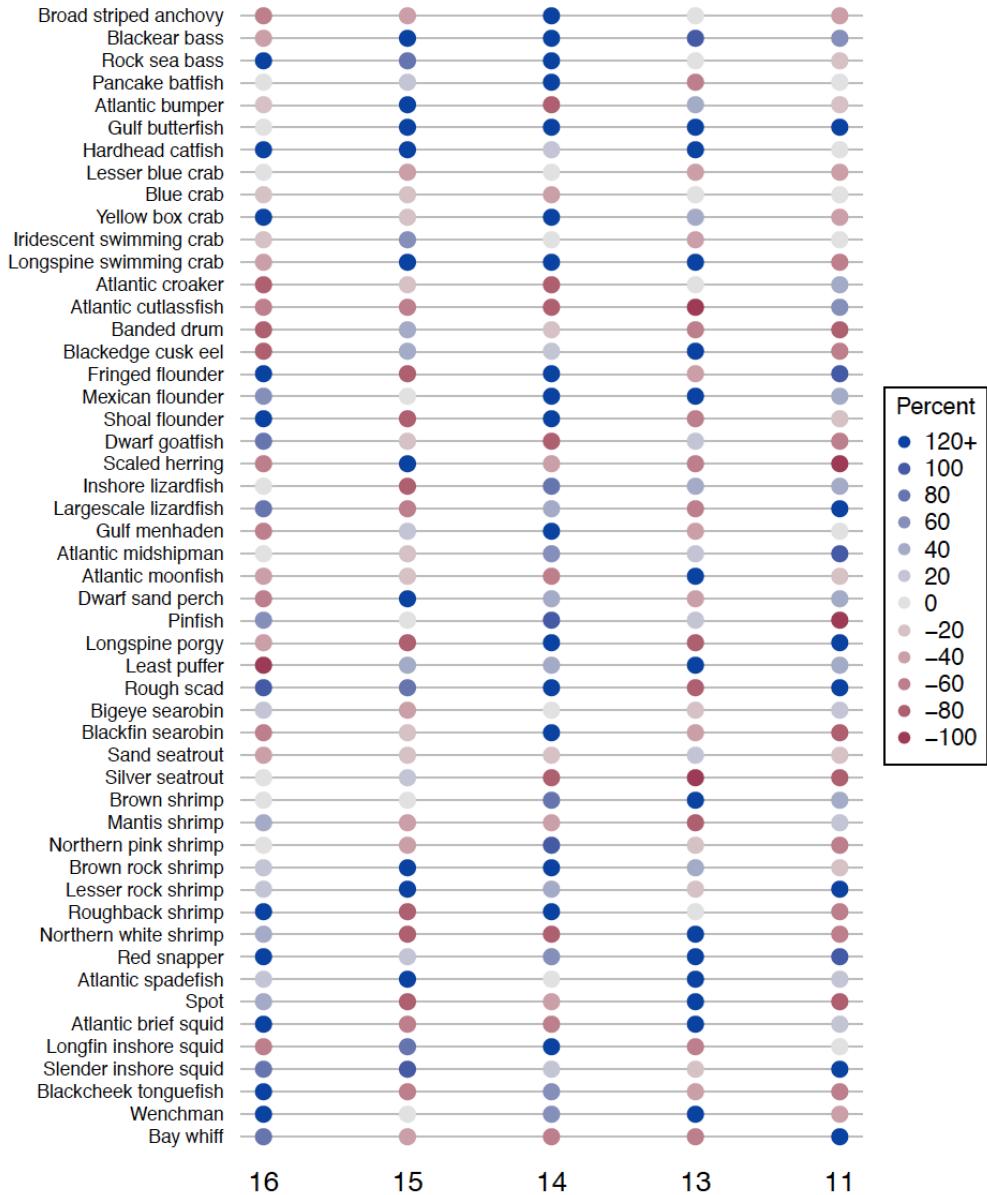
How did abundance change post-spill?

Quarterly survey data from 1982-present

50+ species of fish & inverts

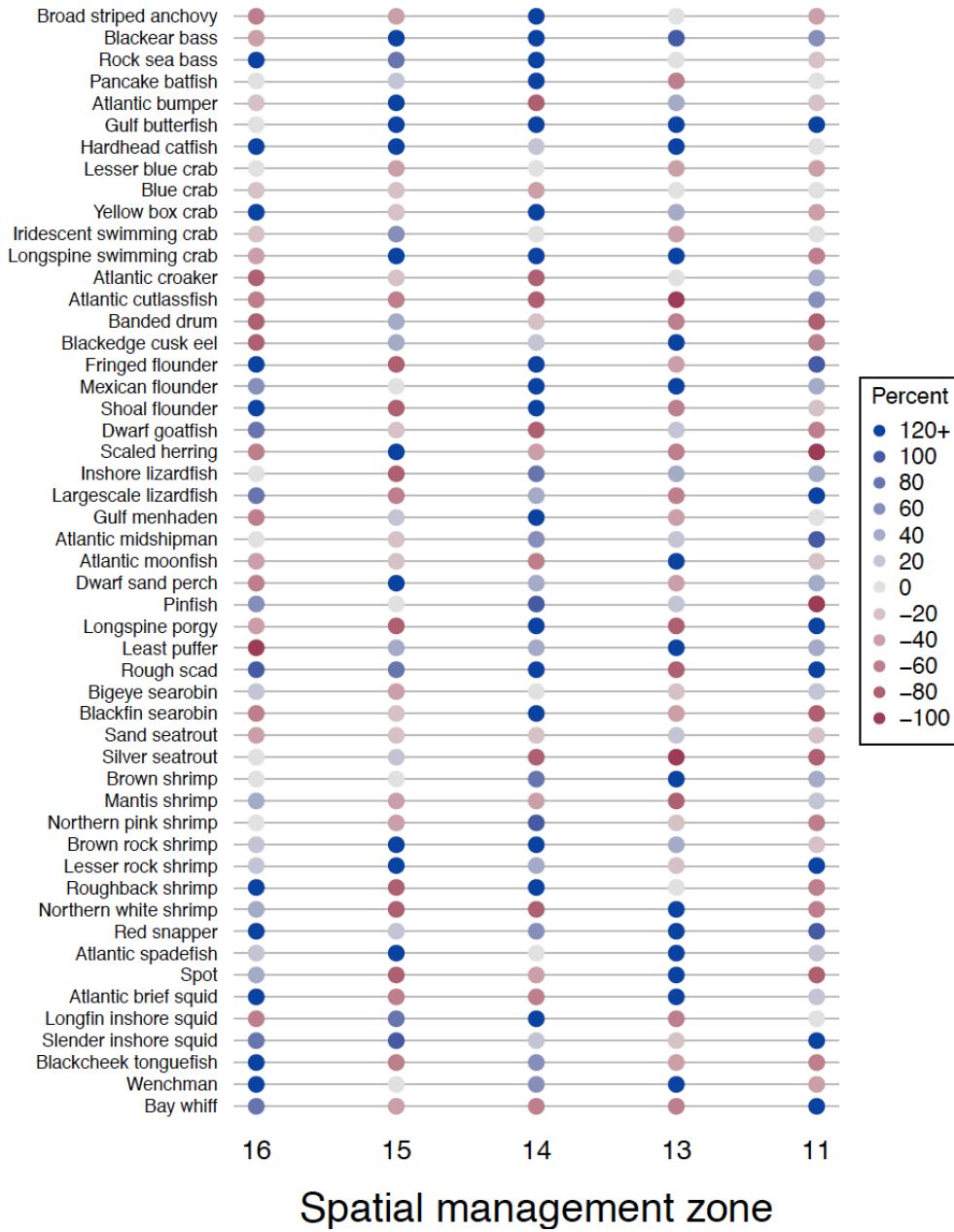
Spatial mgmt zones



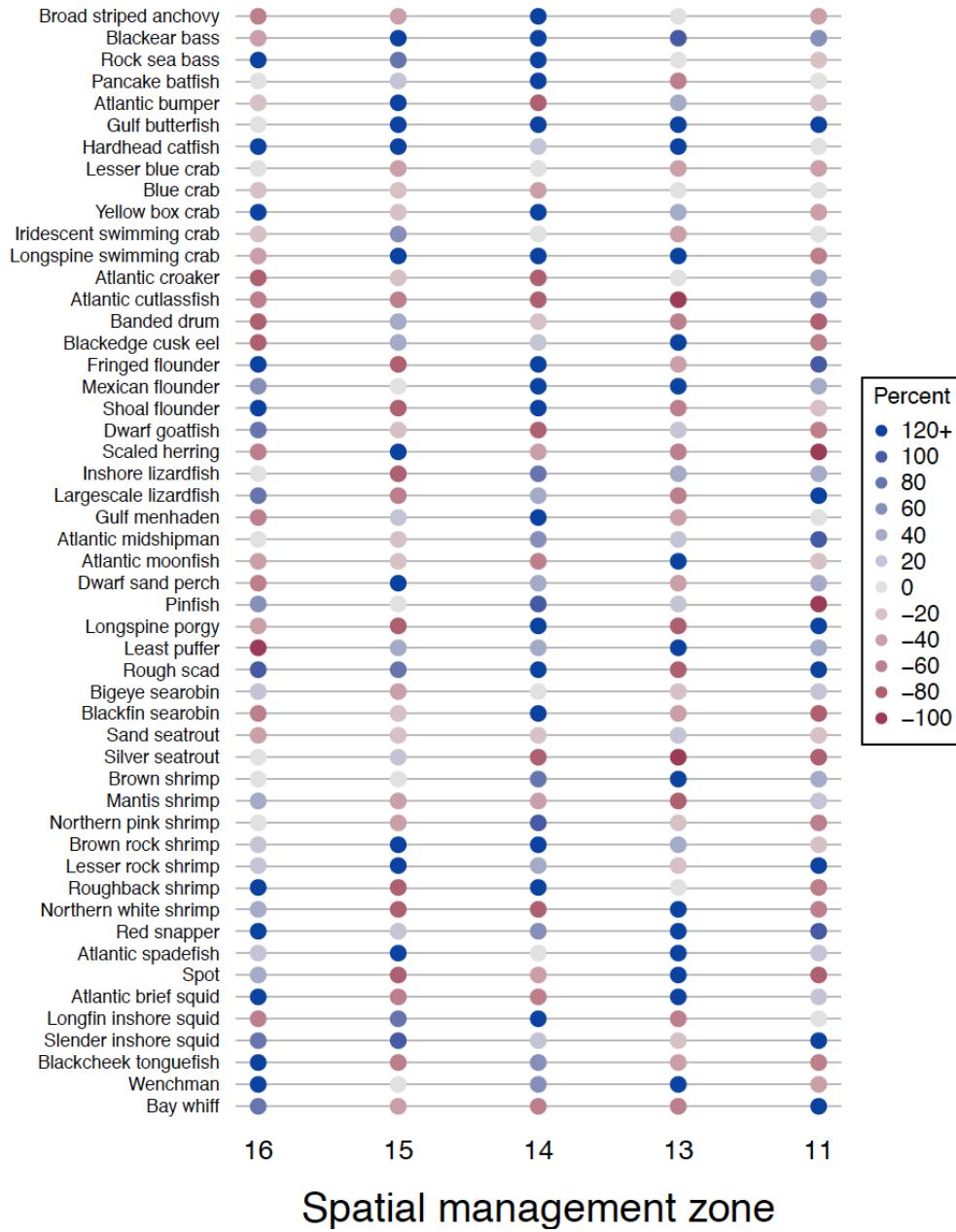


Oil spill (-)

No Fishing (+)



Only 3 yrs later

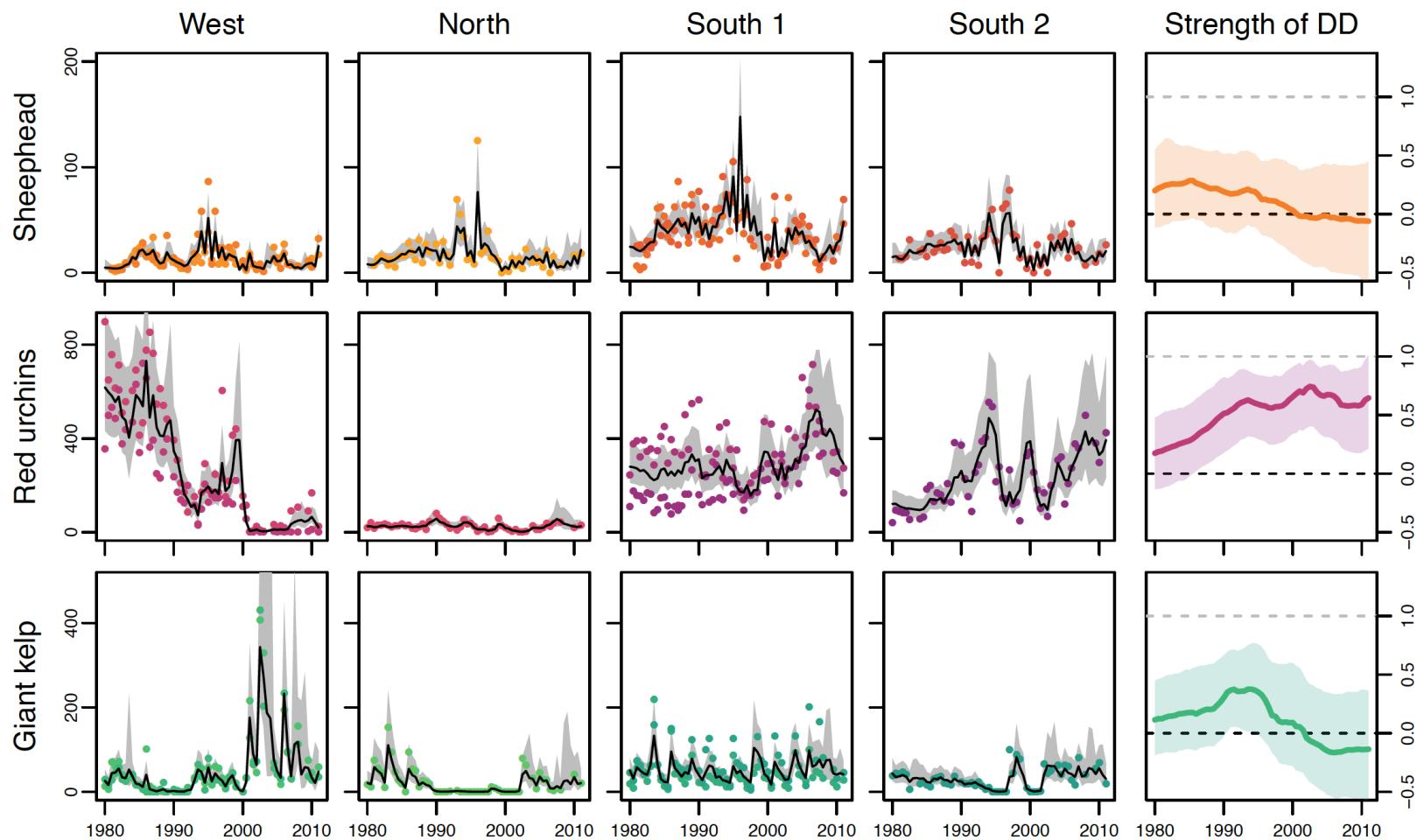


Future directions

Marine & freshwater food-webs

How do species interactions change over time?

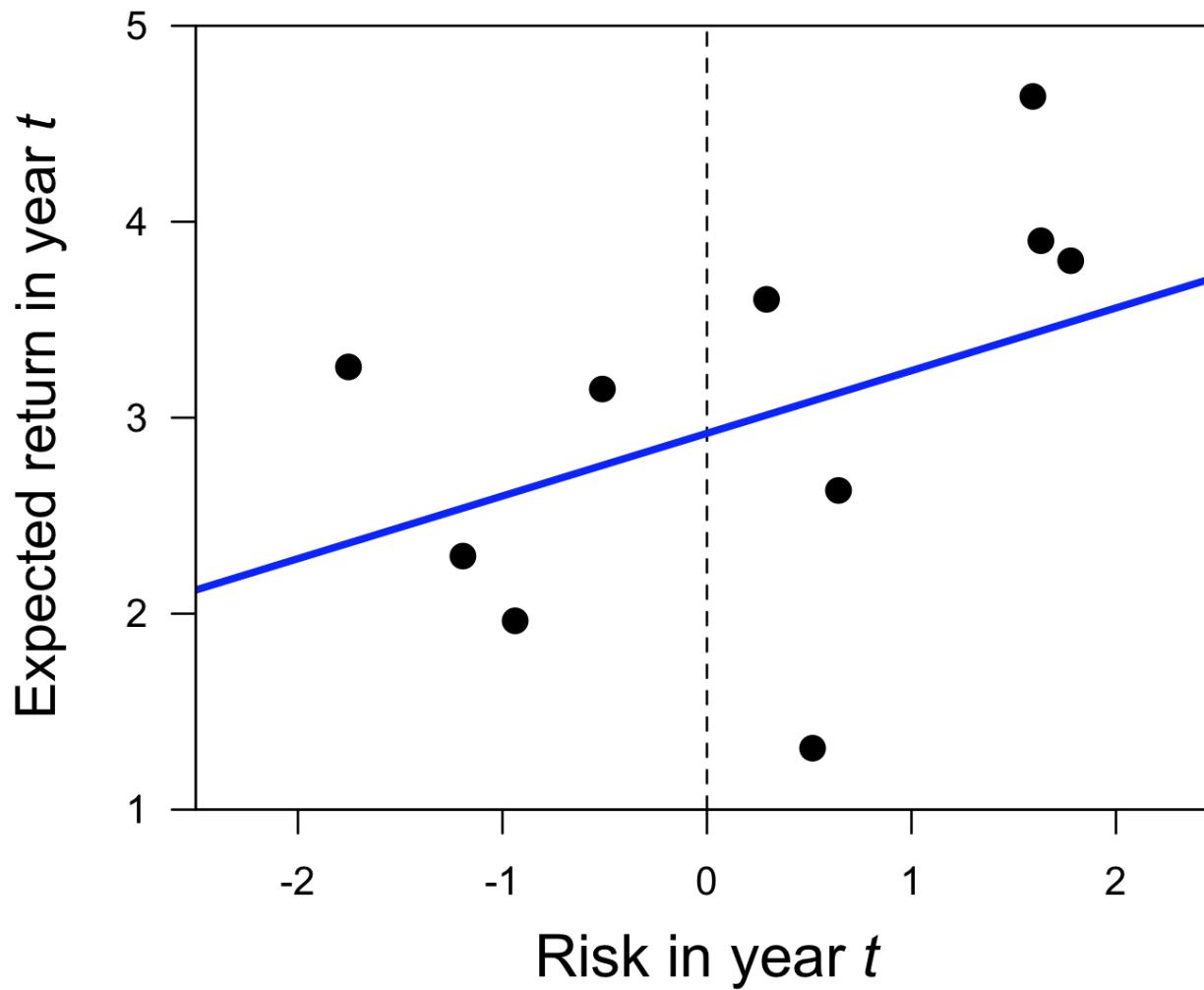
Kelp forest food webs



Ecological portfolios

How do risks vs rewards change over time?

Risk vs returns of assets



In summary

Much of our data is "noisy"

Identifying signals in the noise can be challenging

Hierarchical models offer great promise,

but they are *not* a panacea

Open science

I'm dedicated to open, reproducible research

As a public servant my work should be accessible

Development

<https://github.com/mdscheuerell/>

Slide deck

<https://github.com/mdscheuerell/UAF2018>

Image sources

MN map: *Chandler O'Leary (2013)*

WI map: *Cat's Meow Village*

LIDAR: *NOAA*

DNA: *fizzgig (2016)*

Janet Leigh: *Paramount Studios*

Carnival: *Frank Kovalchek (2010)*

Snake oil: *The Register*

Shakespeare's plays: *Sir John Gilbert (1849)*

Robin Hood: *John Escott*

DWH: *US Coast Guard*

