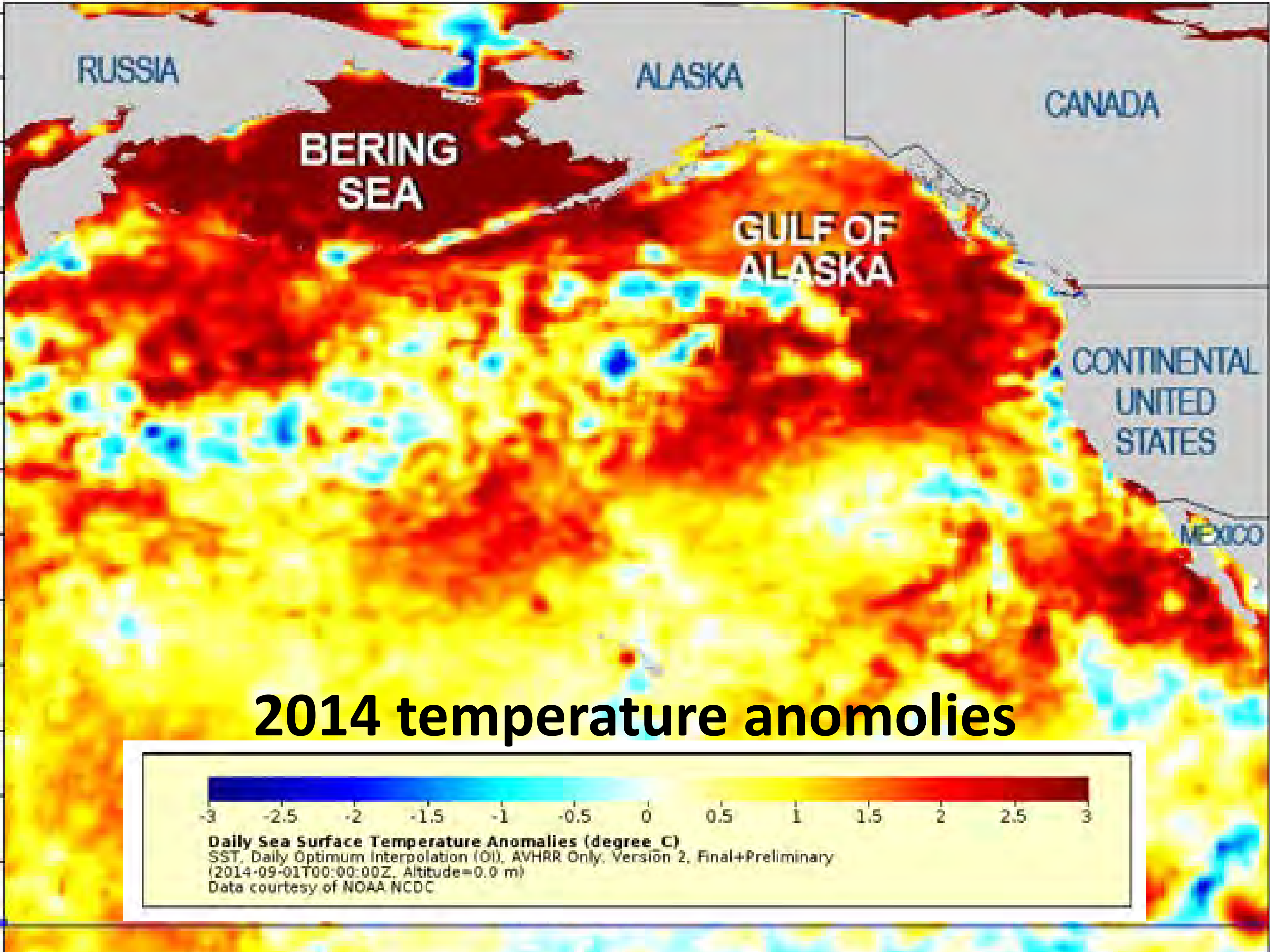
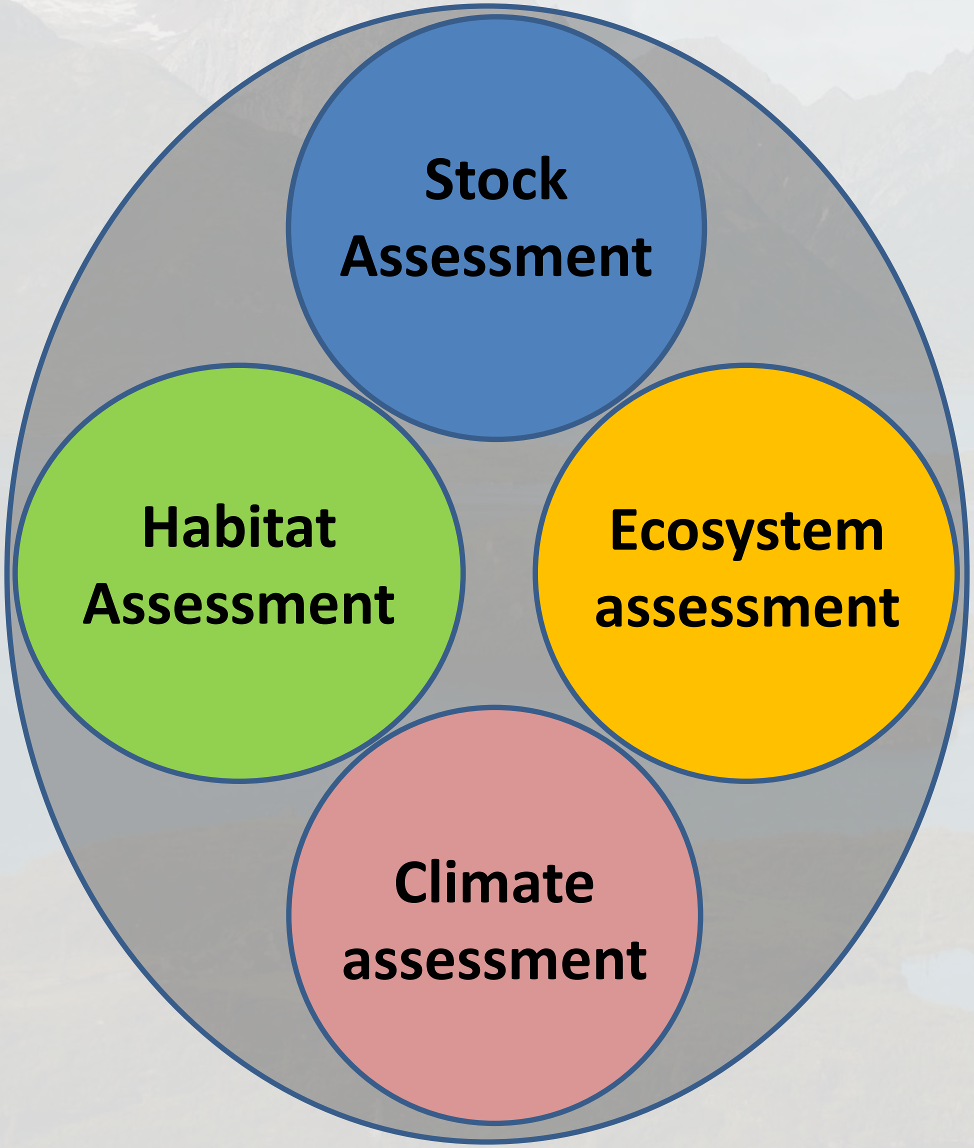
James Thorson

Measuring portfolio effects and climate-drivers in the North Pacific using spatio-temporal models and causal statistics


RUSSIA
ALASKA
CANADA
BERING SEA
GULF OF ALASKA
CONTINENTAL UNITED STATES
MEXICO
2014 temperature anomolies
-3 -2.5 -2 -1.5 -1 -0.5 0 0.5 1 1.5 2 2.5 3
Daily Sea Surface Temperature Anomalies (degree_C)
SST, Daily Optimum Interpolation (OI), AVHRR Only, Version 2, Final+Preliminary
(2014-09-01T00:00:00Z, Altitude=0.0 m)
Data courtesy of NOAA NCDC

Spatio-temporal model



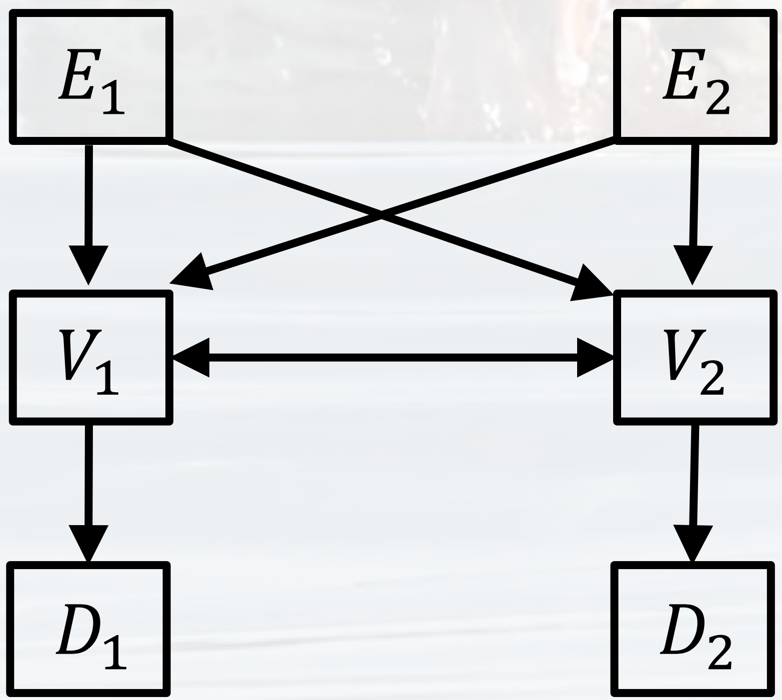
Benefits of unified approach

1. Include biological mechanism
2. Improved communication
3. Share models and research progress

Causality and statistics

We can define a structural model:

- $E_1, E_2, \ldots, E_n$ are some unobserved errors
- $V_1, V_2, \ldots, V_n$ are some unobserved variables
- $D_1, D_2, \ldots, D_n$ are some observed data

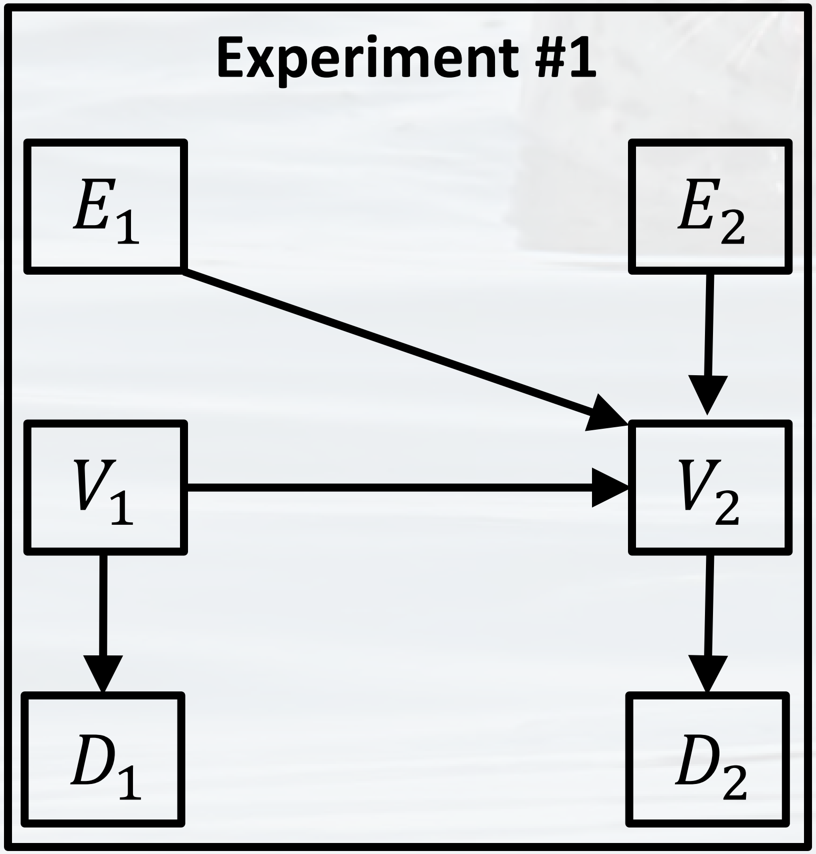


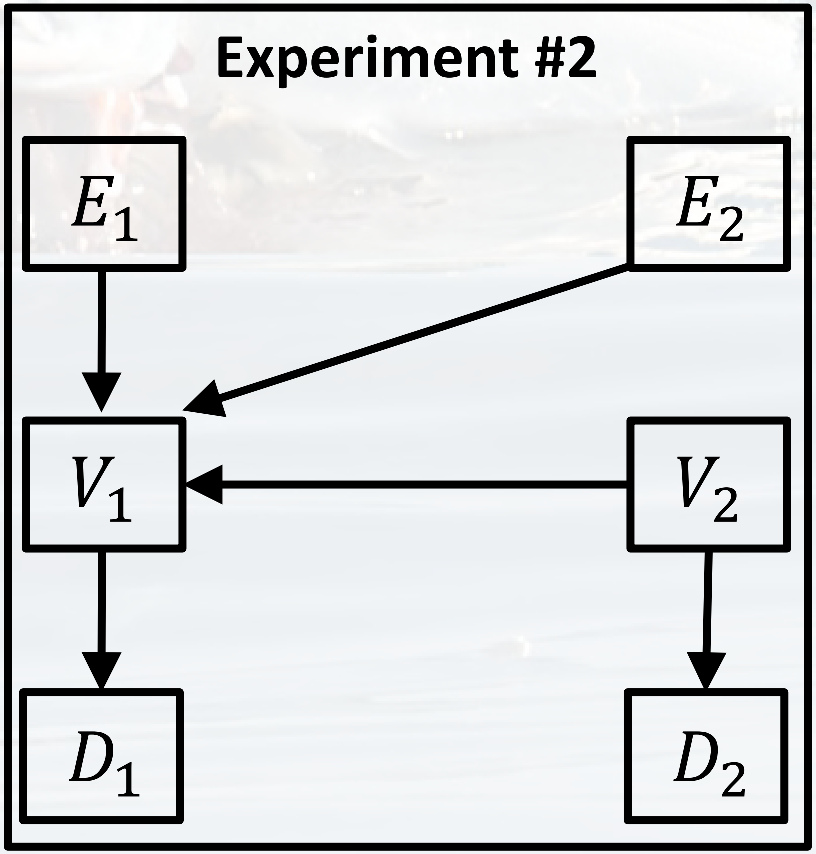
Causality and statistics

How do we estimate this?

Use experiments!

1. Fix V_1 at a value experimentally and get data
2. Fix V_2 at a value experimentally and get data

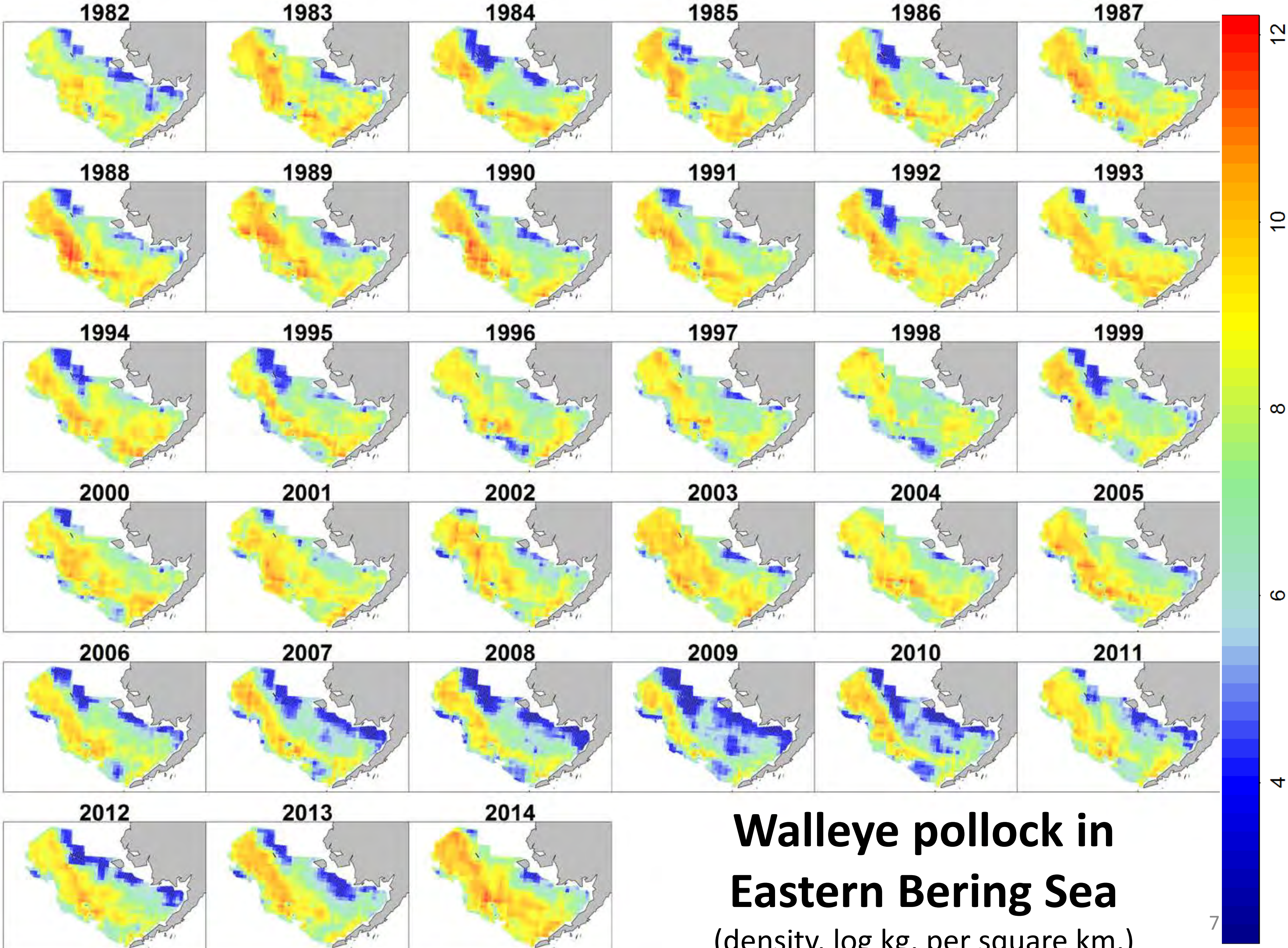




Attribution of climate impacts

Photo: Chris Miller, csmphotos.com

Thorson, Ianelli, Kotwicki. In press. The relative influence of temperature and size structure on fish distribution shifts: a case study on walleye pollock in the Bering Sea. *Fish and Fisheries*



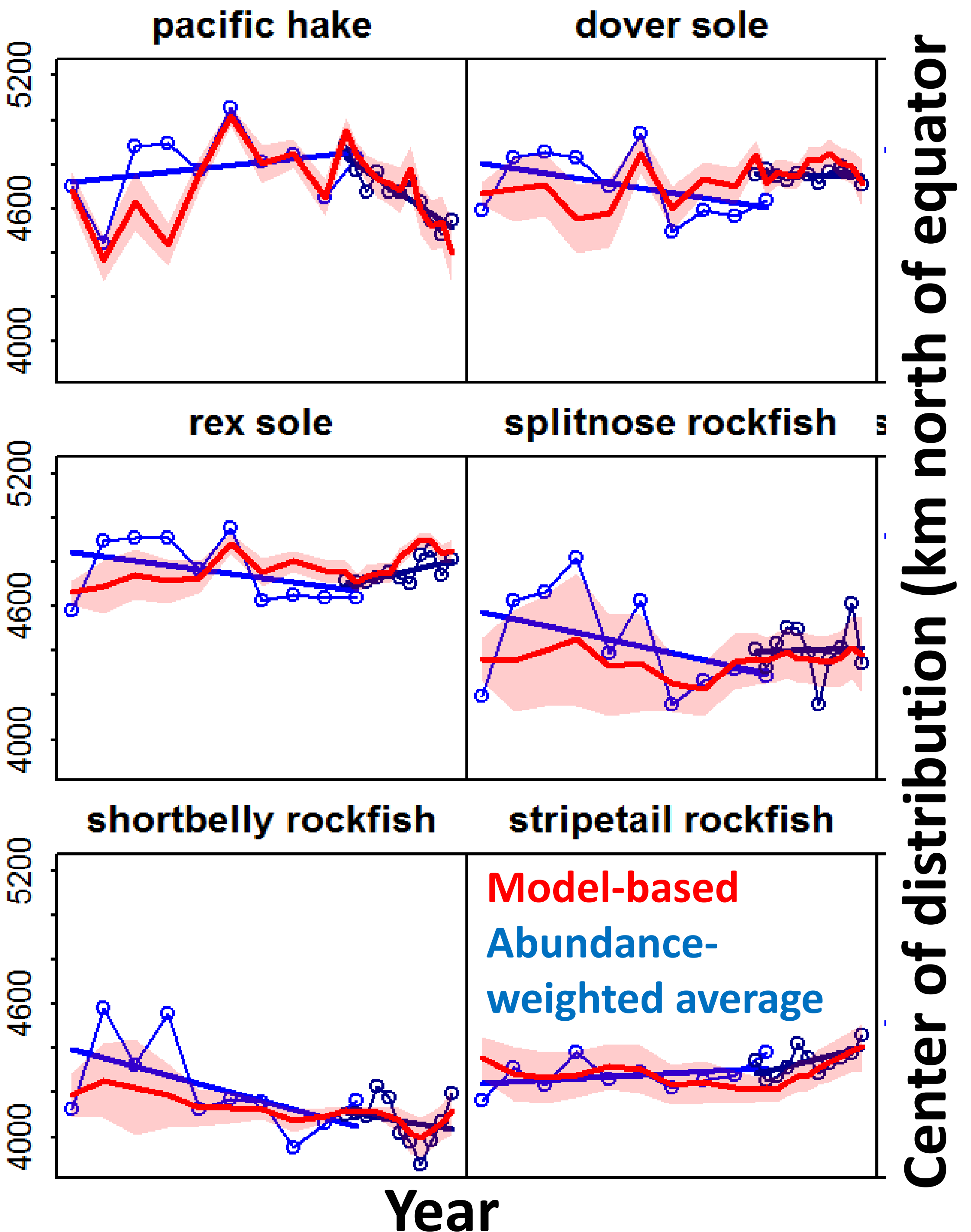
Walleye pollock in Eastern Bering Sea

(density, log kg. per square km.)

Distribution shifts

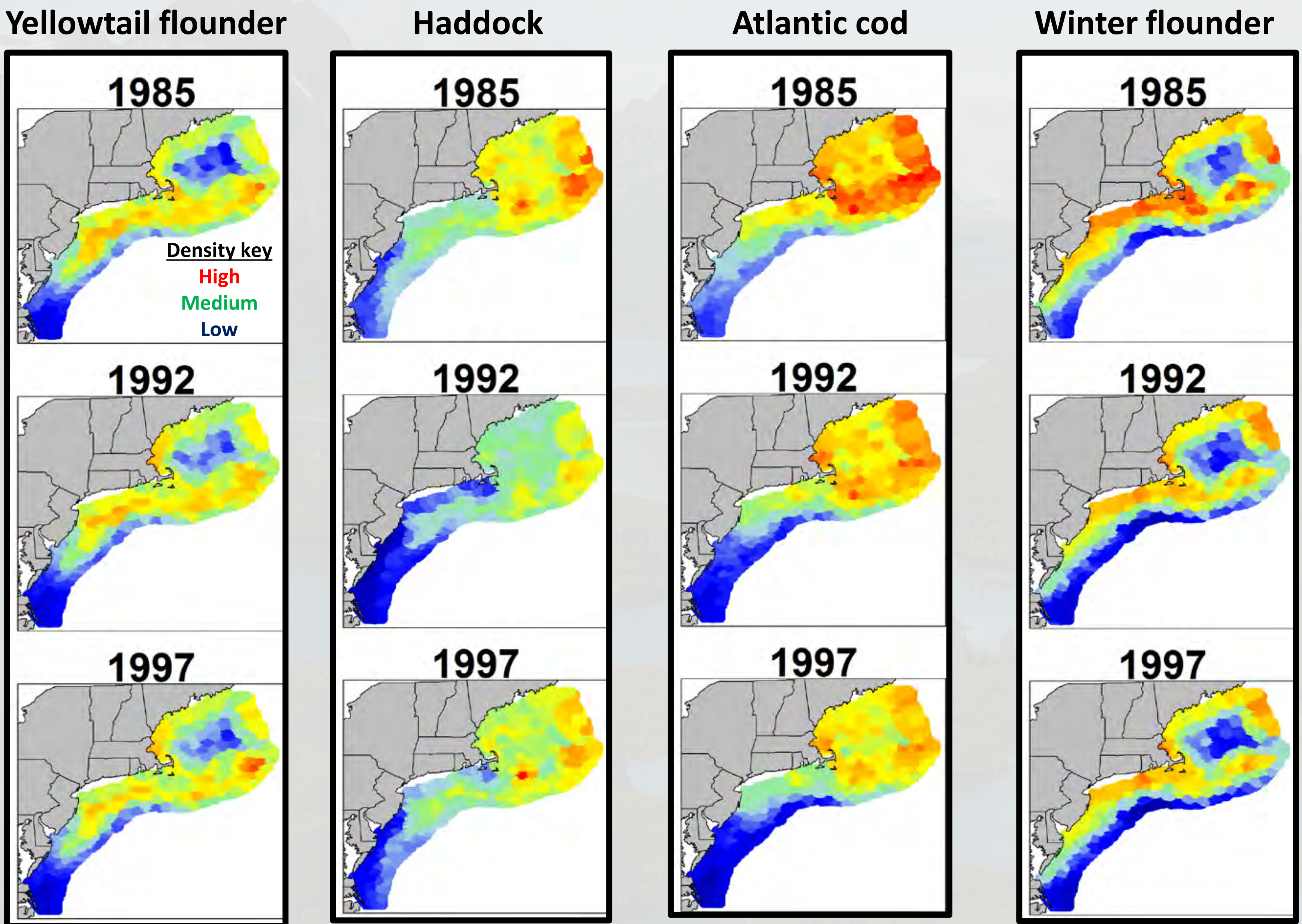
- Highly variable distribution for semi-pelagic species
  - Dogfish
  - Hake
- Few clear trends
  - Depends on time-scale

Thorson, Pinsky, and Ward. 2016. Model-based inference for estimating shifts in species distribution, area occupied and centre of gravity. Methods Ecol. Evol. **7**(8): 990–1002.



Vector Autoregressive Spatio-Temporal (VAST) model

(log-density estimates by species)



Vector Autoregressive Spatio-Temporal (VAST) model

Can estimate covariance among species

- Share information among species
- “niche” (spatial) vs. shared environmental response (spatio-temporal) term

Spatial covariance

	AC	HD	YF	WF
Atlantic cod (AC)	2.6	2.3	2.2	1.7
Haddock (HD)	2.3	4.0	2.9	0.8
Yellowtail flounder (YF)	2.2	2.9	5.1	2.6
Winter flounder (WF)	1.7	0.8	2.6	4.8

Spatio-temporal covariance

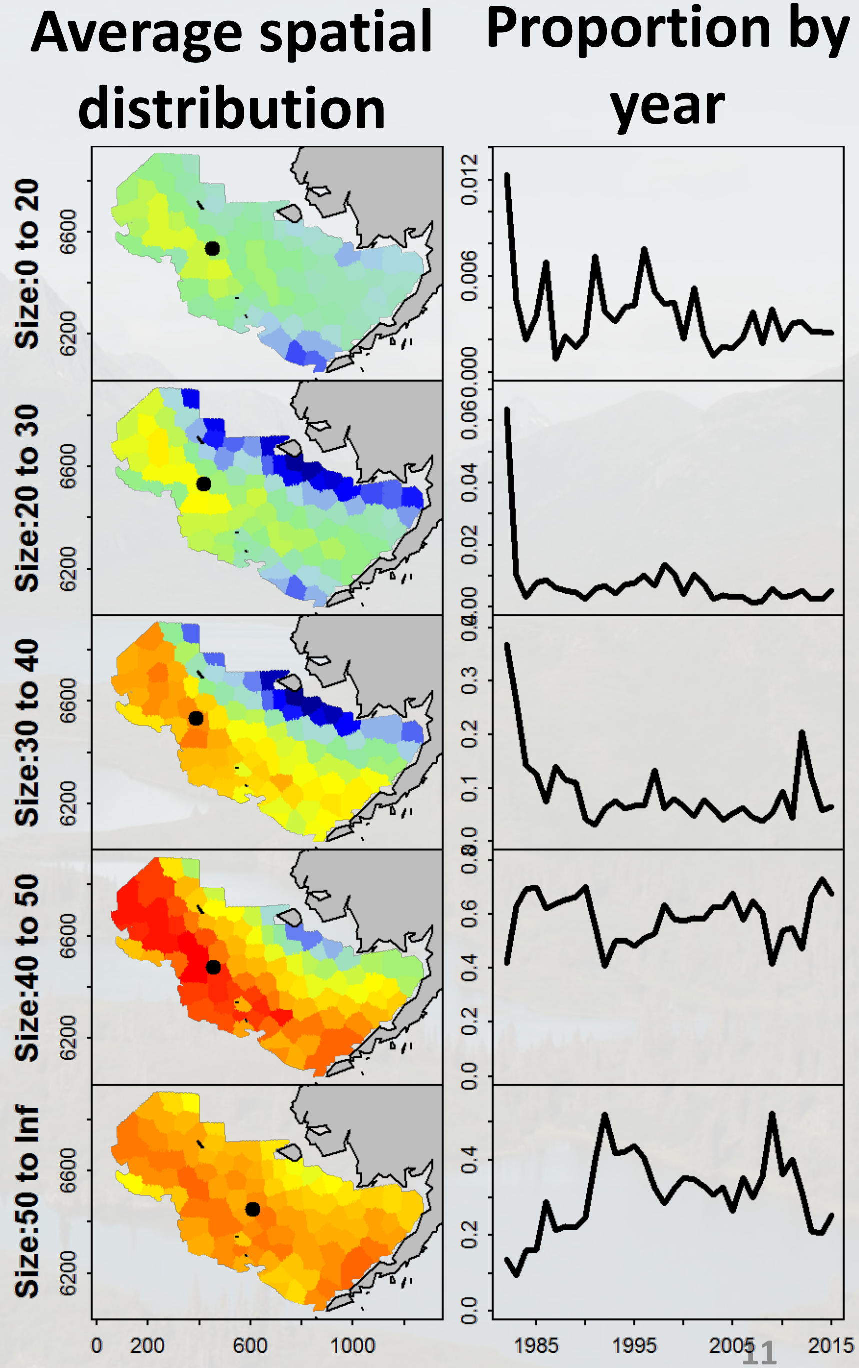
	AC	HD	YF	WF
Atlantic cod (AC)	0.4	0.4	0.4	0.3
Haddock (HD)	0.4	1.2	0.5	0.1
Yellowtail flounder (YF)	0.4	0.5	0.9	0.6
Winter flounder (WF)	0.3	0.1	0.6	0.7

Pollock has shifting distribution

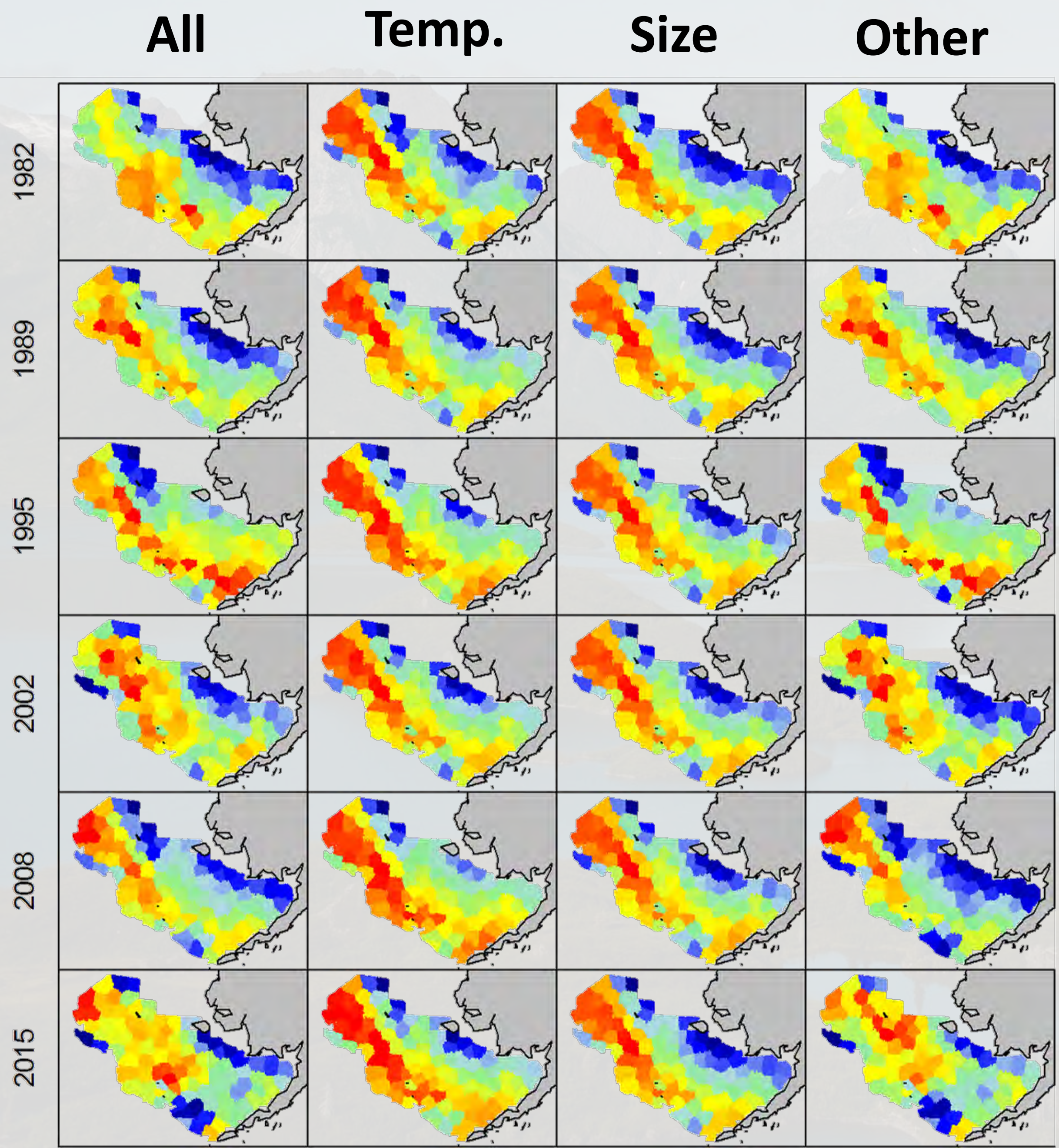
- Important fishery in Alaska

Three mechanisms for distribution shift

1. Regional or local temperature
2. Shifts in size distribution + habitat partitioning
3. Unexplained variation

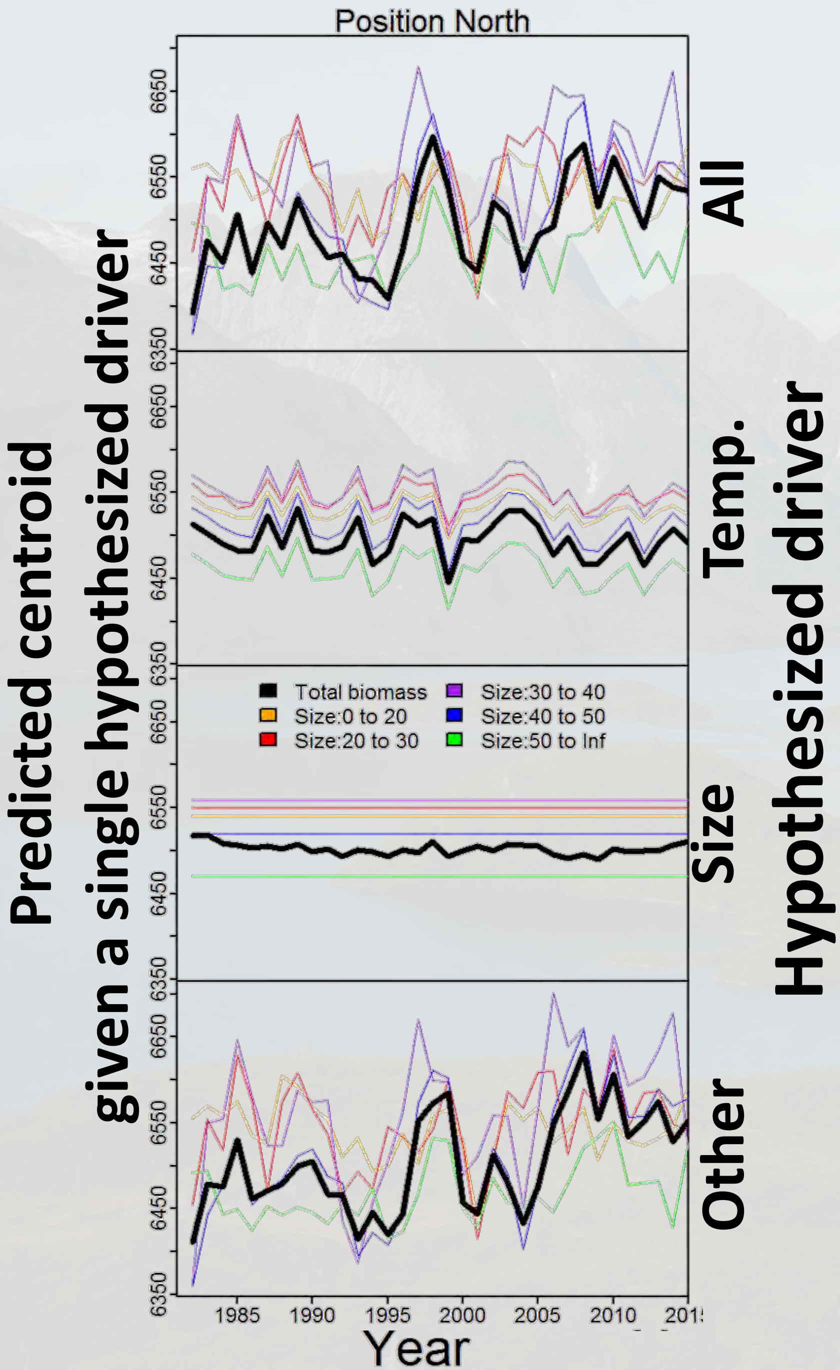


Predicted density given driver



Procedure

1. Fit model with all three mechanisms
2. Run counter-factuals that exclude all but one mechanism
3. Inspect variance explained



Summary

- Pollock has shifted north over time
- Bottom temperature and size-structure explain little of historical change
  - Explaining distribution shifts requires more than temperature

Hypothesis

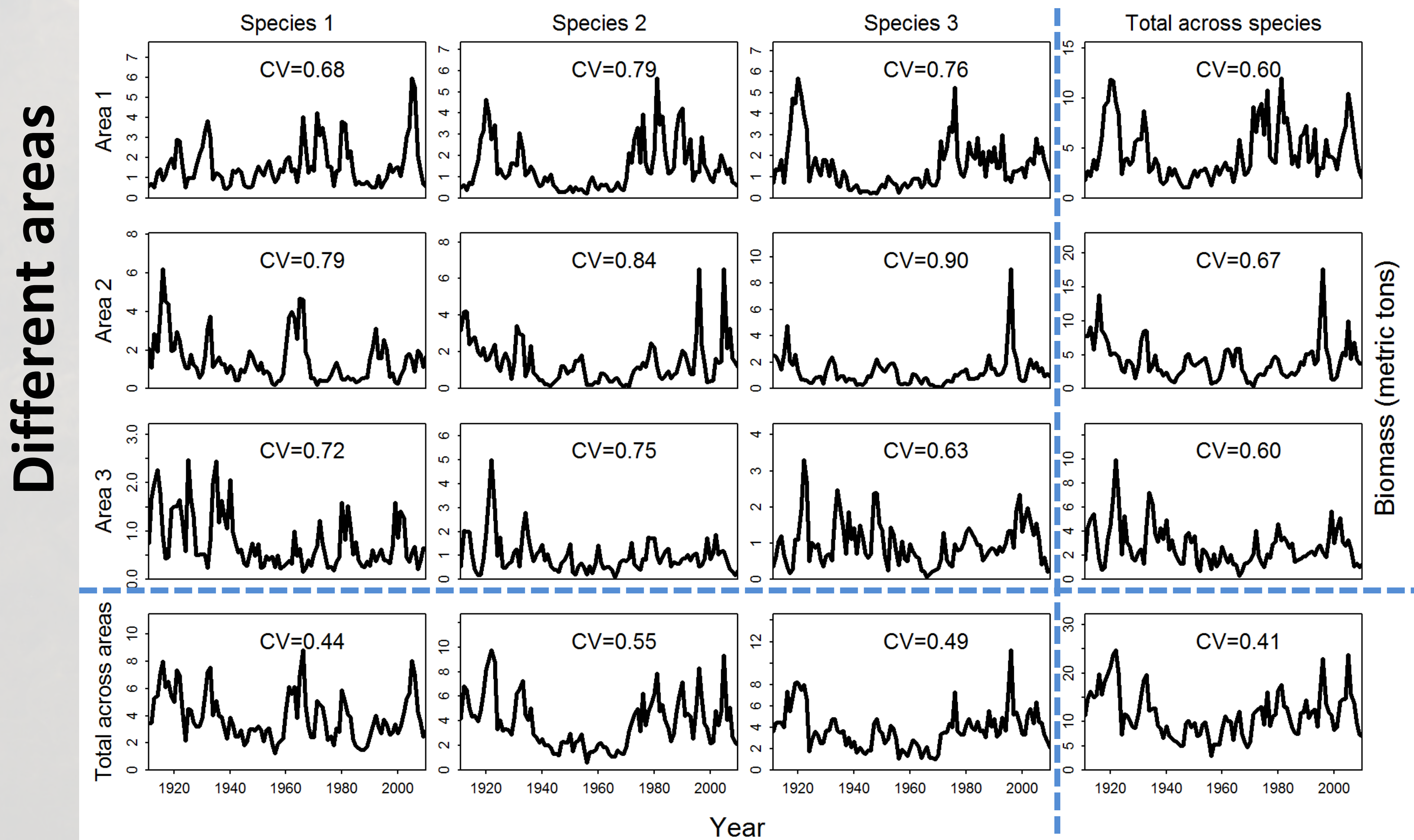
- Driven by spatial distribution of fishing

Part 2: Spatio-temporal synchrony

Thorson, Scheuerell, Olden, and Schindler. Spatial heterogeneity contributes more to portfolio effects than species differences in bottom-associated marine fishes.

Synchrony increases aggregate variance

Different species



Spatio-temporal portfolios

Defining synchrony (ϕ)

$$\phi = \frac{\sigma^2_{aggregate}}{\sigma^2_{max\_possible}}$$

where

- $\sigma^2_{aggregate}$ is the variance over time in aggregate biomass
  - Aggregate across species, locations, or both
- $\sigma^2_{max\_possible}$ is the theoretical maximum variance (given variance for each component)
  - Based on perfect correlation among components

Portfolio effects (P)

$$P = 1 - \phi$$

- High synchrony → Low portfolio effects

Spatio-temporal portfolios

Three types of synchrony

1. Species synchrony, $\phi_{species}(s)$
    - Varies among locations s
    - Can average across locations, $\bar{\phi}_{species}$
2. Spatial synchrony, $\phi_{spatial}(p)$
    - Varies among species c
    - Can average across species, $\bar{\phi}_{spatial}$
3. Total synchrony, ϕ_{total}

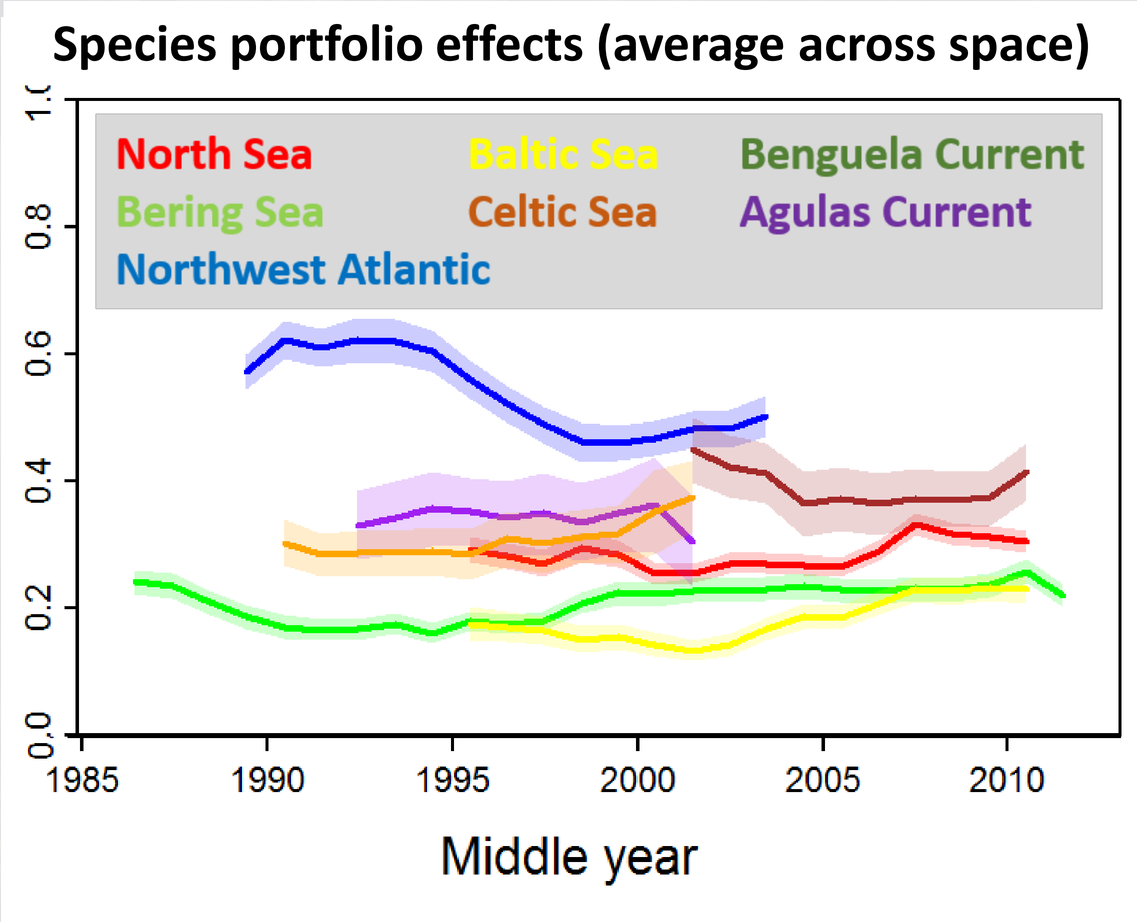
Approach

- Measure using 10-year moving windows to detect decadal changes

Spatio-temporal portfolios

Species portfolios

- Decreasing
  - Northwest Atlantic
- Increasing
  - Baltic Sea
- Stable
  - Eastern Bering Sea
  - Benguela and Agulas Currents (South Africa)
  - North Sea
  - Celtic Sea

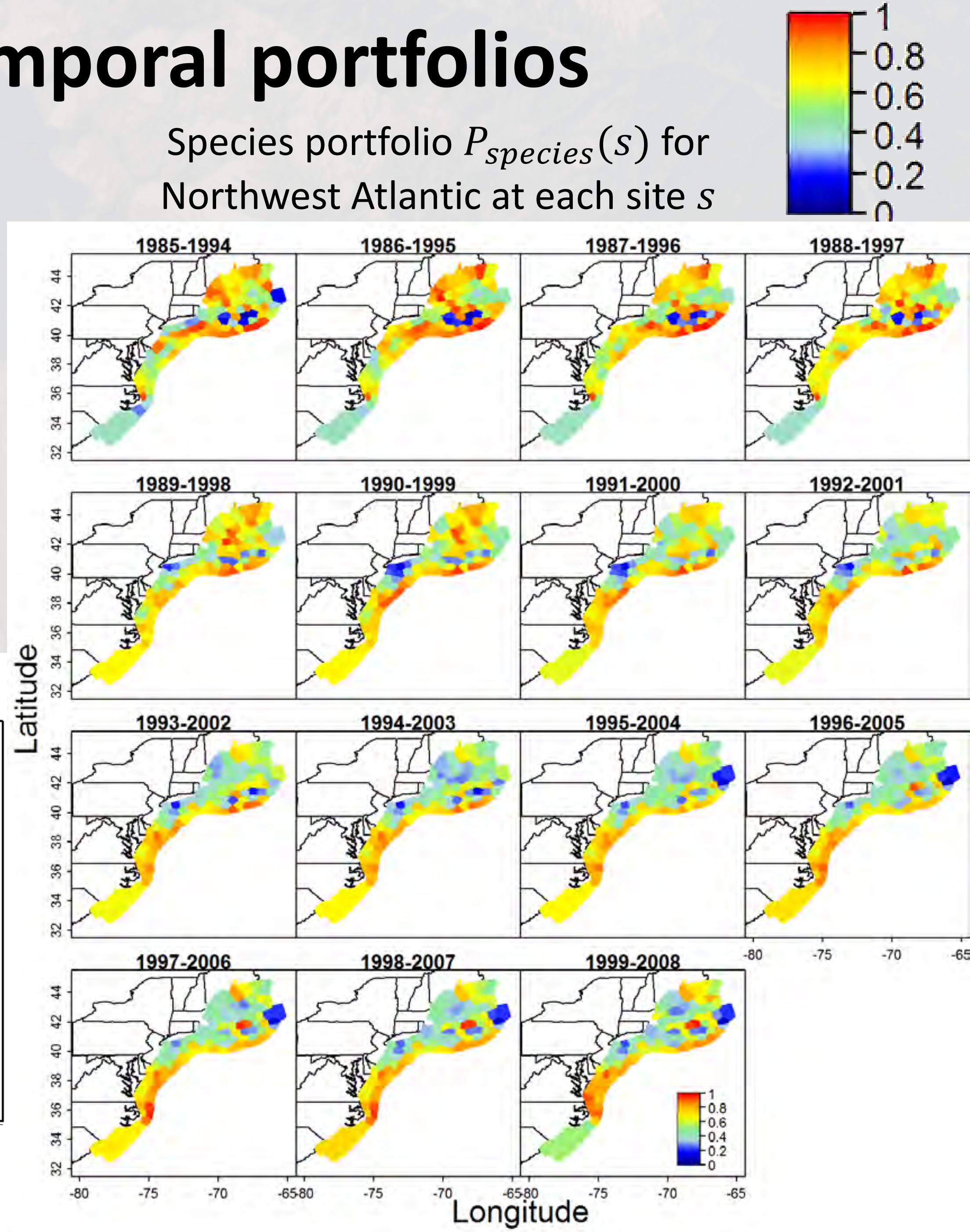


Spatio-temporal portfolios

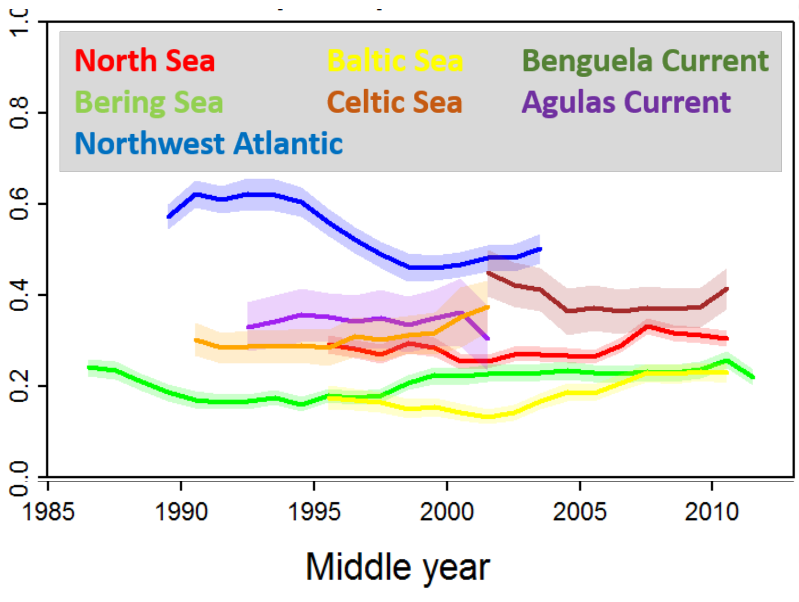
Species portfolios

- Decrease for Northwest Atlantic caused by decrease inshore

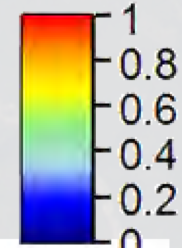
Species portfolio $P_{species}(s)$ for Northwest Atlantic at each site s



Species portfolio effects (average across space)



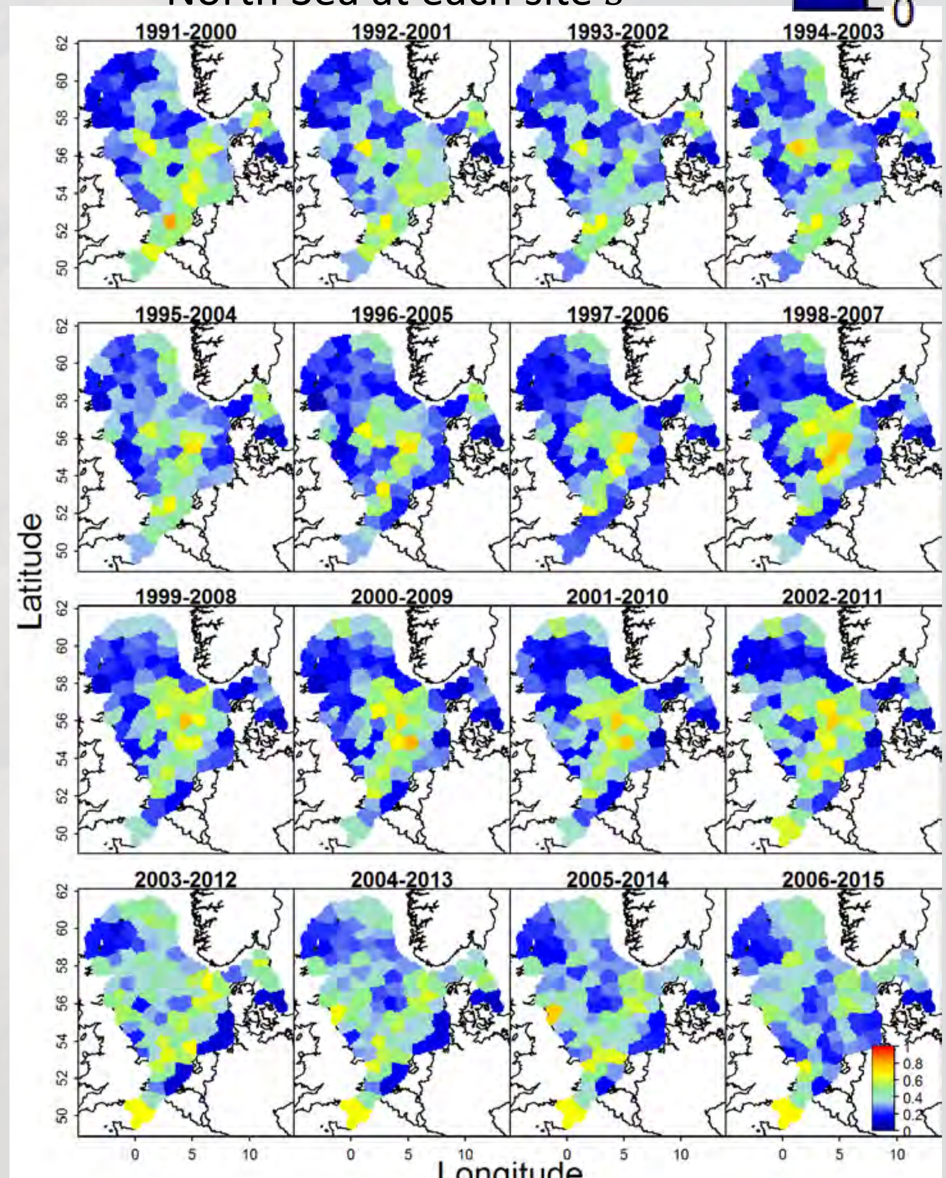
Spatio-temporal portfolios

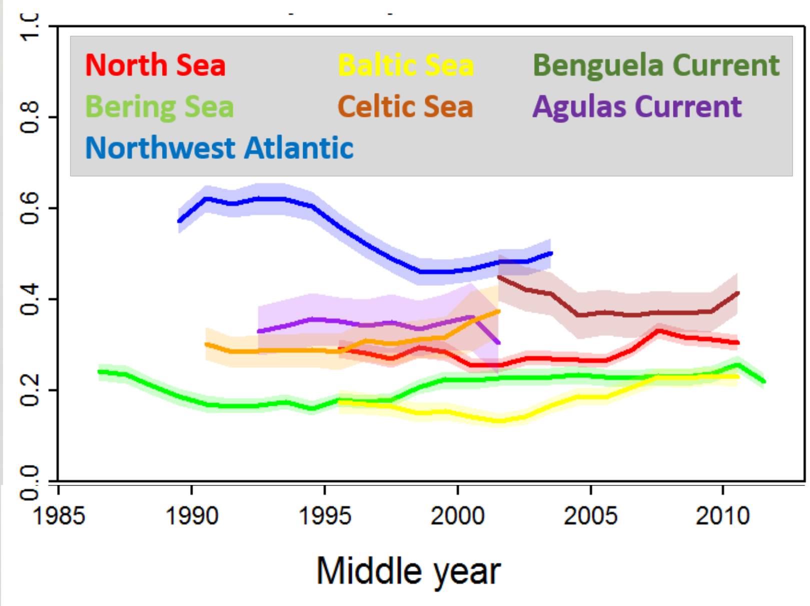


Species portfolios

- Stability for North Sea masks decrease inshore and increase offshore

Species portfolio $P_{species}(s)$ for North Sea at each site s





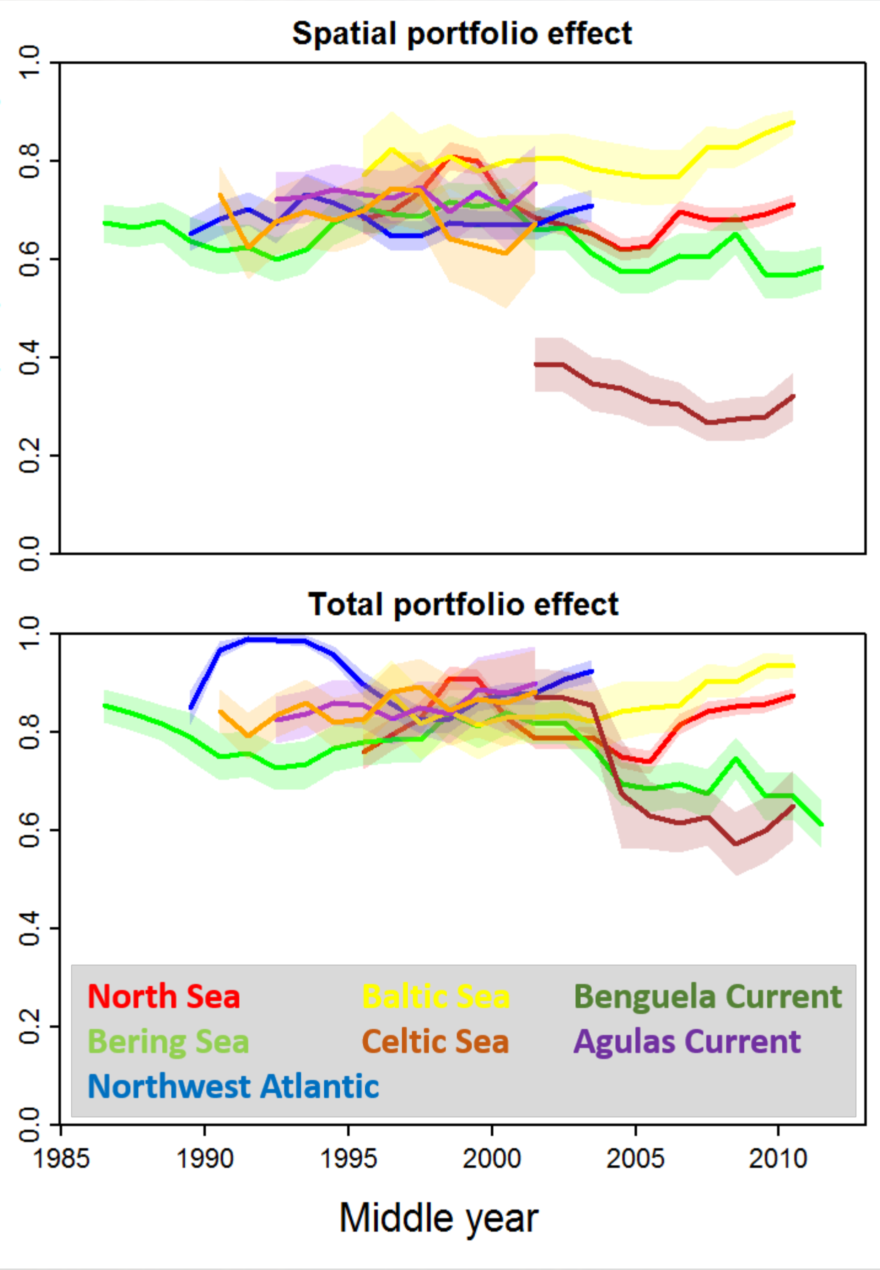
Spatio-temporal portfolios

Spatial portfolio

- Stronger than species portfolios
  - Except weak for Celtic Sea

Total portfolios

- Cannot be weaker than Spatial or species portfolio
- Decrease for Eastern Bering Sea
  - Started around 2000



Spatio-temporal portfolios

Discussion

1. Total portfolio effect as “dynamic ecosystem indicator”
   - Indicates change in fishing risk
   - Especially important when spatial portfolio is weak
2. Surprisingly stable for most marine ecosystems
   - Monitored systems are intensively managed
3. Can use spatio-temporal model to monitor portfolios
   - Automated output in R package *VAST* for marine fishes

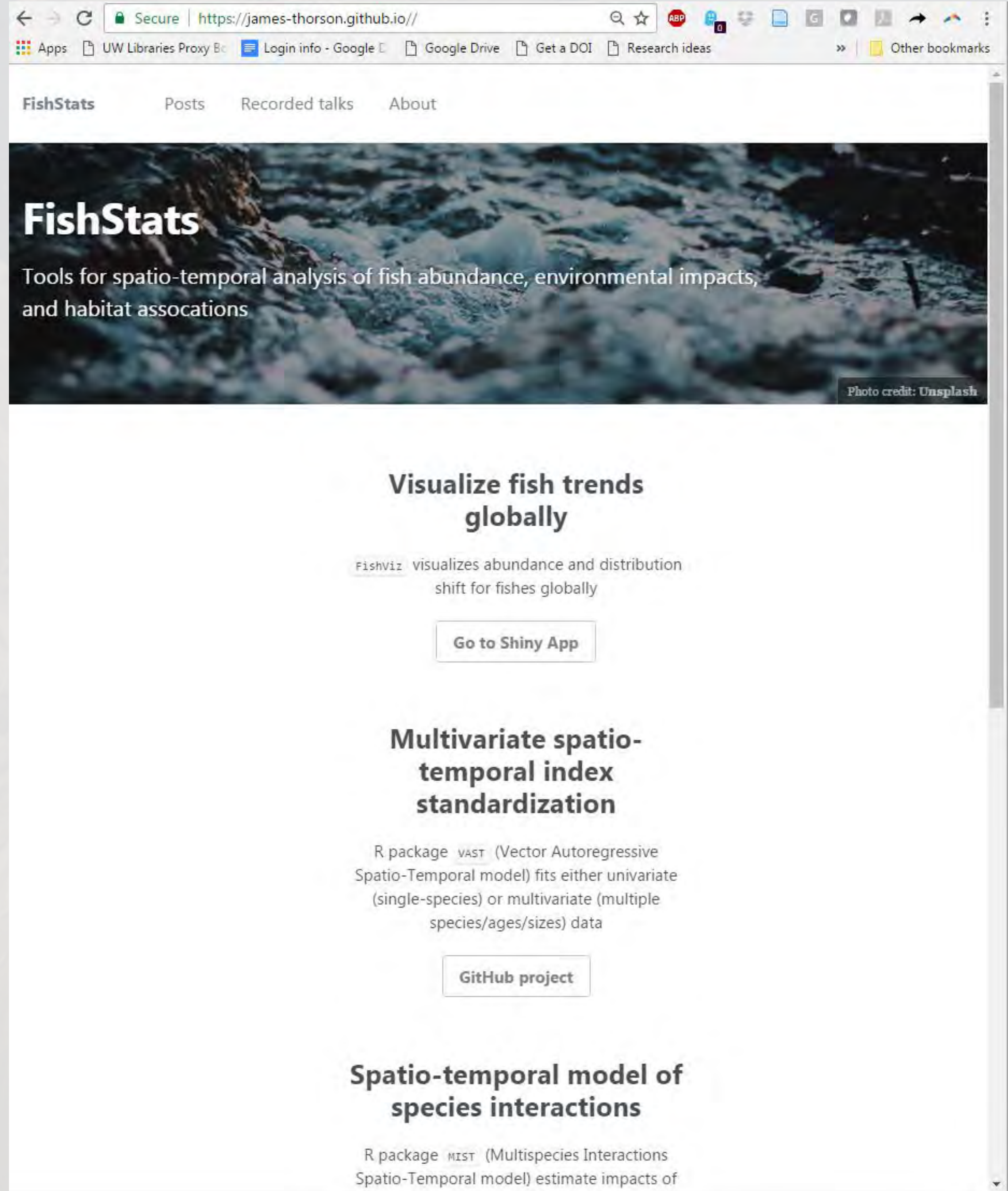
Understanding causal drivers for global oceans

Spatio-temporal toolbox

www.FishStats.org

Public R packages

1. FishViz
   - Visualizes results worldwide
2. VAST
   - Multi-species index model
3. MIST
   - Estimate multispecies interactions
4. FishData
   - Scrape data worldwide

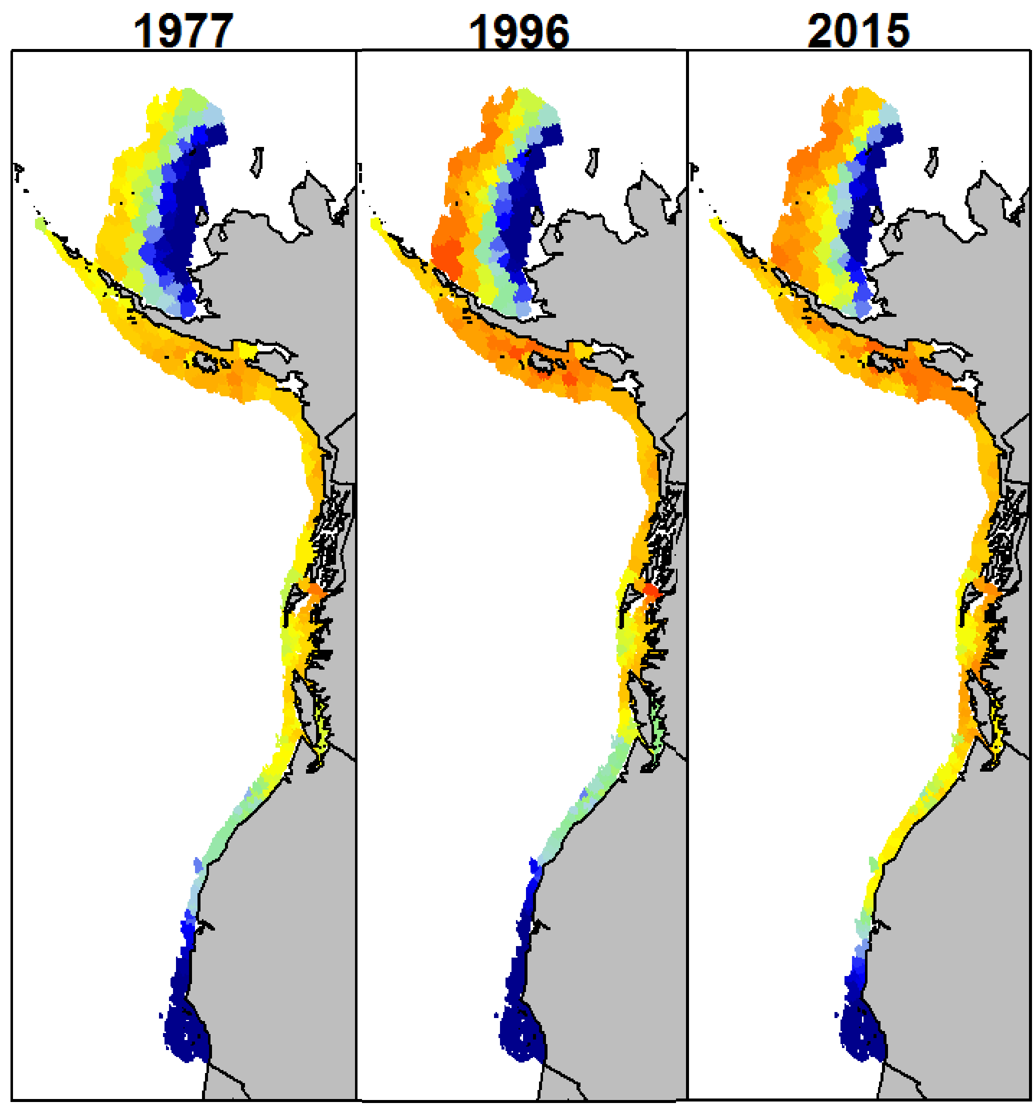


Future research

1. Combining data from multiple sources

- If surveys don't overlap spatially
  - Calibration via spatio-temporal correlation
- If surveys do overlap spatially
  - Estimate spatial variation in catchability

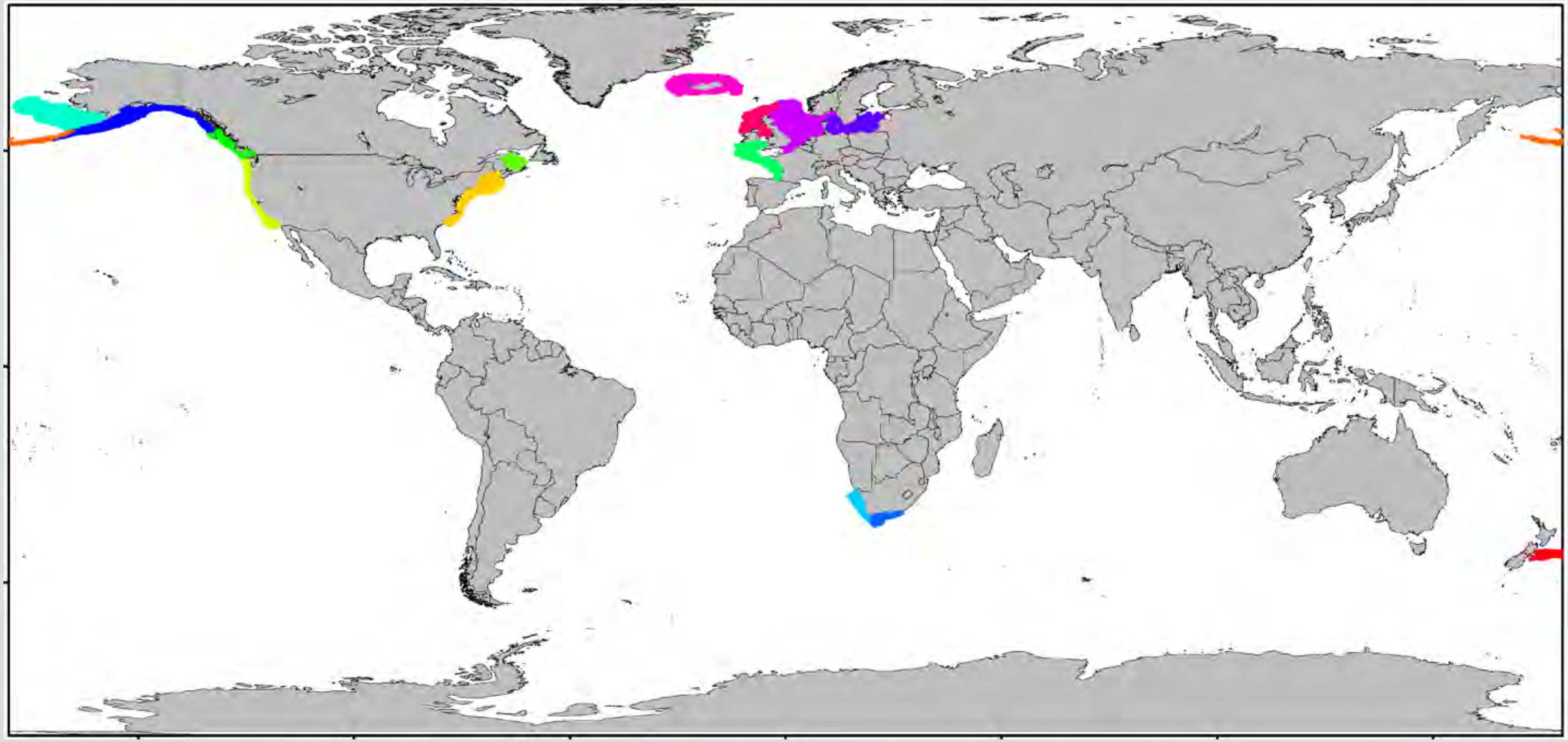
Arrowtooth flounder in the North Pacific



Future research

2. Improve access to survey data worldwide

```
> devtools::install_github("james-thorson/FishData")
Downloading GitHub repo james-thorson/FishData@master
from URL https://api.github.com/repos/james-thorson/FishData/zipball/
Installing FishData
```



Acknowledgements

NOAA: Jim Ianelli, Stan Kotwicki, Eric Ward, Mark Scheuerell

Danish Technical University: Kasper Kristensen

University of Bergen: Hans Skaug

Univ. Wash.: Julian Olden, Daniel Schindler

Further information

1. www.FishStats.org
2. www.FishViz.org