Measuring portfolio effects and climate-drivers in the North Pacific using spatio-temporal models and causal statistics
2014 temperature anomalies
Benefits of unified approach

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

Experiment #1

Experiment #2
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

Vector Autoregressive Spatio-Temporal (VAST) model
(log-density estimates by species)

Density key
- High
- Medium
- Low

Yellowtail flounder
1985
1992
1997

Haddock
1985
1992
1997

Atlantic cod
1985
1992
1997

Winter flounder
1985
1992
1997
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

<table>
<thead>
<tr>
<th></th>
<th>AC</th>
<th>HD</th>
<th>YF</th>
<th>WF</th>
</tr>
</thead>
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<td>2.3</td>
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<td>Haddock (HD)</td>
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<td>Winter flounder (WF)</td>
<td>1.7</td>
<td>0.8</td>
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<td>4.8</td>
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</tbody>
</table>

### Spatio-temporal covariance

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<th>WF</th>
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</tbody>
</table>
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
### Procedure

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

<table>
<thead>
<tr>
<th></th>
<th>All</th>
<th>Temp.</th>
<th>Size</th>
<th>Other</th>
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<td><img src="image23.png" alt="Map" /></td>
<td><img src="image24.png" alt="Map" /></td>
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</table>
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

Different areas

Biomass (metric tons)

Year

CV = 0.68
CV = 0.79
CV = 0.76
CV = 0.60
CV = 0.79
CV = 0.84
CV = 0.90
CV = 0.67
CV = 0.72
CV = 0.75
CV = 0.63
CV = 0.60
CV = 0.44
CV = 0.55
CV = 0.49
CV = 0.41
Spatio-temporal portfolios

Defining synchrony ($\phi$)

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

where

- $\sigma_{aggregate}^2$ is the variance over time in aggregate biomass
  - Aggregate across species, locations, or both

- $\sigma_{max\_possible}^2$ is the theoretical maximum variance (given variance for each component)
  - Based on perfect correlation among components

Portfolio effects ($P$)

$$P = 1 - \phi$$

- High synchrony $\rightarrow$ Low portfolio effects
Spatio-temporal portfolios

Three types of synchrony

1. Species synchrony, $\phi_{\text{species}}(s)$
   - Varies among locations $s$
   - Can average across locations, $\bar{\phi}_{\text{species}}$

2. Spatial synchrony, $\phi_{\text{spatial}}(p)$
   - Varies among species $c$
   - Can average across species, $\bar{\phi}_{\text{spatial}}$

3. Total synchrony, $\phi_{\text{total}}$

Approach

– Measure using 10-year moving windows to detect decadal changes
Species portfolios

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

- Decrease for Northwest Atlantic caused by decrease inshore
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
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
Future research

2. Improve access to survey data worldwide

```r
> 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