FishStats: A toolbox for combining stock assessment, habitat, ecosystem, and climate research
Benefits of single approach

1. Include biological mechanism
2. Improved communication
3. Similar review standards and "burden of proof"
Spatio-temporal fisheries toolbox

www.FishStats.org

1. FishViz
   - Visualizes results worldwide

2. SpatialDeltaGLMM
   - Single-species index model

3. VAST
   - Multi-species index model

4. SpatialVAM
   - Estimate species interactions

5. FishData
   - Scrape data worldwide

6. FishStats-listserv
   - Community updates by email
Spatio-temporal models for populations

Delta-generalized linear mixed model (Delta-GLMM)

- Delta-model for observations

\[ \Pr(B = b) = \begin{cases} 
1 - \gamma(s, t) & \text{if } B = 0 \\
\gamma(s, t) \times g(B; \lambda(s, t)) & \text{if } B > 0 
\end{cases} \]

- Where \( \gamma(s, t) \) is the probability of encountering the species
- \( g(B; \lambda(s, t)) \) is a distribution for positive catches

- Spatio-temporal variation in encounter probability

\[ \text{logit} (\gamma(s, t)) = \alpha_\gamma(t) + \omega_\gamma(s) + \varepsilon_\gamma(s, t) \]

- \( \alpha_\gamma(t) \) is the intercept for each year
- Where \( \omega_\gamma \) and \( \varepsilon_\gamma(t) \) follow a spatial distribution

- Spatio-temporal variation in density

\[ \text{log} (\lambda(s, t)) = \alpha_\lambda(t) + \omega_\lambda(s) + \varepsilon_\lambda(s, t) \]

- Where parameters are defined similarly to \( \gamma(s, t) \)

- Used to predict local density

\[ \hat{d}(s, t) = \hat{\gamma}(s, t) \times \hat{\lambda}(s, t) \]

- Where \( \hat{\gamma}(s, t) \) and \( \hat{\lambda}(s, t) \) are predictions conditioned on data
Walleye pollock in Eastern Bering Sea
(density, log kg. per square km.)
Useful outputs

1. Total abundance (units: kilograms)

\[ \hat{I}(t) = \int \hat{d}(s, t) ds \]

2. Average density (units: kilograms per square-kilometer)

\[ \hat{\mu}(t) = \int \frac{\hat{d}(s, t)}{\hat{I}(t)} \hat{d}(s, t) ds \]

3. Center of distribution (units: kilometers relative to reference location)

\[ \hat{\mathcal{X}}(t) = \int \frac{\hat{d}(s, t)}{\hat{I}(t)} x(s, t) ds \]

4. Effective area occupied (units: square-kilometers)

\[ \hat{h}(t) = \frac{\hat{I}(t)}{\hat{\mu}(t)} \]
Density-dependent habitat selection

- Do populations shrink their range when abundance is low?
- Average
  - Small contraction in range
  - Greatest in Eastern Bering Sea

Distribution shifts

- Highly variable distribution for semi-pelagic species
  - Dogfish
  - Sablefish
  - Hake

- Few clear trends
  - Depends on time-scale

Has been applied to >15 regions 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
```
Currently showing results for >500 stocks

@ www.FishViz.org
Spatio-temporal models for ecological communities

Vector-autogressive spatio-temporal model (VAST)

• Delta-model for observations
  – Same as single-species model

• Spatio-temporal variation in density

\[
\log(\lambda_i) = \alpha(t) + \sum_{f=1}^{n_f} L_\omega(c_i, f)\omega(s_i, f) + \sum_{f=1}^{n_f} L_\varepsilon(c_i, f)\varepsilon(s_i, f, t_i) + \sum_{f=1}^{n_f} L_\delta(c_i, f)\delta(f, v_i)
\]

  – \(\sum_{f=1}^{n_f} L_\omega(c_i, f)\omega(s_i, f)\) is spatial covariation
  – \(\sum_{f=1}^{n_f} L_\varepsilon(c_i, f)\varepsilon(s_i, f, t_i)\) is spatio-temporal covariation
  – \(\alpha_t\) is the intercept for each year
  – Where \(\omega(f)\) and \(\varepsilon(f, t)\) follow a spatial distribution with variance of one
  – \(L_\omega, L_\varepsilon,\) and \(L_\delta\) are loadings matrices

• Used to predict total density

\[
\hat{d}(s, c, t) = \hat{\gamma}(s, c, t) \times \hat{\lambda}(s, c, t)
\]
Covariance for spatial and spatio-temporal components of encounter probability and positive catch rates
Standardizing fishery-dependent CPUE data using VAST

Fishery-dependent index standardization

- Construct indices from fishery catch rates

\[ \mathbb{E}(B_c) = F_c D_c Q_c \]

Where

- \( B_c \) is catch for each species \( c \)
- \( Q_c \) is catchability
- \( F_c \) is fishing effort
- \( D_c \) is density

**Goal**: Use multispecies data to “account” for fisher targeting (unexplained variation in catch-rates at a given location, caused by catchability differences)
Case study: Petrale sole winter fishery

Results

• Fit to data for Petrale, dover, sablefish, and thornyheads

• Account for targeting via residual correlations
Covariance in catchability

- \( \text{Cov}(Q_c) = L_\delta L_\delta^T \)
- Dover, Thornyhead, Sablefish are caught together
- Winter petrale fishery is “clean”

<table>
<thead>
<tr>
<th></th>
<th>Petrale</th>
<th>Dover</th>
<th>Thornyhead</th>
<th>Sablefish</th>
</tr>
</thead>
<tbody>
<tr>
<td>Petrale</td>
<td>0.901</td>
<td>-0.276</td>
<td>-0.530</td>
<td>-0.415</td>
</tr>
<tr>
<td>Dover</td>
<td>0.630</td>
<td>0.836</td>
<td>0.769</td>
<td></td>
</tr>
<tr>
<td>Thornyhead</td>
<td>1.433</td>
<td>1.201</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sablefish</td>
<td></td>
<td></td>
<td>1.040</td>
<td></td>
</tr>
</tbody>
</table>
Index is plausible:

- Matches survey index
- Timing of recovery consistent with assessment model
Conclusions about VAST

1. Can fit indices using multi-species data
2. Uses similar techniques as single-species survey indices
3. Gives identical results to single-species model when fitting data from a single species
Community dynamics modeling

- Dynamical model
  \[ d(s, t + 1) = (I + B)d(s, t) + \omega(s) + \varepsilon(s, t) \]
  - \( B \) is the community-interaction matrix
  - \( \omega(s) \) is spatial variation
  - \( \varepsilon(s, t) \) is spatio-temporal variation

- Constraints
  1. Parsimony:
     - \( 0 \leq \text{rank}(B) \leq n_p \)
  2. Stability:
     - \(-2 \leq \text{eigenvalues}(B) \leq 0 \)
1. Can estimate community matrix
2. Can identify rank

Community matrix, \( C = B + I \)

Rank of community matrix, 
\( C = B + I \)
Case study

- Gulf of St. Lawrence
- Grey seals increasing
- Fishes decreasing
  - White hake have biggest decrease
  - Atlantic cod decreasing near grey seal haul-outs
Conclusions for community interactions

- One unregulated axis
  - Increasing grey seals and decreasing fishes

### Impact of abundance for...

<table>
<thead>
<tr>
<th></th>
<th>Atlantic cod</th>
<th>white hake</th>
<th>thorny skate</th>
<th>grey seal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atlantic cod</td>
<td>0.860 (0.024)</td>
<td>0.095 (0.024)</td>
<td>-0.031 (0.010)</td>
<td>-0.060 (0.033)</td>
</tr>
<tr>
<td>white hake</td>
<td>-0.013 (0.007)</td>
<td>0.999 (0.008)</td>
<td>0.004 (0.003)</td>
<td>-0.021 (0.015)</td>
</tr>
<tr>
<td>thorny skate</td>
<td>0.165 (0.048)</td>
<td>0.124 (0.045)</td>
<td>0.631 (0.060)</td>
<td>-0.213 (0.078)</td>
</tr>
<tr>
<td>grey seal</td>
<td>-0.000 (0.002)</td>
<td>-0.004 (0.003)</td>
<td>0.000 (0.001)</td>
<td>0.985 (0.005)</td>
</tr>
</tbody>
</table>

Photo: Chris Miller, csmphotos.com
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
Conclusions

• Pollock has shifted north over time
• Bottom temperature and size-structure explain little of historical change
  — Explaining distribution shifts is hard!
How do we move forward?

Photo: Jonny Armstrong @ OSU
Difficulties to resolve

1. Improved data sharing and documentation

   – Add machine-readable database for all NMFS regions
   – Improve link to OceanAdapt @ Rutgers
   – Provide NOAA scientific support for sharing data from other regions internationally
Difficulties to resolve

2. Regional evaluation and benchmarking

– Add spatial meta-data for more regions
  • Defines area for “expanding” density estimates when calculating abundance
  • Requires regional collaboration

– Add comparison data set for more regions
  • Already available for 12 species
  • Used to confirm that code updates don’t “break” model
Difficulties to resolve

3. Combining data

- 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
Difficulties to resolve

4. Spatial data-poor models
   - Index-based methods
     - Widely used in AK
   - Stock reduction analysis
     - Replace assumptions with abundance index

5. Ecosystem indicators and stability

- Are species strongly correlated?
- Is community variance reduced by species covariation?
- Are ecosystems become more variable over time?
- Do species interactions increase ecosystem variance?
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DAFF: Henning Winker

UC Santa Barbara: Cody Szuwalski

Resources

1. www.FishStats.org

2. Training workshop at AFSC Feb. 8-10

3. FishStats-listserv

4. Rmarkdown tutorials for software

5. Peer-reviewed papers listed for each model