Understanding the role of variability in fish population response to changing environmental conditions in the Great Lakes Basin

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Northeast Climate Science Center Webinar
UMass Amherst

April 11, 2018
Variability

Photo: NOAA
Do source components of variability have a role as indicators of ecological shifts?
   Oneida Lake, New York → MA inshore trawl survey

Are demographic shifts altering the vulnerability of a prey fish to environmental variability?
   Lake Michigan → black sea bass in the Northwest Atlantic

Are environmental drivers influencing the structure of a fish community as a whole?
   Bay of Quinte, Ontario → MA inshore fish community
Using variance structure to quantify responses to perturbation in fish catches

Oneida Lake, New York
Background: Regime Shifts

http://oceantippingpoints.org
Background: Regime Shifts

Guttal and Jayaprakash 2008
Objectives

- Limitations with identified signals
  - Evaluate if variance components are responsive to large-scale perturbation
  - Determine if the structure of variability can be used to better understand ecological reorganization
Featured paper

Using Variance Structure to Quantify Responses to Perturbation in Fish Catches

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Case Study: Oneida Lake
Variability

Irwin et al. 2013
Time-varying Mixed Model

\[ Y_{ij} \sim NB(\mu_{ij}, \kappa_p) \]
\[ \mu_{ij} = e^{\eta_{ij}} \]

\[ \eta_{ij} = \nu + a_{ip} + b_{jp} + \lambda \cdot \text{year}_i \]
\[ i = \text{year}; \ j=\text{site}; \ p=\text{time period} \]

Random effects
\[ a_{j\text{pre}} \sim N(0, \sigma_{a\text{pre}}^2) \]
\[ a_{j\text{post}} \sim N(0, \sigma_{a\text{post}}^2) \]
\[ b_{j\text{pre}} \sim N(0, \sigma_{b\text{pre}}^2) \]
\[ b_{j\text{post}} \sim N(0, \sigma_{b\text{post}}^2) \]
Model Fit

1958-1988
- Observed
- Predicted

1989-2014
- Observed
- Predicted

Proportion vs. Catch

- Catches: 1-10, 11-20, 21-30, 31-40, 41-50, 51-75, 76-125, 126-250

- Proportion: 0.0, 0.1, 0.2, 0.3, 0.4, 0.5
Results

Spatial

\[ \sigma^2_{\text{pre}} = 0.35 \]
\[ \sigma^2_{\text{post}} = 0.10 \]

Temporal

\[ \sigma^2_{\text{pre}} = 0.10 \]
\[ \sigma^2_{\text{post}} = 0.12 \]
Results

\( \sigma^2_{site} = 0.35 \quad \sigma^2_{site} = 0.10 \)
Summary:

- Variance structure can be responsive to large ecological perturbations
- The grouping level effects provide insight into how communities are changing over time
- Mixed modeling approach is appropriate and flexible
  - compare response to alternative management regimes
  - compare variability across physiographic regions
  - describe difference among climate zones
  - evaluate monitoring programs
• Develop a model with time-varying variance components (e.g., random walk, dynamic linear models)
• Apply this approach to a suite of species that have exhibited declines/increases
• Begin to evaluate if early warning signals can be detected in a reliable manner
Demographic structure influences how environmental forcing affects Alewife recruitment in Lake Michigan.
Alewife in Lake Michigan
Survey time-series

![Graph showing spawner abundance and normalized recruitment over years from 1980 to 2010. The graph displays peaks and troughs in spawner abundance, with normalized recruitment indicated on the right y-axis.](image-url)
Age Structure

USGS Fall Bottom Trawl Survey
Vulnerability to environmental signals may increase because:

- loss of buffering capacity
- reduction in genetic and spatial structure
- increased importance of a few reproducing age classes
Resonance
Waves vs Wavelets
Wave Characteristics

\[ \lambda \]

Time

Amp
Understanding Wavelets

Abundance

Year


Amplitude

Year

Understanding Wavelets
Understanding Wavelets

Abundance


Amplitude


Year

Year
Understanding Wavelets
Wavelet analysis

Recruits

SSB
\[
\begin{pmatrix}
  x_1(t+1) \\
  x_2(t+1) \\
  x_3(t+1) \\
  \vdots \\
  x_n(t+1)
\end{pmatrix}
= \begin{pmatrix}
  R(t) \\
  s_1(t)x_1(t) \\
  s_2x_2(t) \\
  \vdots \\
  s_{n-1}x_{n-1}(t)
\end{pmatrix}
\]

\[
P(t) = \sum_{i=1}^{n} p_i f_i x_i(t)
\]

\[
R(t) = \frac{\alpha Pe^{-\epsilon t}}{1 + \beta P}
\]
Simulations

- Expected recruitment vs. Time (years)
- Spawner biomass vs. Time (years)
- CV vs. Full, Mid, Trunc
- Spawner biomass vs. Full, Mid, Trunc
Spawner Biomass
Age truncation
Predicted recruitment

![Graph showing predicted recruitment with axes labeled "Recruits" and "Eggs". Legend includes lines labeled "LEP - full", "LEP - 5", and "LEP - 4". The graph reaches a peak and then declines.]
The Alewife population in Lake Michigan:
- predation induced age truncation
- low total abundance
- strong signal \(\sim\) mean spawner age develops
- population appears to be tracking the environment more closely
- implications for management - need to manage for age structure and not just abundance/biomass
Future work

- Evaluate a broader range of species that have experienced age truncation
- Attempt to identify mechanisms contributing to the amplification or dampening of signals
- Evaluate how to use this information in predictive ways
Influence of environmental variability on fish community composition

Bay of Quinte, Ontario
Community indicators

Data:
Gillnet data from standardized survey: 1995-2015
Abundance and biomass estimates for fish encountered (41 different species)

Reduced to indicators:
- Mean fish length
- Species richness
- Origin: native versus exotic
- Energy transfer: trophic niche and level
- Habitat use: benthic, benthopelagic, pelagic
- Thermal preference: cold, cool, warm-water

Abundance · Biomass · Proportion
Environmental predictors

- Level (m)
- Precip (mm)
- Secchi (m)
- Spr Temp (°C)
- Sum Temp (°C)
- Min Temp (°C)
Gradient forest analysis

Ellis et al. 2012
Threshold response
Cumulative importance of predictors

- Cumulative importance vs. SECCHI
- Cumulative importance vs. CUM.SP
- Cumulative importance vs. SUM

Legend:
- Orange: Abundance of warm water species
- Green: Mean trophic level
- Blue: Proportion of piscivores
Summary of gradient forest

3 community indicators were predicted (to some degree) by the environmental drivers

- mean trophic level
- proportion of piscivores
- abundance of warm water species

3 environmental drivers were (relatively) important predictors of the community indicators

- secchi depth
- cumulative spring temperatures
- mean summer temperature
Analysis of beta diversity

low spatial turnover

high spatial turnover
Analysis of beta diversity
Analysis of beta diversity
Summary

- Environmental variables (collected at this scale) aren’t strong predictors of community shifts.
- Gradient forest has potential for evaluating ecosystem changes across a large set of variables.
- Indicators: good and bad.
- Fine-scale resolution of environmental data often lacking.
- Expand to ecosystem level approach.
Promising tools to assess large data sets
Applications for ecosystem-based approaches
Provide information to support Management Strategy Evaluation/ Structured Decision Making
Acknowledgments

Brian Irwin

Northeast Climate Science Center, UGA & Warnell, USGS Coop Unit

Richard Chandler, Seth Wenger, Nicole Lazar

Jim Bence, Lars Rudstam, Randy Jackson, Ty Wagner, Tony VanDeValk, John Forney, Tom Brooking

Chuck Madenjian, Tim Hunter, Paris Collingsworth

Jeremy Holden, Mike Yuille, Jim Hoyle
Work at DMF

- Analyses and research projects related to recreational fisheries
  - black sea bass, fluke, tautog, scup, bluefish, and weakfish
- Serve on ASMFC Technical and Monitoring Committees
- Participate in stock assessments

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