Developing a classification system for Caribbean seagrass communities

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Speaker Introduction by Professor Bill Dennison
Regional Scale Climate Forcing of Chesapeake Bay Trophic Dynamics

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Outline

- Chesapeake Bay Ecology 101
- Relating climate to surface conditions
- Ecological response
- Crystal ball
Chesapeake Bay Ecology 101

Watershed area 172,000 sq km
Chesapeake Bay area 13,000 sq km
Average depth 8.5 m
Simple Chesapeake Bay Food Web

Simpler Chesapeake Bay Food Web

- **Nutrients**
  - **Phytoplankton**
    - **Zooplankton**
      - **Planktivorous Fish**
      - **Piscivorous Fish**
Population has risen from 5 million around 1900 to over 15 million today. That is equivalent to 10 busloads of people arriving every day for the past 100 years.
Anthropogenic Impacts – Oyster Harvest

Maryland and Virginia Commercial Landings

Source: NMFS Fisheries Statistics of the U.S.; calendar year data.
Nutrients and phytoplankton

<table>
<thead>
<tr>
<th>1918</th>
<th>1950s</th>
<th>1970s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fritz Haber invents</td>
<td>Widespread artificial</td>
<td>Nutrient input into</td>
</tr>
<tr>
<td>process to transform</td>
<td>fertilizer use in the</td>
<td>Chesapeake Bay increases</td>
</tr>
<tr>
<td>atmospheric N gas</td>
<td>United States</td>
<td></td>
</tr>
<tr>
<td>into ammonia</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Today’s sorry state of affairs
How will climate change impact this ecosystem?

- **What we know**
  - Freshwater input is a major forcing factor of physical and biological changes in Chesapeake Bay

- **Question:** Is the variability in freshwater input the result of climate variability?
  - Is a large scale climate link evident (North Atlantic Oscillation, El Niño-Southern Oscillation, etc.)?

- **Question:** What is the link between climate, freshwater input and trophic dynamics in Chesapeake Bay?
The North Atlantic Oscillation

NAO positive phase

NAO negative phase
NAO positive phase

- Low pressure over Iceland is strong
- High pressure over the Azores is strong
- Storm track is pushed north
- Wet winter in Eastern US
- Wet winter in N Europe and dry in S Europe

NAO negative phase

- Low pressure over Iceland is weak
- High pressure over the Azores is weak
- Storm track is pushed south
- Dry winter in Eastern US
- Dry winter in N Europe and wet in S Europe
Large Scale Climate Indices


<table>
<thead>
<tr>
<th>Variable</th>
<th>p-value</th>
<th>$r^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Niño3.4</td>
<td>0.068</td>
<td>0.073</td>
</tr>
<tr>
<td>NAO</td>
<td>0.621</td>
<td>0.006</td>
</tr>
<tr>
<td>PDO</td>
<td>0.578</td>
<td>0.007</td>
</tr>
<tr>
<td>PNA</td>
<td>0.625</td>
<td>0.005</td>
</tr>
<tr>
<td>Temp</td>
<td>0.116</td>
<td>0.055</td>
</tr>
<tr>
<td>Precip</td>
<td>0.028</td>
<td>0.104</td>
</tr>
<tr>
<td>Temp+Precip</td>
<td>0.019</td>
<td>0.167</td>
</tr>
</tbody>
</table>
Wet and Dry Period Anomalies

Kimmel et al. 2006 *Estuaries* (in press)
Paleoclimate Record

Water Balance in the Susquehanna Basin

Classifying climate variability: synoptic climatology

- The relationship between the atmospheric circulation and the surface environment of a region (Yarnal 1993)

Select Sea Level Pressure (SLP) Data (mb) and Grid Area

- Use Principal Components Analysis (PCA) to describe variability in SLP data using fewer variables (data reduction step)

- Rotate PCs to maximize the variability explained in each PC

- Select number of PCs that will be retained in the analysis

- Use hierarchical cluster analysis to find similarities between the PCs and determine the number of clusters to be used in classification of the SLP data

Use k-means cluster analysis to classify the PCs based on the hierarchical cluster solution

- Classify each day into one of the cluster types and take the average SLP at each grid point

- Produce a SLP map for each cluster by contouring the average SLP
Weather Patterns

Seasonality of Weather Pattern Frequency of Occurrence

- Each Day (1950-2002) associated with a weather pattern
- Average Monthly Frequency of Occurrence
- Identifies Seasonality

Daily Temperature Anomaly Associated with Each Weather Pattern

- Determined from area weighted Climate Division Data
- Average Anomaly from Long-Term Monthly Mean
- Consistent Patterns

Daily Precipitation Anomaly Associated with Each Weather Pattern

- Similar Consistent Patterns
- Identifies Dry and Wet Weather Patterns

## Meteorological Conditions

<table>
<thead>
<tr>
<th>Weather Pattern</th>
<th>%</th>
<th>Temperature Anomaly (±SD) (°C)</th>
<th>Precipitation Anomaly (±SD) (mm)</th>
<th>Wind Direction</th>
<th>Wind Speed (m s⁻¹)</th>
<th>Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>6.8</td>
<td>3.4 (±4.6)</td>
<td>1.0 (±5.2)</td>
<td>W</td>
<td>3.0</td>
<td>warm/wet</td>
</tr>
<tr>
<td>2</td>
<td>17.0</td>
<td>-3.4 (±5.0)</td>
<td>-0.9 (±3.1)</td>
<td>NW</td>
<td>3.7</td>
<td>cool/dry</td>
</tr>
<tr>
<td>3</td>
<td>6.1</td>
<td>-0.3 (±4.5)</td>
<td>0.7 (±5.1)</td>
<td>N</td>
<td>3.4</td>
<td>seasonal/wet</td>
</tr>
<tr>
<td>4</td>
<td>4.5</td>
<td>2.3 (±4.1)</td>
<td>2.5 (±6.7)</td>
<td>W</td>
<td>3.9</td>
<td>warm/wet</td>
</tr>
<tr>
<td>5</td>
<td>17.4</td>
<td>2.5 (±5.2)</td>
<td>0.4 (±4.7)</td>
<td>W</td>
<td>2.7</td>
<td>warm/wet</td>
</tr>
<tr>
<td>6</td>
<td>7.7</td>
<td>-0.1 (±4.9)</td>
<td>0.0 (±4.5)</td>
<td>NE</td>
<td>2.3</td>
<td>seasonal</td>
</tr>
<tr>
<td>7</td>
<td>13.0</td>
<td>-2.1 (±4.9)</td>
<td>-0.3 (±3.2)</td>
<td>W</td>
<td>4.7</td>
<td>cool/dry</td>
</tr>
<tr>
<td>8</td>
<td>3.3</td>
<td>3.2 (±5.0)</td>
<td>1.5 (±5.7)</td>
<td>NE</td>
<td>2.5</td>
<td>warm/wet</td>
</tr>
<tr>
<td>9</td>
<td>9.2</td>
<td>2.1 (±5.0)</td>
<td>-0.5 (±3.1)</td>
<td>S</td>
<td>2.0</td>
<td>warm/dry</td>
</tr>
<tr>
<td>10</td>
<td>15.0</td>
<td>-1.3 (±5.2)</td>
<td>-0.7 (±3.1)</td>
<td>S</td>
<td>2.0</td>
<td>cool/dry</td>
</tr>
</tbody>
</table>

Predicting spring freshwater discharge of the Susquehanna River

Cumulative frequency of winter (Dec-Feb) climate patterns is used to predict spring (Mar-May) cumulative discharge.

Least Trimmed Squares

Predicting spring freshwater discharge of the Susquehanna River

Cumulative frequency of winter (Dec-Feb) climate patterns is used to predict spring (Mar-May) cumulative discharge.

Precipitation variability

SUSQUEHANNA RIVER BASIN
PRECIPITATION
AVERAGE ANNUAL PRECIPITATION FROM 1961 TO 1990

Legend:
- 31-34 inches
- 35-37 inches
- 38-40 inches
- 40-44 inches
- 45-49 inches
- 50-51 inches
Food web reminder

- Nutrients
- Phytoplankton
- Eastern Oyster
- Zooplankton
- Planktivorous Fish
- Piscivorous Fish
- Jellyfish
Photic depth and nitrogen

![Graph showing Photic depth and nitrogen](image)

**a)**

- **Zp (m)**
- Bars represent different regions with error bars indicating variability.

**b)**

- **DIN (μmoles N L⁻¹)**
- Bars for Warm/Wet, LTA, Cool/Dry regions with error bars.
- Region labels: 6, 5, 4, 3, 2, 1

Legend:
- Warm/Wet
- LTA
- Cool/Dry
Ecosystem Response: Chlorophyll a

The image shows maps of different years (LTA 84-04, DRY 1985, WET 1998) with various color concentrations indicating chlorophyll a levels in mg m$^{-3}$. The maps display the distribution and change in chlorophyll a across different latitudes and longitudes, with the color scale ranging from 2 to 20 mg m$^{-3}$. The maps depict the ecological response to different conditions, highlighting variations in chlorophyll a levels over time.
Ecosystem Response:
Chlorophyll $a$

Ecosystem response: zooplankton

Ecosystem response: zooplankton

Ecosystem response: gelatinous zooplankton

DNR Juvenile Fish Survey

Sampling sites

Striped bass
White perch
Bay anchovy

http://www.dnr.state.md.us/fisheries/juvindex/
Ecosystem response: fish

Graph 1: Striped bass juvenile index

Graph 2: White perch juvenile index
Ecosystem response: fish

Bar chart 1: Bay anchovy juvenile index
- DRY: 4
- NORMAL: 2
- WET: 1

Bar chart 2: American shad juvenile index
- DRY: 0.5
- NORMAL: 0.75
- WET: 0.25
Ecosystem response: fish


![Graph showing the relationship between mean latitude of SSB in April and mean river flow from June to February.](image)
Ecosystem response: fish

Spring Trophic Dynamics

Wet Conditions

Light

Phytoplankton

A. tonsa

M. leidyi

E. affinis

C. quinquecirrhna

Anadromous fish larvae

Bay anchovy
Spring Trophic Dynamics

Dry Conditions

Light
Phytoplankton
E. affinis
A. tonsa
M. leidy
C. quinquecirrh
Anadromous fish larvae
Bay anchovy
What does weather variability indicate?
The crystal ball: implications for climate change

It will be a good year for striped bass recruitment... I think
Ecological Forecasts
Prediction: Lower salinities in the upper Chesapeake Bay and high abundance of *E. affinis*

*Result:* High *E. affinis* abundance in the Patuxent and Choptank Rivers during April cruises

Prediction: A good recruitment year for anadromous fish in Chesapeake Bay

*Result:* DNR striped bass juvenile survey indicates a good year for striped bass juveniles
### Climate change in the Mid-Atlantic coastal region

#### Table 1: Climate Change Predictions (2030 vs. 2095)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>2030 Mean (%)</th>
<th>2030 Range (%)</th>
<th>2095 Mean (%)</th>
<th>2095 Range (%)</th>
<th>Reliability of prediction</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>CO₂ (%)</strong></td>
<td>+25</td>
<td>+20 to +30</td>
<td>+92</td>
<td>+52 to +188</td>
<td>Very high</td>
</tr>
<tr>
<td><strong>Sea level (cm)</strong></td>
<td>+19</td>
<td>+11 to +31</td>
<td>+66</td>
<td>+39 to +102</td>
<td>High</td>
</tr>
<tr>
<td><strong>Temp. (°C)</strong></td>
<td>+2.3</td>
<td>+1.8 to +2.7</td>
<td>+7.2</td>
<td>+2.9 to +9.5</td>
<td>High</td>
</tr>
<tr>
<td><strong>Precip. (%)</strong></td>
<td>+4</td>
<td>-1 to +8</td>
<td>+15</td>
<td>+6 to +24</td>
<td>Medium</td>
</tr>
<tr>
<td><strong>Streamflow (%)</strong></td>
<td>+2</td>
<td>-2 to +6</td>
<td>+11</td>
<td>-4 to +27</td>
<td>Low</td>
</tr>
</tbody>
</table>

Najjar et al. (2000) *Climate Research* 14: 219-233
Predicting change in Susquehanna River discharge in response to CO$_2$ increase

1XCO$_2$ = 1990 CO$_2$ level

T 2XCO$_2$ = doubling of CO$_2$ with temperature factored in the model

P 2XCO$_2$ = doubling of CO$_2$ with precipitation factored into the model

P&T 2XCO$_2$ = doubling of CO$_2$ with precipitation and temperature factored into the model

Increase in Freshwater Input

Increased Frequency of L Systems

↓

+ Precipitation

↓

+ Freshwater Input

+ *E. affinis* range in N. Bay; potential anadromous fish nursery ground increased

- *A. tonsa* range in N. Bay; seasonal succession zone with *E. affinis* expanded

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Kimmel et al. 2006 *Estuaries* (in press)
Decrease in Freshwater Input

- Increased Frequency of H Systems
  - Precipitation
  - Freshwater Input

- E. affinis range in N. Bay; potential anadromous fish nursery ground reduced

+ A. tonsa range in N. Bay; replacement of E. affinis with A. tonsa earlier in the year

Kimmel et al. 2006 Estuaries (in press)
Conclusions

- A regional climate signal clearly forces Chesapeake Bay trophic dynamics largely through freshwater input.
- Using synoptic climatology adds information beyond freshwater input – Allows prediction.
- Climate variability must be taken into account when evaluating ecosystem response to anthropogenic perturbation.
- Understanding how trophic dynamics change in response to climate will allow better prediction of ecosystem response to climate change.
Acknowledgements

This research has been supported by a grant from the United States Environmental Protection Agency’s Science to Achieve Results (STAR) Estuarine and Great Lakes (EaGLe) program through funding to the Atlantic Coast Estuarine Indicators Consortium (ACE INC), US EPA Agreement R82867701.

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This research is funded by
U.S. EPA - Science To Achieve Results (STAR) Program
Grant # R82867701
Question Time

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