Effects of climate change on Chesapeake Bay

Co-authors: John Jacobs; Ed Martino; Xinsheng Zhang; & Jackie Johnson (ICPRB)
Goals & Approach

• ‘drill down’ to extend our view into the effects of climate change on the Bay & its restoration

• leverage the Bay Program’s plankton and water quality data sets

• our field of view will also be limited

• focus estuarine processes that affect the Chesapeake Bay’s striped bass
Why focus on the striped bass?

- Extremely ‘charismatic’ Chesapeake species
  - highly prized gamefish
  - very valuable commercial fishery

- Top predator: good indicator:
  integrates across Bay’s
  - estuarine processes
  - Important habitats
  - food web

- Far reaching implications
  - ~70% of Atlantic stock is
  produced in the Chesapeake
Striped bass under pressure

What this talk will touch on…

- reproduction success
  - likely increases in winter and spring flow
  - water temperature increases
  - reduced dissolved oxygen levels

- habitat quality/quantity

- trophic interactions

- disease causing pathogens
A reminder...temperature & winter/spring precipitation are expected to increase

Najjar et al. (2009)
Flow & Nutrients: driving forces
both should impact the bay’s planktonic food web
Plankton response to flow & nutrients

**Cheapeake Bay**

**Planview Plot of Surface Conditions**

- **Chlorophyll (Chla)**
  - **Apr** 1999
  - **Apr** 1993

**Drought**
- More abundant, further downstream

**Bloom downstream**
- Wet
- More abundant, further downstream

**Apr Eurytemora 1999**

**Apr Eurytemora 1993**
Plankton response to flow & nutrients

CHESAPEAKE BAY
Planview Plot of Maximum Conditions
Chlorophyll - Apr 1, 2002 - May 1, 2002

- April Chlorophyll 2002: Drought

CHESAPEAKE BAY
Planview Plot of Maximum Conditions
Chlorophyll - Apr 4, 1994 - Apr 26, 1994

- April Eurytemora 2002

CHESAPEAKE BAY
Planview Plot of Maximum Conditions
Chlorophyll - Apr 4, 1994 - Apr 26, 1994

- Bloom downstream

CHESAPEAKE BAY
Planview Plot of Surface Conditions
Eurytemora - Apr 1, 1994 - Apr 30, 1994

- More abundant, further downstream

April Chlorophyll 1994: Wet
April Eurytemora 1994
Why does this matter?

Reproduction &

juvenile striped bass prey abundance
Ultimately, the answer is...because menhaden are a very important part of the striped bass diet.

- Young-of-the-year striped bass do not eat menhaden.
- However, menhaden are an important part of resident (1-6 years old) striped bass in the Chesapeake Bay.

Striped bass diet composition (% by weight)

- Menhaden: 61%
- Anchovy: 8%
- Blue crab: 9%
- Croaker: 9%
- Spotted hake: 7%
- White perch: 6%

458-710 mm striped bass from the mesohaline Bay
Data from: Walters & Austin, 2003
Fish production in Chesapeake Bay
young-of-the-year (YOO) recruitment scatter plots (1965-2004)

The ‘CBASS’ recruitment pattern

(+) correlation among anadromous fishes

(+) correlation among shelf-spawners

(-) correlation between the 2 groups...

strongest with striped bass & menhaden

Wood & Austin, 2009
Both species utilize the same springtime nursery area…

- **Striped Bass**
- **Menhaden**

**Common nursery areas**

---

**POTOMAC RIVER ESTUARY**

**Striped Bass**

**Spring**

**March through May**

**Adults**
- Major spawning run
- Migration of smaller numbers

**Immatures**
- General distribution
- Primary movement towards shore
- Low numbers move upstream

**Maximun Egg Densities (1974-75)**

- 1000-10,000 eggs per 1000 m³
- 100-1000 eggs per 1000 m³
- < 100 eggs per 1000 m³

---

**Atlantic Menhaden**

**Nursery Areas**

- Postlarvae (3-4 cm long)
  - Late March-June
  - Peak concentrations
  - High concentrations
  - Moderate numbers
  - Sparse
- Prejuveniles (4-13 cm long)
  - June-September
  - Gradual migration downstream

**Distribution of Immature Adults**

- 1 to 2 years old
  - Abundant
  - Moderate
  - Sparse
  - Rare

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Potomac R.
And different life history strategies

<table>
<thead>
<tr>
<th>Spawning</th>
<th>Estuarine fresh-saltwater boundary late April</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Retention within oligohaline-mesohaline transition zone (OMTZ)</td>
</tr>
<tr>
<td></td>
<td>Oligohaline, winter-spring zooplankton species (May-Jun)</td>
</tr>
</tbody>
</table>

| Peak Mid-Atlantic coastal spawning Dec-Feb |
| Up-estuary migration to OMTZ Feb-June (late-postlarvae to early juveniles) |
| First-feeding larvae: zooplankton |
| YOY to early juvenile: phytoplankton |
Creating a simple CBASS index
the CBASS ratio-based-index (CBASS_{rbi})

\[ \text{CBASS}_{rbi} = \log_{10} \left( \frac{\text{menhaden JAI}}{\text{striped bass JAI}} \right) \]

- Juvenile abundance indices (JAI) publicly available:
  www.dnr.state.md.us/fisheries/juvindex/index.html

- extends CBASS index to 2009

- correlation w/ pca-based CBASS index = 0.89

- ratio is normally distributed
Plankton index (for PCA)

Mean monthly plankton counts: March-June

aggregated across the northern Bay’s oligohaline-mesohaline transition zones (OMTZ)

Note: OMTZ spans the nursery grounds for striped bass & menhaden YOY
# Strong phyto-zooplankton variation (PC1)

<table>
<thead>
<tr>
<th>Taxa</th>
<th>March</th>
<th>April</th>
<th>May</th>
<th>June</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chlorophytes</td>
<td>0.67</td>
<td>0.60</td>
<td>0.12</td>
<td>0.26</td>
</tr>
<tr>
<td>Cryptophytes</td>
<td>0.47</td>
<td>0.71</td>
<td>0.84</td>
<td>0.50</td>
</tr>
<tr>
<td>Cyanophytes</td>
<td>(\leq 0.29)</td>
<td>(\leq 0.19)</td>
<td>(\leq 0.25)</td>
<td>(\leq 0.25)</td>
</tr>
<tr>
<td>Diatoms</td>
<td>0.79</td>
<td>0.51</td>
<td>0.09</td>
<td>-0.28</td>
</tr>
<tr>
<td>Dinoflagellates</td>
<td>-0.23</td>
<td>0.32</td>
<td>0.65</td>
<td>-0.37</td>
</tr>
<tr>
<td>Acartia sp.</td>
<td>0.36</td>
<td>0.57</td>
<td>-0.67</td>
<td>-0.50</td>
</tr>
<tr>
<td>Cladocera</td>
<td></td>
<td>-0.42</td>
<td>-0.53</td>
<td>-0.60</td>
</tr>
<tr>
<td>Copepod nauplii</td>
<td>0.79</td>
<td>0.13</td>
<td>-0.56</td>
<td>-0.73</td>
</tr>
<tr>
<td>Cyclopoidea</td>
<td>-0.25</td>
<td>-0.70</td>
<td>-0.65</td>
<td>-0.69</td>
</tr>
<tr>
<td>Eurytemora</td>
<td>-0.07</td>
<td>-0.57</td>
<td>-0.68</td>
<td>-0.78</td>
</tr>
<tr>
<td>Harpacticoida</td>
<td>-0.5</td>
<td>-0.58</td>
<td>-0.54</td>
<td>-0.40</td>
</tr>
<tr>
<td>Ctenophora</td>
<td></td>
<td></td>
<td></td>
<td>-0.26</td>
</tr>
</tbody>
</table>

**Phytoplankton filter feeding**

**Zooplankton predation**

**Spawning**
Plankton community PCA results

Not only was PC1 strong…

But it was also strongly correlated with the ‘CBASS’ pattern (↑striped bass / ↓menhaden production)

<table>
<thead>
<tr>
<th>Plankton PC #</th>
<th>Eigenvalue</th>
<th>Plankton data set’s proportion of variance</th>
<th>Cumulative variance %</th>
<th>Correlation w/ CBASS&lt;sub&gt;rbi&lt;/sub&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>14.5</td>
<td>0.26</td>
<td>26%</td>
<td>0.92</td>
</tr>
<tr>
<td>2</td>
<td>8.01</td>
<td>0.14</td>
<td>40%</td>
<td>-0.10&lt;sup&gt;*p&lt;0.0001&lt;/sup&gt;</td>
</tr>
<tr>
<td>3</td>
<td>6.9</td>
<td>0.12</td>
<td>52%</td>
<td>-0.07</td>
</tr>
<tr>
<td>4</td>
<td>5.2</td>
<td>0.09</td>
<td>61%</td>
<td>0.02</td>
</tr>
<tr>
<td>5</td>
<td>4.7</td>
<td>0.08</td>
<td>69%</td>
<td>0.29</td>
</tr>
</tbody>
</table>
US climate division weather correlations with...

- **CBASS**
  - $\text{rbi}$

- **Plankton PC1 scores**

- **Winter-Spring precipitation**
  - (Dec-Jun)

- **Spring temperature**
  - (March-May)

- **r value**
  - Scale: -0.6 to 0.6
Flow, salinity, the CBASS$_{rbi}$, & plankton PC1

Mean spring salinity
spring Bay flow(-1x)
Plankton PC1
CBASS
Implication

sustained increases in annual winter/spring flow may lead to:

• increased striped bass reproduction

• reduced abundance of menhaden
  - an important prey item for juvenile & adult striped bass
How would enhanced flow and warming temperature affect striped bass habitat later in life?
Summer striped bass habitat “squeeze” (Coutant, 1990)

A narrow band of optimal conditions between high surface temperature and low oxygen in deep waters.

Striped bass habitat suitability index & growth rate potential (1985-2006)
July striped bass habitat suitability index & growth rate potential
Hypoxia worsens with warm & wet conditions

- **1999**: Warm & wet conditions in May 1999.
- **1996**: Cool & wet conditions in May 1996.
- **1998**: Warm & wet conditions in May 1998.

Expanding hypoxia.
Implication

sustained increases in annual winter/spring flow, coupled with warmer temperatures would lead to

enhanced summer habitat squeeze for juvenile & adult striped bass caused by:

• warmer surface water temperatures
• expanded hypoxic zones
Disease stress
Disease: Mycobacteriosis

- Mycobacteriosis is an infectious disease caused by bacteria in the genus *mycobacterium*.

- Chesapeake stripers exposed early in life: infection rates increasing with age: age 1 - 11% | 3-5 yrs - 60%

- 10 species of mycobacteria have been isolated from striped bass lesions
Mycobacterium monitoring
dry year (‘07) vs. wet year (‘08)

Will higher winter/spring flow
enhance myco abundance?

Abundance
(Cells/ml)

0.00 - 20.00
20.01 - 40.00
40.01 - 60.00
60.01 - 80.00
80.01 - 100.00
100.01 - 120.00
120.01 - 140.00
140.01+

Jacobs et al, in press
Mycobacterium Modeling

<table>
<thead>
<tr>
<th>Variable</th>
<th>AIC</th>
<th>% Concordance</th>
<th>% Discordance</th>
</tr>
</thead>
<tbody>
<tr>
<td>PC1 and PC2</td>
<td>178.6</td>
<td>71.9</td>
<td>27.8</td>
</tr>
<tr>
<td>DO and TN</td>
<td>173.6</td>
<td>76.6</td>
<td>23.2</td>
</tr>
<tr>
<td>DO and Salinity</td>
<td>162.7</td>
<td>81.4</td>
<td>18.4</td>
</tr>
<tr>
<td>Salinity and TN</td>
<td>161.0</td>
<td>79.0</td>
<td>20.7</td>
</tr>
<tr>
<td><strong>TN, DO, and Salinity</strong></td>
<td><strong>152.1</strong></td>
<td><strong>83.8</strong></td>
<td><strong>15.9</strong></td>
</tr>
</tbody>
</table>

Quarterly monitoring at CBP water quality monitoring stations, N = 150

- Elevated abundance (75th quartile)
**Mycobacterium spp. Logistic Model**

With ↑ total nitrogen in the Bay Myco expands into waters with ↑ salinity and ↑ dissolved oxygen.
Implication

Higher winter spring flows & warmer temperatures may lead to

• Higher abundance of mycobacteria

• Longer mycobacteria ‘season’

• Potential exists that these changes could impact myco infection rates in striped bass & other organisms, including humans
Putting it together: Striped bass under pressure

- warm surface temperatures
- declining prey abundance
- hypoxia
- enhanced recruitment
- Disease
policy / actions

• The striped bass population is likely to be stressed by projected climate changes

• Enhanced habitat ‘squeeze’ & Mycobacteria abundance that could be induced by projected climate changes may be mitigated by nutrient reductions

• Fisheries management must accelerate its evolution towards ecosystem-based approaches

• An effective & efficient strategic monitoring plan could provide further mechanistic insights into the combined effects of climate and nutrient changes (expect the unexpected)
Thank You
Dissolved Oxygen in the Bay

Mainstem low dissolved oxygen over the past 20 years

- Stressed (2-5 mg l⁻¹)
- Hypoxia (0.2-2 mg l⁻¹)
- Anoxia (0-0.2 mg l⁻¹)

Volume of mainstem (km²)

Other potential players

• loss of intertidal wetlands & eelgrass
  – loss of nursery habitat & trophic transfer to fish

• High flow = ↑ctenophores = ↓anchovies
  – Another important prey of striped bass
  – Serve as substitute prey when menhaden are lacking
  – Ctenophores prey on anchovy eggs, juveniles, & key prey of the anchovy (copepod Acartia tonsa)

• Warmer weather…
  – Invasive species and new diseases?
Approach: anchovy growth rate potential

Observations

Anchovy growth response

Growth Rate Potential

Response functions from Klebasko, 1991; Brandt et al. 1992; Luo & Brandt 1993
Long term decline in anchovy growth (model results)
CHESAPEAKE BAY
Planview Plot of Surface Conditions
Chlorophyll - Apr 1, 1988 - Apr 30, 1988

CHESAPEAKE BAY
Planview Plot of Surface Conditions
Eurytemora - Apr 1, 1988 - Apr 30, 1988

CHESAPEAKE BAY
Planview Plot of Maximum Conditions
Chlorophyll - Apr 1, 1998 - Apr 27, 1998

CHESAPEAKE BAY
Planview Plot of Surface Conditions
Eurytemora - Apr 1, 1998 - Apr 30, 1998
Model Performance: comparing modeled GRP to fish surveys.
Changes in extratropical winter storms in the Northern Hemisphere

Total storms

Intense storms

Percent change

Low emissions (B1)
High emissions (A2)

2046-2065
2081-2100

Lambert & Fyfe (2006)
Correlation maps (scale -0.5 to 0.5)

**CBASS\textsubscript{rbi}**

Plankton PC1

**AMO\textsuperscript{*}**
Striped bass landings and the AMO

- 8-yr lagged striped bass mid-Atlantic+Chesapeake harvest
- AMO index (Dec-Jun)
- lowess AMO index (65-yr smoothing span)
Atlantic menhaden landings & the AMO

- 2-yr lagged Atlantic menhaden Chesapeake harvest
- detrended harvest, as above

-1x AMO index (Dec-Jun)  -1x lowess AMO index
Monitoring Program

Water Quality Monitoring Programs
NPS, MDNR, VADEQ Coastal Bays (2005 -) and Chesapeake (2007 -)

Quantitative PCR *Mycobacterium* spp.

Model development
Myco Concentration and Water Quality

Jacobs et al. (In Press)
Mycobacterium spp.

Correlation Coefficient

Do  Secchi  Salinity  Temp  TP  PP  Vp  NO3_NO2  PN  TOT_SS  TDN  TN

P < 0.05
Preliminary Model Development

2006 – 2008 data (April, July, October)

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<td>255.9</td>
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<td>241.8</td>
<td>81.0</td>
<td>18.8</td>
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<tr>
<td>DO and Salinity</td>
<td>240.7</td>
<td>80.7</td>
<td>19.1</td>
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<tr>
<td>Salinity, DO, Wtemp</td>
<td>224.0</td>
<td>83.1</td>
<td>16.6</td>
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- Elevated abundance (75th quartile)
Chesapeake Bay is subjected to pronounced climate variability...

The Bay straddles subtropical & temperate climate zones

Köppen climate classification

- Temperate mild summers (Dfb)
- Temperate hot summers (Dfa)
- Humid subtropical (Cfa)

This makes the Bay a good ‘laboratory’ to help learn more about the effects of present and past climate variability/changes.

Influenced by many air mass types:
- Continental Polar
- Maritime Polar
- Maritime Tropical

Köppen map source: Godfrey, B.R., 1999
### Plankton community PCA results

#### Eigenvalue scree plot

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<th>Correlation with CBASS(_{rbi})</th>
<th><em>p</em> &lt; 0.0001</th>
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Chesapeake Bay has warmed in recent decades

Source: CBP & VIMS archive, Kaushal et al. (2010)
Correlation:
Spring hydrography & plankton PC1 scores

<table>
<thead>
<tr>
<th>Environmental variable</th>
<th>Plankton PC1</th>
<th>CBASS$_{rbi}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>water temp. March</td>
<td>0.16</td>
<td>-0.04</td>
</tr>
<tr>
<td>water temp. April</td>
<td>0.20</td>
<td>-0.02</td>
</tr>
<tr>
<td>water temp. May</td>
<td>-0.21</td>
<td>-0.36</td>
</tr>
<tr>
<td>water temp. June</td>
<td>0.32</td>
<td>0.09</td>
</tr>
<tr>
<td>salinity March</td>
<td>0.51*</td>
<td>0.21</td>
</tr>
<tr>
<td>salinity April</td>
<td>0.76**</td>
<td>0.51*</td>
</tr>
<tr>
<td>salinity May</td>
<td>0.81**</td>
<td>0.68**</td>
</tr>
<tr>
<td>salinity June</td>
<td>0.61**</td>
<td>0.41</td>
</tr>
<tr>
<td>Salinity March-June</td>
<td>0.76**</td>
<td>0.51*</td>
</tr>
</tbody>
</table>

*p<0.05     **p<0.01
A starting point: general circulation of the atmosphere

Climates are determined by the heat imbalance from equator to poles.

Earth’s rotation breaks up equator to pole heat flow into ‘cells’.

Coriolis effect at the surface:
- Low-cyclonic-counter clockwise
- High-anticyclonic-clockwise

Tilting of the earth & seasonal shifting of cell boundaries.

Precipitation is governed by complex processes affected at very fine scales.
Sea level change in Chesapeake Bay

Projected 0.7 to 1.6-m rise by 2100 (includes subsidence)
Consequences for fisheries

• Degradation and loss of nursery area habitat
• Weaker ‘trophic relay’ or ‘trophic transfer’
Climate & Disease...the links to humans, habitats, & fisheries

Example: Distribution of the most important oyster pathogen in Chesapeake Bay, *Perkinsus marinus* (Dermo)

Prior to 1980

1980’s …

- warm winters
- & drought

facilitated range expansion

From: Burreson & Calvo (1996)
Pathogens: degraded habitats; diseased fish; & human health risks

Marine *Vibrio’s*

Fecal Coliforms

*Mycobacterium*
Can We Predict Where *Vibrio vulnificus* (Vv) will occur?

- controlled by temperature and salinity, associated with plankton

- current ecological forecasting efforts capable of predicting temperature and salinity
  
  *(ChesROMS – r.hood @ UMCES\HPL)*

- Can these variables be used to develop a reliable model to predict Vv distribution in the Chesapeake Bay?
Various pathogens – microorganisms which are capable of causing disease – are present in the Chesapeake Bay and pose potential threats to human health. Knowing where and when to expect these biotic risks may help mitigate their effects.

The goal of this regional study is to predict the abundance or likelihood of occurrence of several pathogens in Chesapeake Bay and its tidal tributaries. Our target species is the bacterium *Vibrio vulnificus*, which naturally occurs in the bay.

Maps of the likelihood of *V. vulnificus* in the Bay are routinely generated by identifying locations where the current environmental conditions are favorable to them. This is accomplished using data acquired and derived from various sources, such as hydrodynamic computer models and satellites. The latest available map is provided below.

These near-real-time maps of *V. vulnificus* likelihood are experimental products and should be considered provisional.
The linkage between the AMO & CBASS

SST-AMO correlation

SLP correlation w/ CBASS

SLP-AMO correlation

SST correlation with the AMO for the winter-spring season (Dec-Jun)
NCEP/NCAR Reanalysis (NOAA/ERSL)
Potential effects of habitat “squeeze” on striped bass individual & population

- **Squeeze SB & prey**
- **Squeeze SB only**
- **No squeeze**
GRP is declining in the prime anchovy spawning & nursery area

Anchovy biomass (TIES 1995-2000)

Adults (jun-aug)  YOY (Oct)

Model indicates declining conditions 1986-2002
Potential influence of habitat squeeze on striped bass forage: implications for fisheries

1999 prey has refuge

1999 predator “squeezed” - prey refuge

1996 predator – prey habitat overlap

1996 no temp squeeze – pred-prey overlap
Freshwater flow and striped bass recruitment by location

UB.F$FLOW
log10(REC$UB)

POTO.F$FLOW
log10(REC$POTO)

CHOP.F$FLOW
log10(REC$CHOP)

NANT.F$FLOW
log10(REC$NANT)
Baywide Recruitment Model

Aggregated flow
Temperature (MD Clim. Division)
Adj r² = 0.38