Effects of climate change on Chesapeake Bay

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NOAA

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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

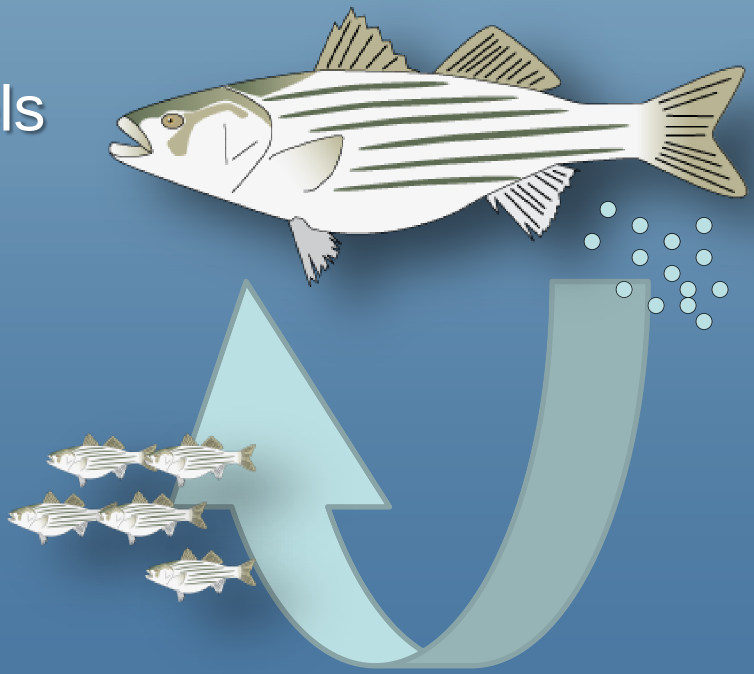
- Top predator: good indicator: integrates across Bay’s
  - estuarine processes
  - Important habitats
  - food web

- Far reaching implications
  - ~70% of Atlantic stock is
  - produced in the Chesapeake

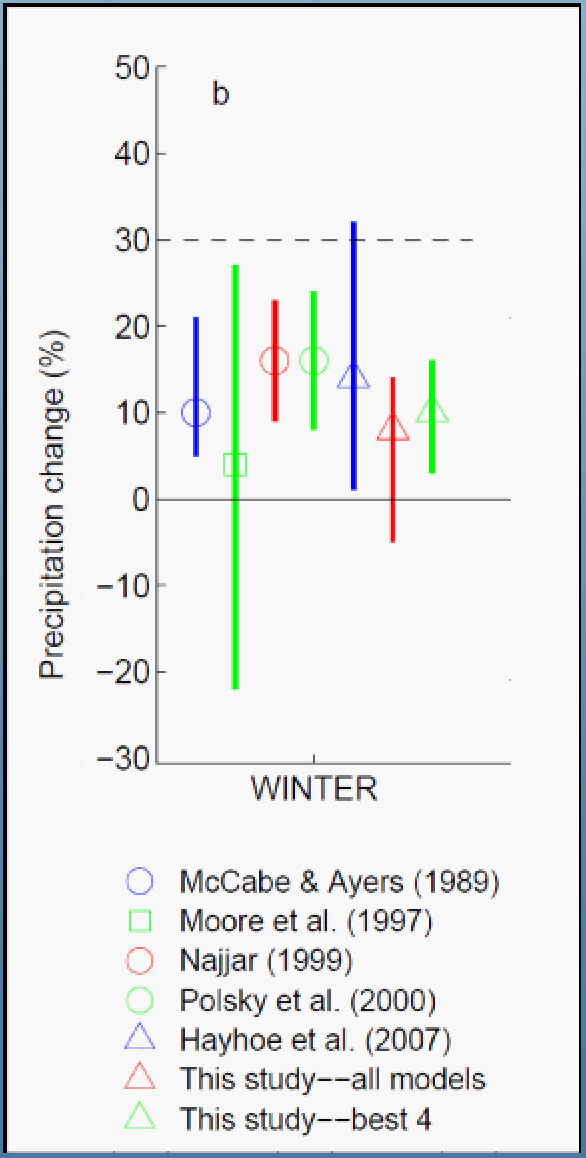
Striped bass under pressure

What this talk will touch on…

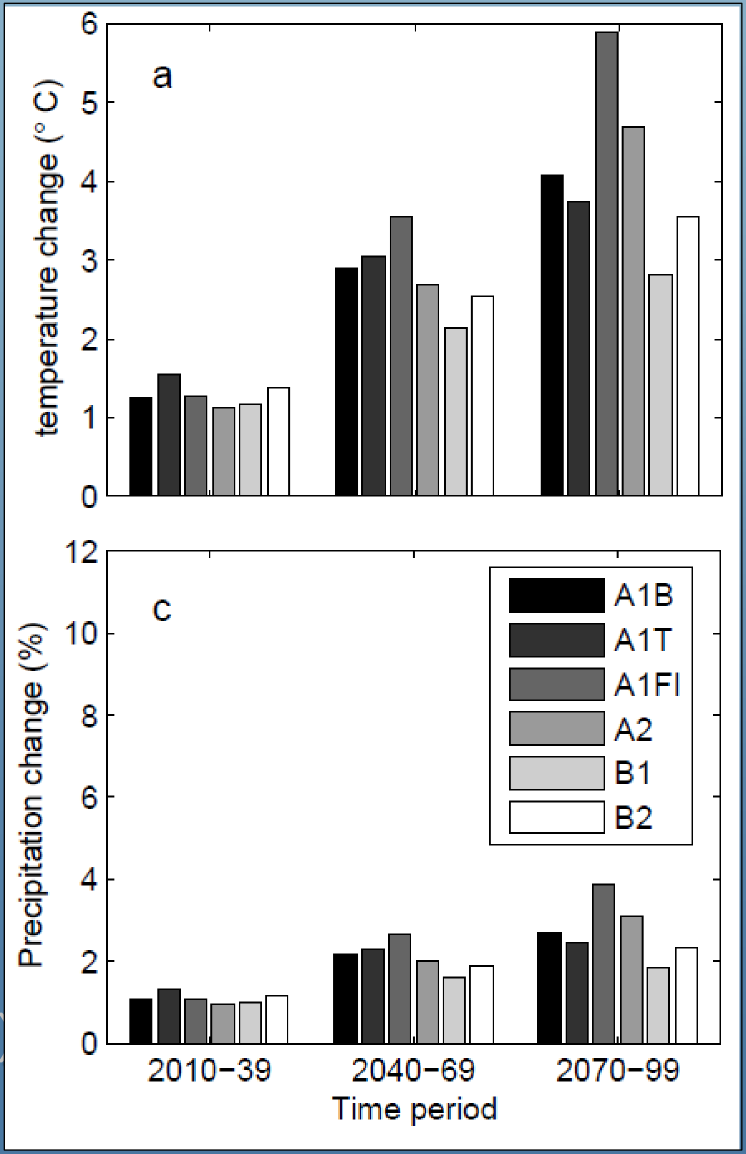
- reproduction success
  - likely increases in winter and spring flow
  - water temperature increases
  - reduced dissolved oxygen levels
- habitat quality/quantity
- trophic interactions
- disease causing pathogens



A reminder…temperature & winter/spring precipitation are expected to increase

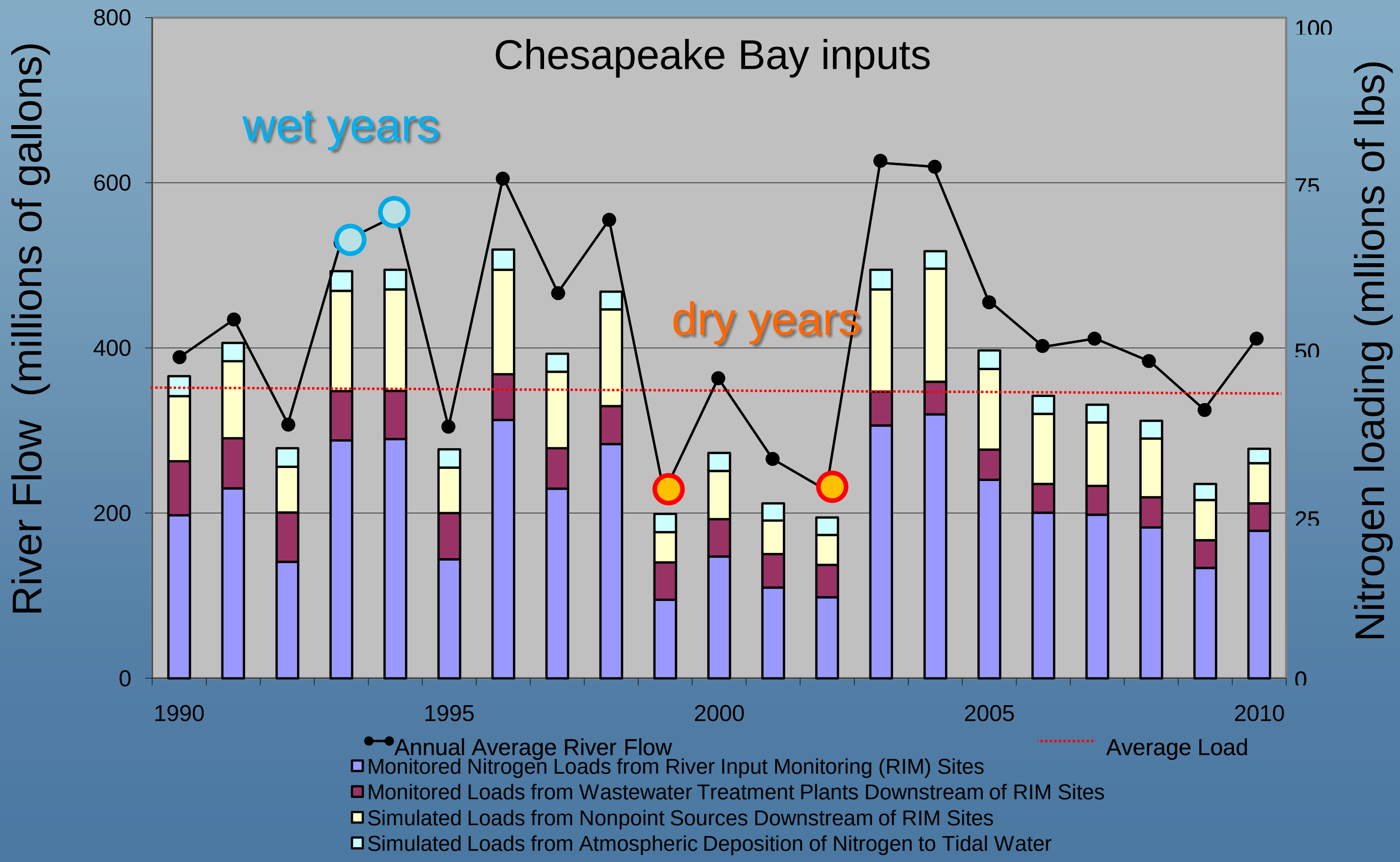


Najjar et al. (2009)

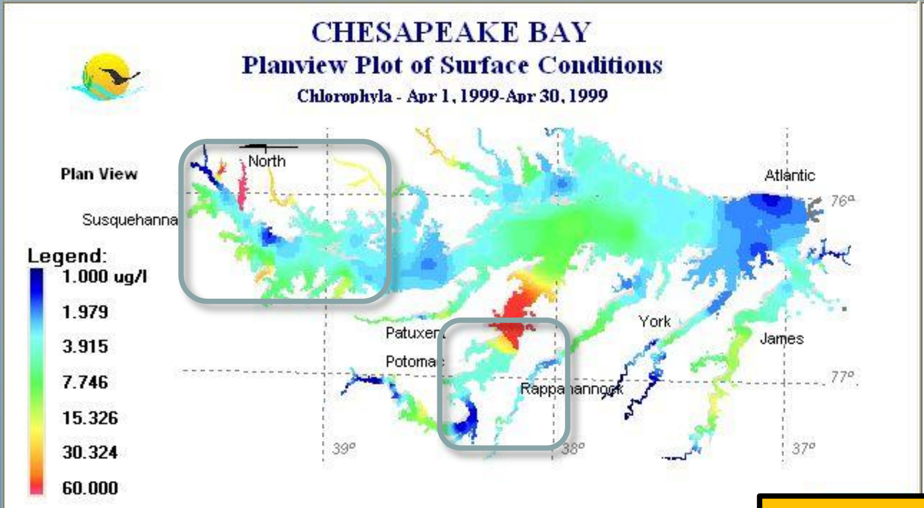


Flow & Nutrients: driving forces

both should impact the bay's planktonic food web

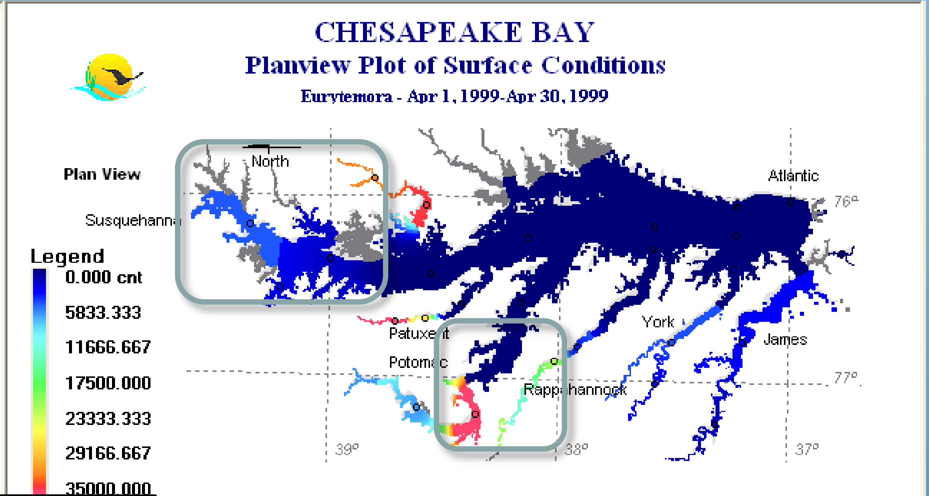


Plankton response to flow & nutrients

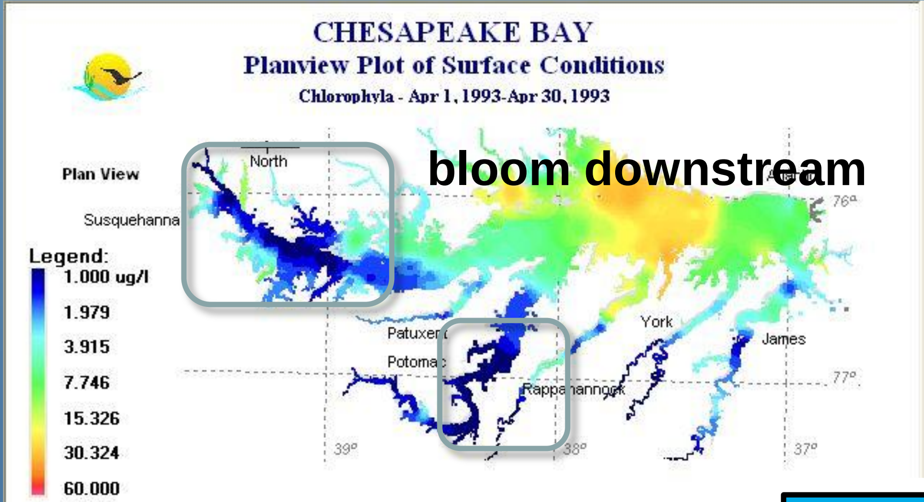

CHESAPEAKE BAY
Planview Plot of Surface Conditions
Chlorophyla - Apr 1, 1999-Apr 30, 1999

Apr Chla 1999

Drought


CHESAPEAKE BAY
Planview Plot of Surface Conditions
Eurytemora - Apr 1, 1999-Apr 30, 1999

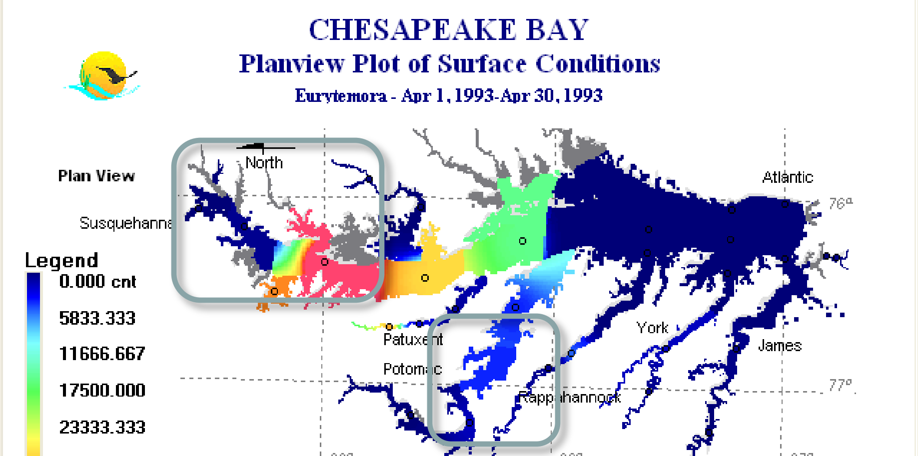
Apr Eurytemora 1999


CHESAPEAKE BAY
Planview Plot of Surface Conditions
Chlorophyla - Apr 1, 1993-Apr 30, 1993

bloom downstream

Apr Chla 1993

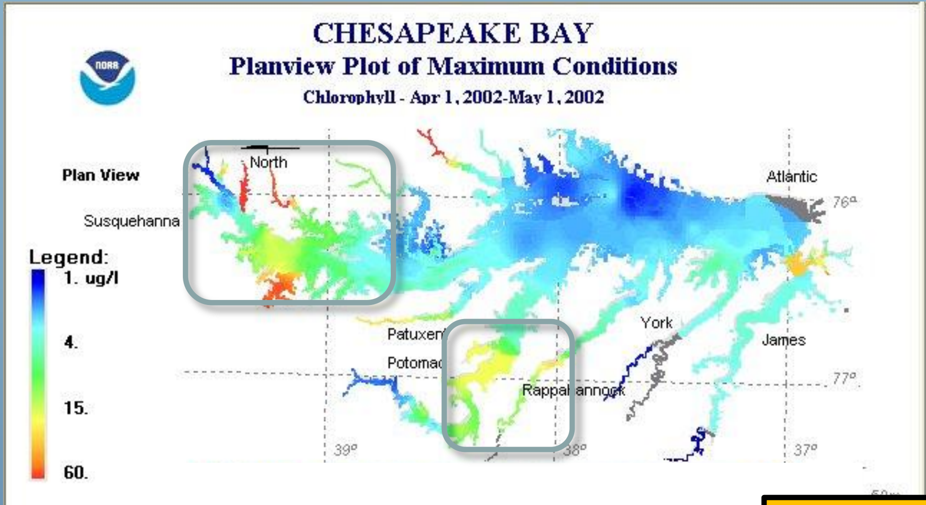
Wet


CHESAPEAKE BAY
Planview Plot of Surface Conditions
Eurytemora - Apr 1, 1993-Apr 30, 1993

More abundant, further dnstrm

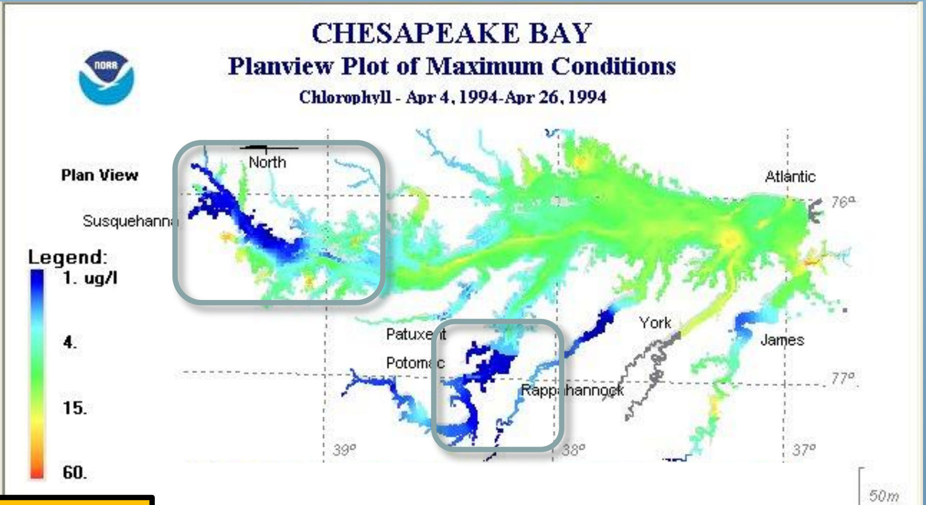
Apr Eurytemora 1993

Plankton response to flow & nutrients

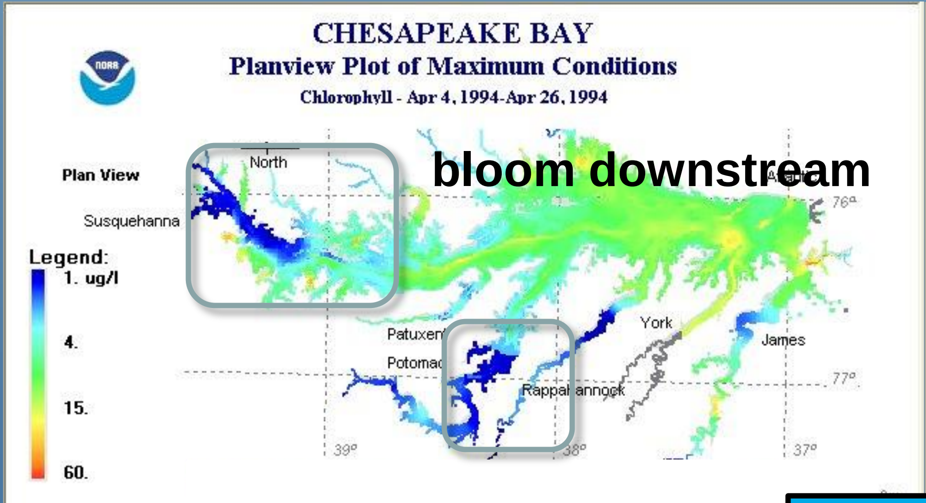


Apr Chla 2002

Drought



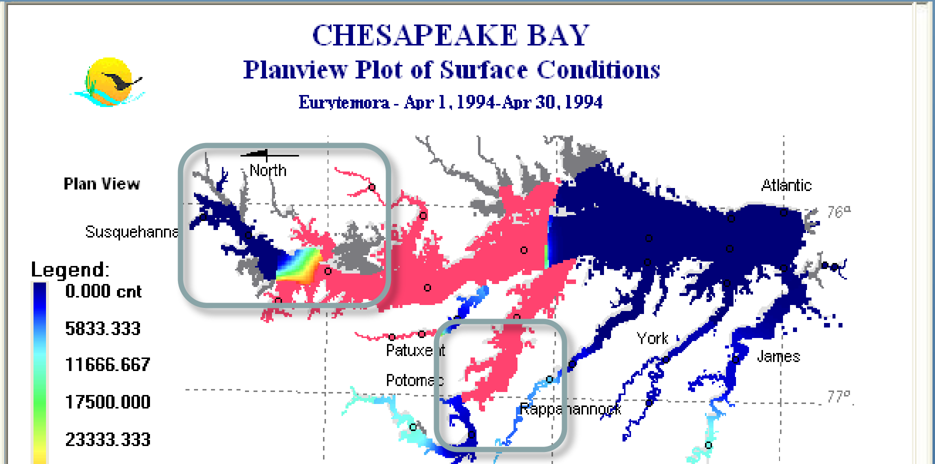
Apr Eurytemora 2002



bloom downstream

Apr Chla 1994

Wet



More abundant, further dnstrm

Apr Eurytemora 1994

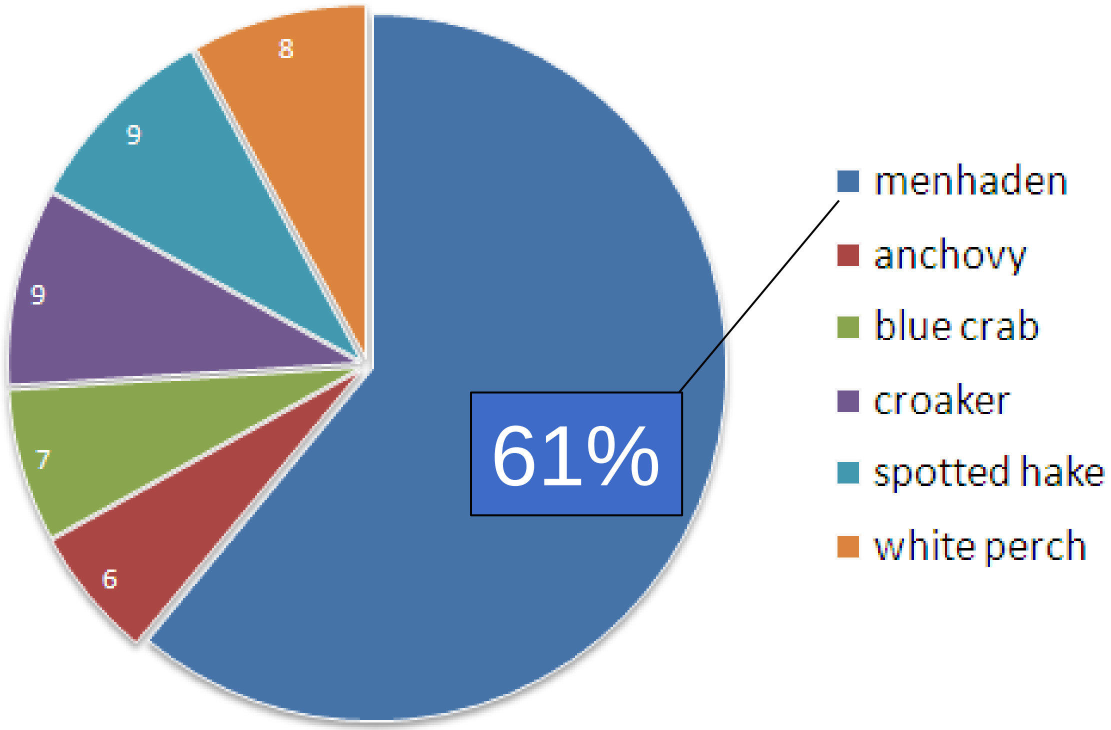
Why does this matter?

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)

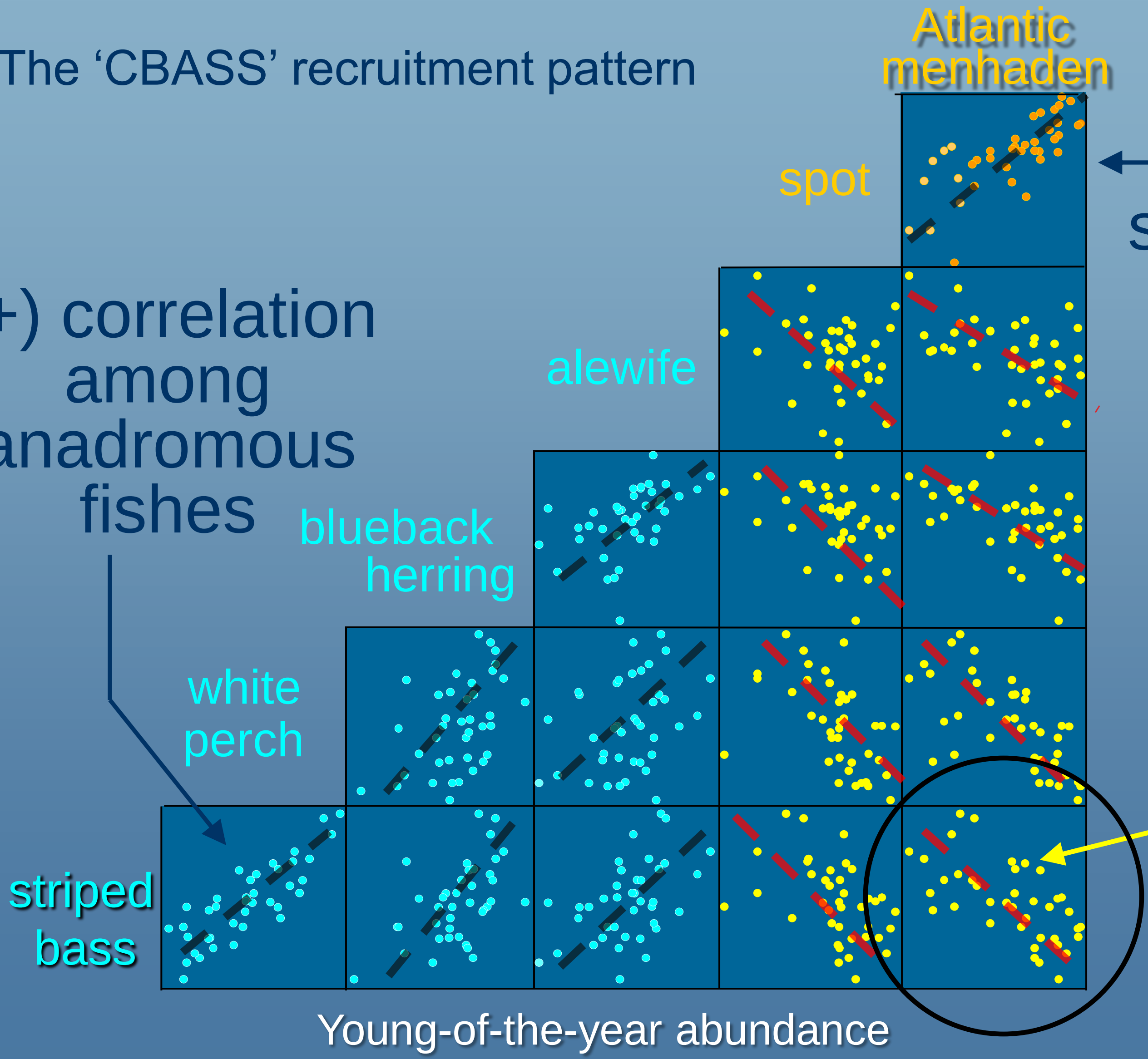


458-710 mm striped bass from the mesohaline Bay
Data from: Walters & Austin, 2003

Fish production in Chesapeake Bay

young-of-the-year (YOY) recruitment scatter plots (1965-2004)

The 'CBASS' recruitment pattern



(+) correlation among shelf-spawners

(+) correlation among anadromous fishes

(-) correlation between the 2 groups…

strongest with striped bass & menhaden

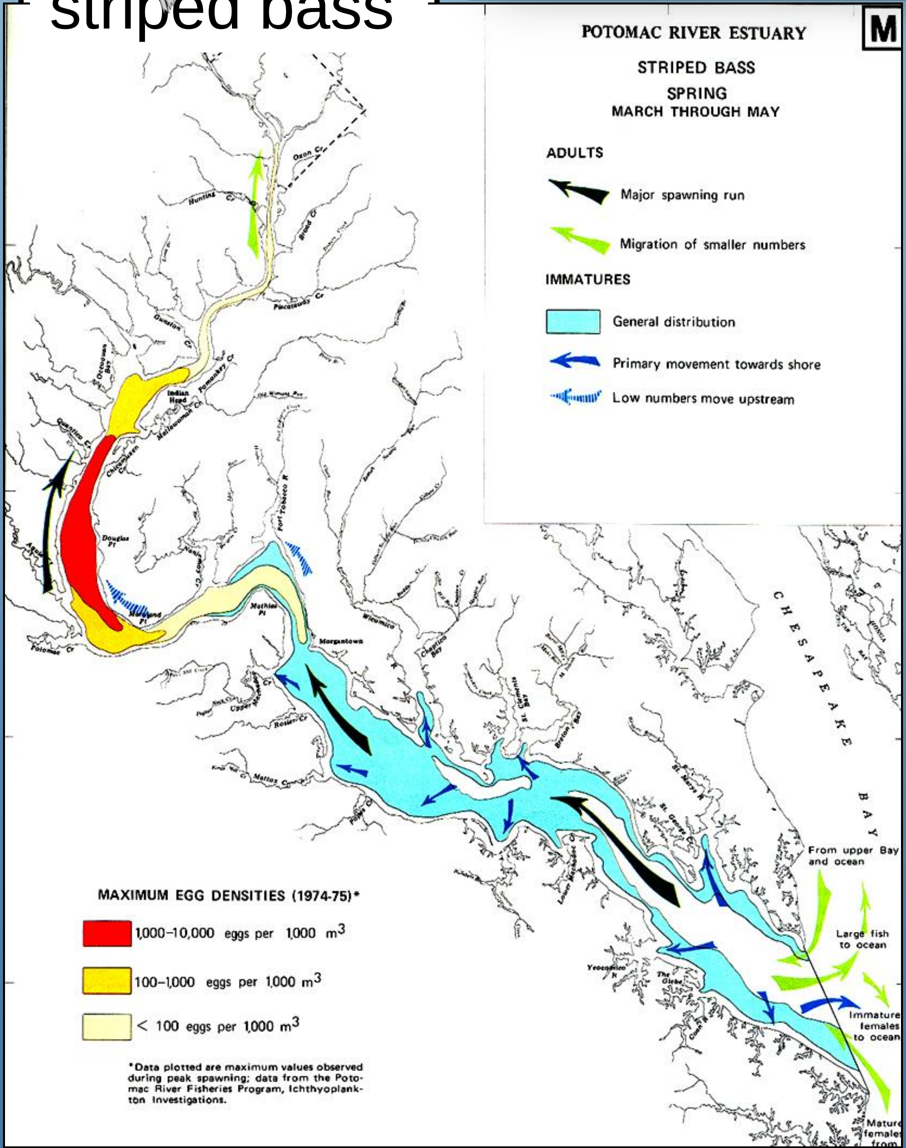
Wood & Austin, 2009

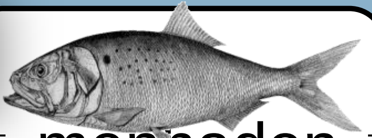
Both [illegible] a…

the oligohaline-mesohaline transition zone (OMTZ)

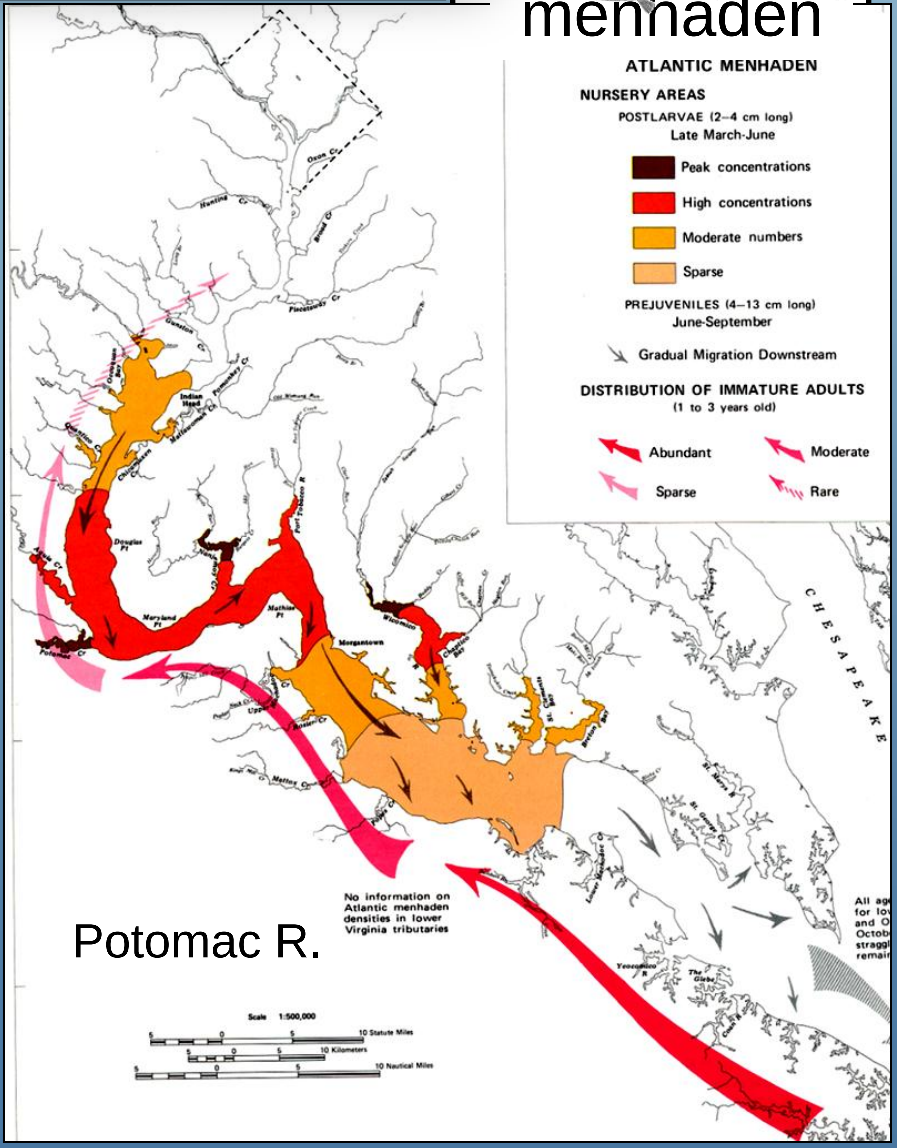
Common nursery areas

striped bass



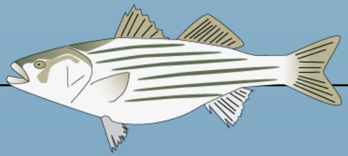
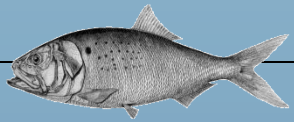


menhaden



Potomac R.

And different life history strategies

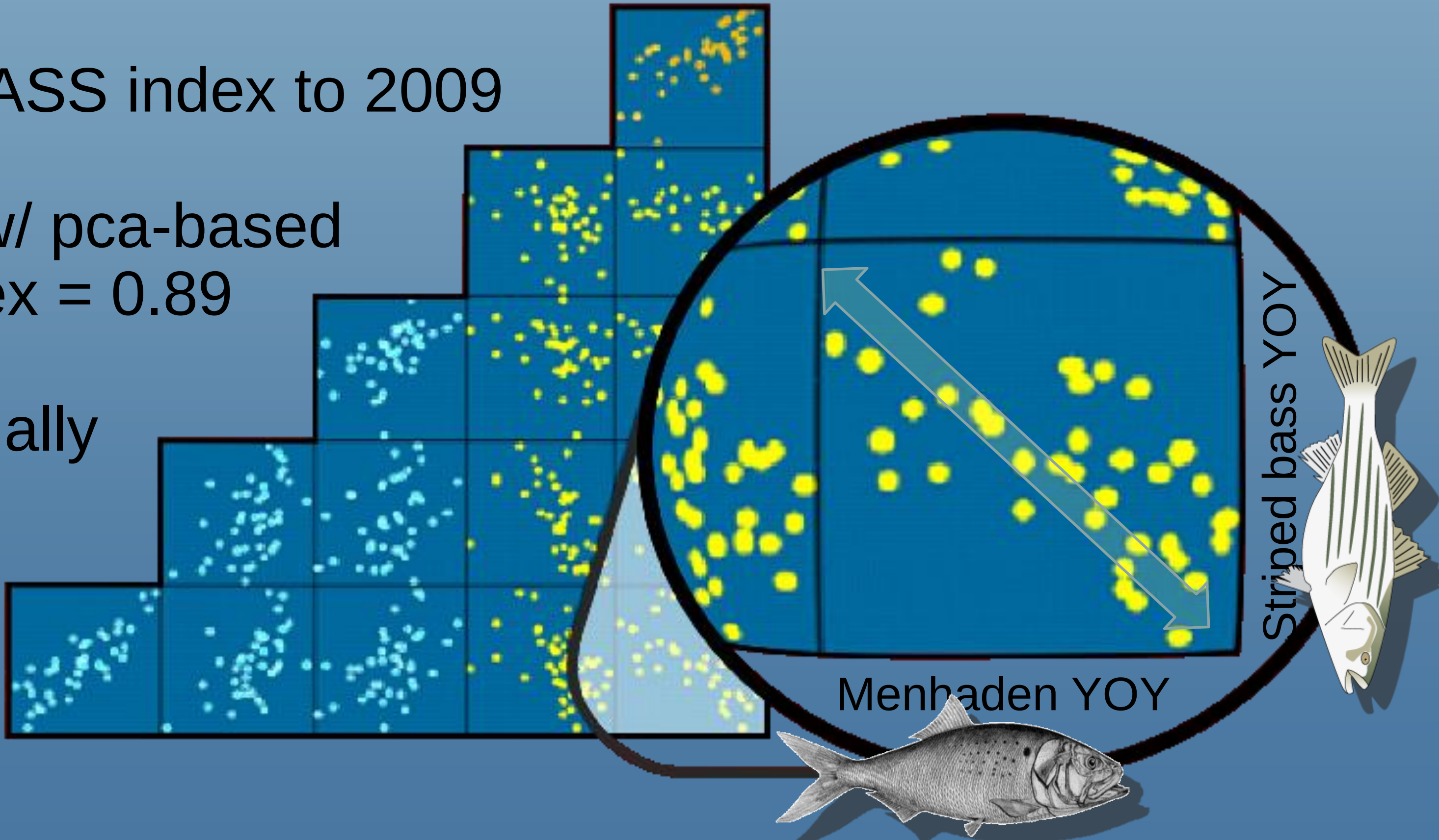
		
Spawning	Estuarine fresh-saltwater boundary late April	Peak Mid-Atlantic coastal spawning Dec-Feb
Estuarine nursery area	Retention within oligohaline-mesohaline transition zone (OMTZ)	Up-estuary migration to OMTZ Feb-June (late-postlarvae to early juveniles)
First feeding YOY prey (Mar-Jun)	Oligohaline, winter-spring zooplankton species (May-Jun)	First-feeding larvae: zooplankton YOY to early juvenile: phytoplankton

Creating a simple CBASS index

the CBASS ratio-based-index ($\text{CBASS}_{\text{rbi}}$)

$$\mathit{CBASS}_{rbi} = \text{Log}_{10}\ (\text{menhaden JAI / striped bass JAI})$$

- 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

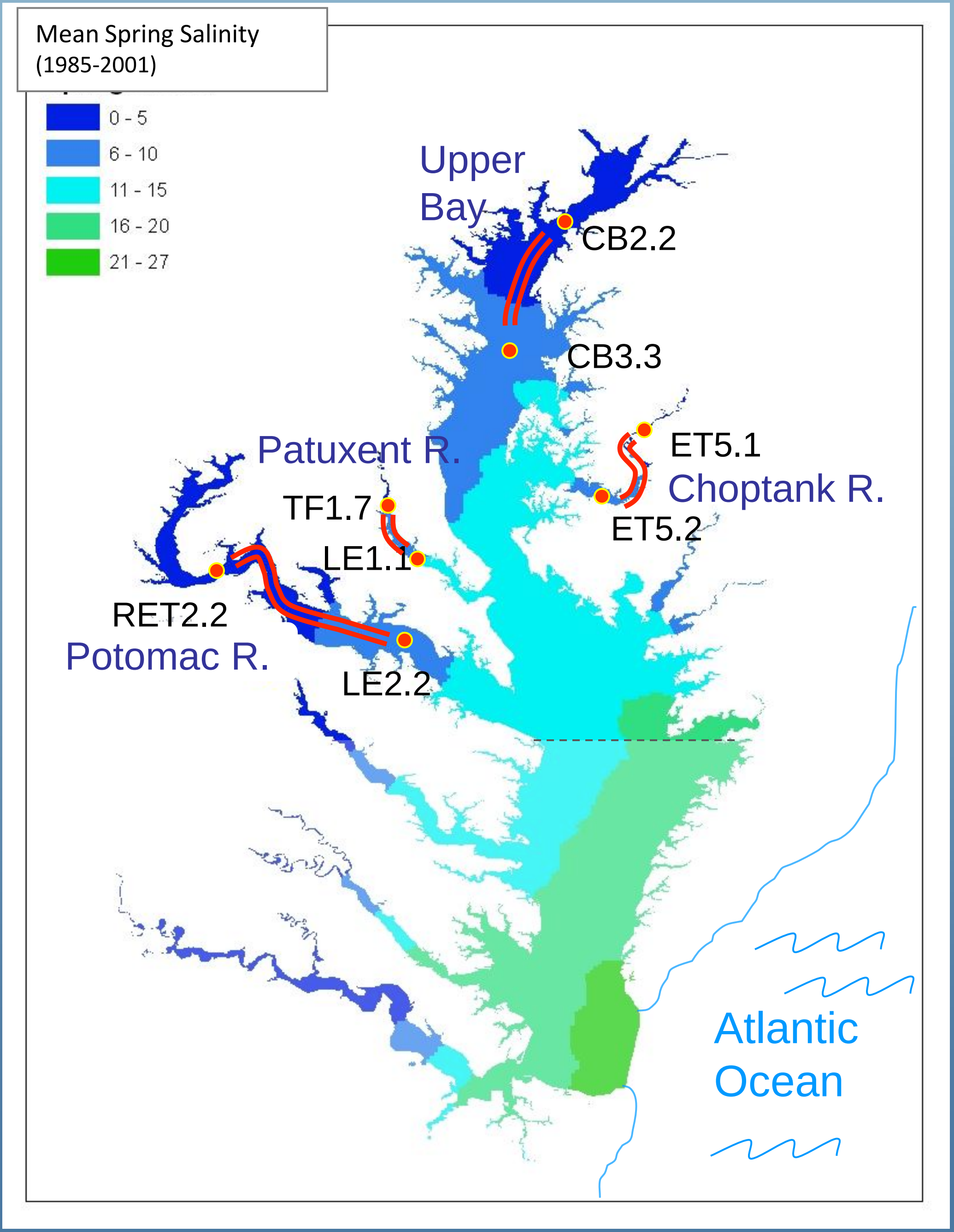


Plankton index
(for PCA)

Mean monthly plankton counts: March-June

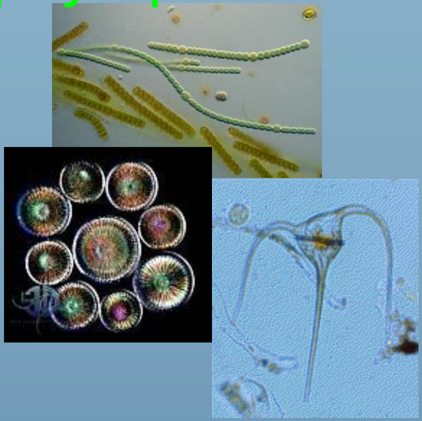
aggregated across the northern Bay's oligohaline-mesohaline transition zones (OMTZ)

Note: OMTZ spans the nursery grounds for striped bass & menhaden YOY



Strong phyto-zooplankton variation (PC1)

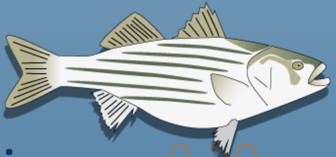
phytoplankton



zooplankton

Taxa	**March**	**April**	**May**	**June**
Chlorophytes	0.67	0.60	0.12	0.26
Cryptophytes	0.47	0.71	0.84	0.50
Cyanophytes	☐	0.29	-0.19	-0.25
Diatoms	0.79	0.51	0.09	-0.28
Dinoflagellates	-0.23	0.32	0.65	-0.37
Acartia sp.	0.36	0.57	-0.67	-0.50
Cladocera	[illegible]	-0.42	-0.53	-0.60
Copepod nauplii	0.39	-0.13	-0.56	-0.73
Cyclopoida	-0.25	-0.70	-0.65	-0.69
Eurytemora	-0.07	-0.57	-0.68	-0.78
Harpacticoida	-0.5	-0.58	-0.54	-0.40
Ctenophora	☐	☐	☐	-0.26

Phytoplankton filter feeding



spawning

Zooplankton predation

Plankton community PCA results

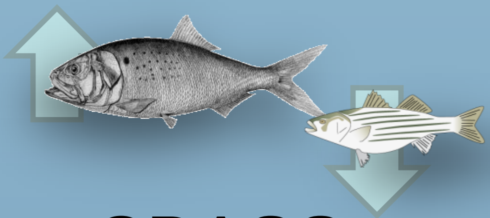
Not only was PC1 strong…

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

Plankton PC #	Eigenvalue	Plankton data set’s proportion of variance	Cumulative variance %	Correlation w/ CBASS_{rbi}
1	14.5	0.26	26%	**0.92**
2	8.01	0.14	40%	-0.10
3	6.9	0.12	52%	-0.07
4	5.2	0.09	61%	0.02
5	4.7	0.08	69%	0.29

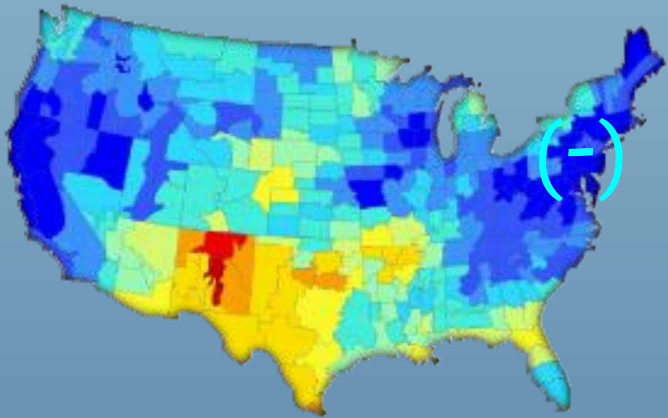
*p<0.0001

US climate division weather correlations with…

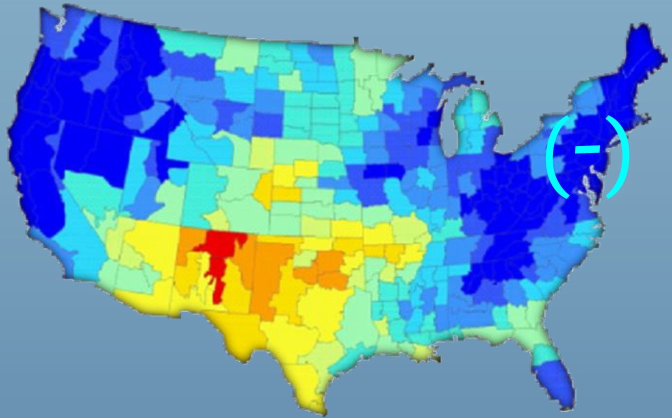


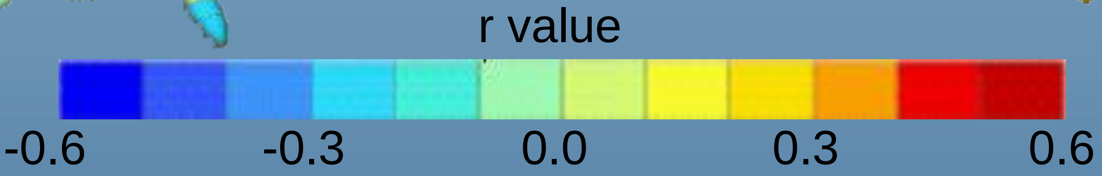
CBASS$_{rbi}$

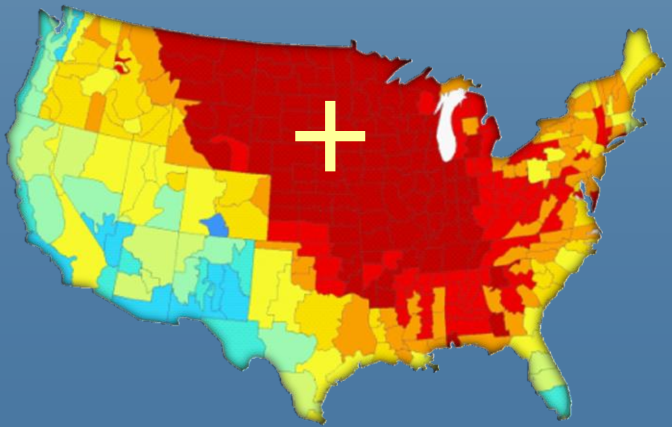
Plankton PC1 scores



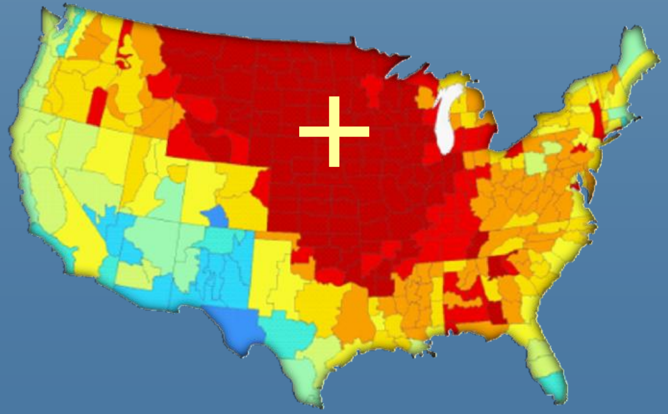
Winter-Spring precipitation
(Dec-Jun)



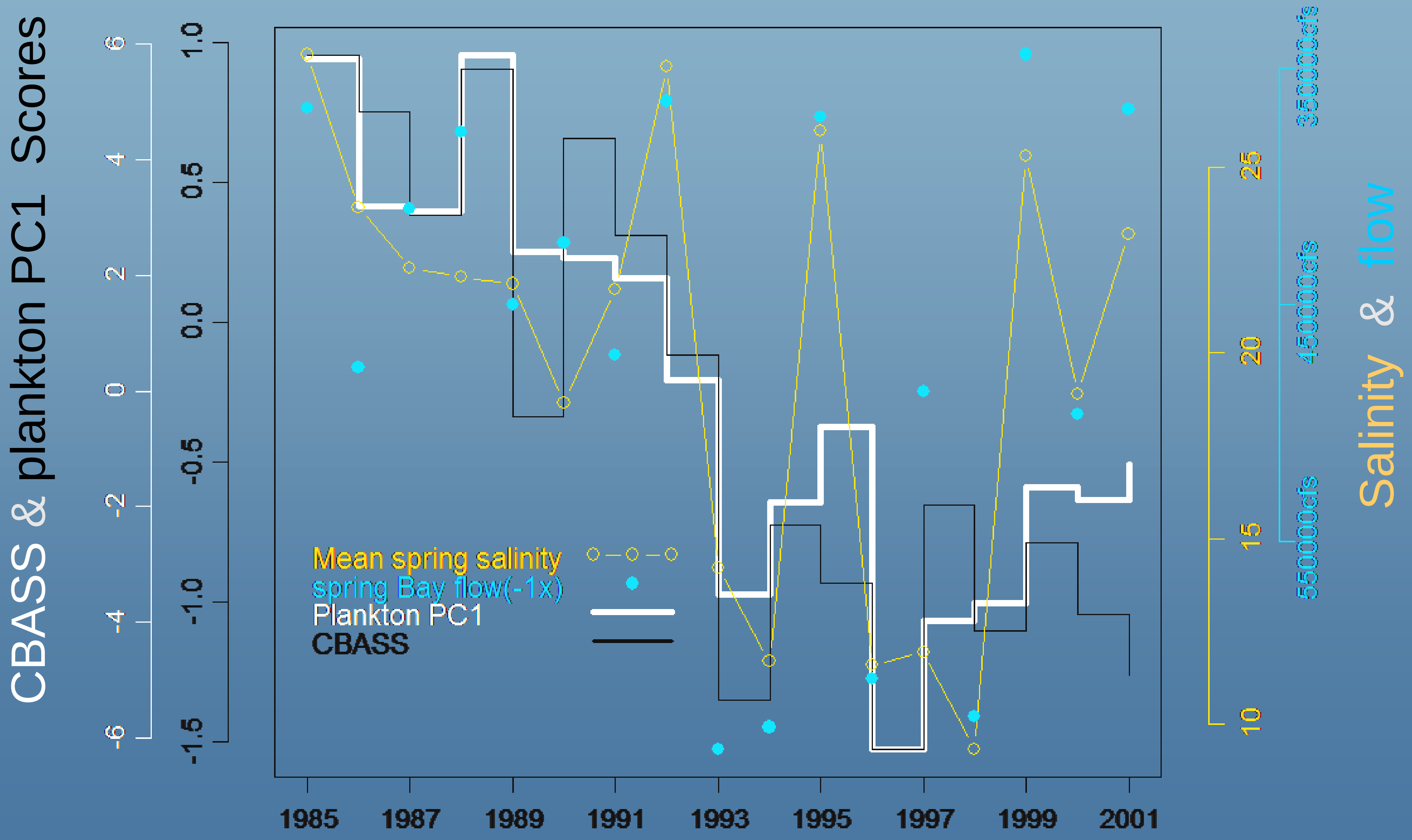




Spring temperature
(March-May)



Flow, salinity, the CBASS$_{rbi}$, & plankton PC1



Implication

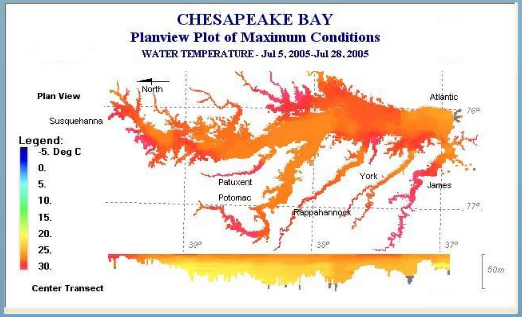
sustained increases in annual winter/spring flow may lead to:

- increased striped bass reproduction
- reduced abundance of menhaden
  - an important prey item for juvenile & adult striped bass

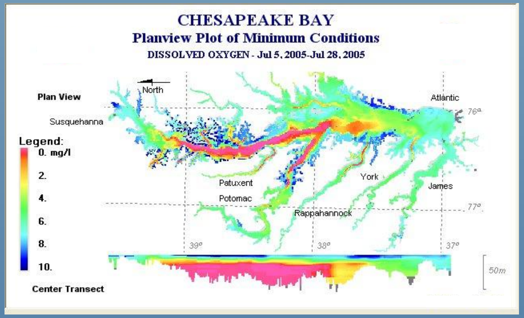
How would enhanced flow and warming temperature affect striped bass habitat later in life?

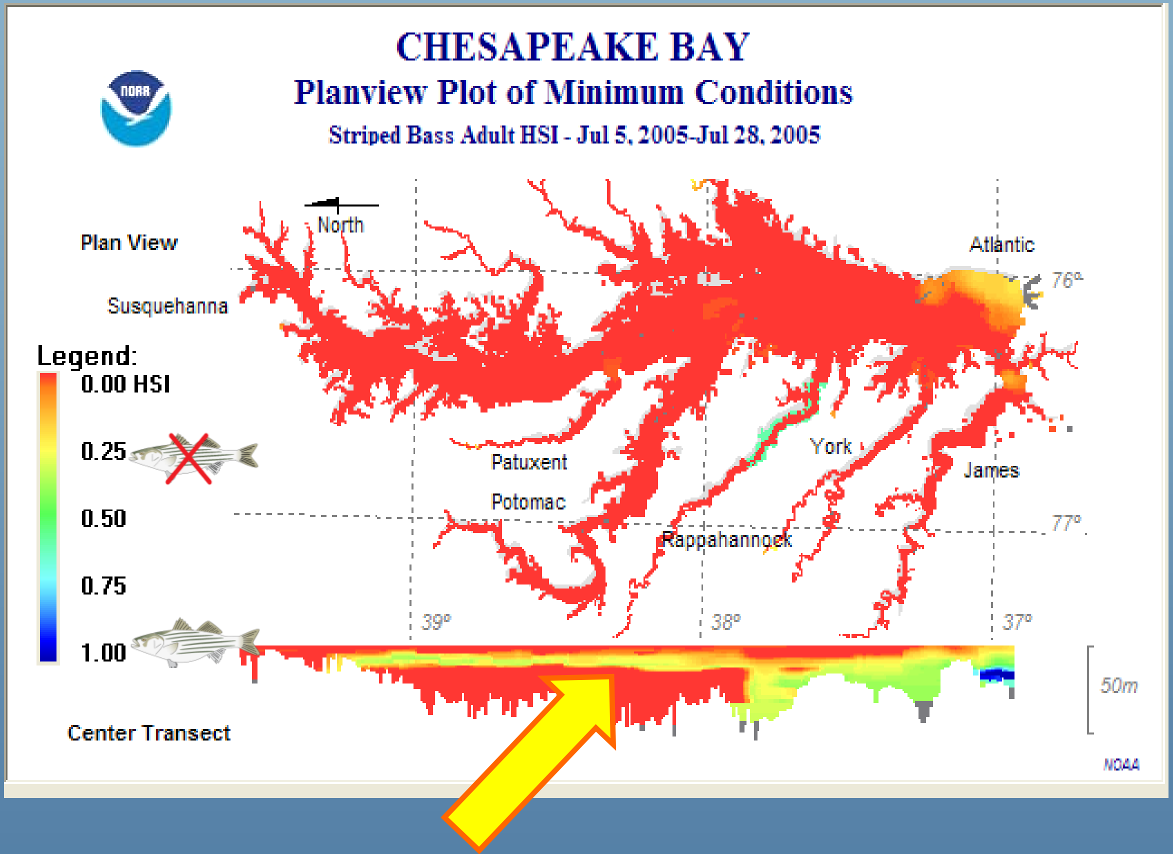
Summer striped bass habitat “squeeze” (Coutant, 1990)

Temperature



Dissolved Oxygen

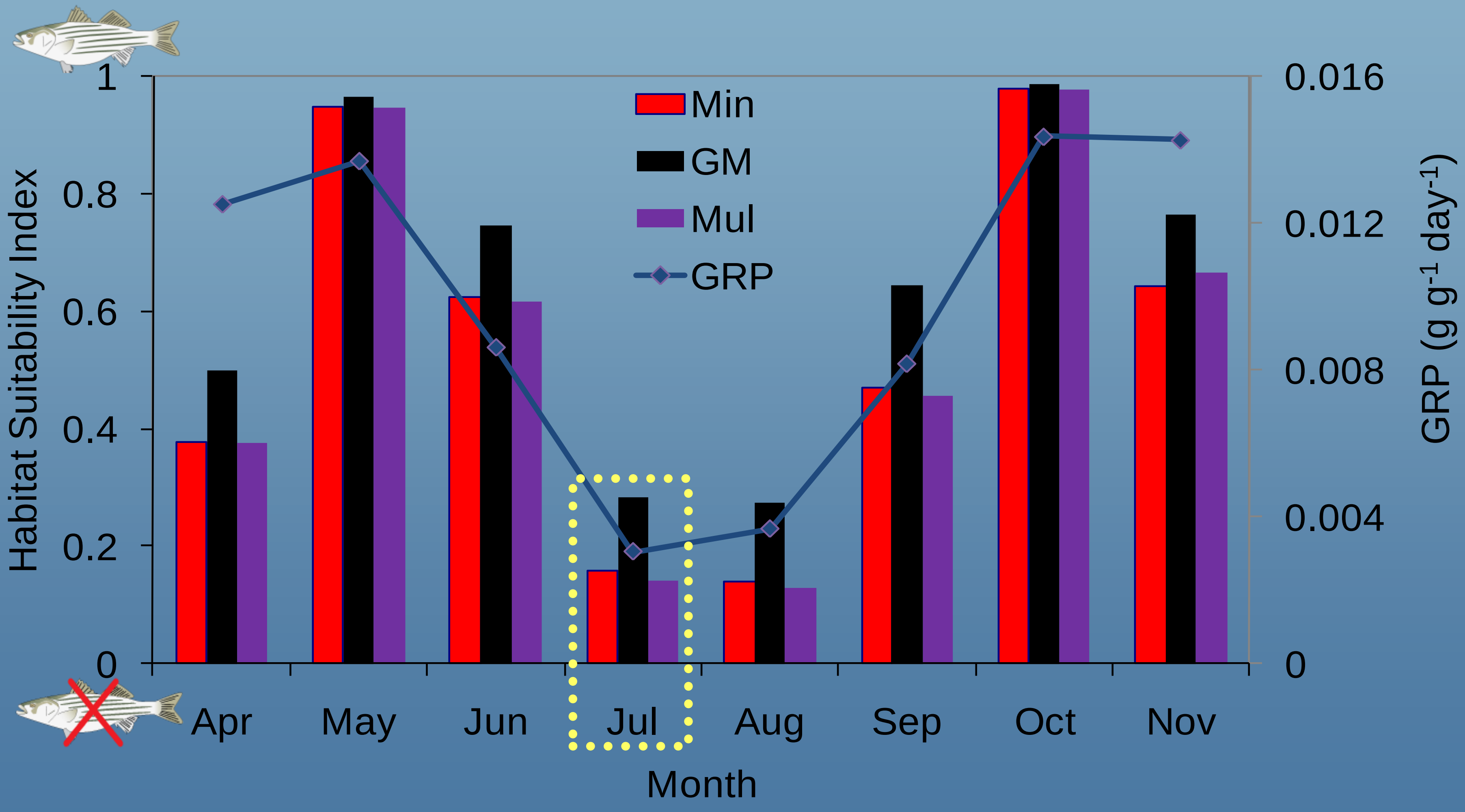




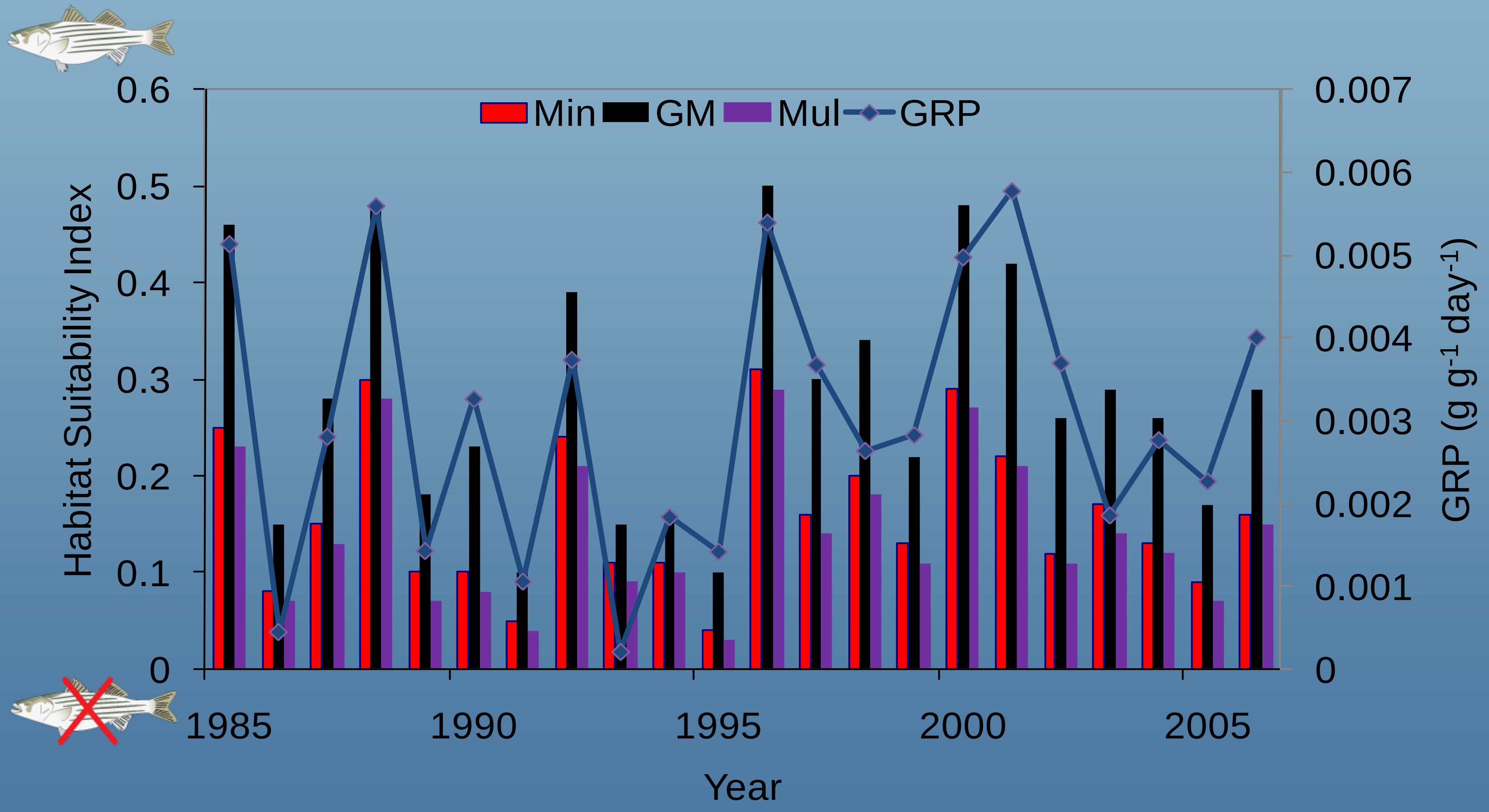
Narrow band of optimal conditions between *high surface temperature* & *low oxygen* in deep waters

O_2 & temperature functions: Bain & Bain,1982: bioenergetics model adapted: Costantini et al. 2008.

Striped bass habitat suitability index & growth rate potential (1985-2006)



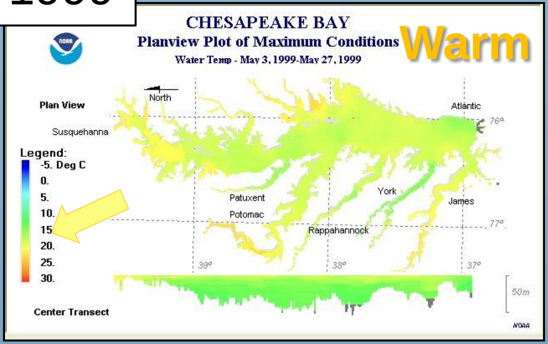
July striped bass habitat suitability index & growth rate potential



Hypoxia worsens with warm & wet conditions

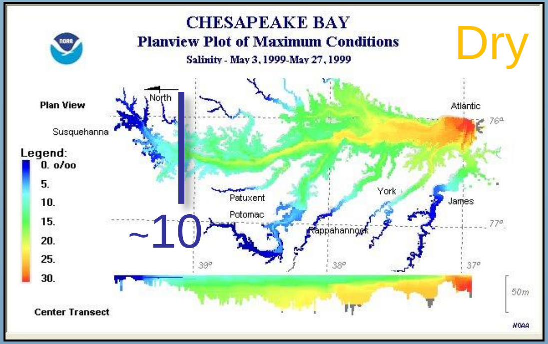
month of May

1999



CHESAPEAKE BAY
Planview Plot of Maximum Conditions
Water Temp - May 3, 1999-May 27, 1999

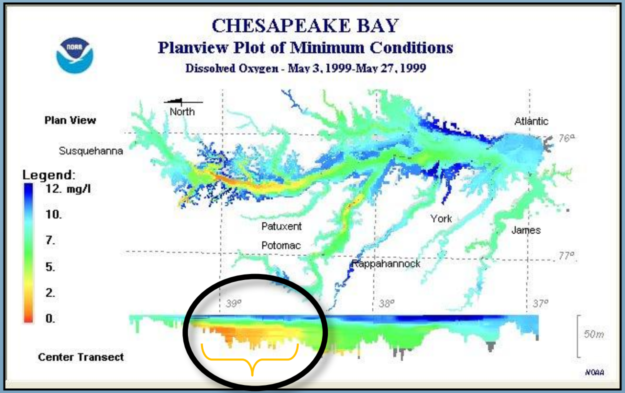
Warm



CHESAPEAKE BAY
Planview Plot of Maximum Conditions
Salinity - May 3, 1999-May 27, 1999

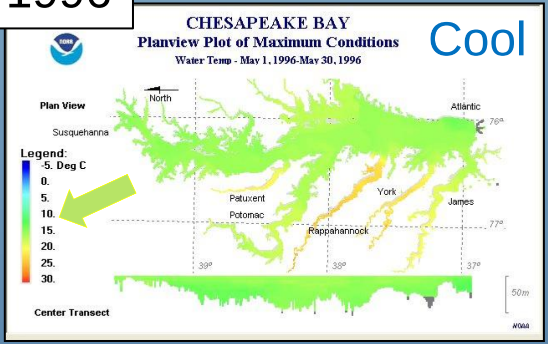
Dry

~10



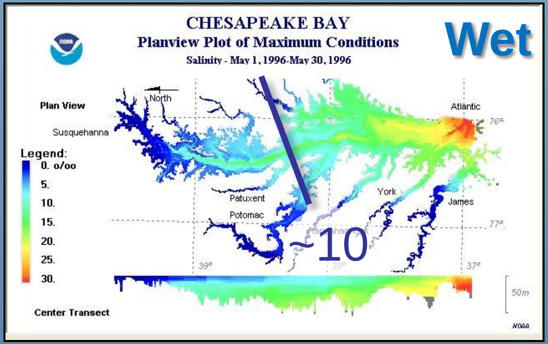
CHESAPEAKE BAY
Planview Plot of Minimum Conditions
Dissolved Oxygen - May 3, 1999-May 27, 1999

1996



CHESAPEAKE BAY
Planview Plot of Maximum Conditions
Water Temp - May 1, 1996-May 30, 1996

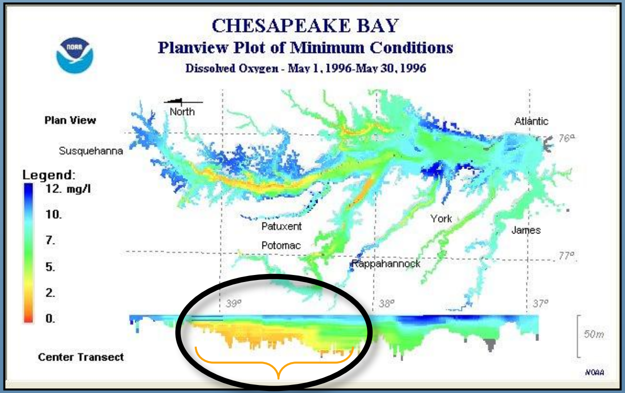
Cool



CHESAPEAKE BAY
Planview Plot of Maximum Conditions
Salinity - May 1, 1996-May 30, 1996

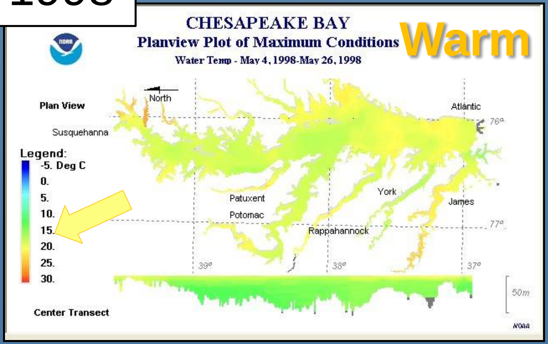
Wet

~10



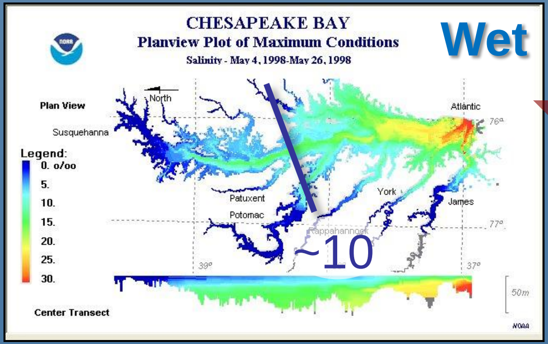
CHESAPEAKE BAY
Planview Plot of Minimum Conditions
Dissolved Oxygen - May 1, 1996-May 30, 1996

1998



CHESAPEAKE BAY
Planview Plot of Maximum Conditions
Water Temp - May 4, 1998-May 26, 1998

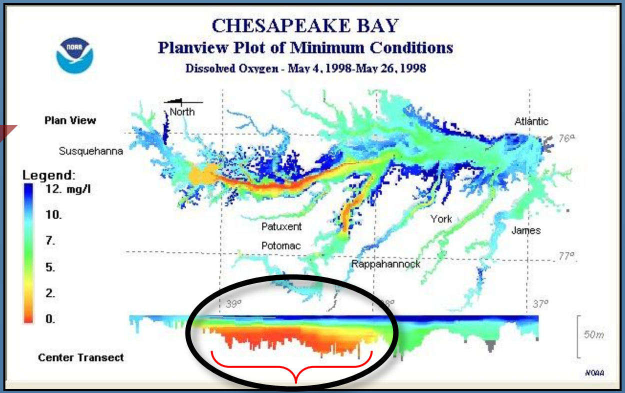
Warm



CHESAPEAKE BAY
Planview Plot of Maximum Conditions
Salinity - May 4, 1998-May 26, 1998

Wet

~10



CHESAPEAKE BAY
Planview Plot of Minimum Conditions
Dissolved Oxygen - May 4, 1998-May 26, 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

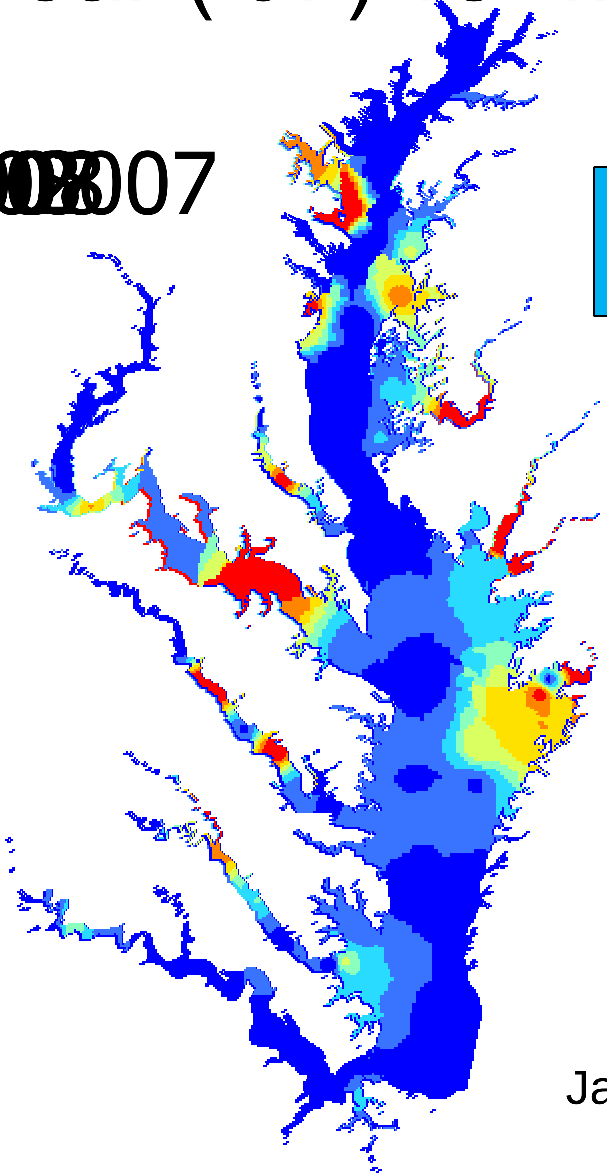
Disease stress

Disease: Mycobacteriosis

- Mycobacteriosis is an infectious disease caused by bacteria in the genus *mycobacterium*.
- Chesapeake stripers exposed early in life: infection rates increasing w/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)

October 2007
April 2008
July 2008



Will higher winter/spring flow enhance myco abundance?

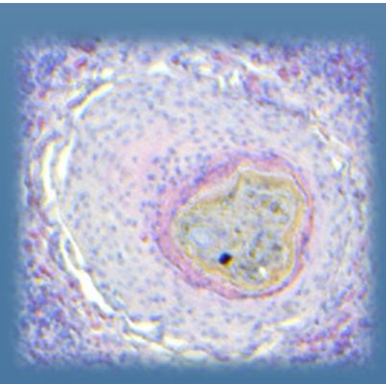
Abundance
(Cells/ml)

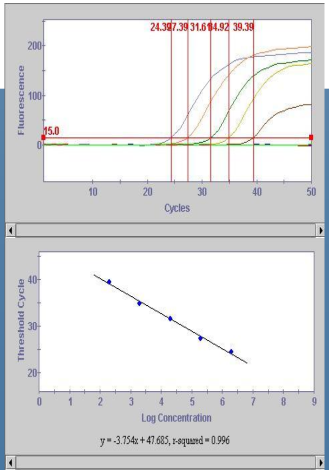
- 🟦 0.00 - 20.00
- 🟦 20.01 - 40.00
- 🟦 40.01 - 60.00
- 🟩 60.01 - 80.00
- 🟨 80.01 - 100.00
- 🟨 100.01 - 120.00
- 🟧 120.01 - 140.00
- 🟥 140.01+

Jacobs et al, in press

Mycobacterium Modeling

Variable	**AIC**	**% Concordance**	**% Discordance**
PC1 and PC2	178.6	71.9	27.8
DO and TN	173.6	76.6	23.2
DO and Salinity	162.7	81.4	18.4
Salinity and TN	161.0	79.0	20.7
TN, DO, and Salinity	**152.1**	**83.8**	**15.9**

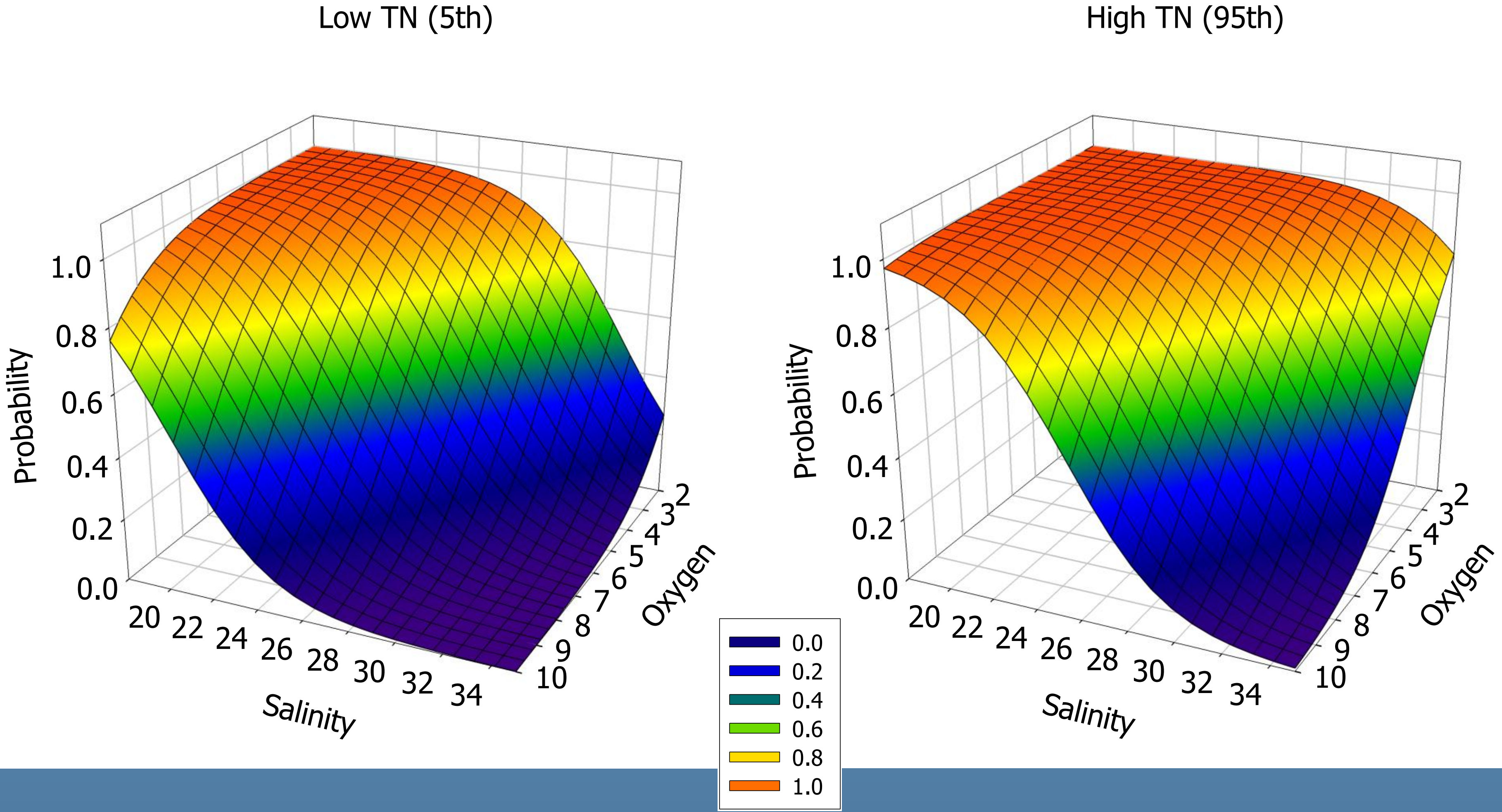




Quarterly monitoring at CBP water quality monitoring stations, N = 150

- Elevated abundance (75th quartile)

Mycobacterium spp. Logistic Model



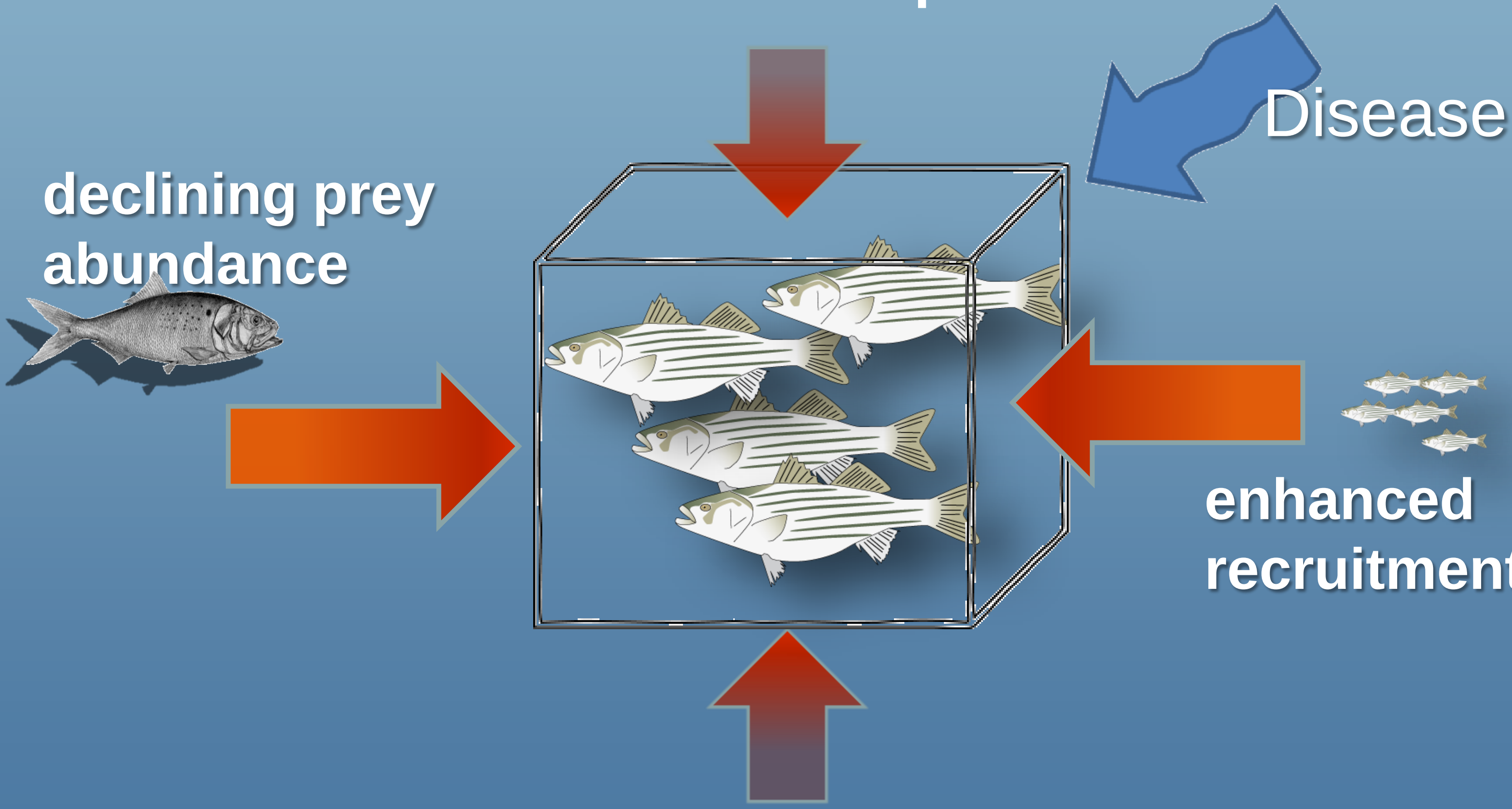
With ⬆total nitrogen in the Bay Myco expands into waters with ⬆ salinity and ⬆ dissolved oxygen

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

Disease

declining prey abundance

enhanced recruitment

hypoxia

policy / actions

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

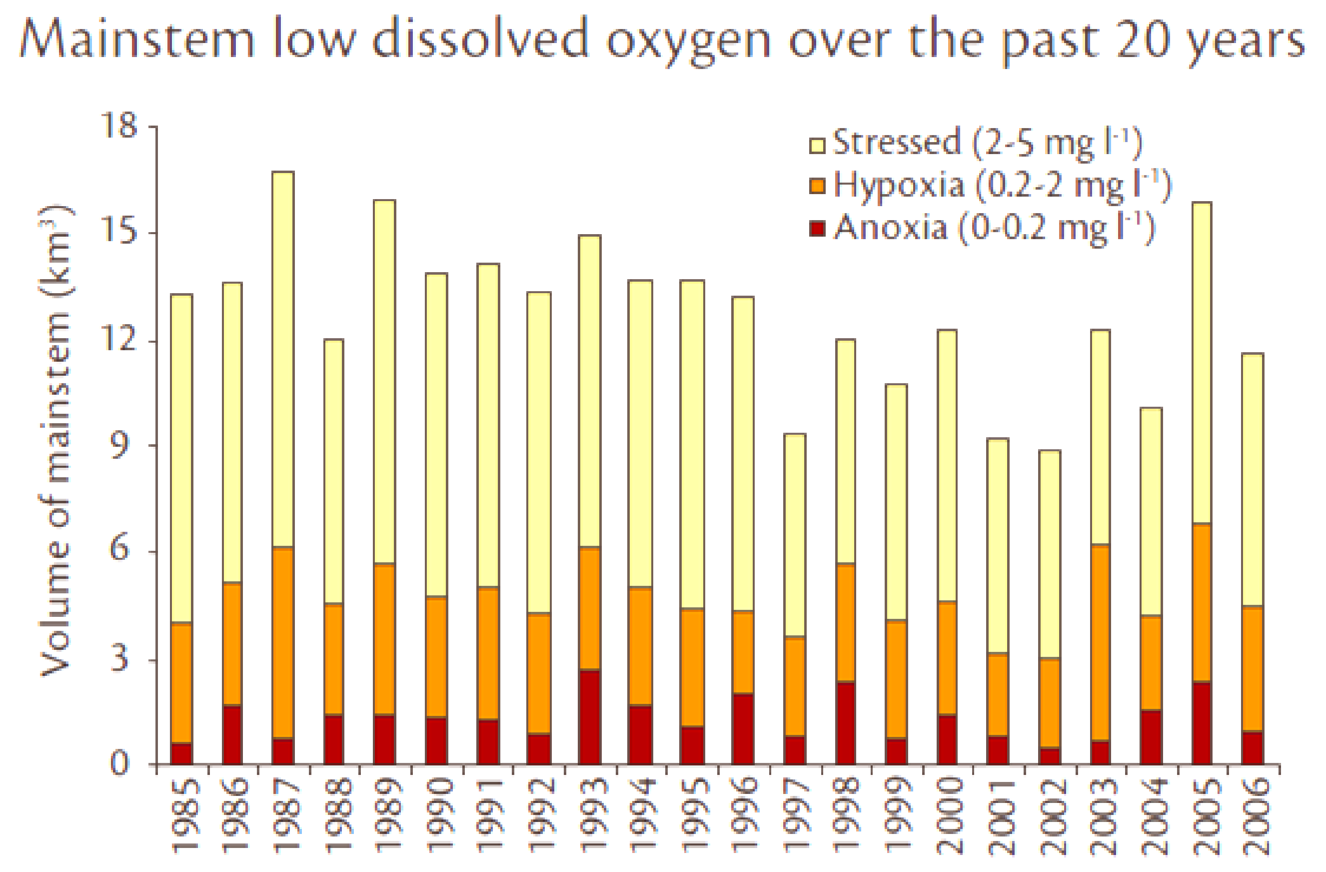
- Enhanced habitat ‘squeeze’ & Mycobacteria abundance that could be induced by projected climate changes may be mitigated by nutrient reductions

- 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

CHESAPEAKE EcoCheck

Assessing and forecasting ecosystem status

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?

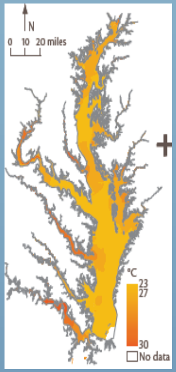
Approach: anchovy growth rate potential

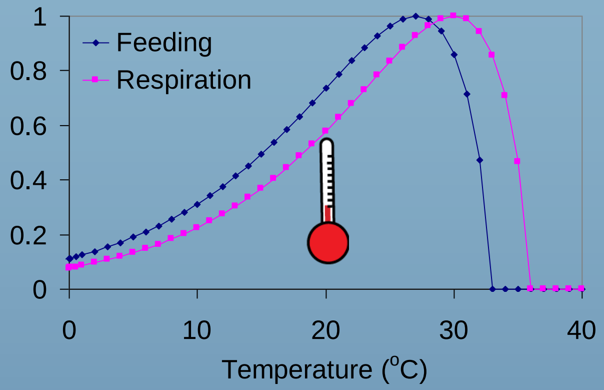
Observations

Anchovy growth response

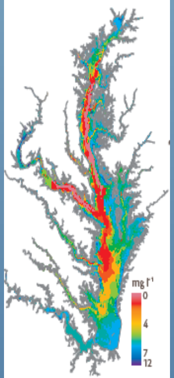
Growth Rate Potential

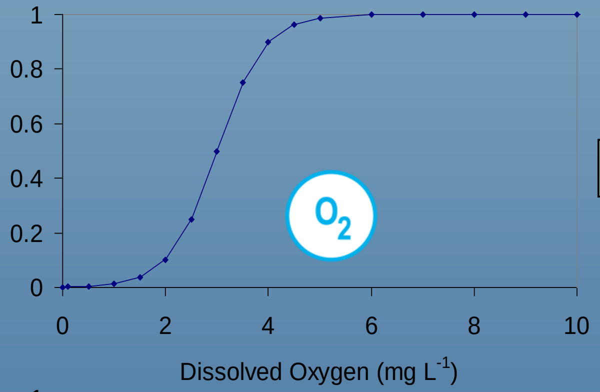
Temperature



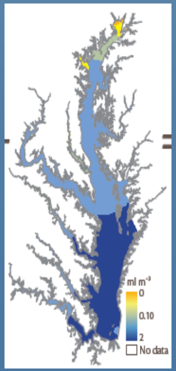


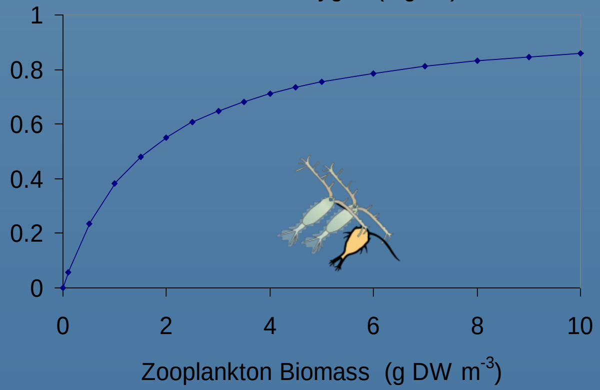
Dissolved Oxygen

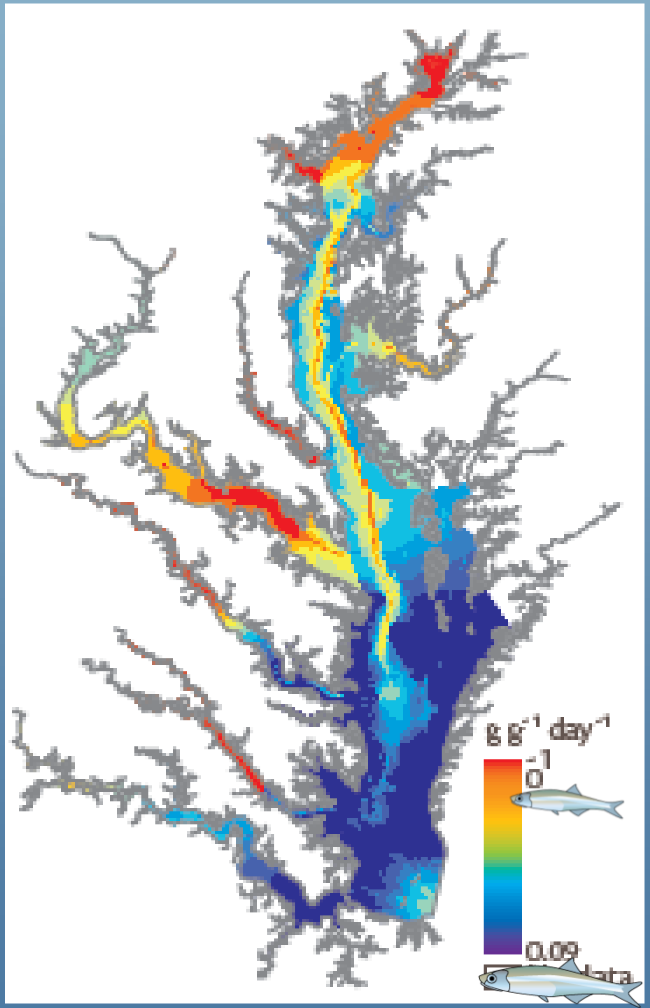




Zooplankton

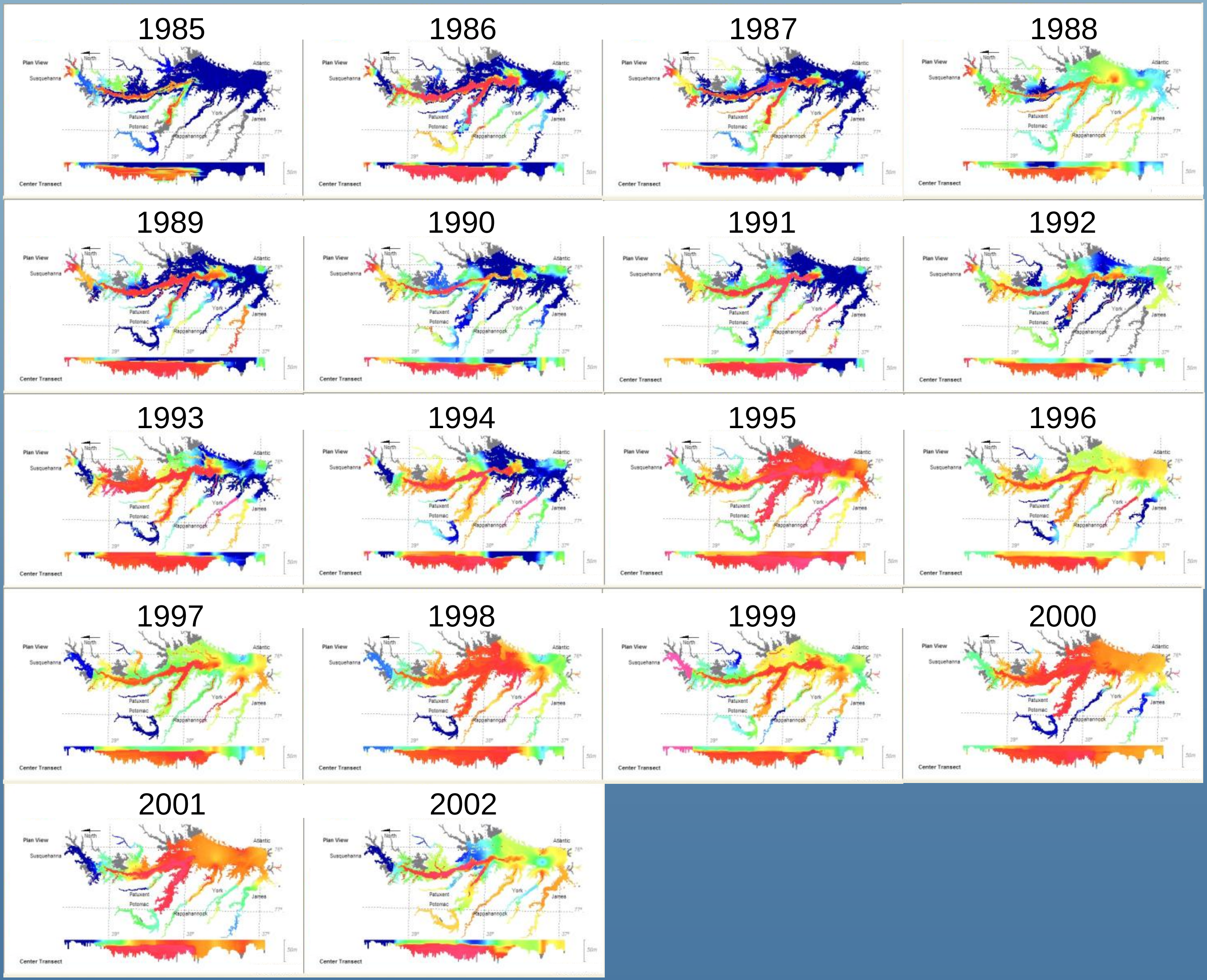


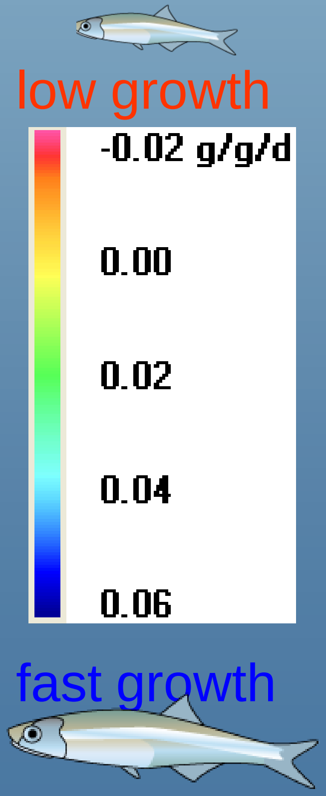


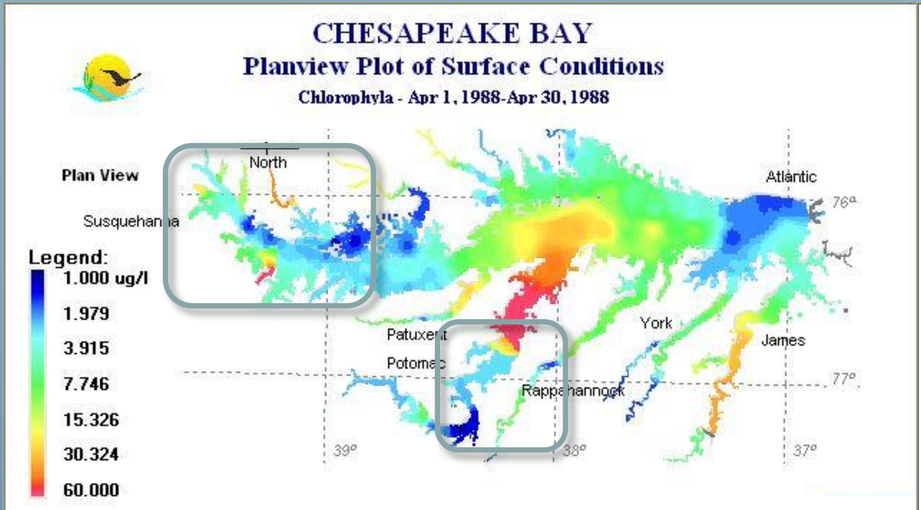


Response functions from Klebasko, 1991; Brandt et al. 1992; Luo & Brandt 1993

Long term decline in anchovy growth (model results)





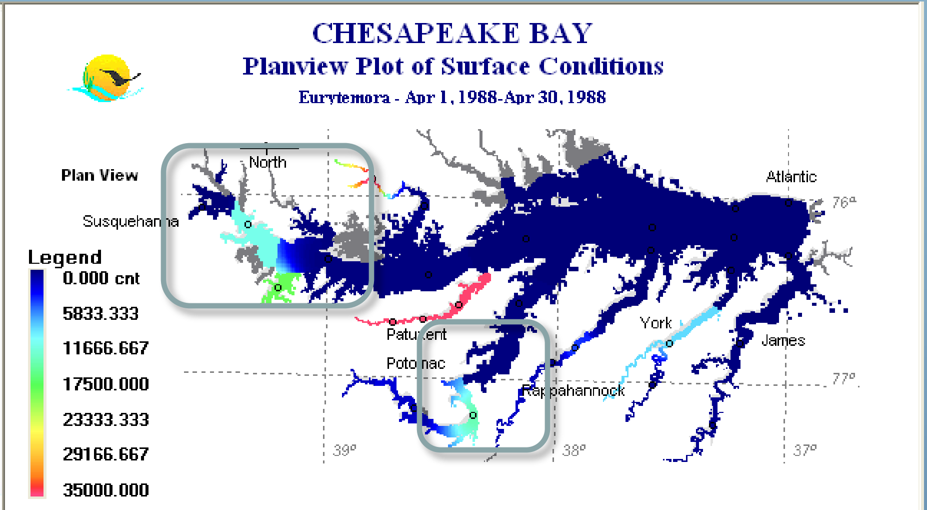


CHESAPEAKE BAY

Planview Plot of Surface Conditions

Chlorophyla - Apr 1, 1988-Apr 30, 1988

Apr Chla 1988

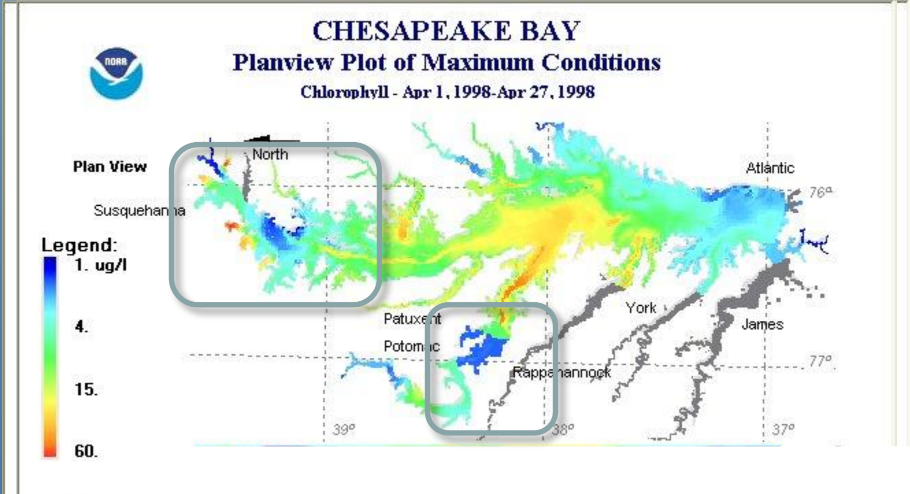


CHESAPEAKE BAY

Planview Plot of Surface Conditions

Eurytemora - Apr 1, 1988-Apr 30, 1988

Apr Eurytemora 1988

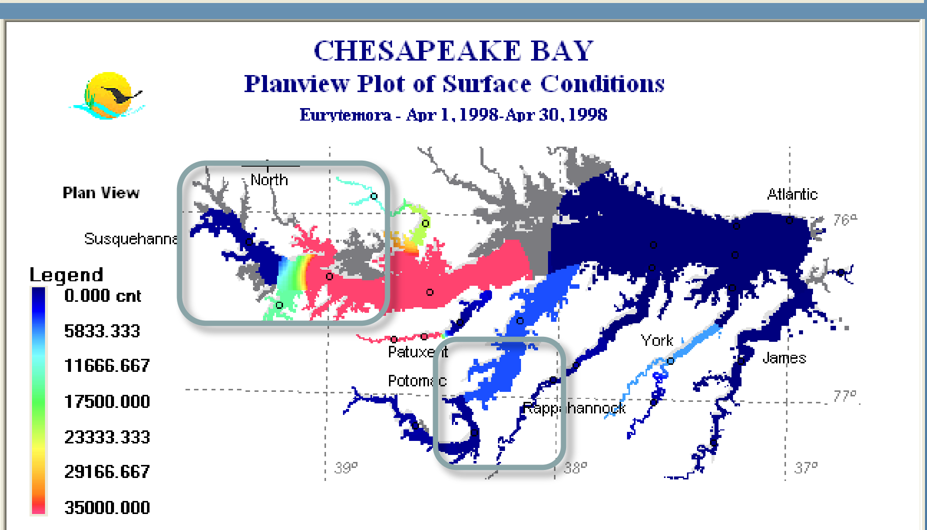


CHESAPEAKE BAY

Planview Plot of Maximum Conditions

Chlorophyll - Apr 1, 1998-Apr 27, 1998

Apr Chla 1998



CHESAPEAKE BAY

Planview Plot of Surface Conditions

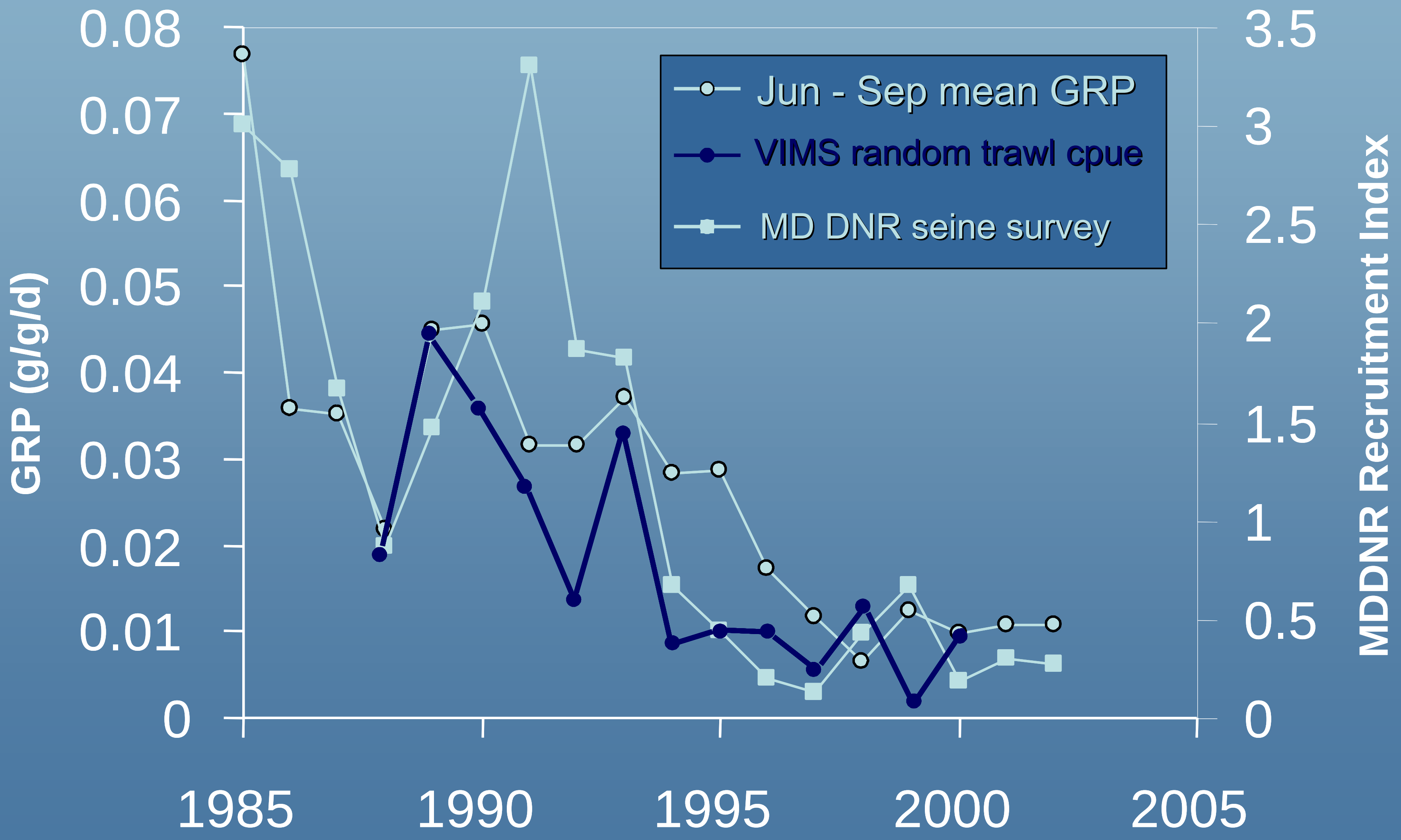
Eurytemora - Apr 1, 1998-Apr 30, 1998

Apr Eurytemora 199

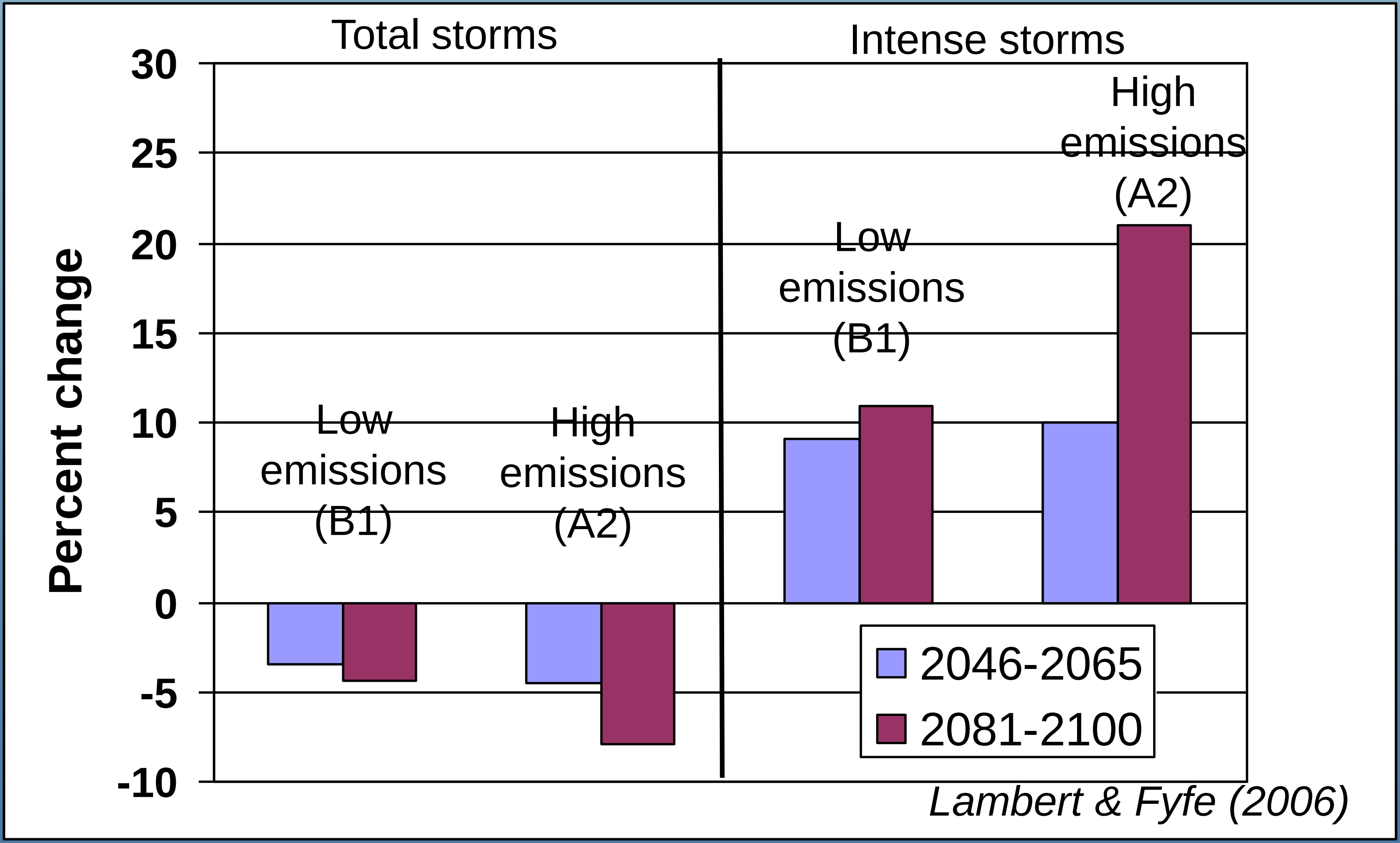
- 2002 - Harding, L.W., M.E. Mallonee, and E.S. Perry: Toward a predictive understanding of primary productivity in a temperate, partially stratified estuary. *Estuar. Coastal Shelf Sci. 55: 437-463.*

Model Performance:

comparing modeled GRP to fish surveys



Changes in extratropical winter storms in the Northern Hemisphere



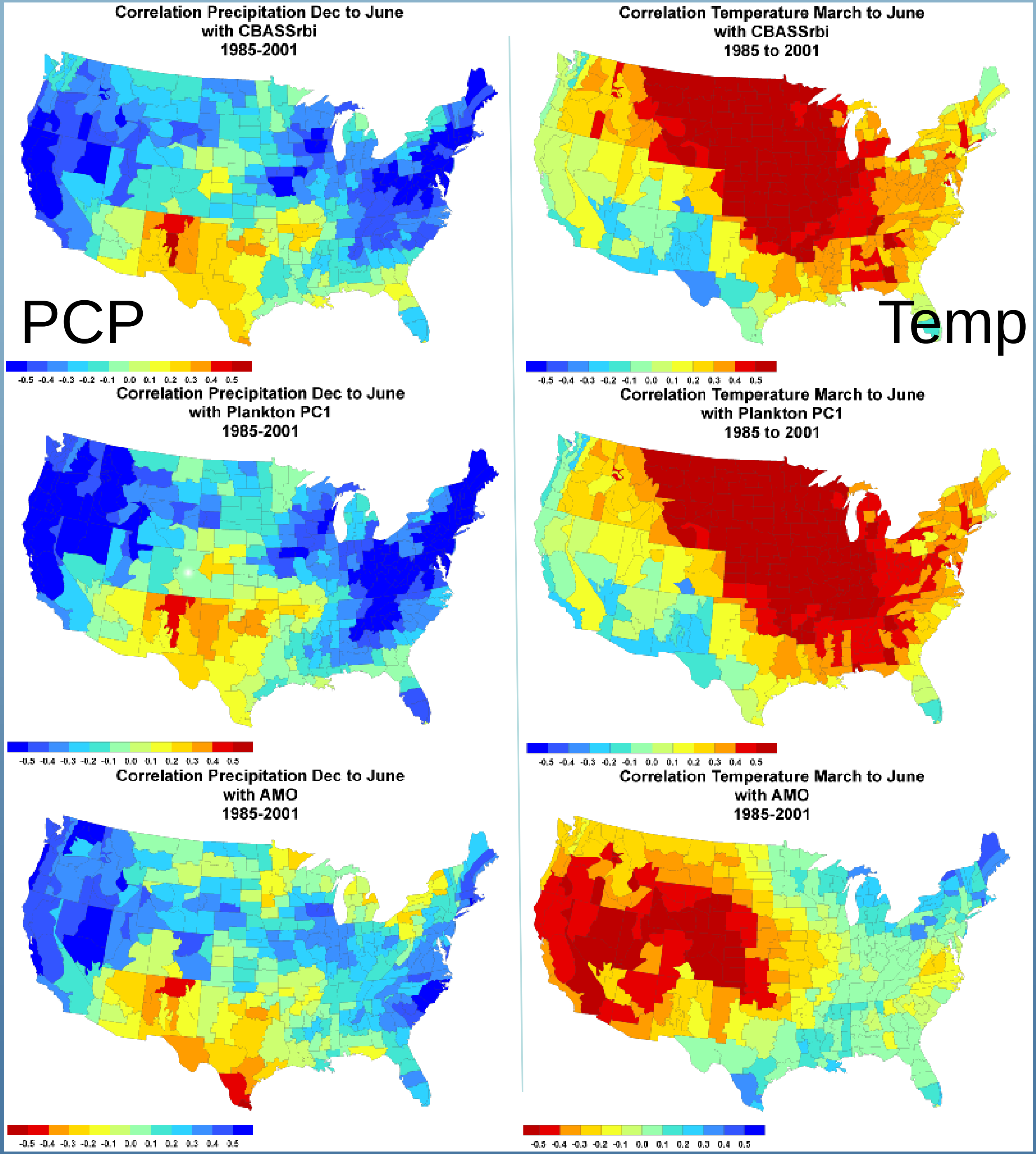
Lambert & Fyfe (2006)

Correlation maps (scale -0.5 to 0.5)

CBASS$_{rbi}$

Plankton PC1

AMO*



PCP

Temp

Correlation Precipitation Dec to June with CBASSrbi 1985-2001

Correlation Temperature March to June with CBASSrbi 1985 to 2001

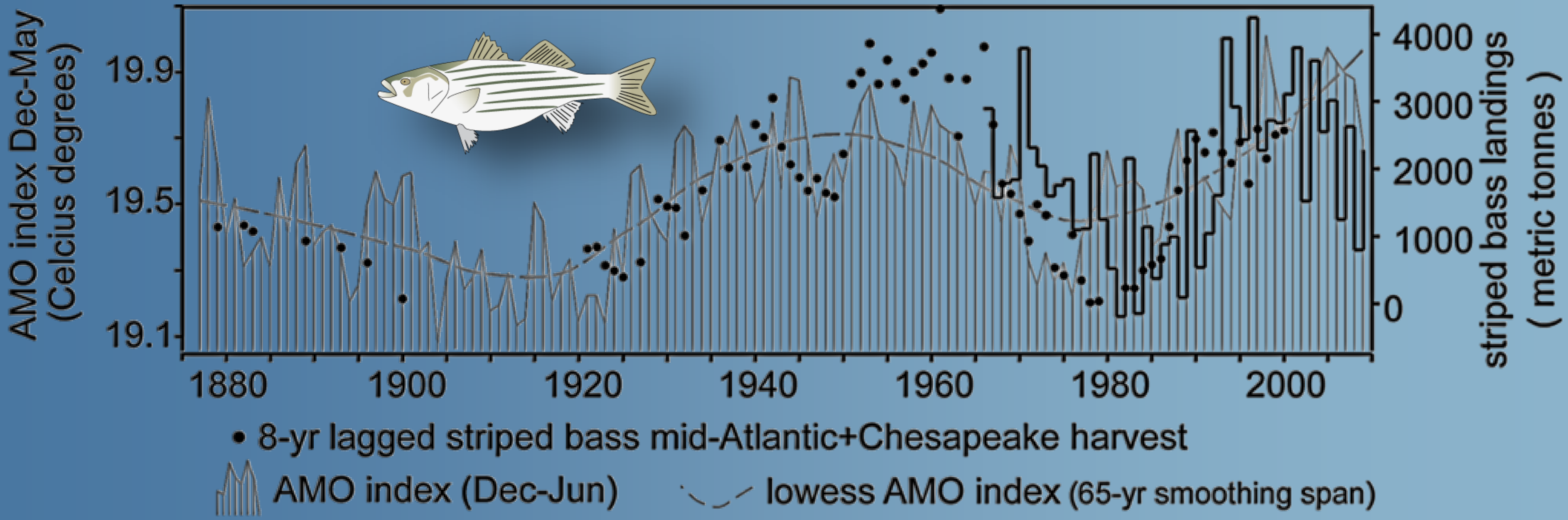
Correlation Precipitation Dec to June with Plankton PC1 1985-2001

Correlation Temperature March to June with Plankton PC1 1985 to 2001

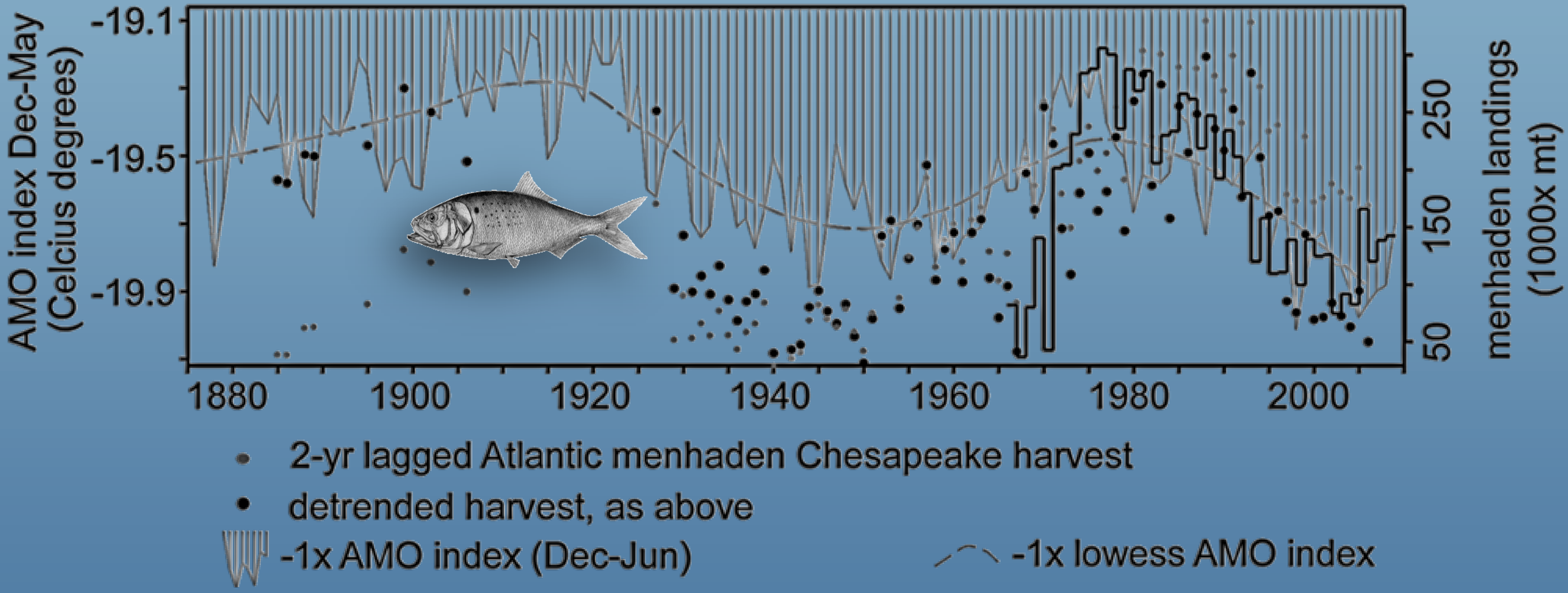
Correlation Precipitation Dec to June with AMO 1985-2001

Correlation Temperature March to June with AMO 1985-2001

Striped bass landings and the AMO



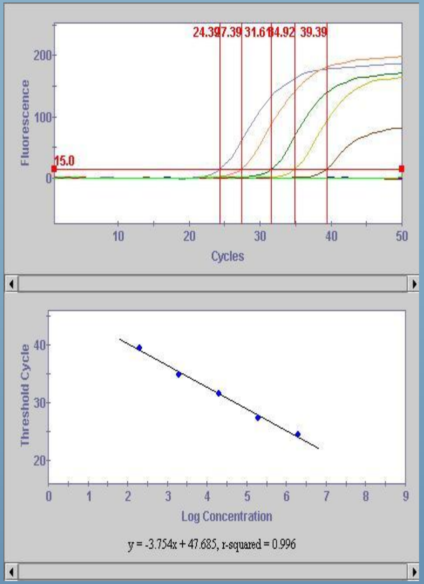
Atlantic menhaden landings & the AMO



Monitoring Program

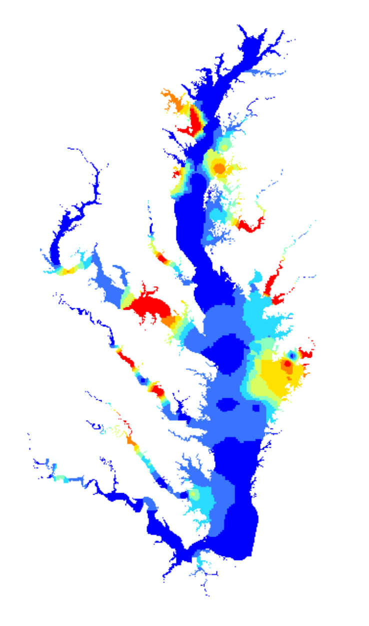
Water Quality
Monitoring Programs

NPS, MDNR, VADEQ
Coastal Bays (2005 -)
and Chesapeake
(2007 -)



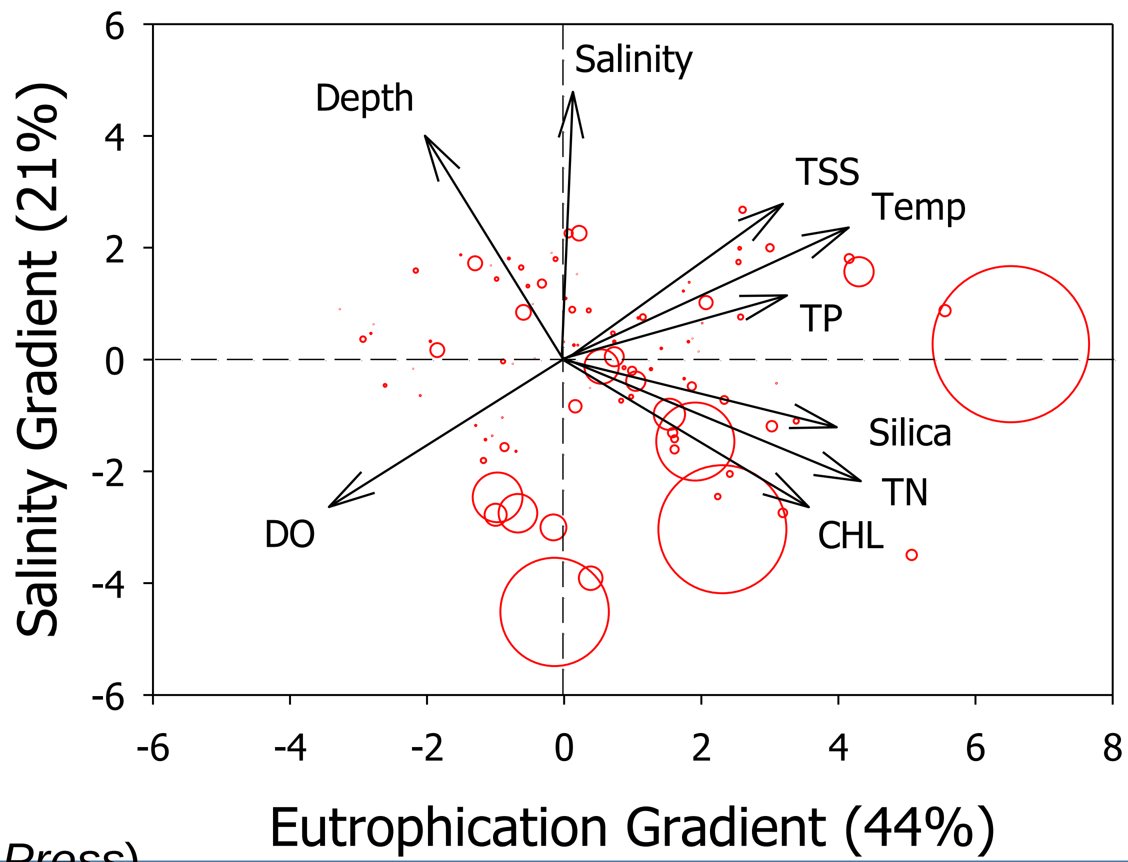
$y = -3.754x + 47.685$, r-squared = 0.996

Quantitative PCR
Mycobacterium spp.



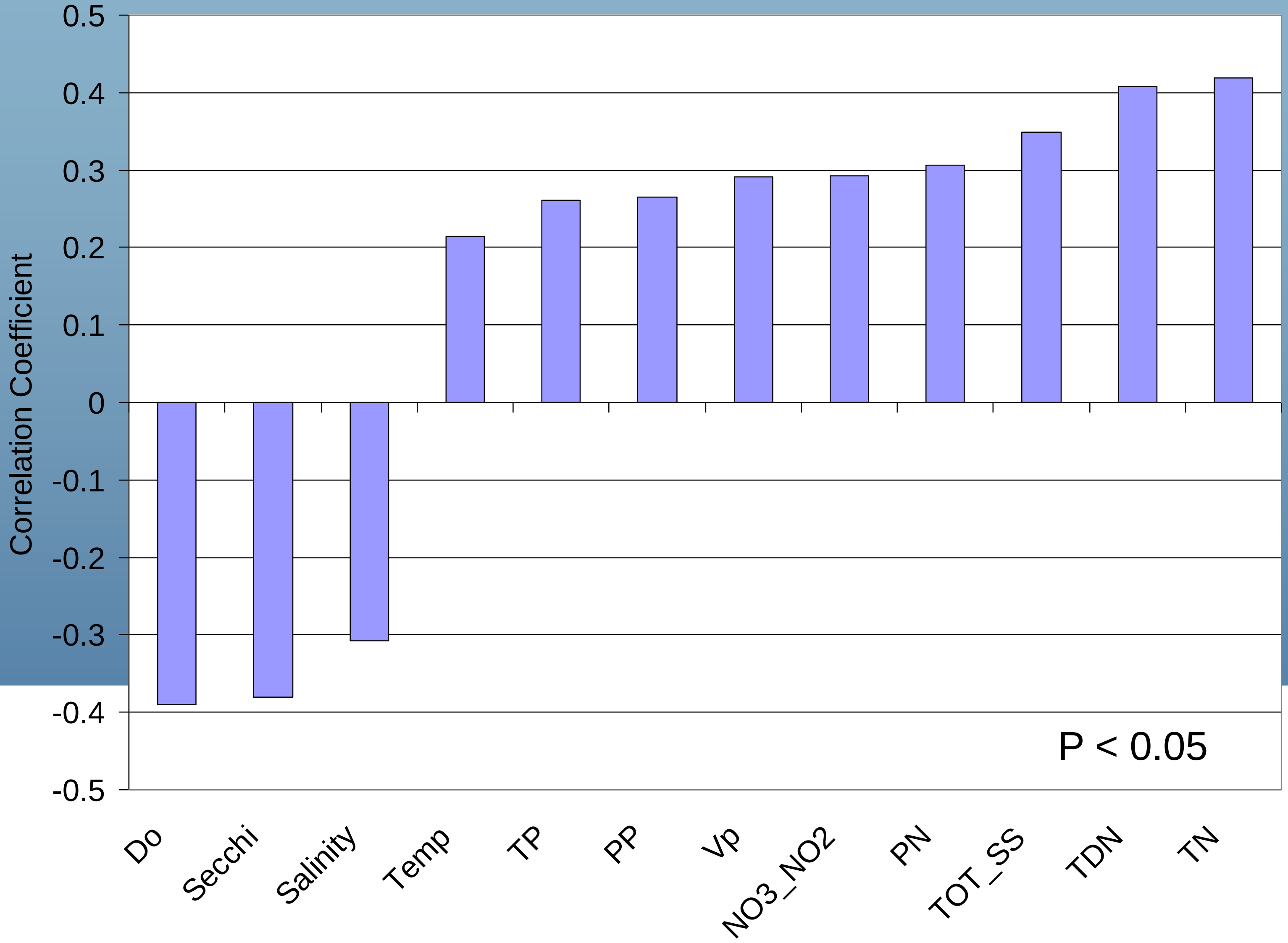
Model development

Myco Concentration and Water Quality

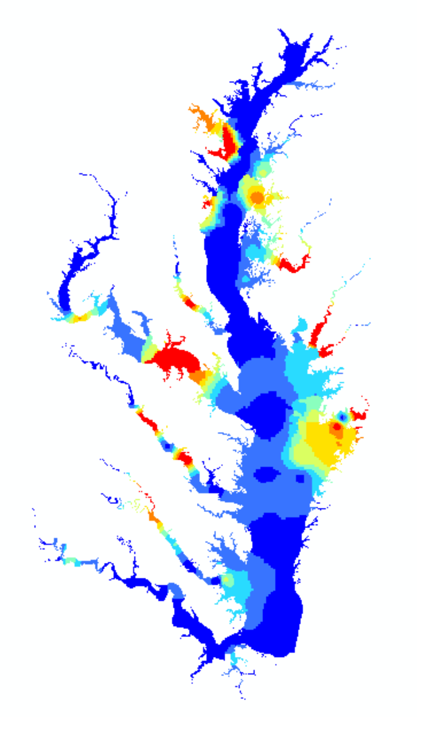


Jacobs et al. (*In Press*)

Mycobacterium spp.



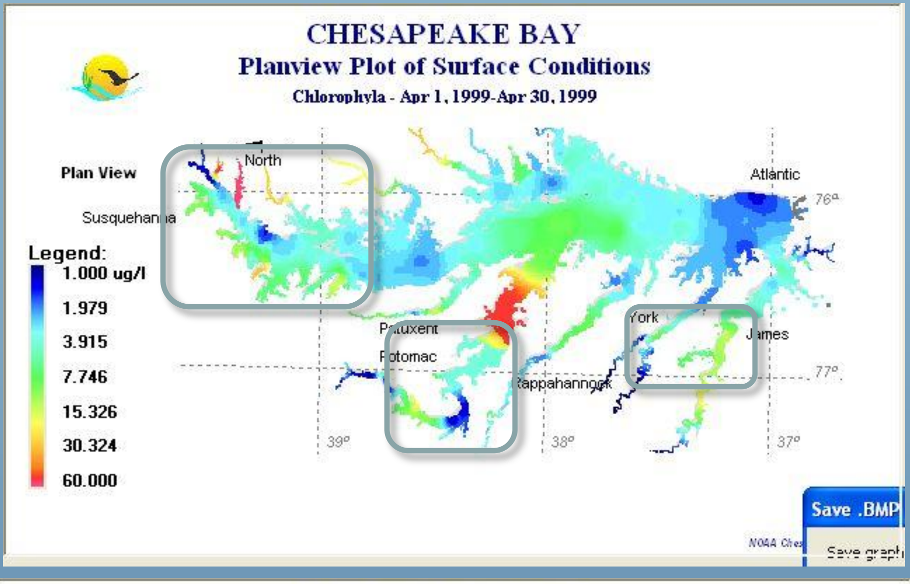
Preliminary Model Development



2006 – 2008 data (April, July, October)

Variables	AIC	Concordance	Discordance
DO and TN	255.9	77.9	21.8
TN, DO, and Salinity	241.8	81.0	18.8
DO and Salinity	240.7	80.7	19.1
Salinity , DO, Wtemp	224.0	83.1	16.6

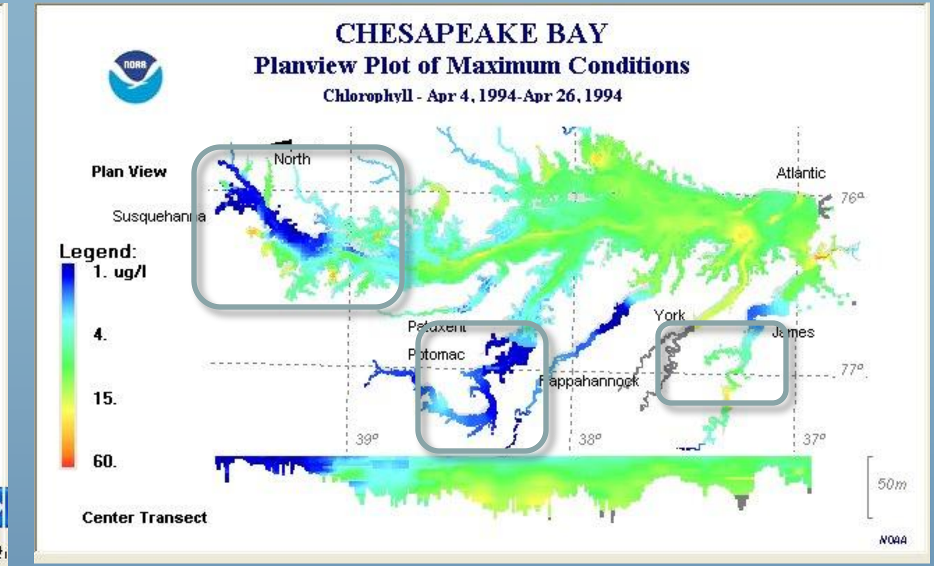
- Elevated abundance (75th quartile)



CHESAPEAKE BAY

Planview Plot of Surface Conditions

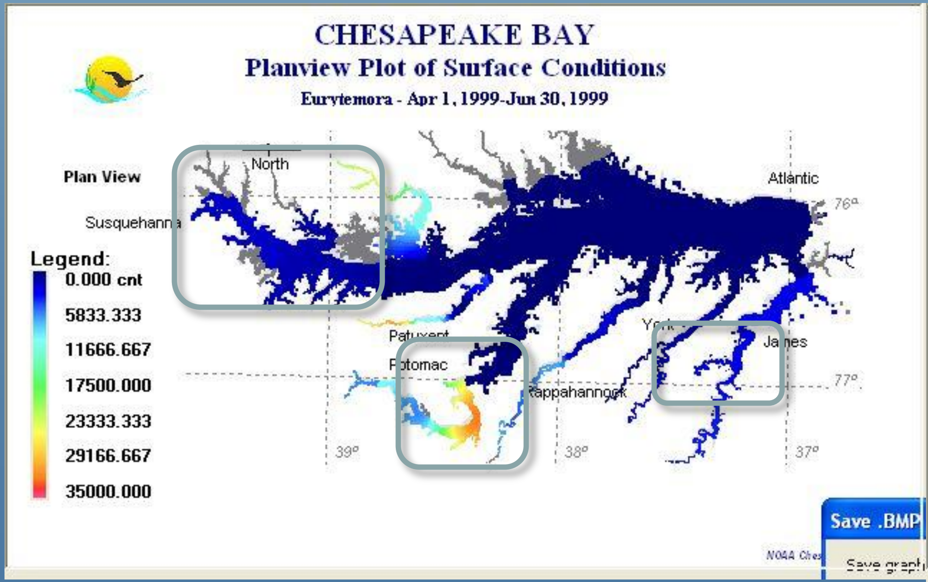
Chlorophyla - Apr 1, 1999-Apr 30, 1999



CHESAPEAKE BAY

Planview Plot of Maximum Conditions

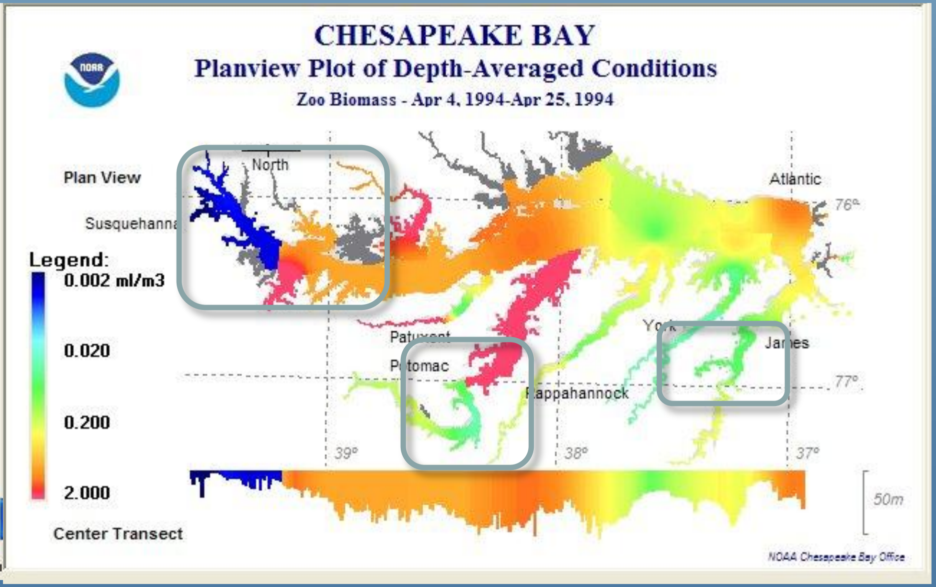
Chlorophyll - Apr 4, 1994-Apr 26, 1994



CHESAPEAKE BAY

Planview Plot of Surface Conditions

Eurytemora - Apr 1, 1999-Jun 30, 1999



CHESAPEAKE BAY

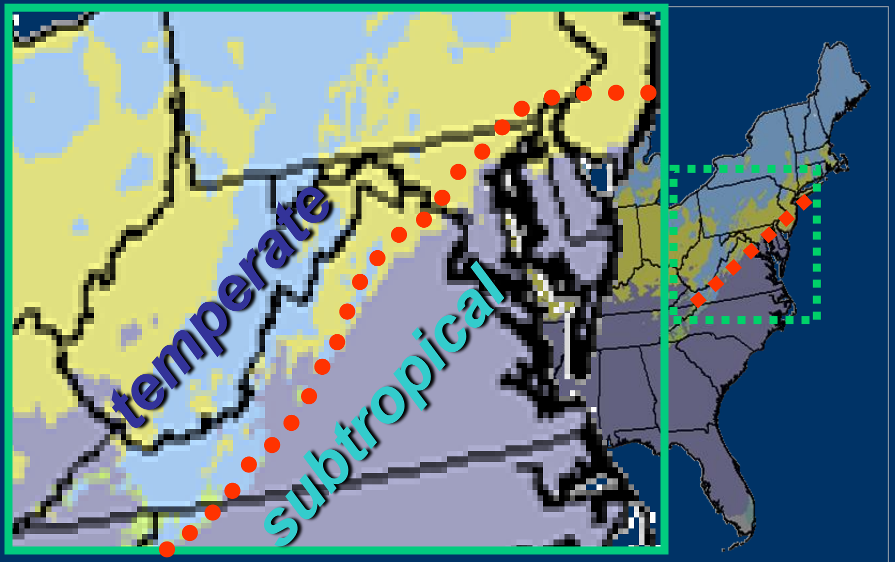
Planview Plot of Depth-Averaged Conditions

Zoo Biomass - Apr 4, 1994-Apr 25, 1994

Chesapeake Bay is subjected to pronounced climate variability…

The Bay straddles subtropical & temperate climate zones

Köppen climate classification

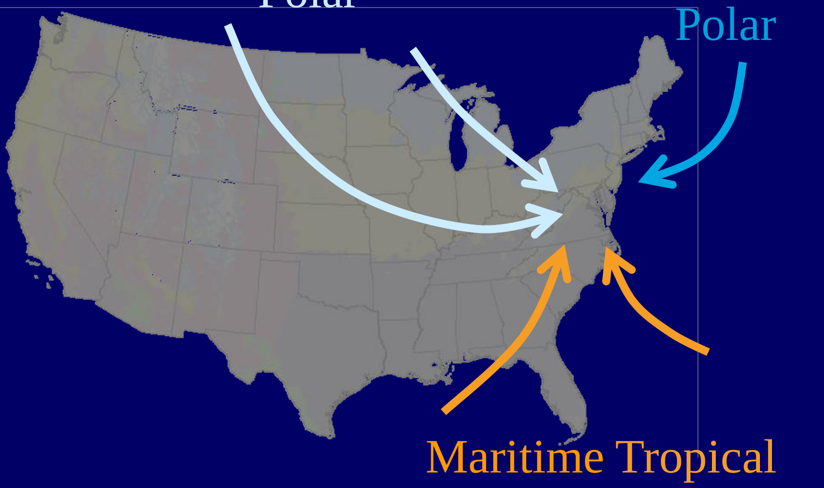


🟦	Dfb	Temperate mild summers
🟨	Dfa	Temperate hot summers
🟪	Cfa	Humid subtropical

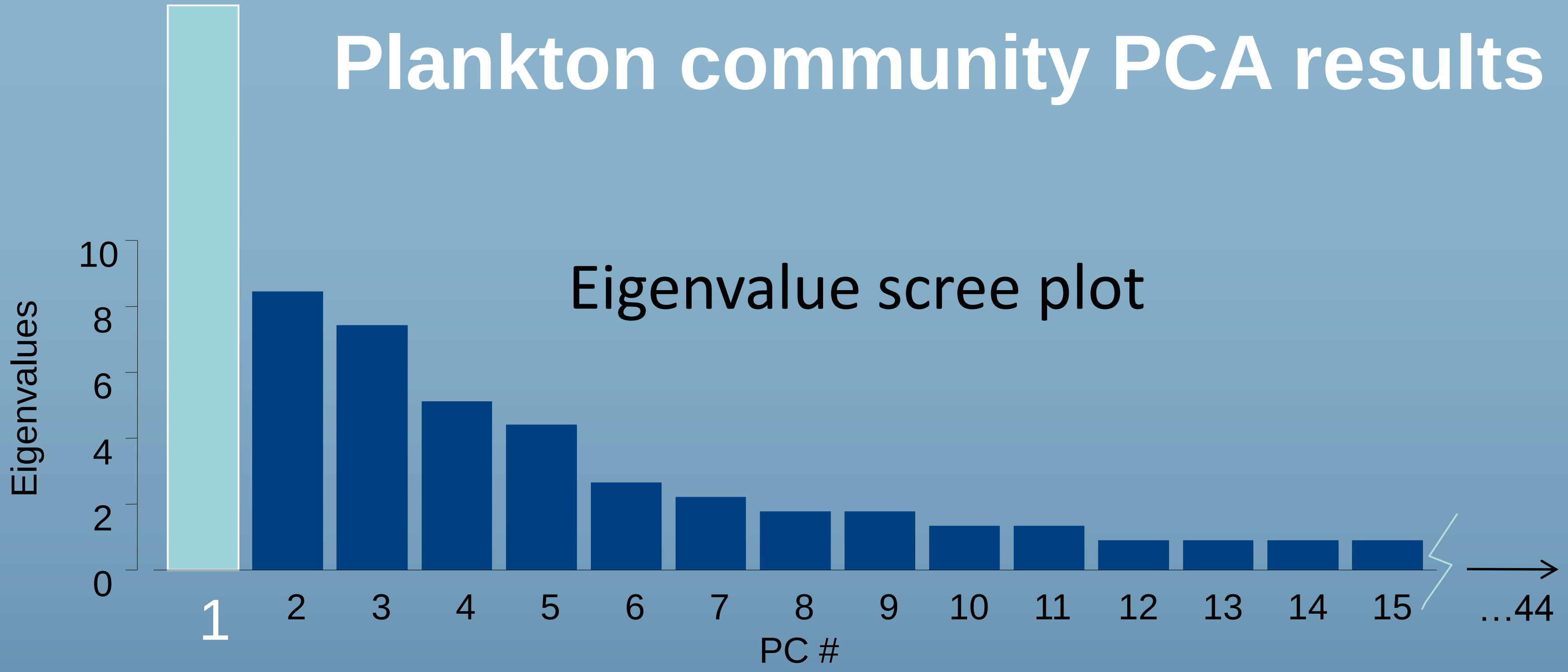
K□ppen map source: Godfrey, B.R., 1999

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

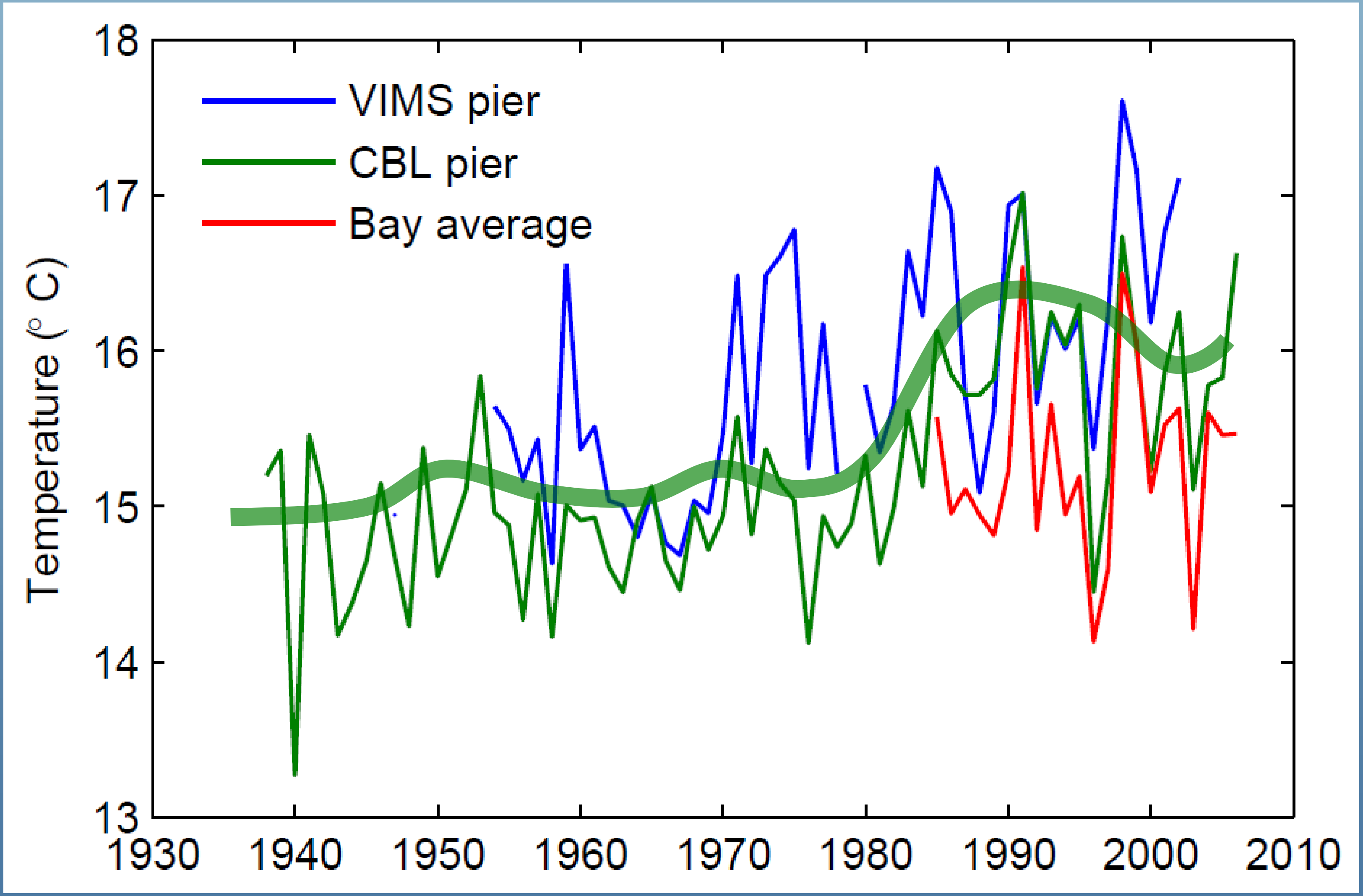


Plankton community PCA results



Plankton PC #	Eigenvalue	Plankton data set's proportion of variance	Cumulative variance %	Correlation with CBASS$_{rbi}$
1	14.5	0.26	26%	**0.92** *p<0.0001
2	8.01	0.14	40%	-0.10
3	6.9	0.12	52%	-0.07
4	5.2	0.09	61%	0.02
5	4.7	0.08	69%	0.29

Chesapeake Bay has warmed in recent decades



Source: CBP & VIMS archive, Kaushal et al. (2010)

Correlation:

Spring hydrography & plankton PC1 scores

Environmental variable	**Plankton PC1**	**CBASS$_{rbi}$**
water temp. March	0.16	-0.04
water temp. April	0.20	-0.02
water temp. May	-0.21	-0.36
water temp. June	0.32	0.09
salinity March	0.51*	0.21
salinity April	0.76**	0.51*
salinity May	0.81**	0.68**
salinity June	0.61**	0.41
Salinity March-June	**0.76****	**0.51***

*p<0.05 **p<0.01

A starting point: general circulation of the atmosphere

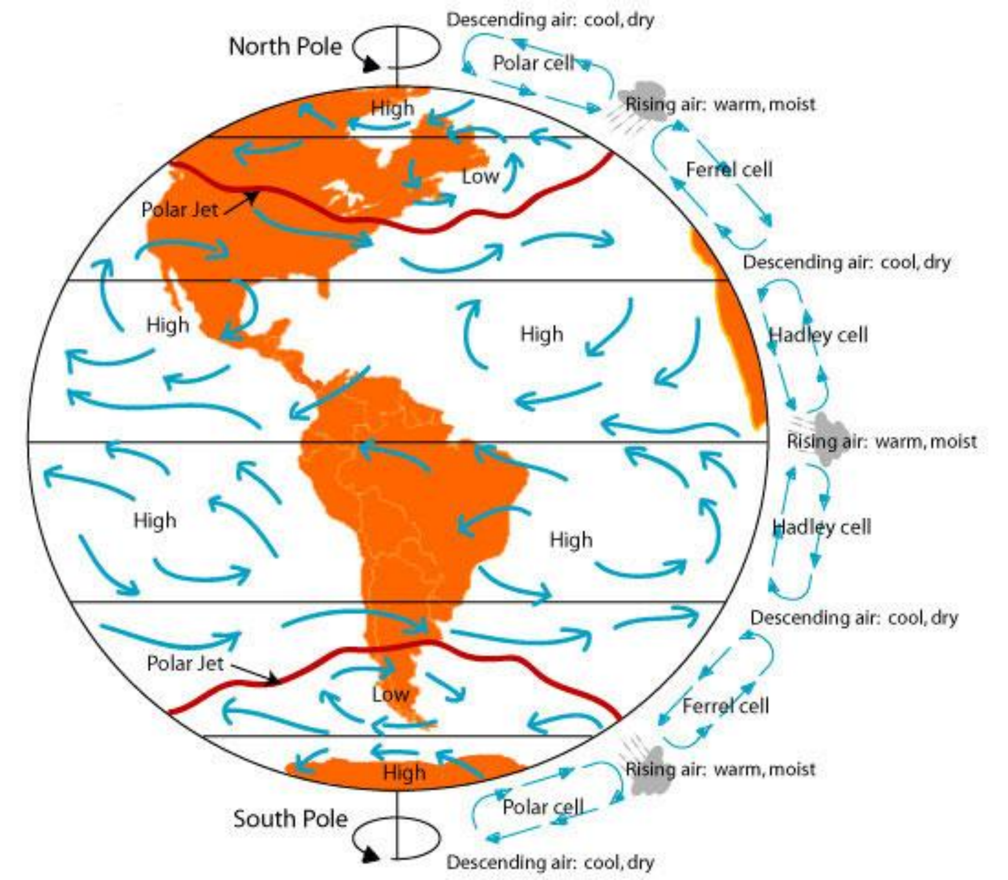
Climates are determined by the heat imbalance from equator to poles

Earth's rotation breaks up equator to pole heat flow into 'cells'

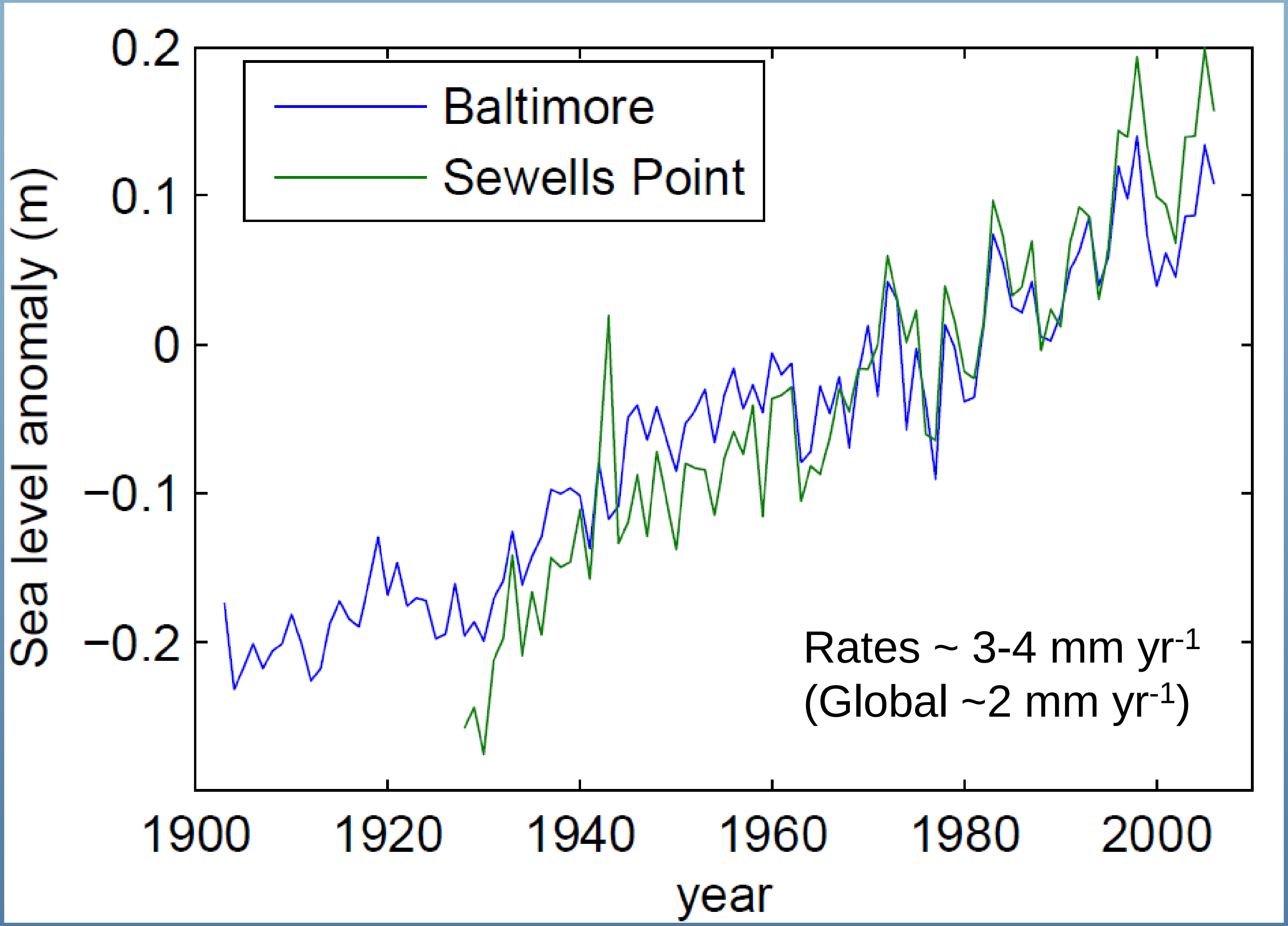
Coriolis effect at the surface
Low-cyclonic-counter clockwise
High-anticyclonic-clockwise

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

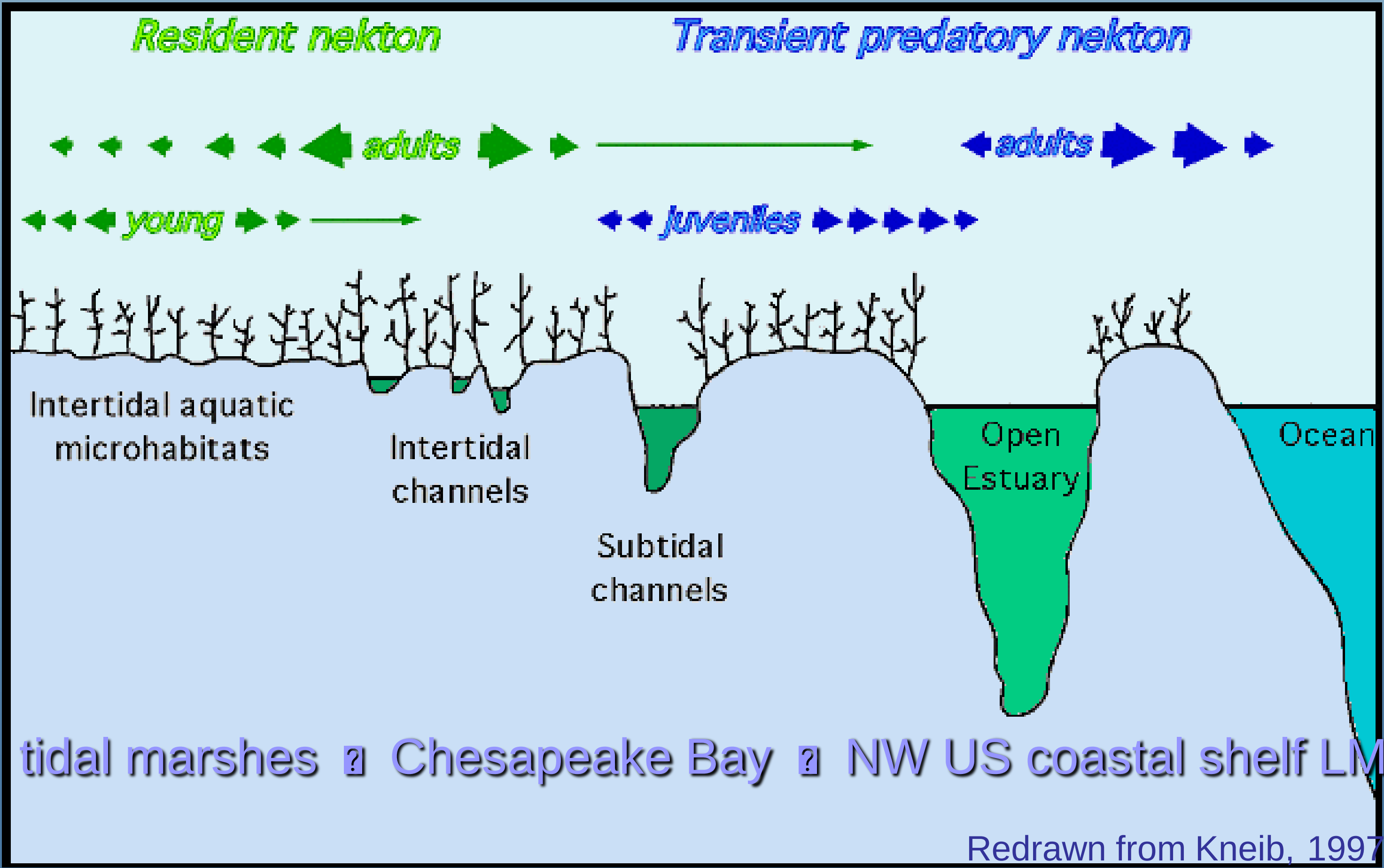


Rates ~ 3-4 mm yr^{-1}
(Global ~2 mm yr^{-1})

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’



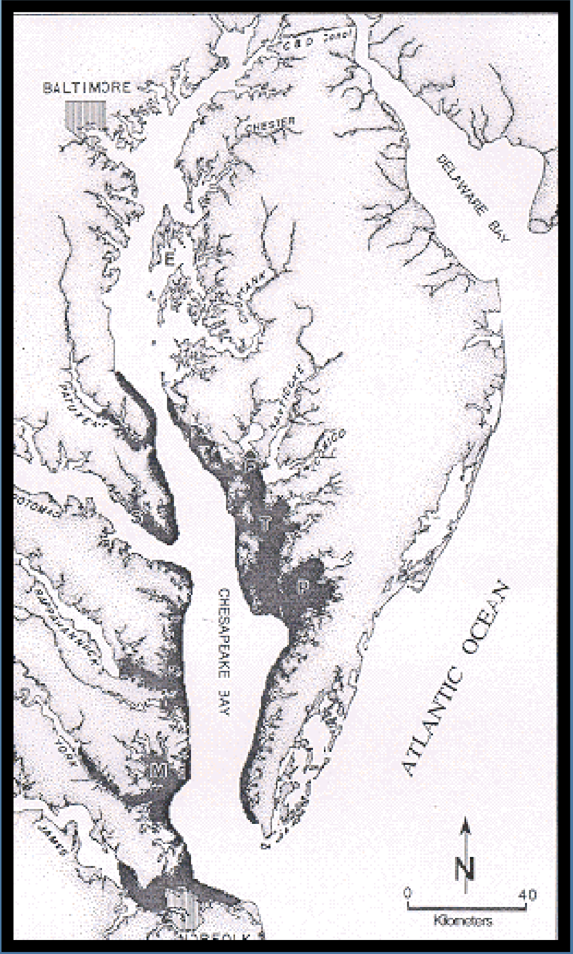
tidal marshes ⍰ Chesapeake Bay ⍰ NW US coastal shelf LME

Redrawn from Kneib, 1997

Climate & Disease…the links to humans, habitats, & fisheries

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

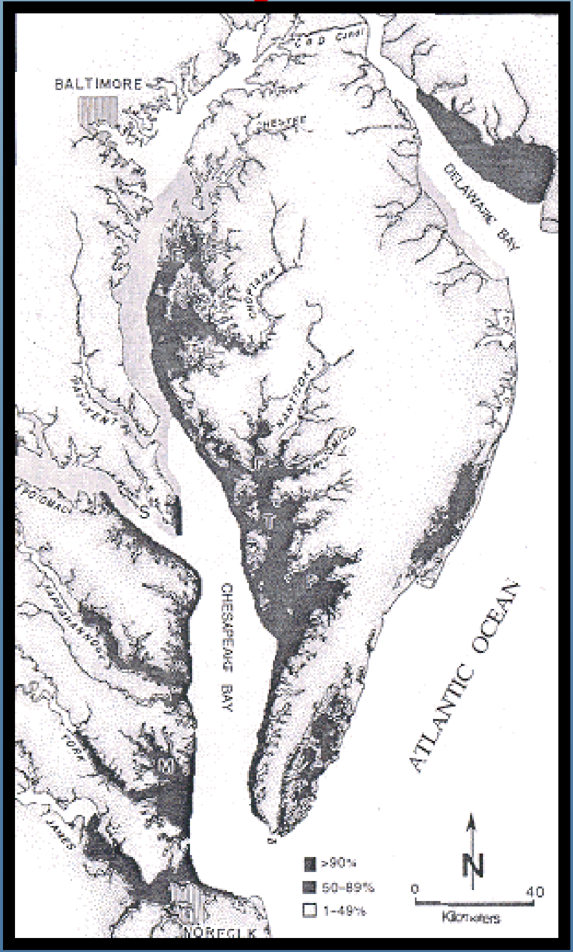
Prior to 1980



**1980's …
warm winters
& drought**

**facilitated
range
expansion**

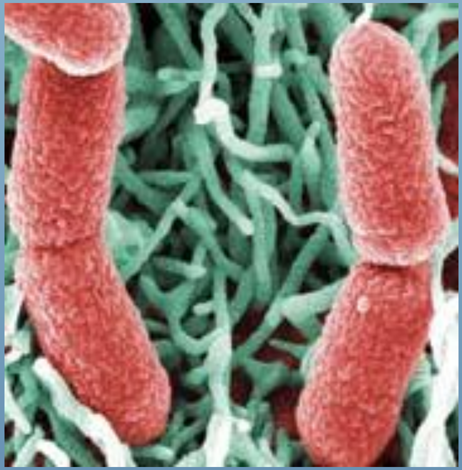
Early 1990's



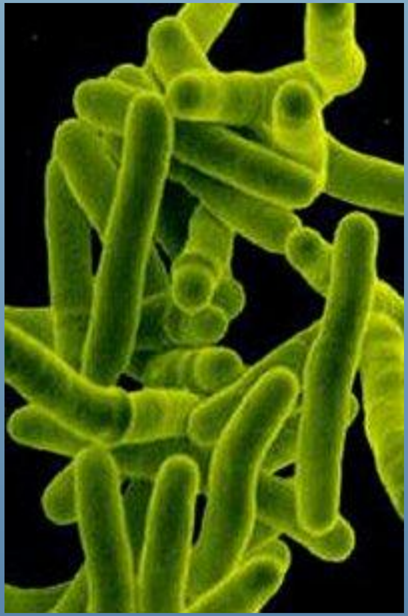
From: Burreson & Calvo (1996)

Pathogens: degraded habitats; diseased fish; & human health risks

Marine *Vibrio's*



Fecal Coliforms



Mycobacterium

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

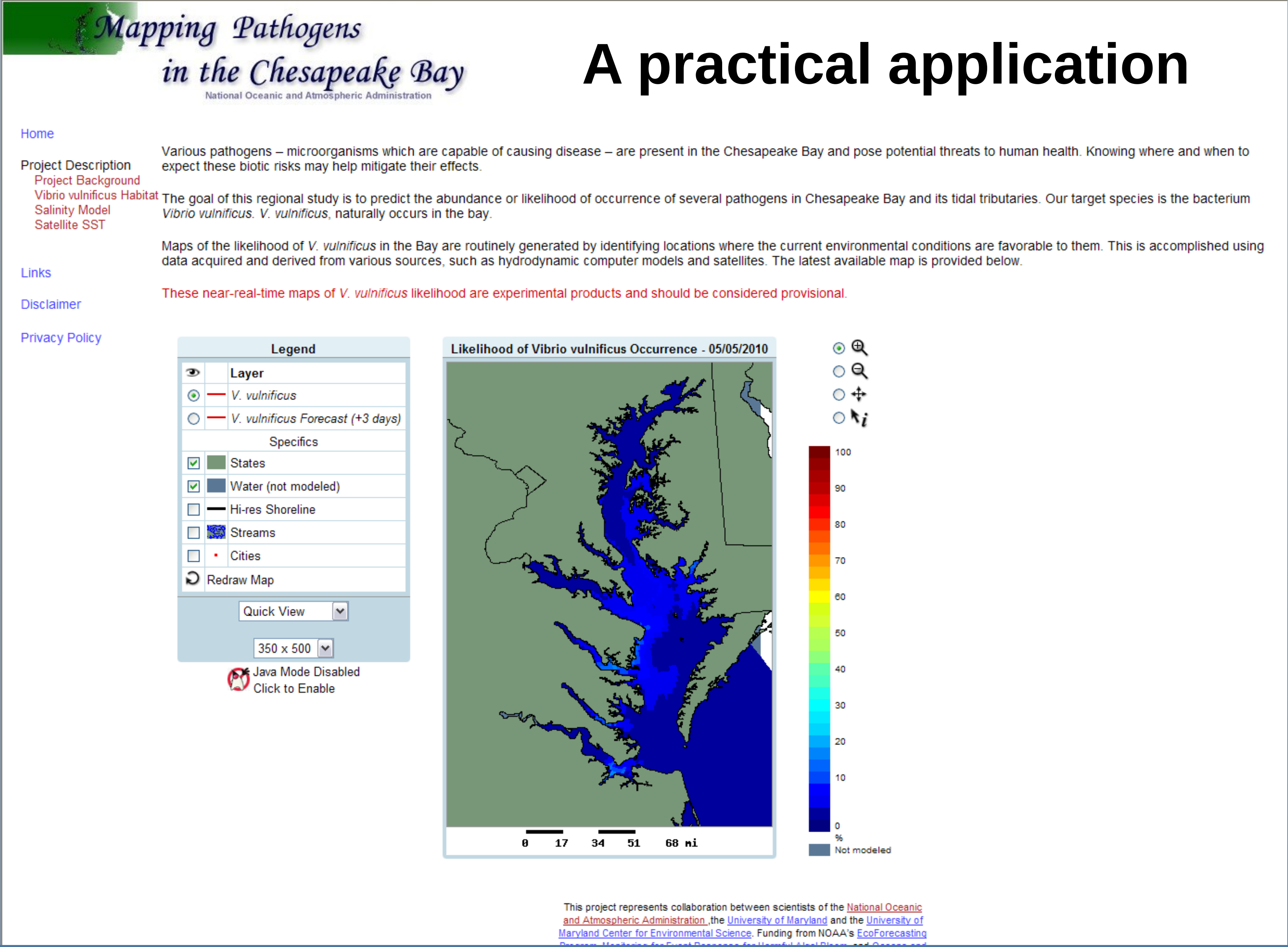
- controlled by temperature and salinity, associated with plankton

- 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?

A practical application



Mapping Pathogens in the Chesapeake Bay

National Oceanic and Atmospheric Administration

- Home
- Project Description
  - Project Background
  - Vibrio vulnificus Habitat
  - Salinity Model
  - Satellite SST
- Links
- Disclaimer
- Privacy Policy

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*. *V. vulnificus*, naturally occurs in the bay.

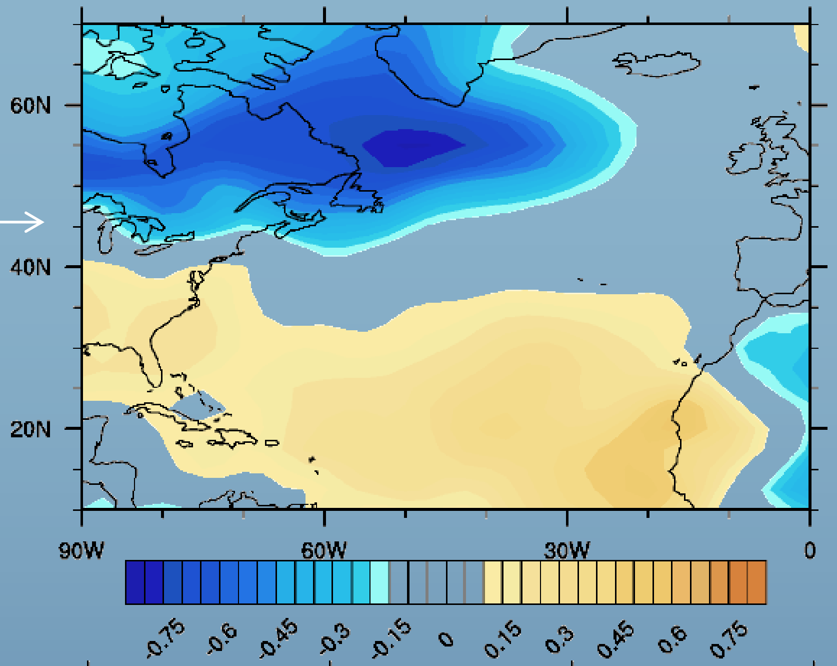
Maps of the likelihood of *V. vulnificus* in the Bay are routinely generated by identifying locations where the current environmental conditions are favorable to them. This is accomplished using data acquired and derived from various sources, such as hydrodynamic computer models and satellites. The latest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

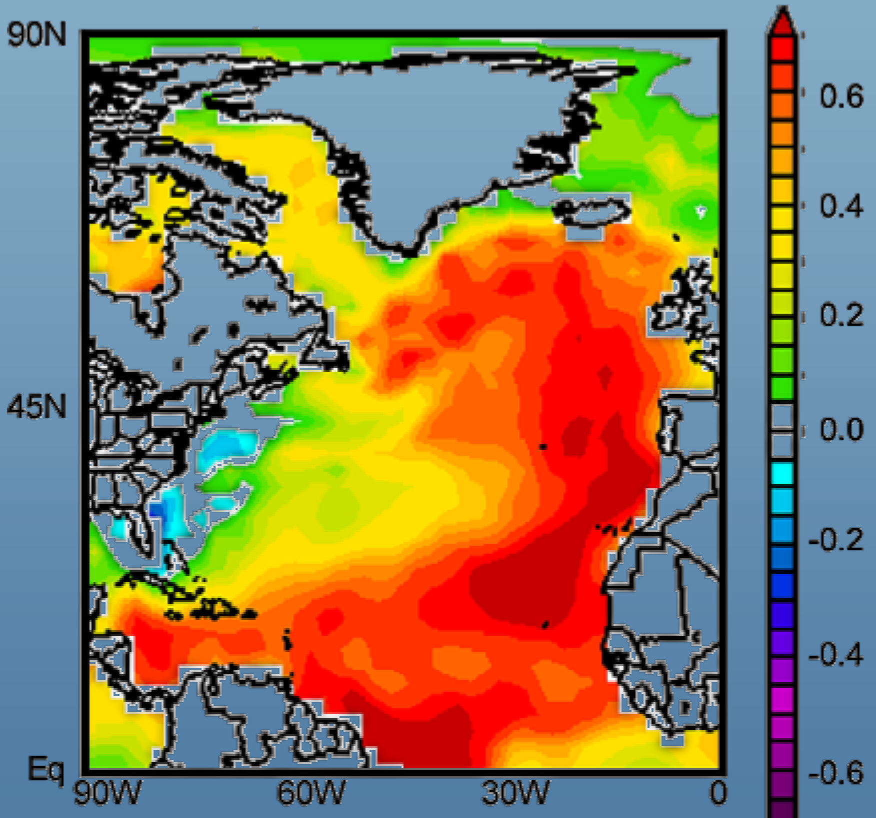
These near-real-time maps of *V. vulnificus* likelihood are experimental products and should be considered provisional.

This project represents collaboration between scientists of the National Oceanic and Atmospheric Administration ,the University of Maryland and the University of Maryland Center for Environmental Science. Funding from NOAA's EcoForecasting

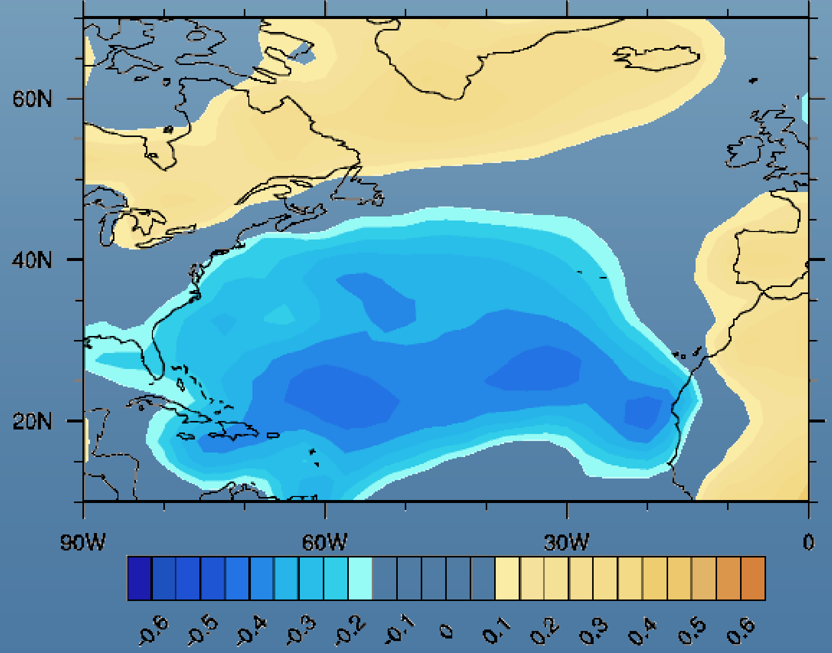
The linkage between the AMO & CBASS

SLP correlation w/CBASS





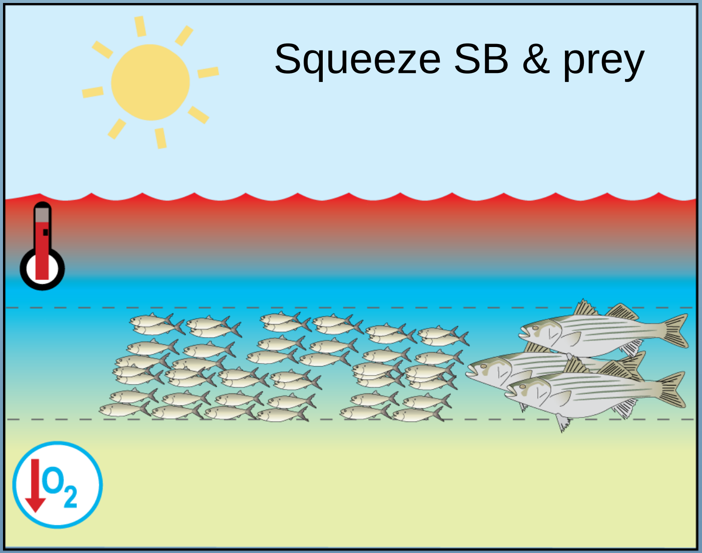
SST correlation with the AMO
for the winter-spring season (Dec-Jun)
NCEP/NCAR Reanalysis (NOAA/ERSL)

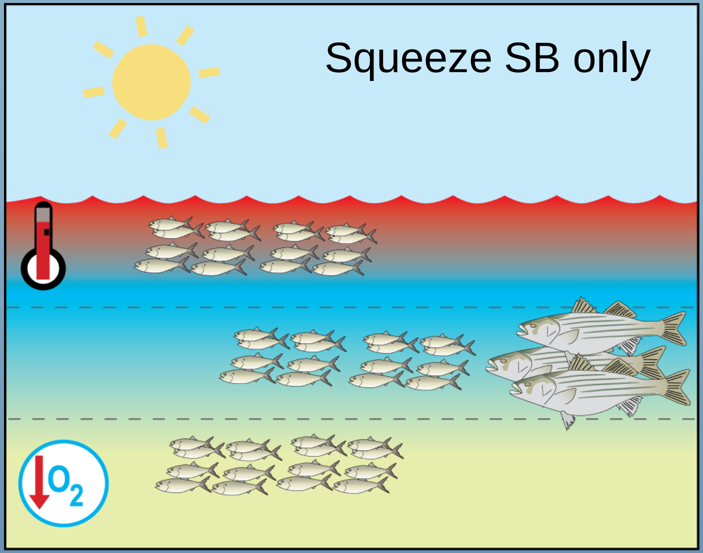


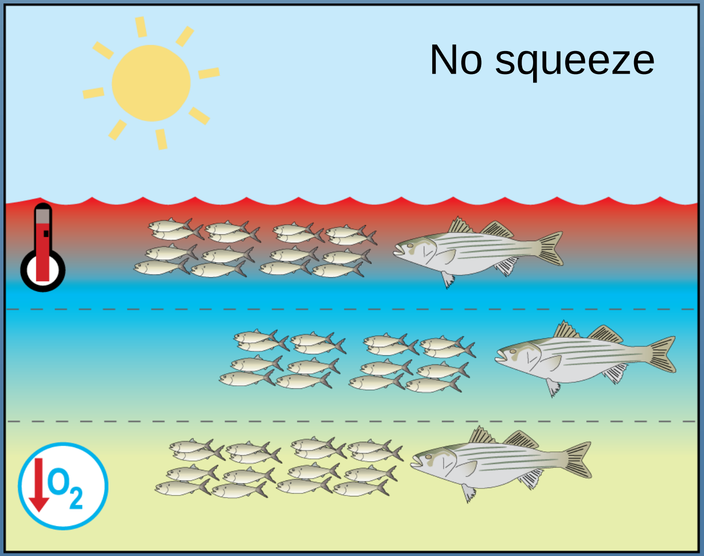
SST-AMO correlation

SLP-AMO correlation

Potential effects of habitat “squeeze” on striped bass individual & population





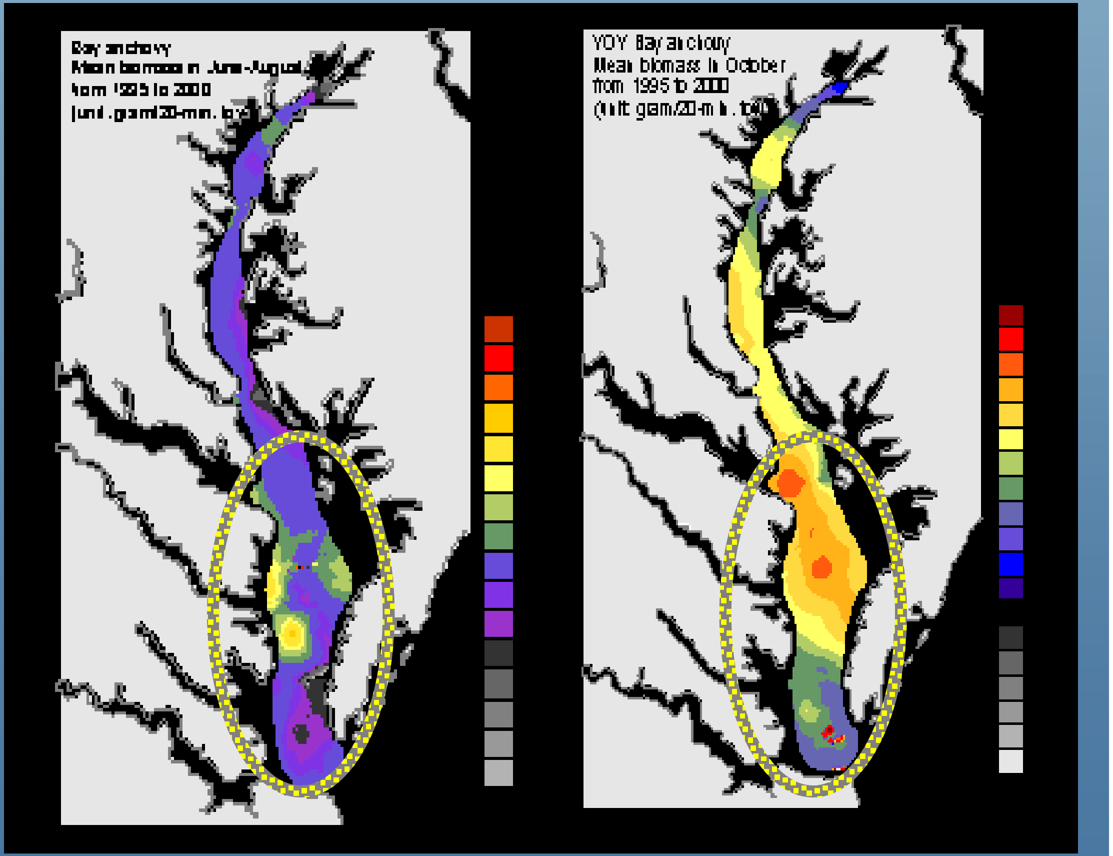


GRP is declining in the prime anchovy spawning & nursery area

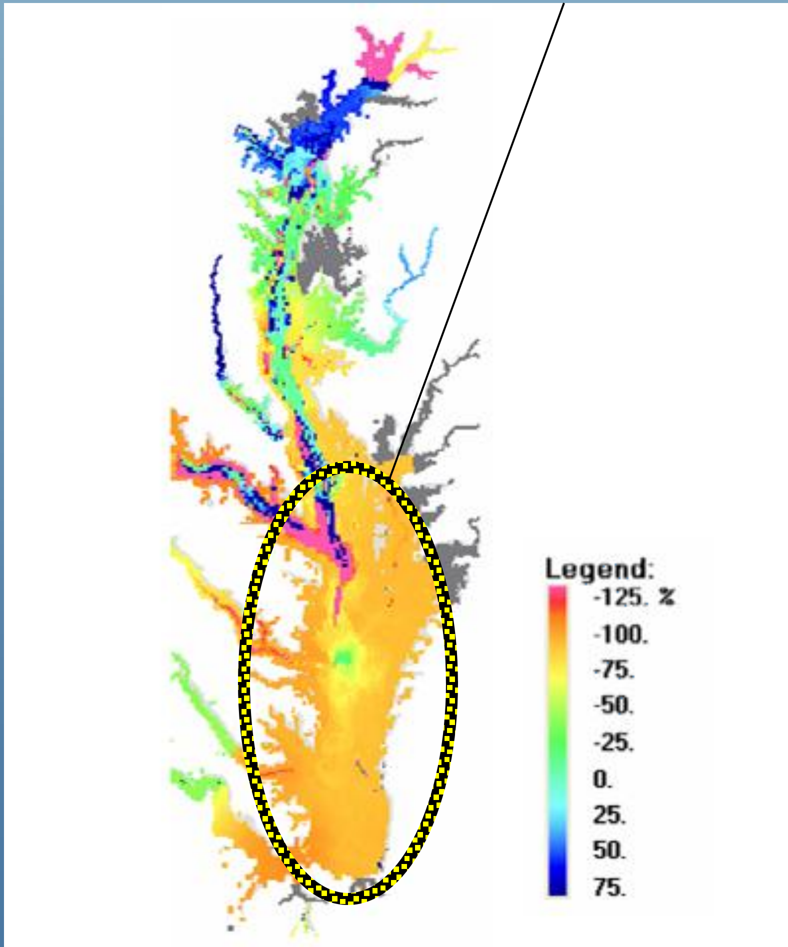
Anchovy biomass (TIES 1995-2000)

Adults (jun-aug)

YOY (Oct)



Model indicates declining conditions 1986-2002

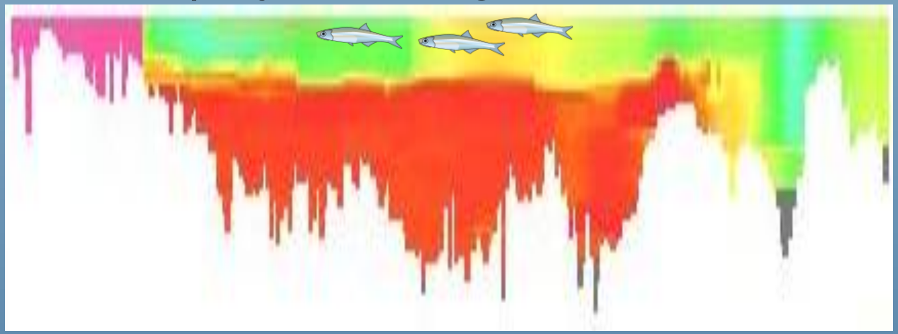


Potential influence of habitat squeeze on striped bass forage: implications for fisheries

Poor

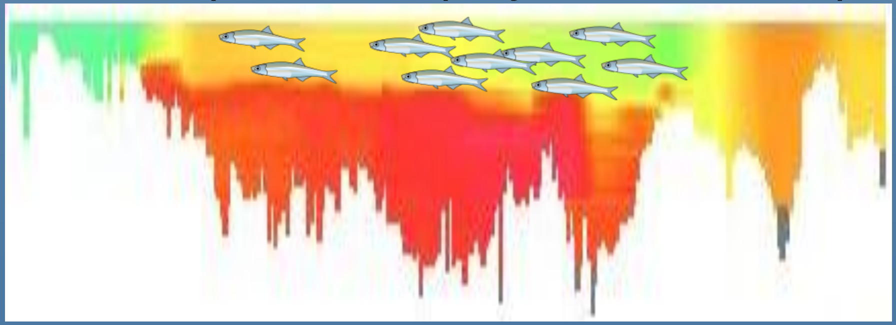
Good

1999 prey has refuge

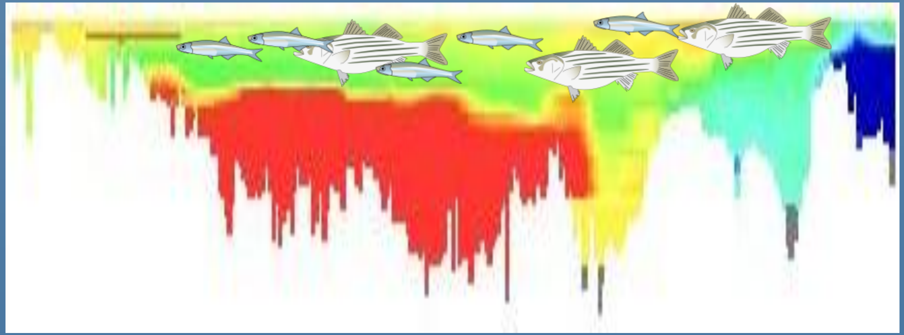


1999 predator “squeezed” - prey refuge

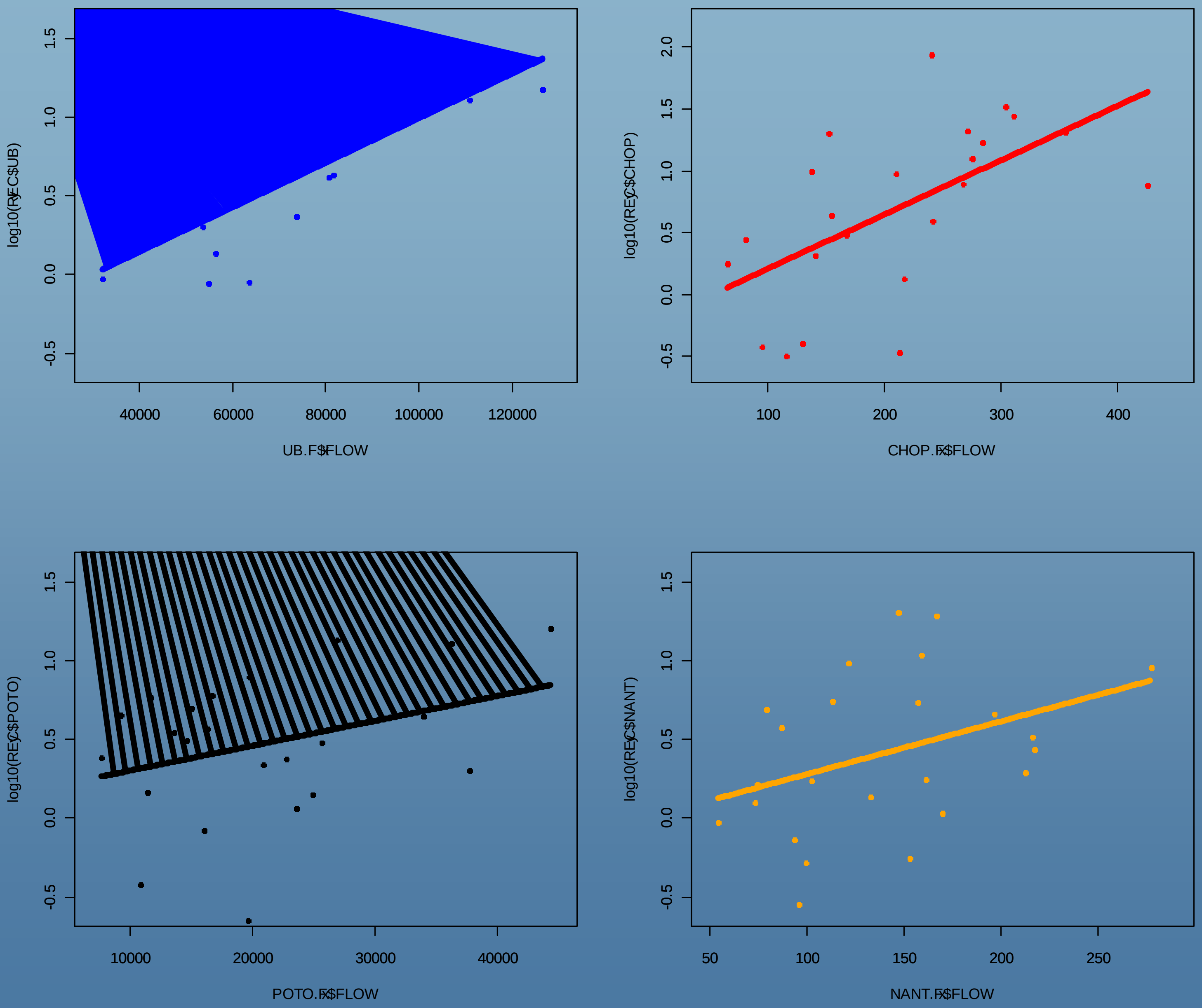
1996 predator – prey habitat overlap



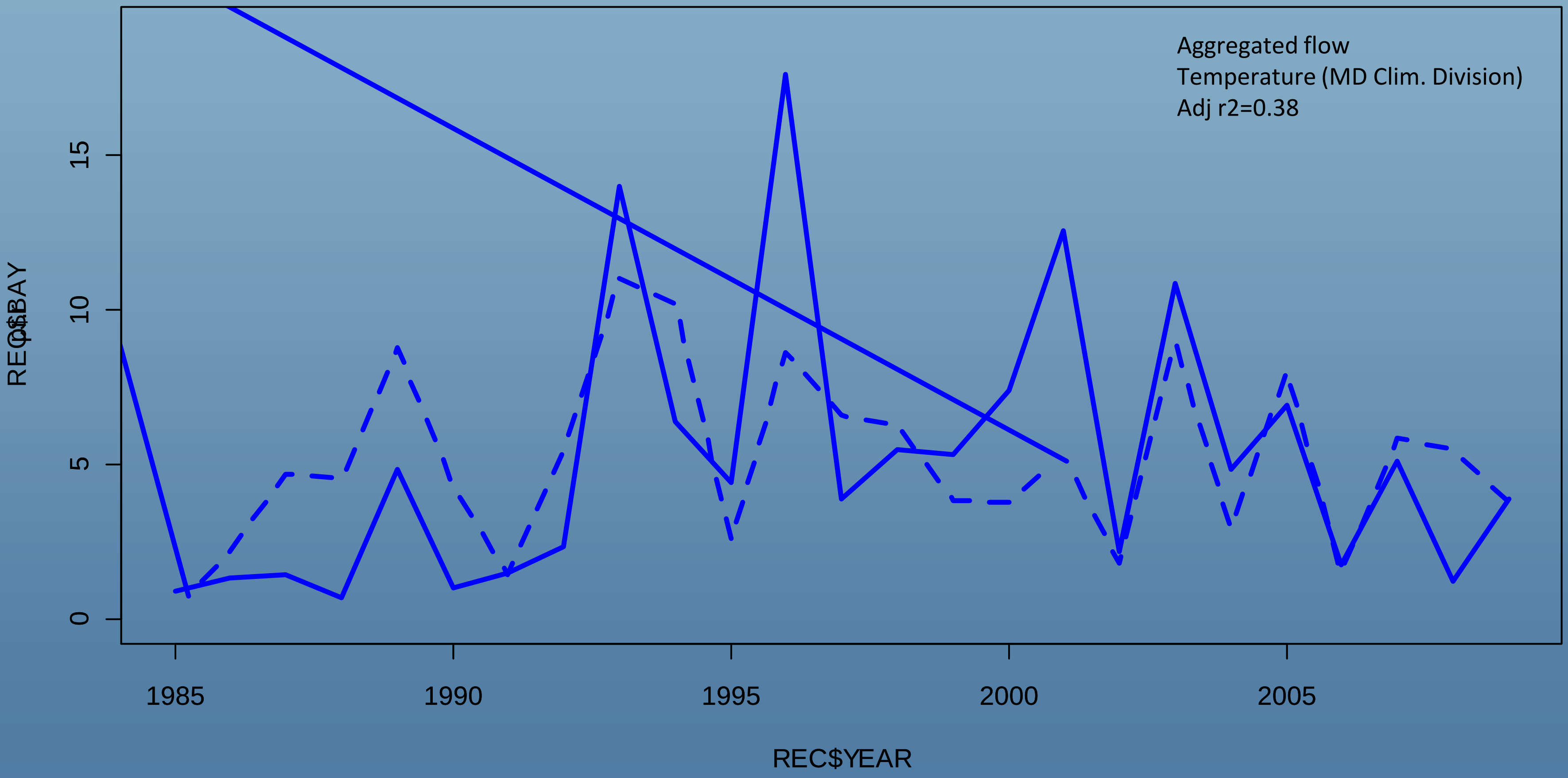
1996 no temp squeeze – pred-prey overlap

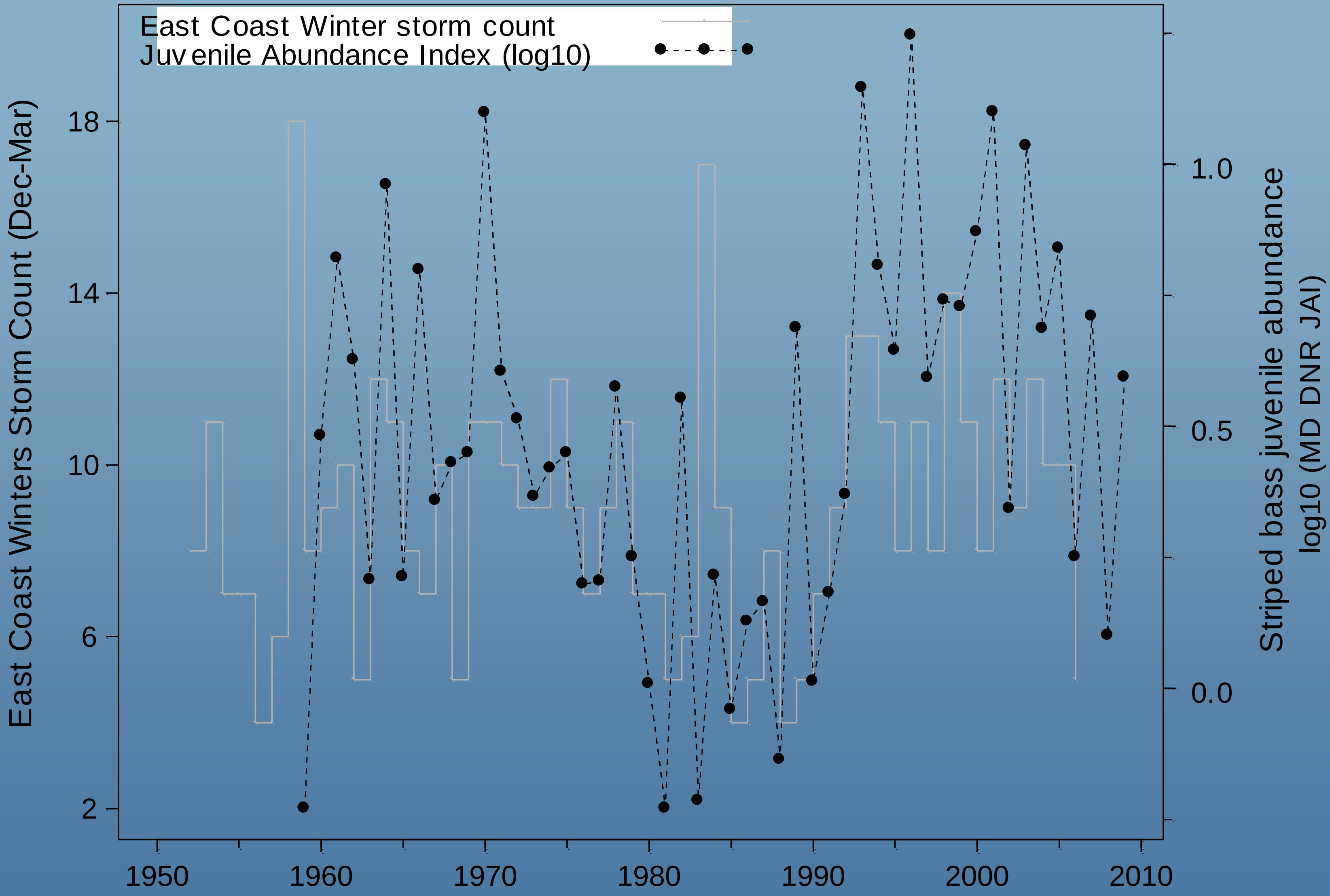


Freshwater flow and striped bass recruitment by location



Baywide Recruitment Model




East Coast Winter storm count
Juv enile Abundance Index (log10)
East Coast Winters Storm Count (Dec-Mar)
18
14
10
6
2
1950
1960
1970
1980
1990
2000
2010
1.0
0.5
0.0
Striped bass juvenile abundance
log10 (MD DNR JAI)