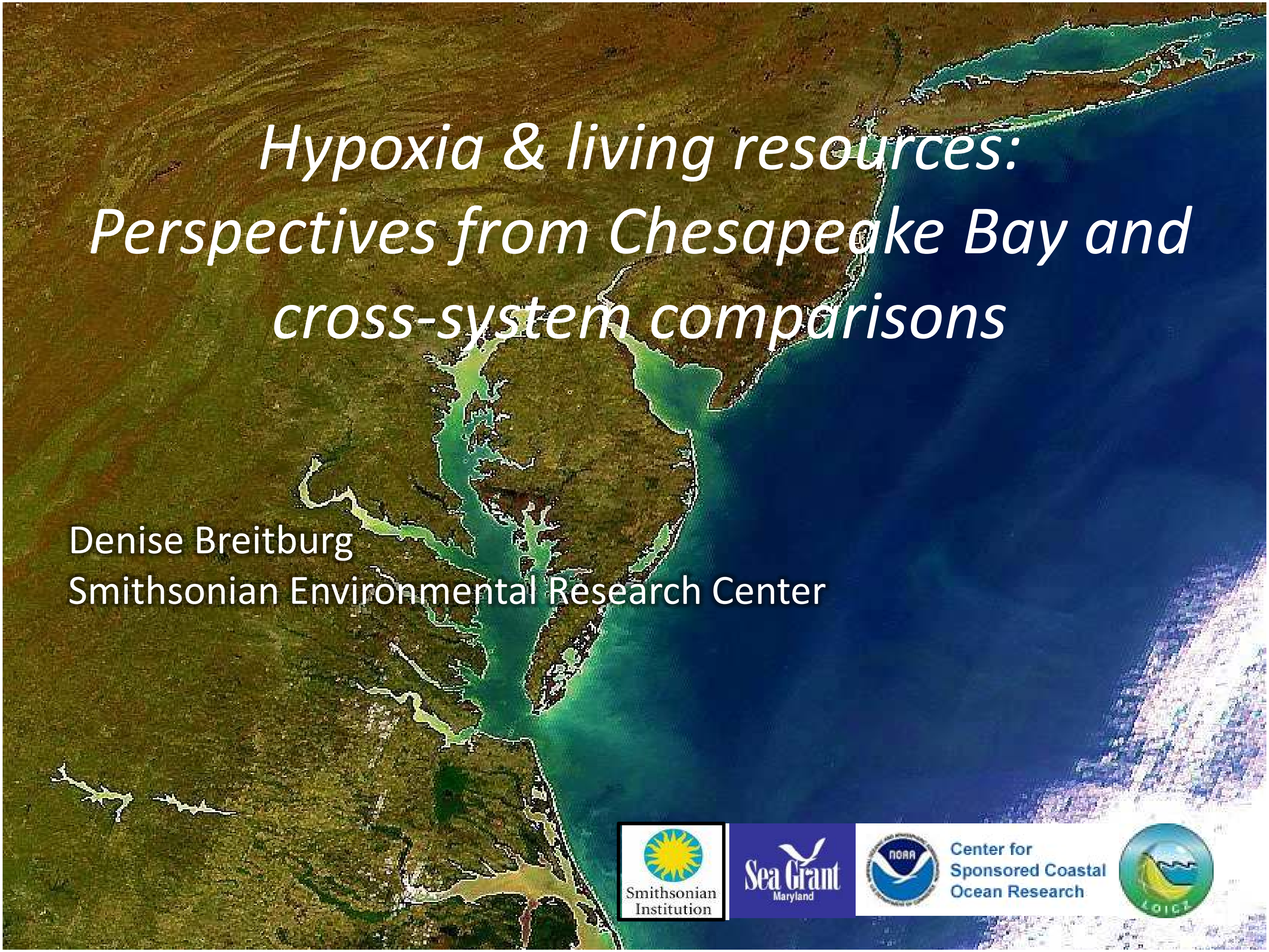
Hypoxia & living resources: Perspectives from Chesapeake Bay and cross-system comparisons

Denise Breitburg
Smithsonian Environmental Research Center



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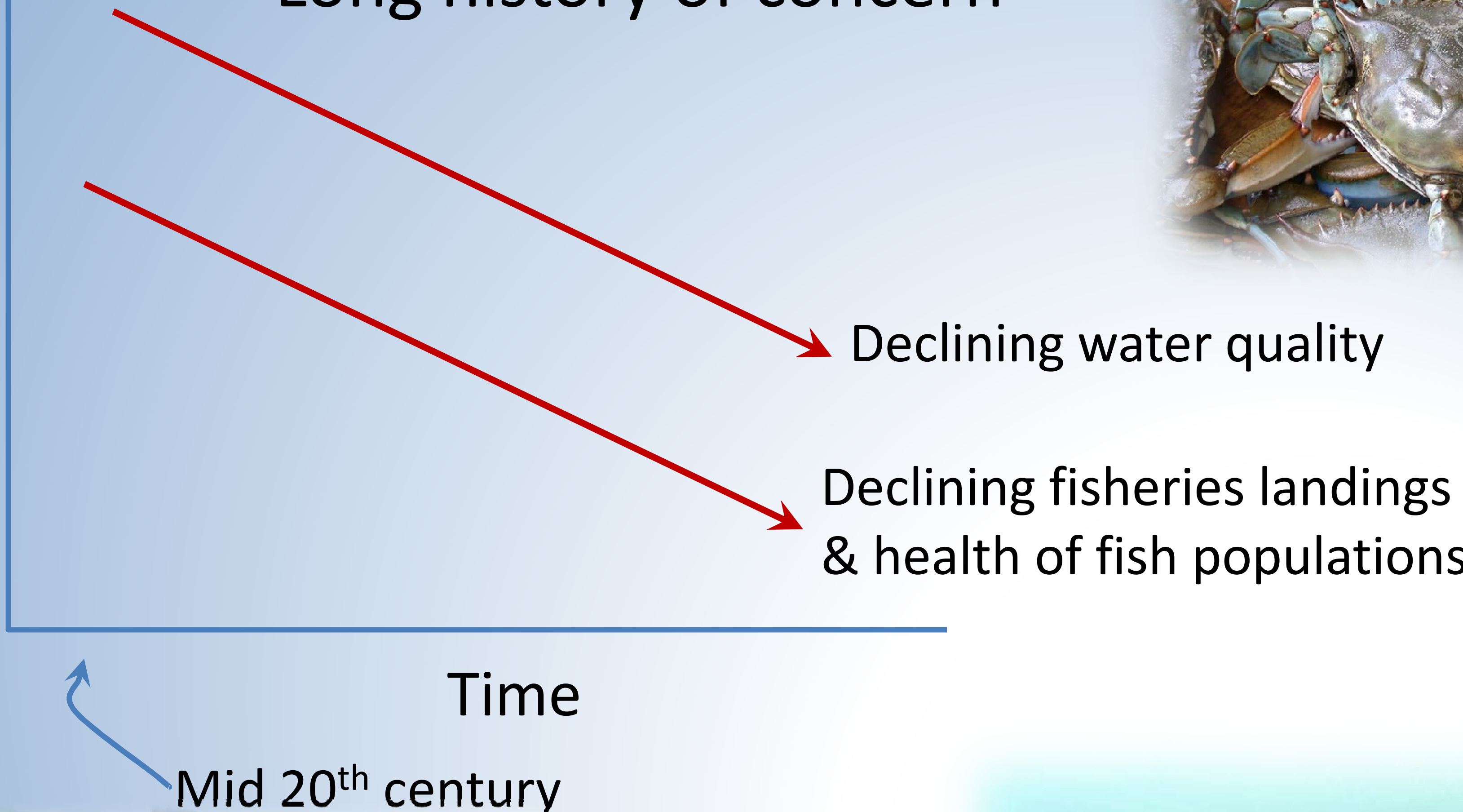
Contrasting effects of nutrient enrichment

Fish kills

Productive Fisheries

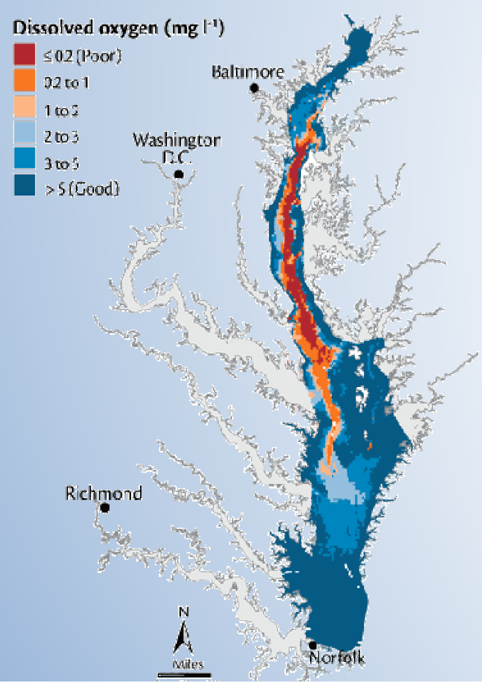
Long history of concern



Understanding the water quality – fish – fisheries link is critically important

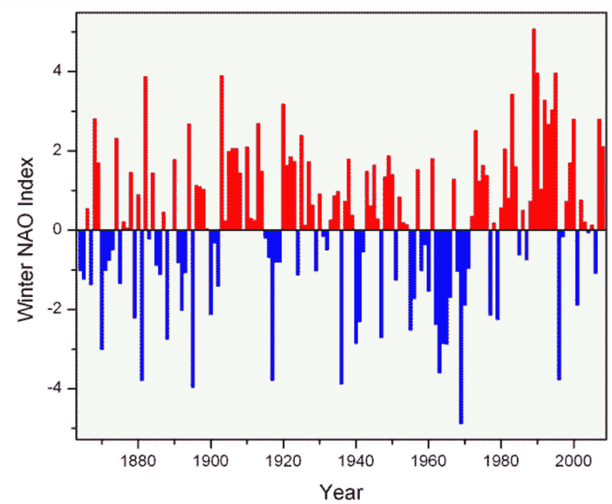
Can't transition to ecosystem-based management and can't implement management actions to restore declining populations *without unfairly penalizing the wrong sectors* unless we understand the contributions of:

Water & habitat quality



Fisheries mortality

Climate cycles & directional change



Chesapeake & beyond - outline

- What we know from experiments & field sampling about effects on mobile consumers
- Why it's hard to scale up to population-level effects
- Cross system comparisons

- Diel cycling hypoxia – mostly oysters
- Scaling up
- The other acidification problem

Effects of hypoxia at the local scale:

Mortality

Reduced Growth/ Avoidance

Altered Trophic Interactions

Reduced Reproduction

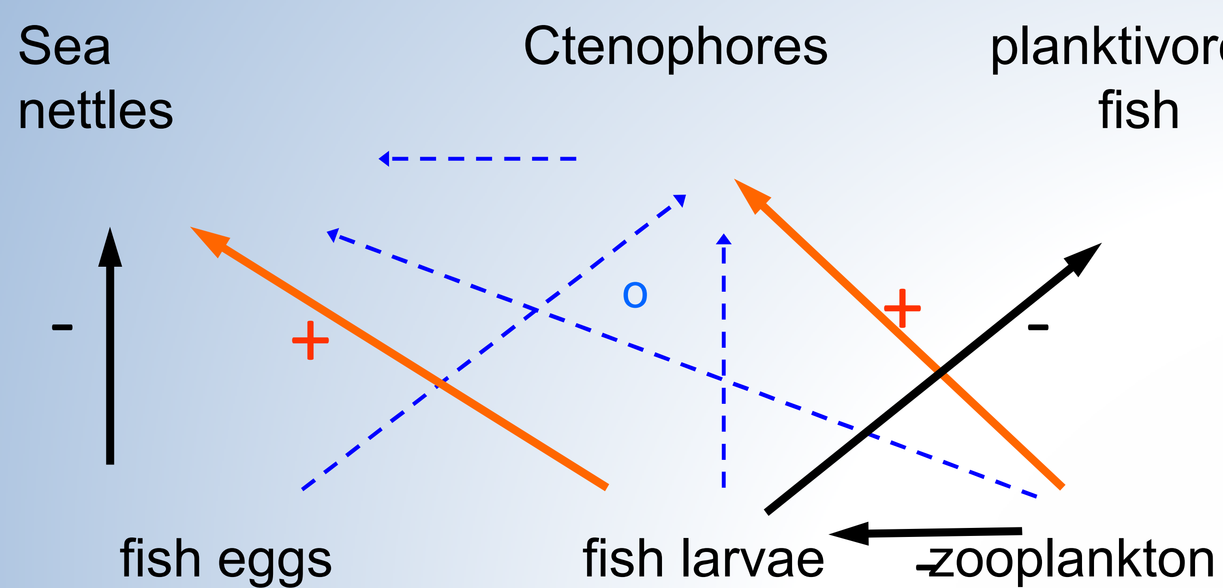
Reduced Immune Response

In Chesapeake Bay:

- Favors gelatinous zooplankton
- Reduces growth rates
- Forces fish (sturgeon, striped bass) into
- surface waters with high temperatures
- Compromises immune response of oysters
- High mortality of bay anchovy and
- maybe weakfish eggs
- Fish kills, mortality of newly settled oyster spat
- Important temperature * hypoxia interactions

…lost habitat, lost production, mortality

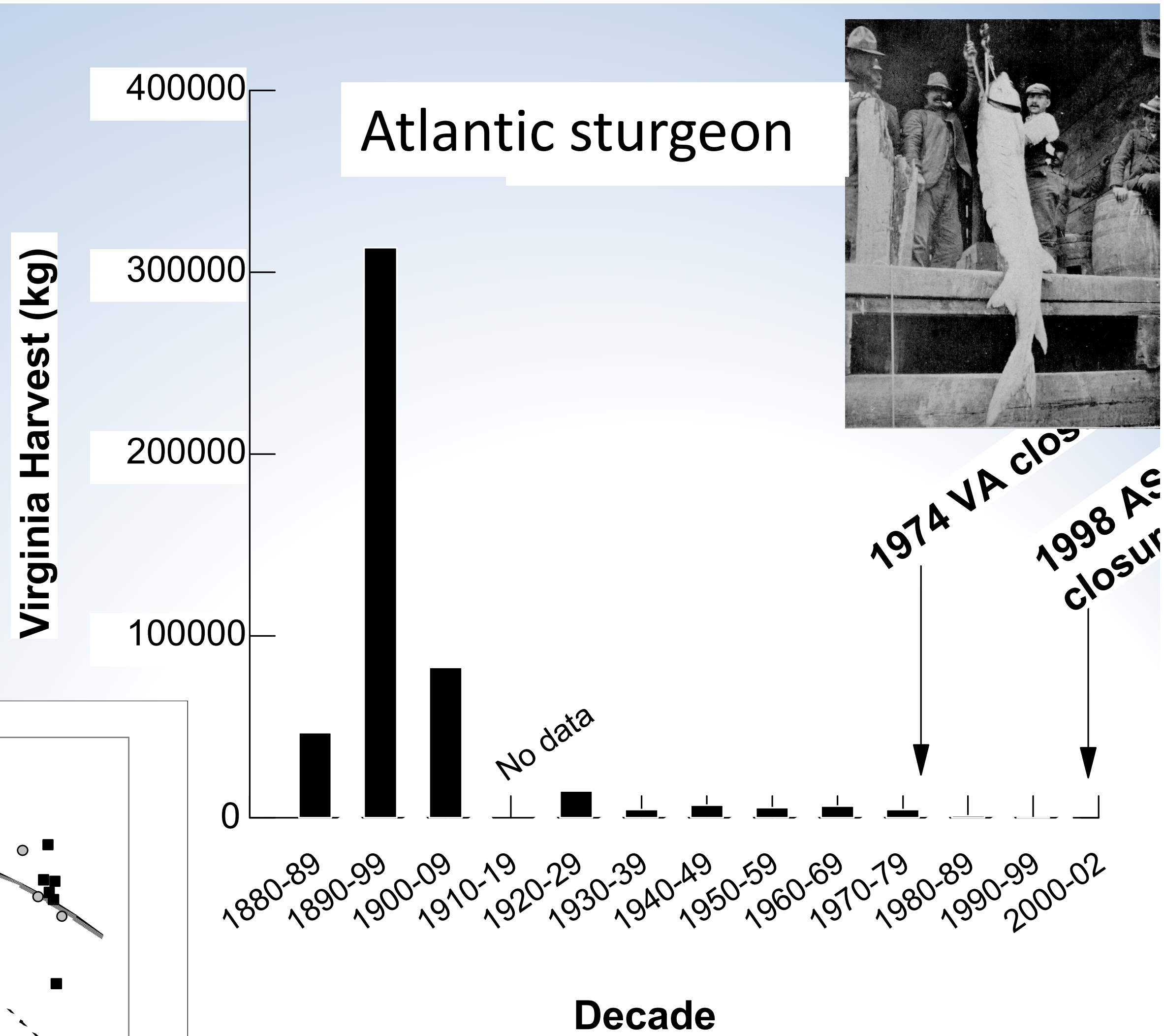
Effect of low dissolved oxygen on trophic interactions



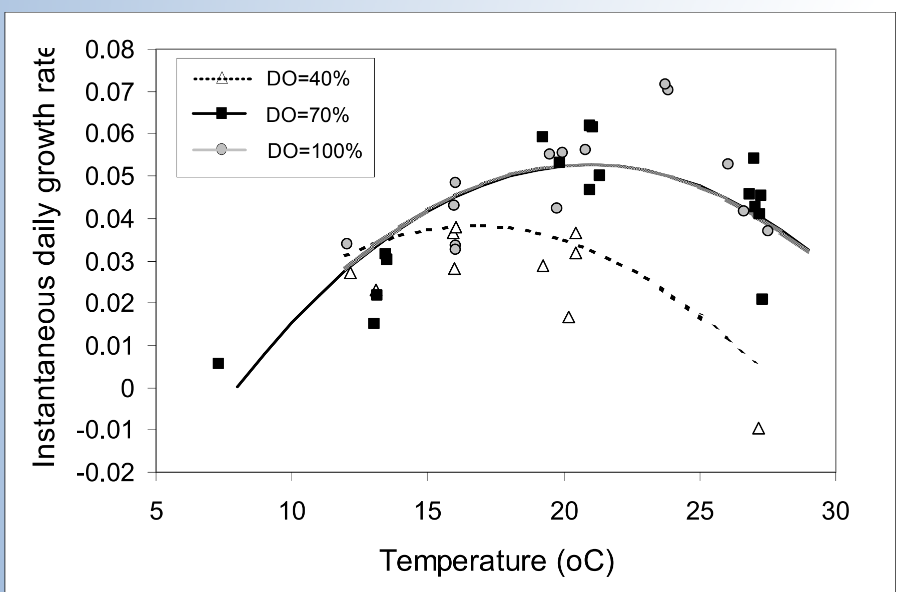
Hypoxic areas can increase predation by and energy flow to tolerant predators such as gelatinous zooplankton

Breitburg et al., 1997, 1999, 2003
Adamack et al., 2012

Some species are particularly sensitive because they show joint sensitivity to fishing and hypoxia



Atlantic sturgeon



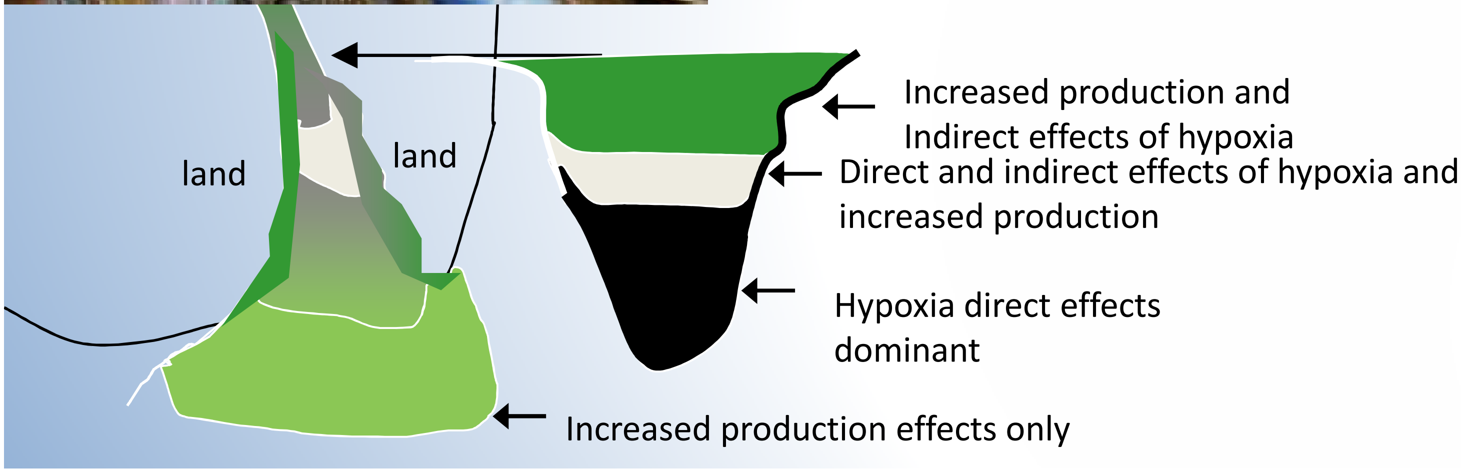
Figures from Dave Secor

See also: Niklitschek, E.J. and Secor, D.H. 200
& Niklitschek 2001

Evidence of negative population-level effects elusive

Compensatory mechanisms

- Behavior, growth and fishing practices result in spatial and temporal averaging by fish and fisheries



Abundant Solomons Island SAV during May 1938

compared to Summer 1999

Compensatory mechanisms

- Behavior, growth and fishing practices result in spatial and temporal averaging by fish and fisheries

- turbidity as a substitute refuge for submerged macrophytes

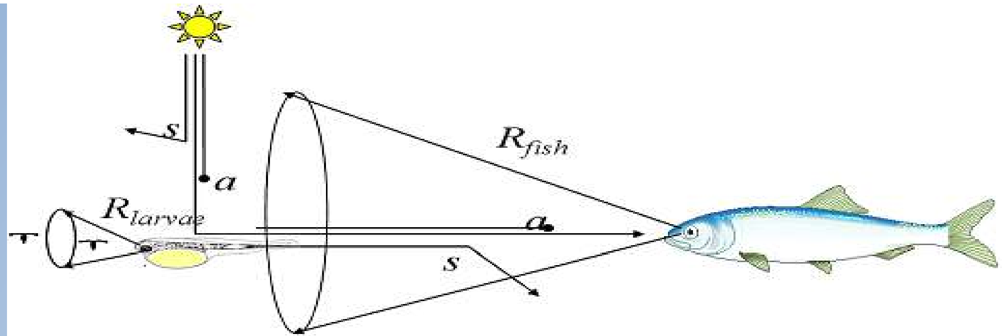
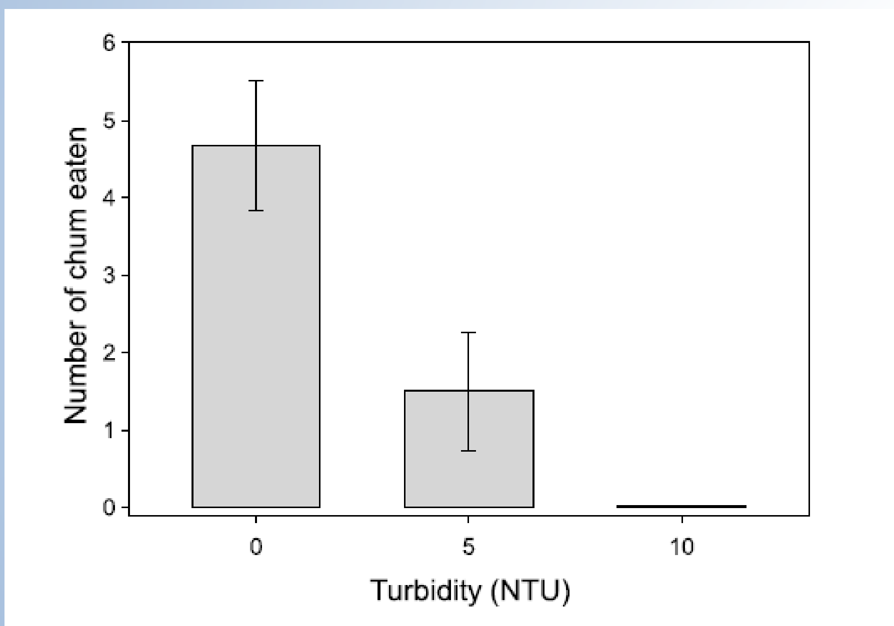
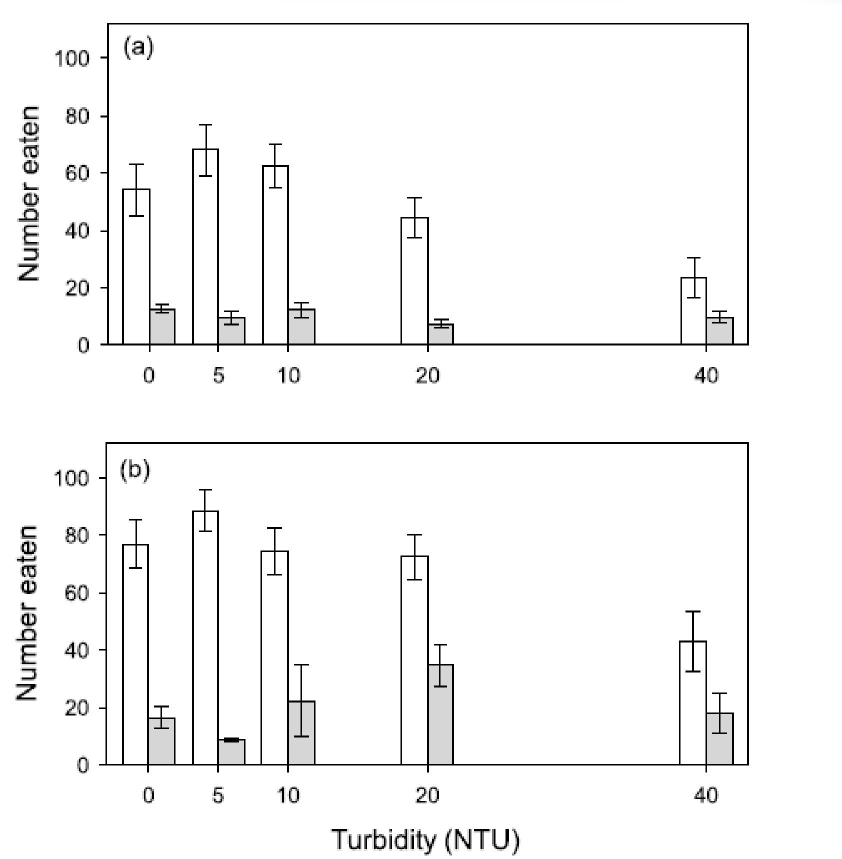


Figure from: http://www.bio.uib.no/modelling/files/fishvision_515x222.bmp

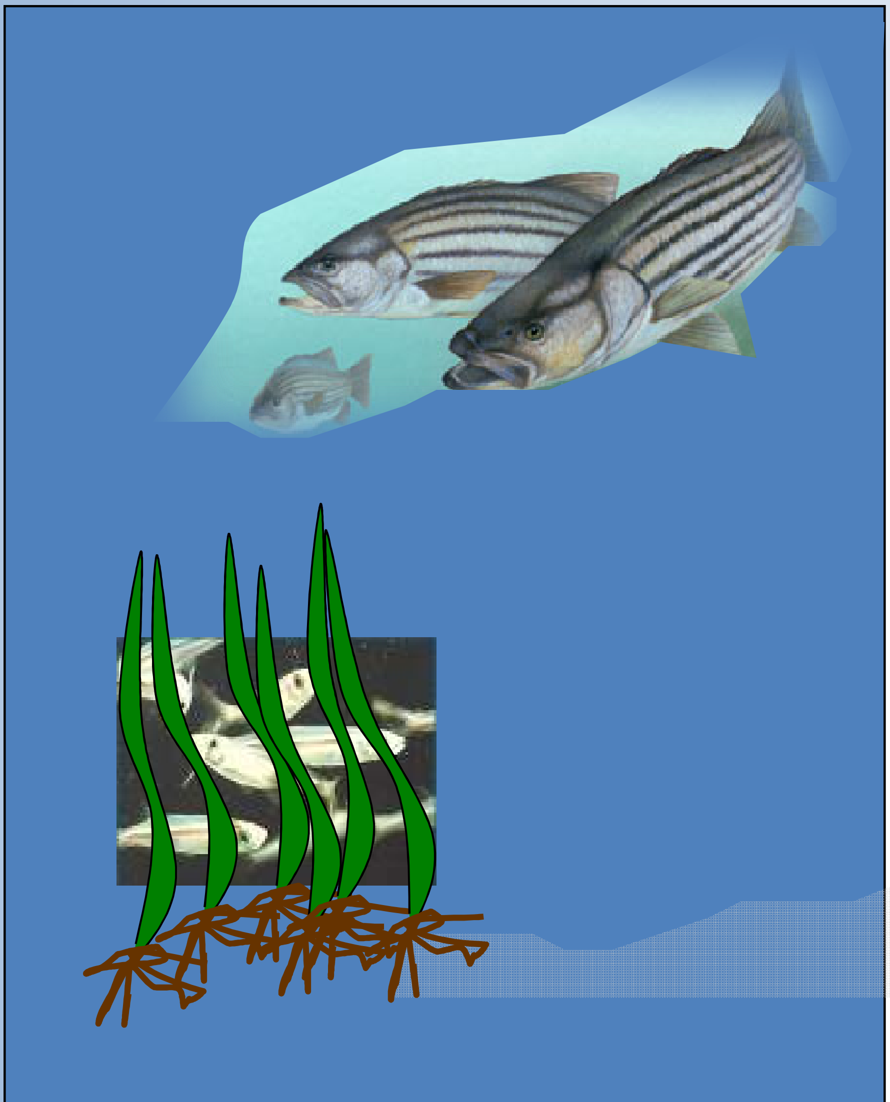
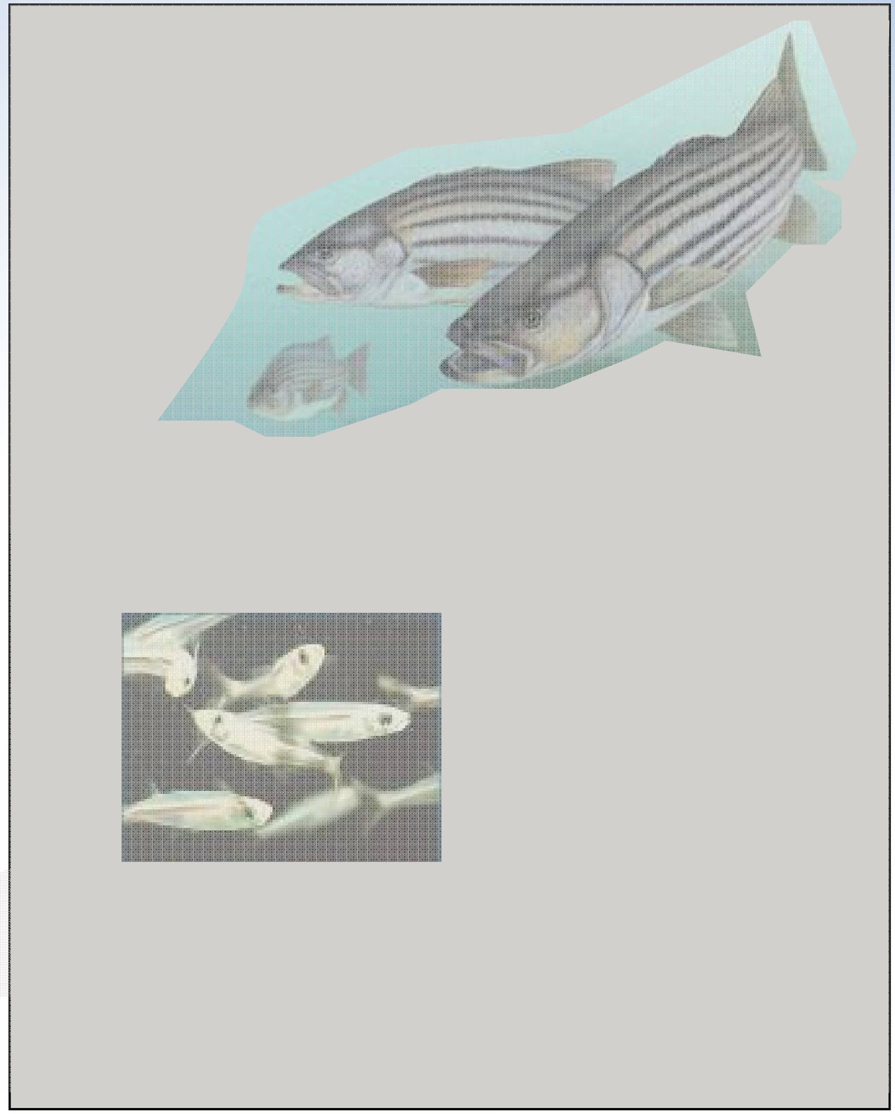
Strong effect of turbidity on piscivore



Lack of turbidity effect on 2 planktivores at high and low light



De Robertis et al. 2003

http://www.statesymbolsusa.org/IMAGES/New_Hampshire/striped_bass_art_380.jpg

Compensatory mechanisms

- Behavior, growth and fishing practices result in spatial and temporal averaging by fish and fisheries

- turbidity as a substitute refuge for submerged macrophytes

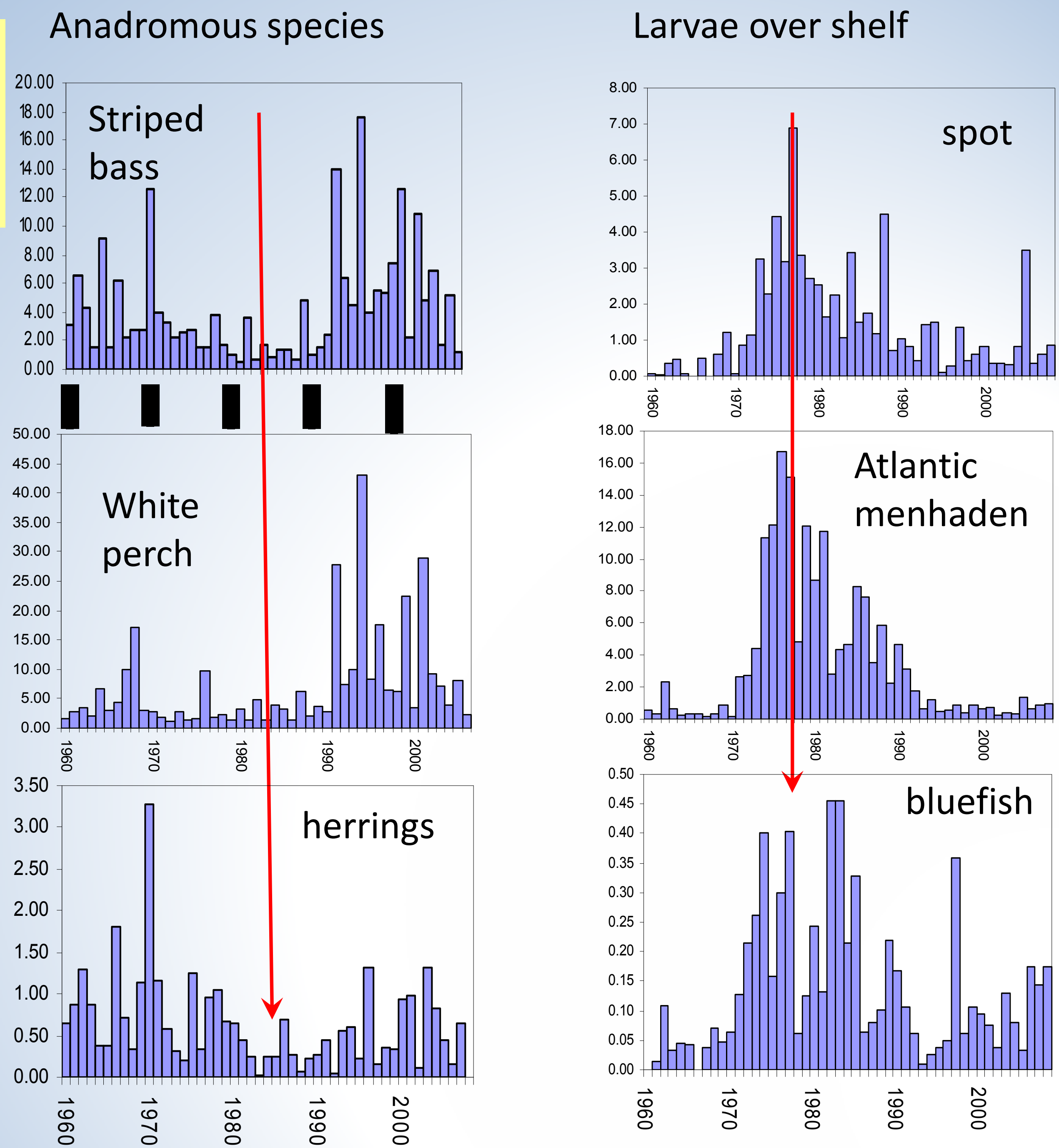
- overfishing keeps populations below habitat-determined carrying capacity – therefore little effect of decreased habitat

effects strongest when pops high and affected habitat is critical and limited

Importance of Climate Cycles

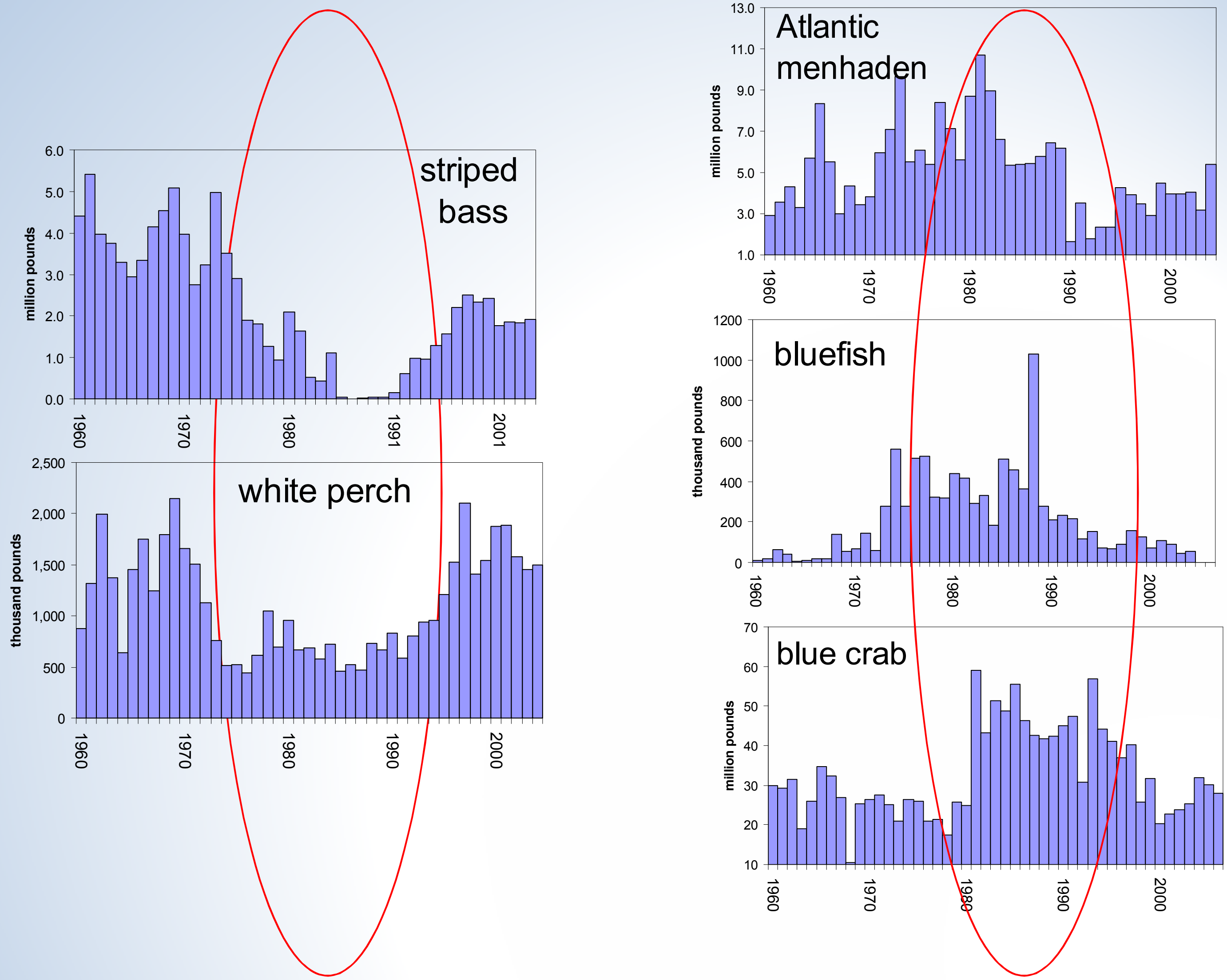
Young- of-Year

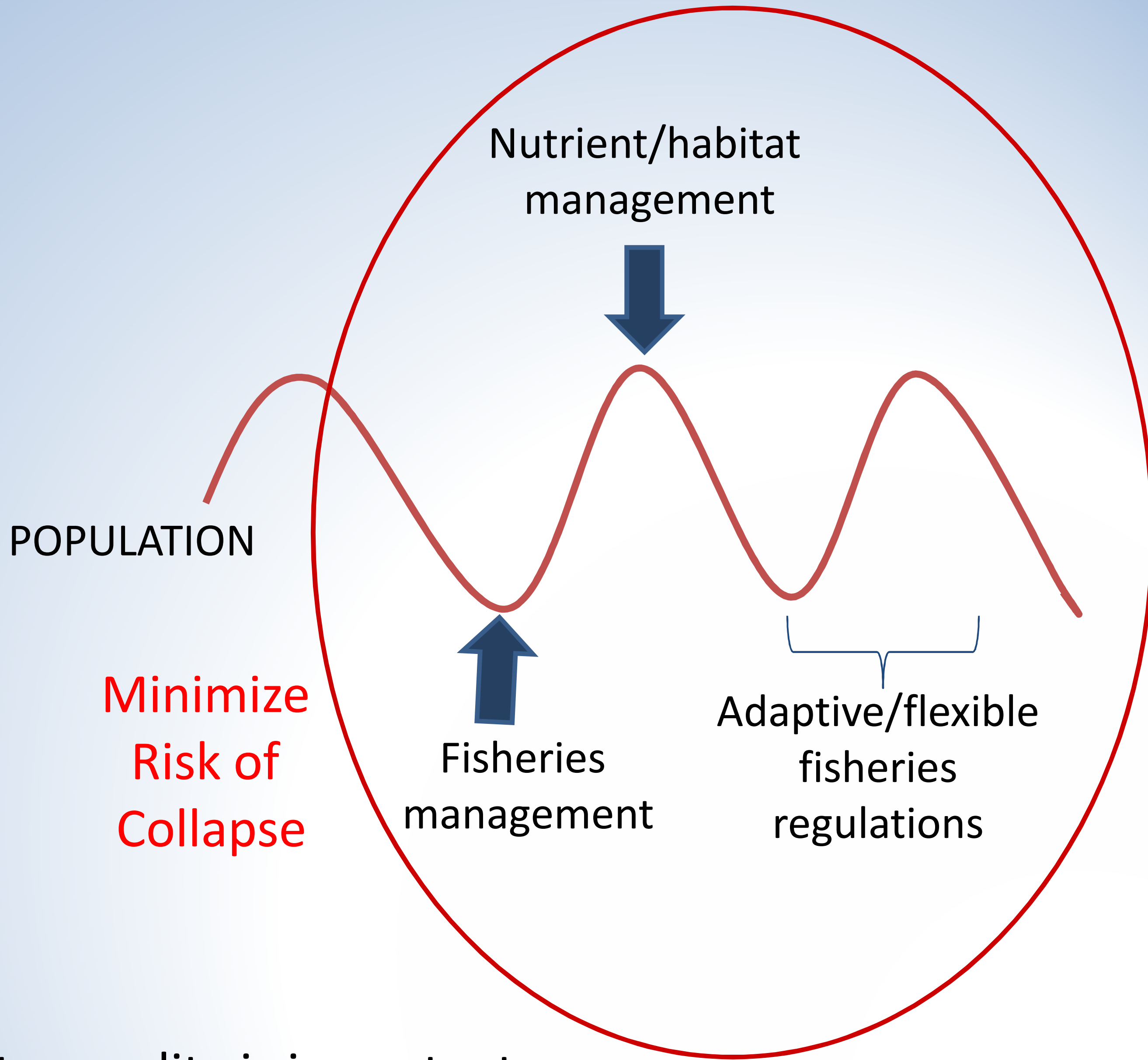
Geometric means of MD shore seine surveys



Based on Wood, et al 2009 & unpubl

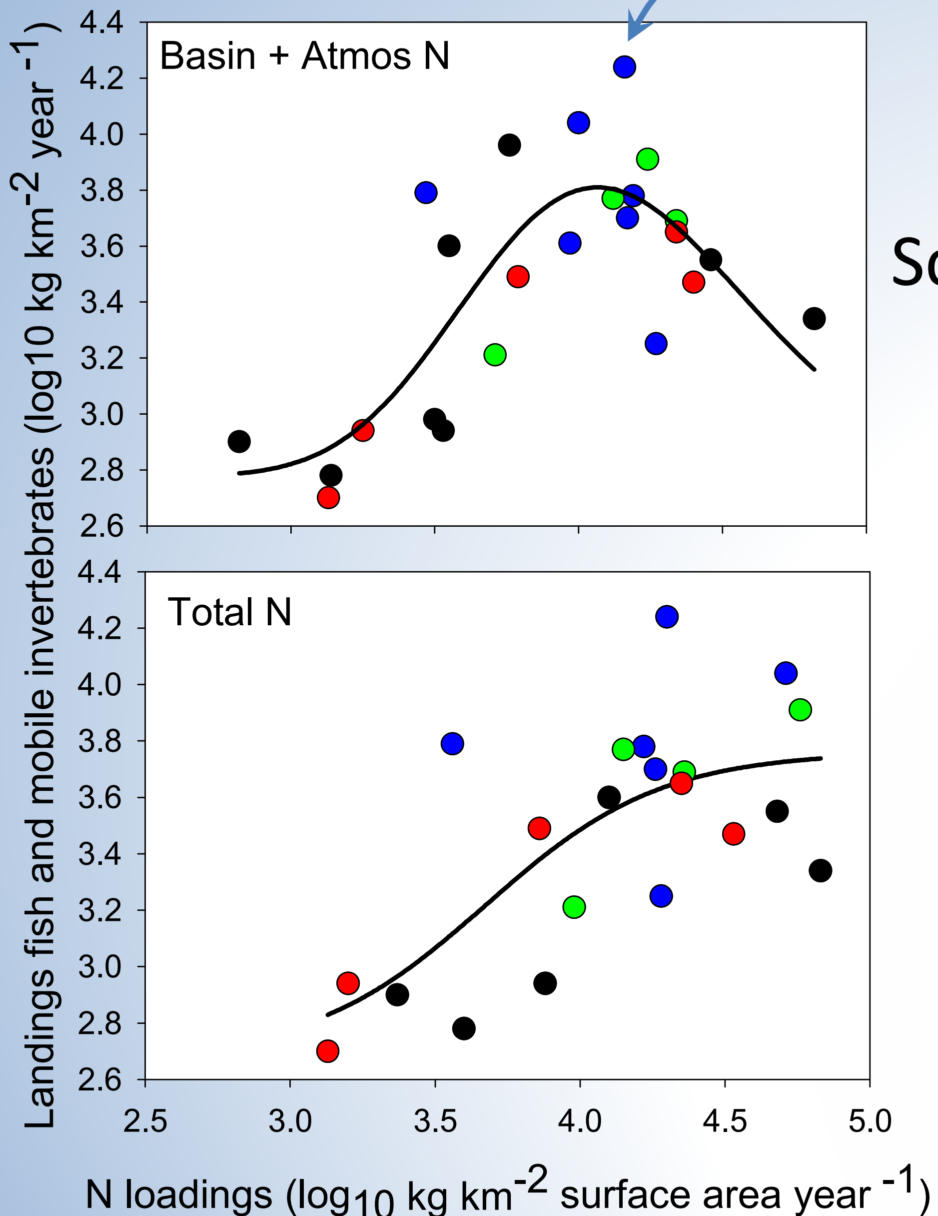
Commercial Landings





Improving water quality is important –
but is not sufficient to restore fisheries species

Scaling up- cross-system comparisons



<2 % hypoxia

4-19% hypoxia

22-31% hypoxia

40-77% hypoxia

Breitburg et al., 2009. Ann Rev Mar Sci

Is the problem relying on fisheries data to ask questions about populations & food webs?

NITROGEN
LOICZ
other system-specific models
Global NEWS model
Global atmospheric deposition models

HYPOXIA
persistence
extent

ECOPATH FOOD WEB MODELS
biomasses
fisheries removals
food web composition
food web & ecosystem metrics

Mobile consumers

Food web characteristics

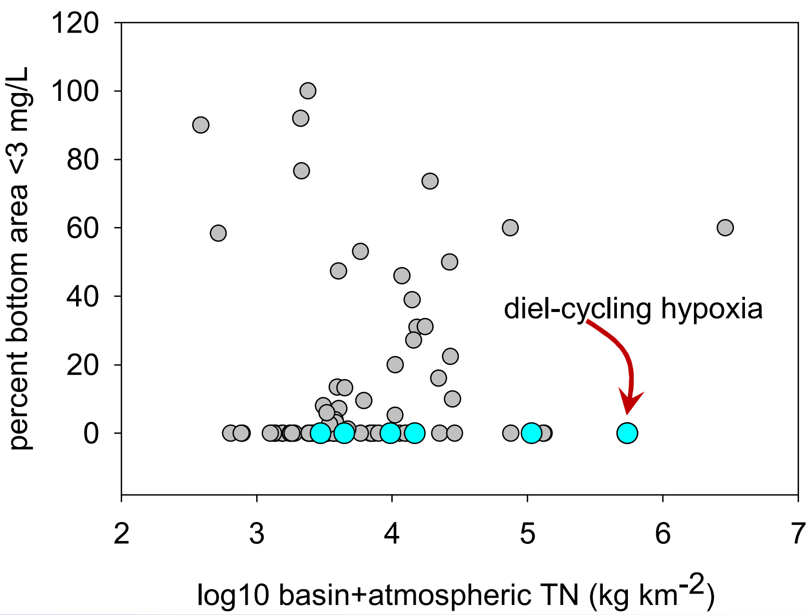
OCEANIC INPUTS
models results
system openness
upwelling

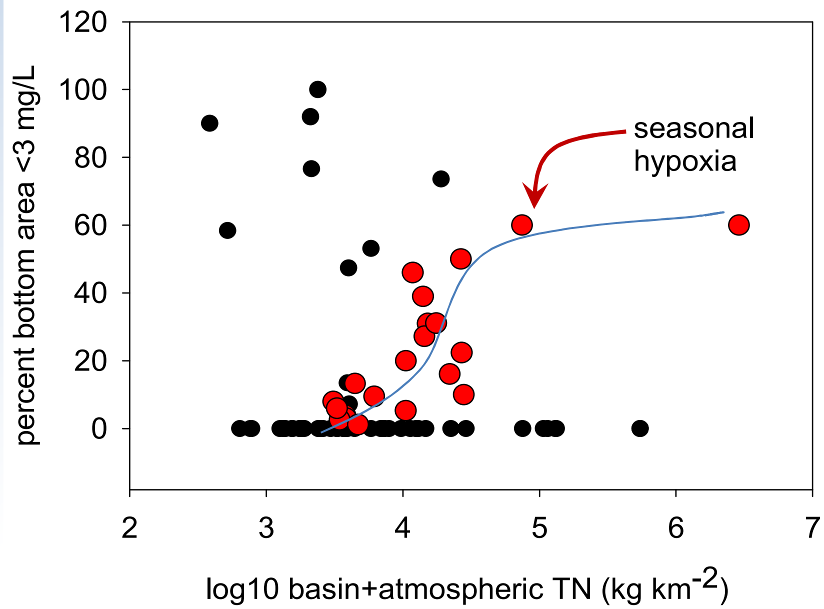
SYSTEM CHARACTERISTICS
area, depth
temperature
tidal range
chl a
primary productivity
additional recreational & commercial landings data

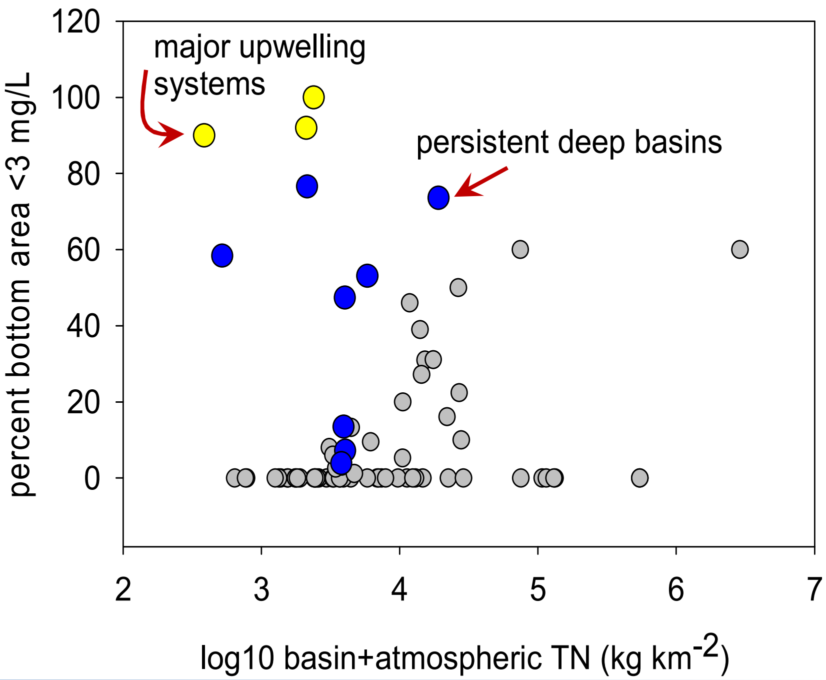
Over 80 systems in database
Over 70 with full data from Ecopath models

HYPOFIN working group

Bob Christian, John Harrison, Roman Zajac, Dave Chagaris, Howard Townsend, Lori Davias, Behzad Mahmoudi, Sheila Heymans, Olle Hjerne, Dennis Swaney, Denise Breitburg, Karin Limburg, Lyne Morissette, Marta Coll, Kenny Rose, Mike Frisk, Bob Diaz, Carrie Byron



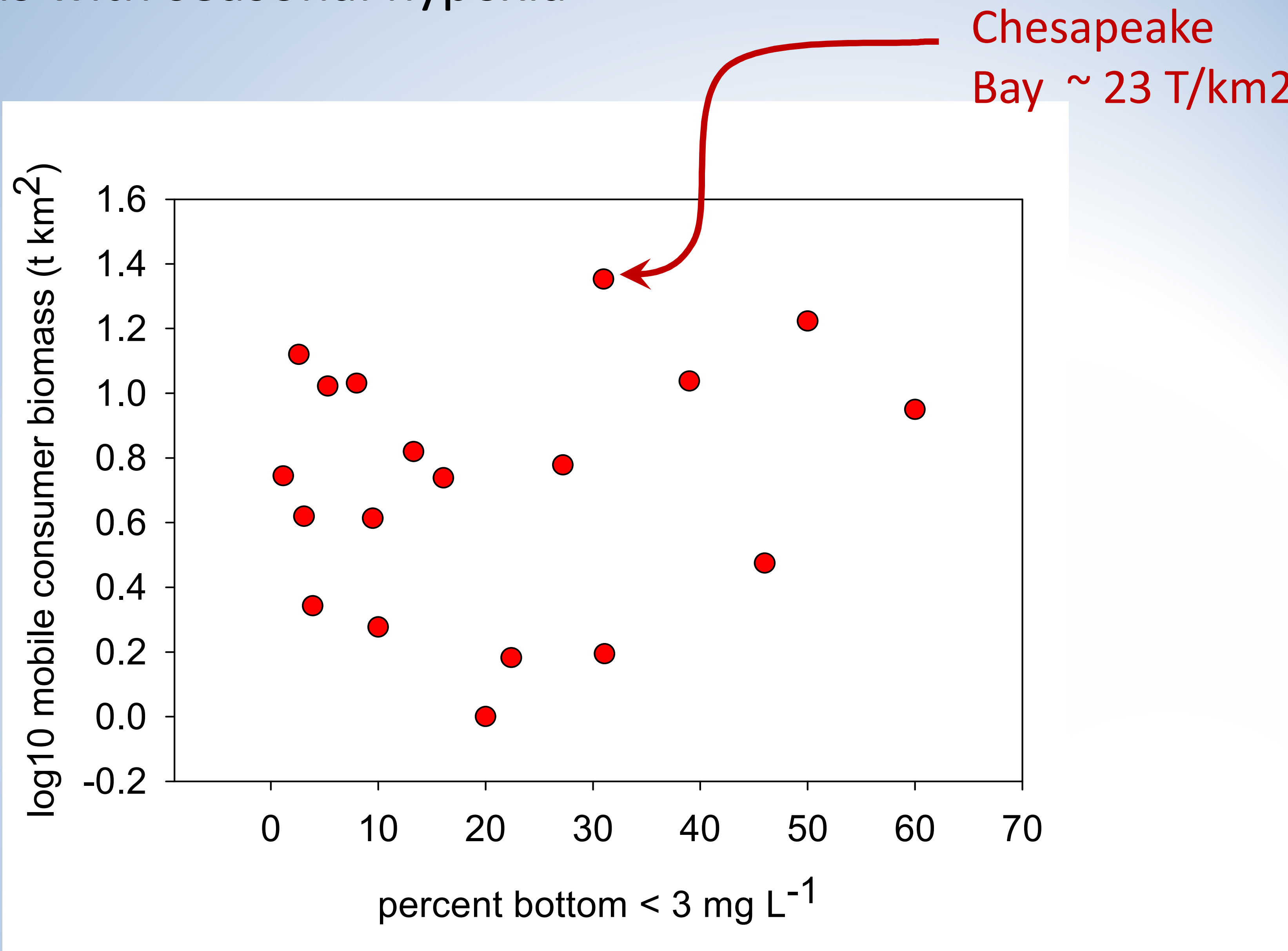


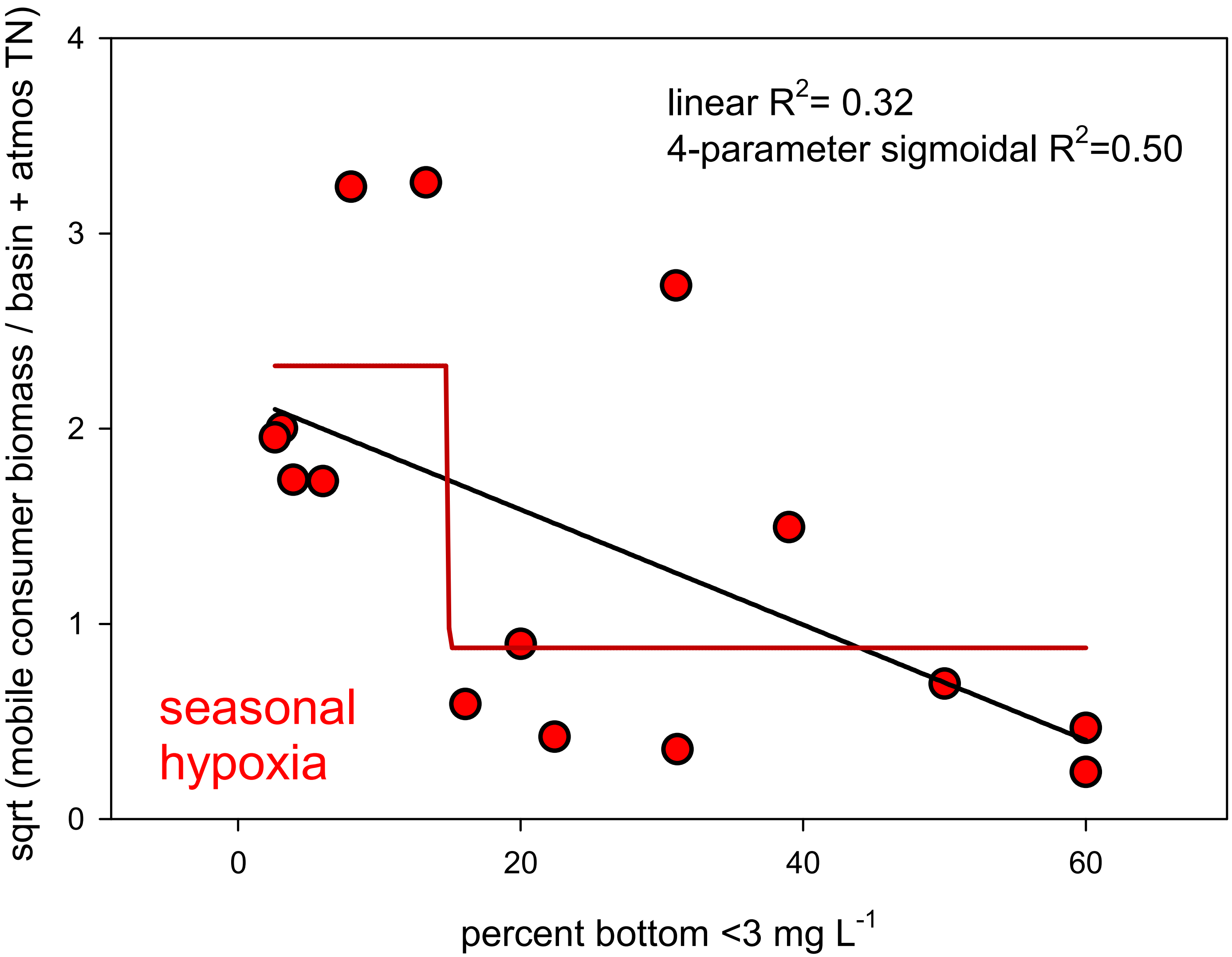


Model R^2= 0.72 $p<0.003$

Source of variation	p
upwelling_category	0.0392
log10 (openness)	0.0237
log10 basin+atmosTN	0.0472
warmest month mean ^{o}C	0.078

Systems with seasonal hypoxia

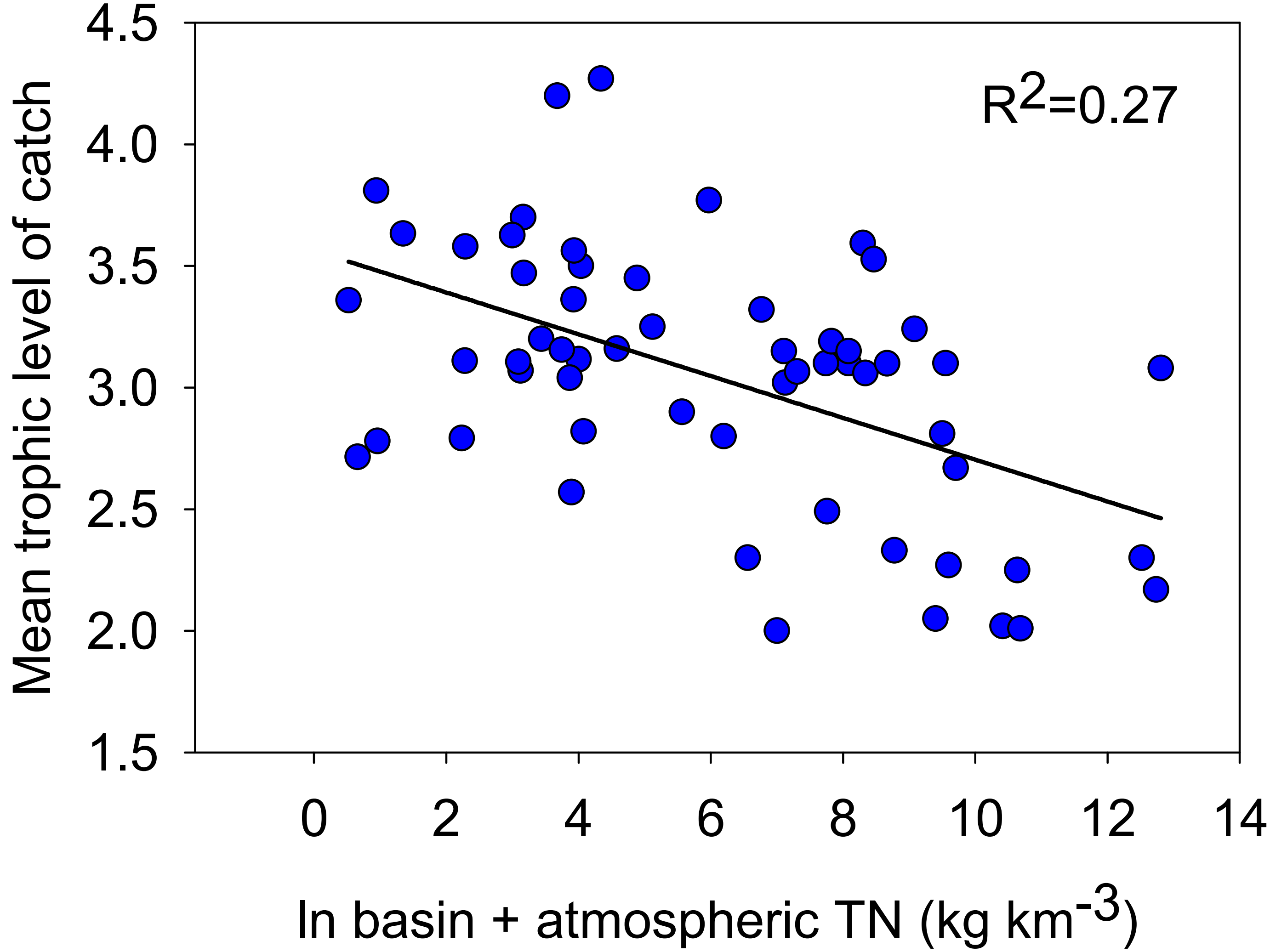


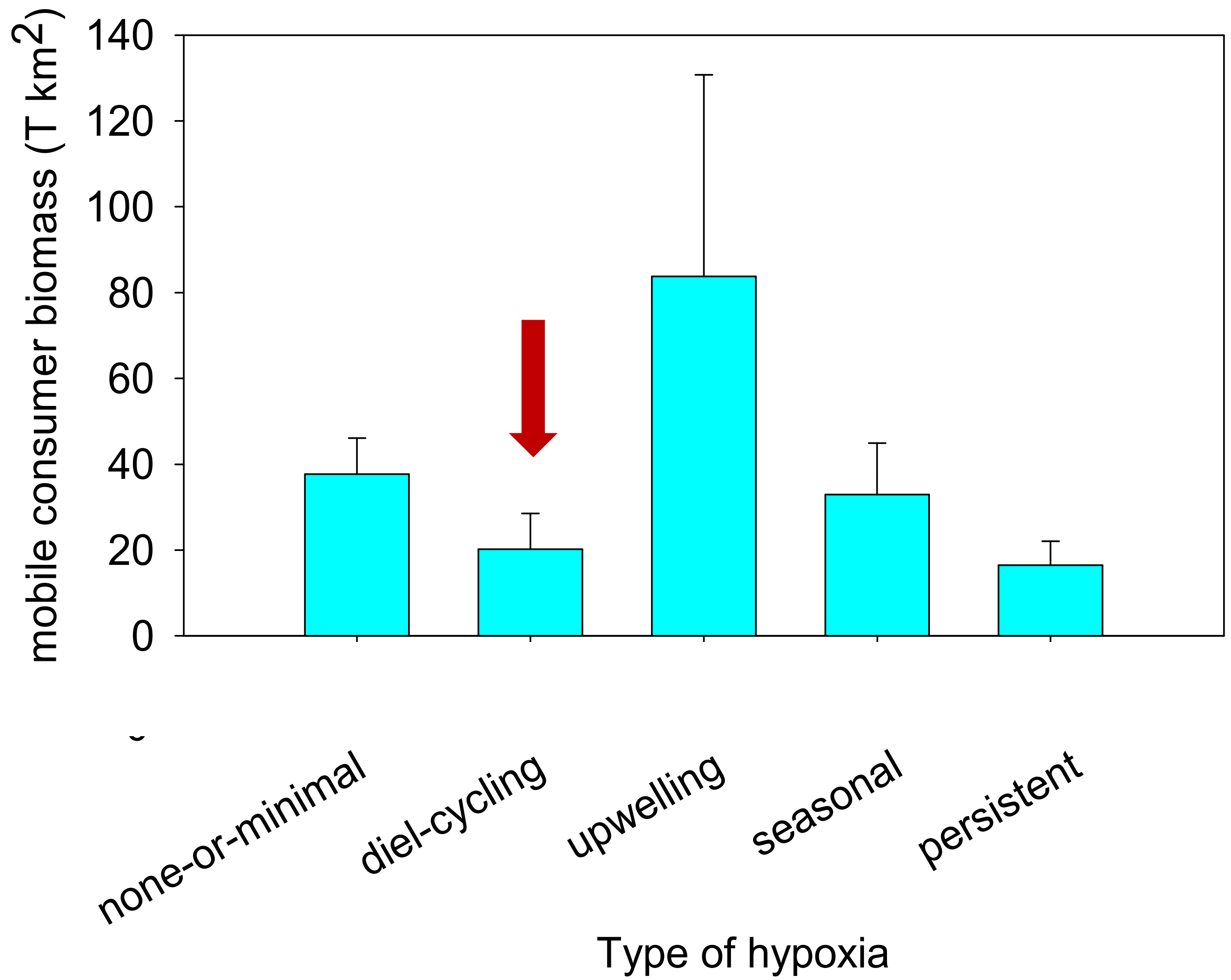


linear R2= 0.32
4-parameter sigmoidal R2=0.50
seasonal hypoxia
sqrt (mobile consumer biomass / basin + atmos TN)
percent bottom <3 mg L-1
0
1
2
3
4
0
20
40
60

HYPOFIN

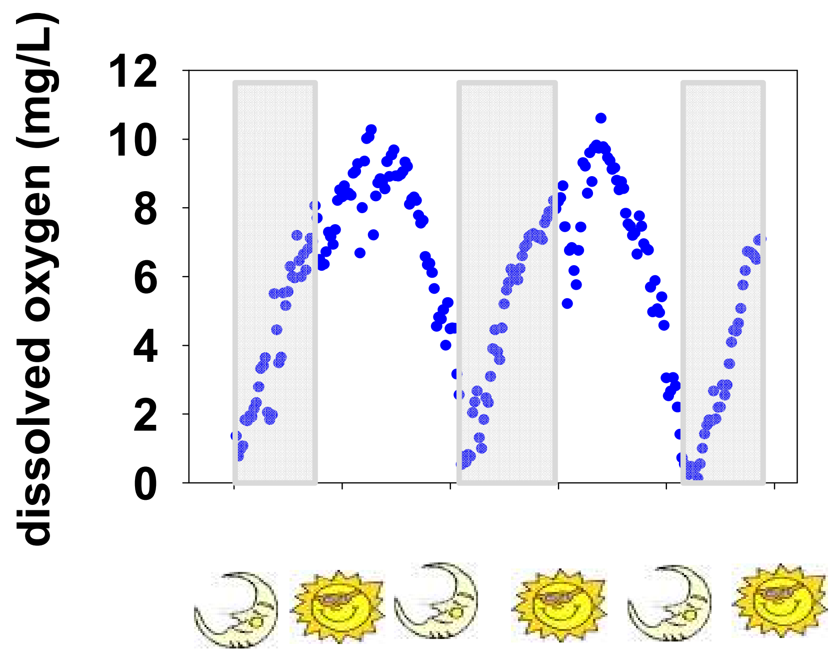
Mean trophic level of catch ~
Basin+atmospheric TN ($p<0.001$)
Upwelling category ($p=.06$)
Annual average temperature ($p=0.02$)



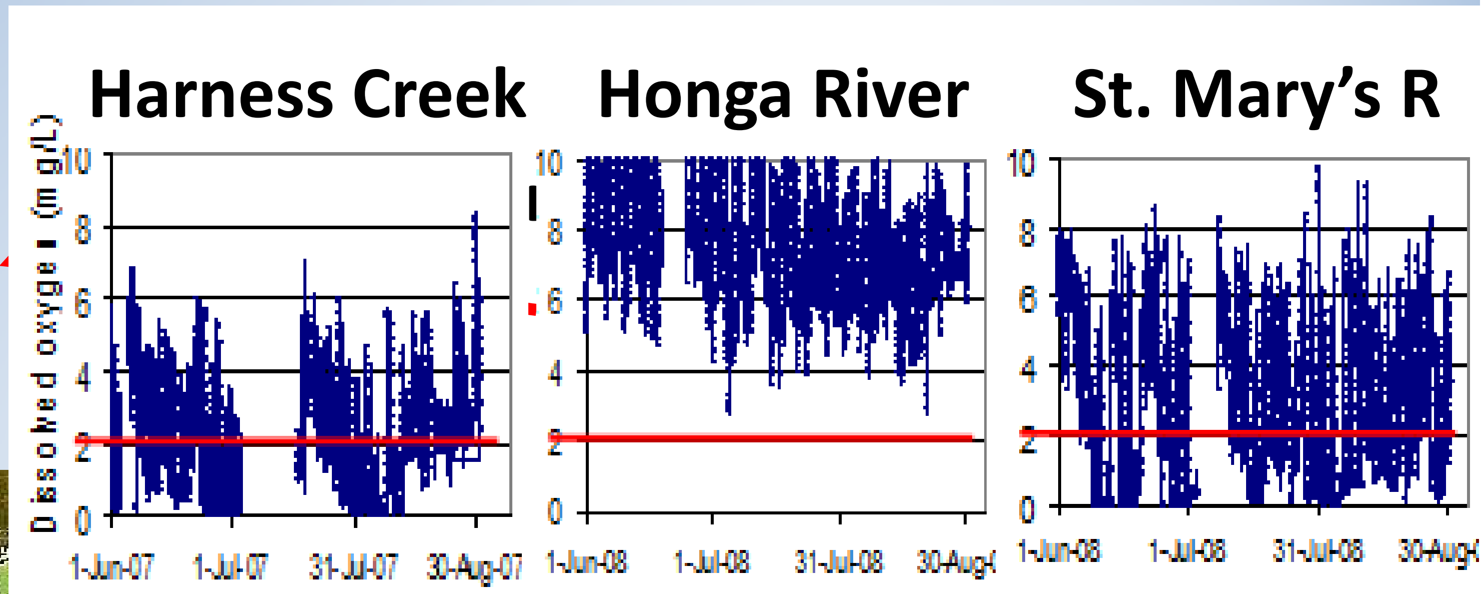

mobile consumer biomass (T km2)
140
120
100
80
60
40
20
0
none-or-minimal
diel-cycling
upwelling
seasonal
persistent
Type of hypoxia

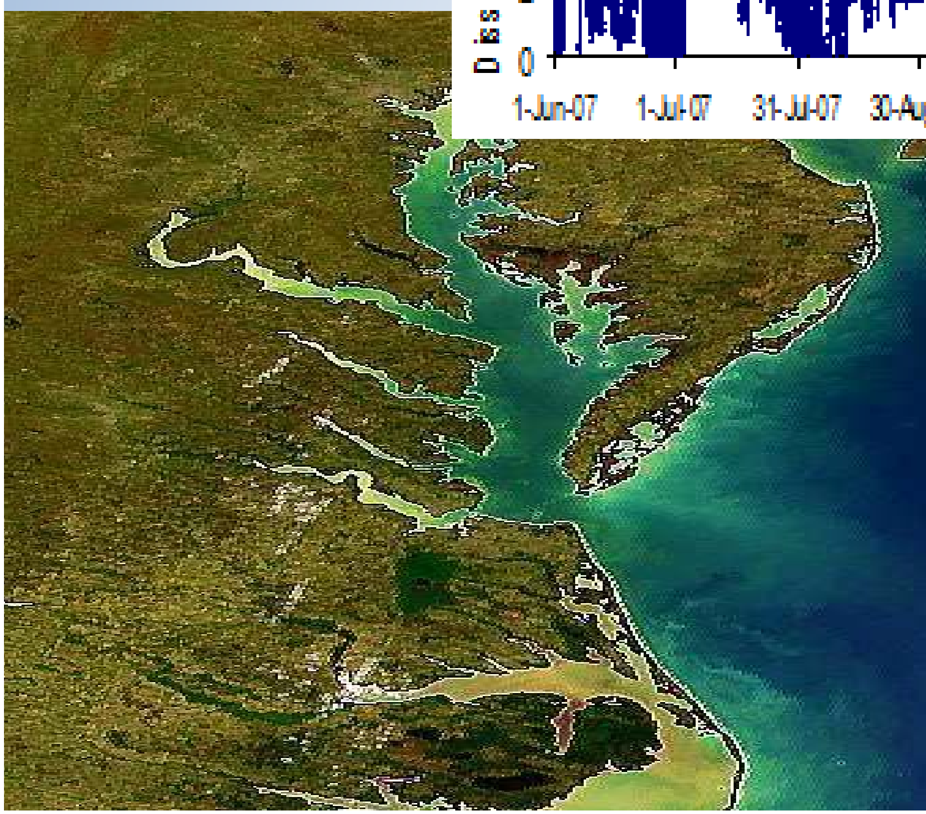
Diel cycling hypoxia

Natural phenomenon
Exacerbated by
- anthropogenic nutrient enrichment
- local hydrodynamics
- weather



Diel-cycling hypoxia



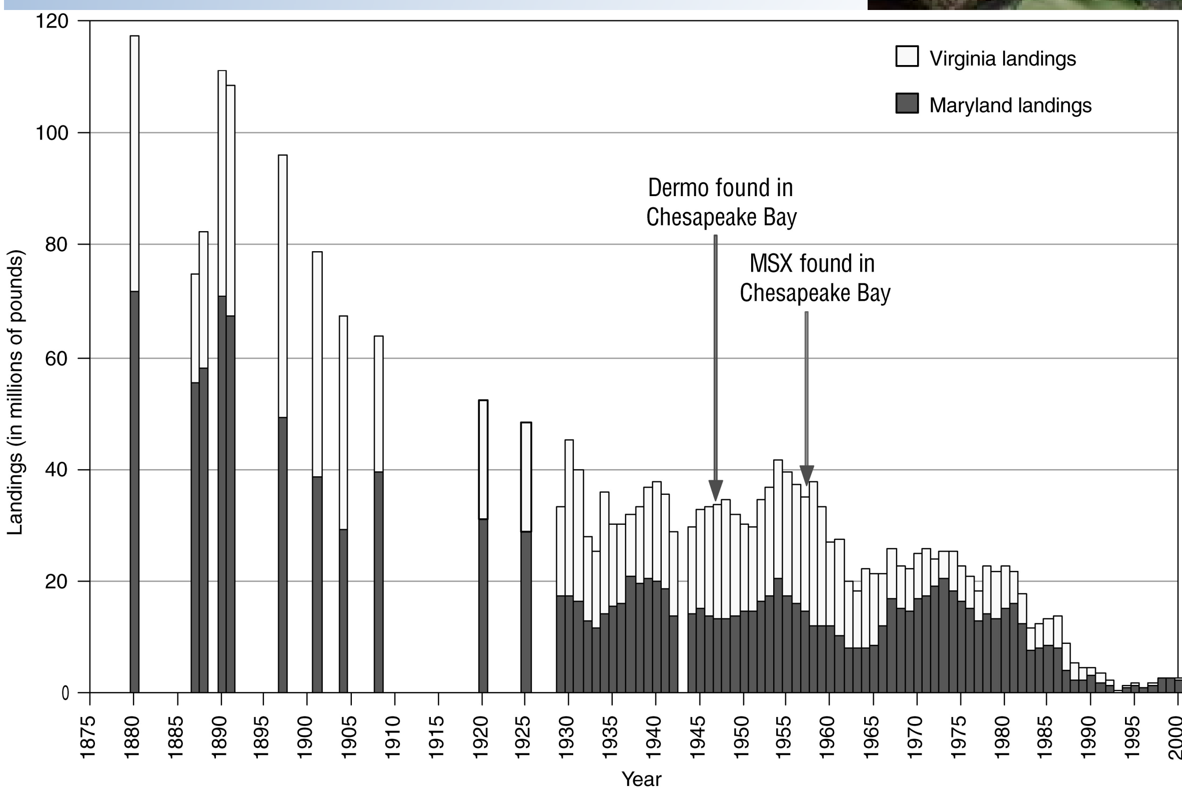


Creates temporal & spatial variability at a variety of scales

Affects productive refuge from deep-water hypoxia

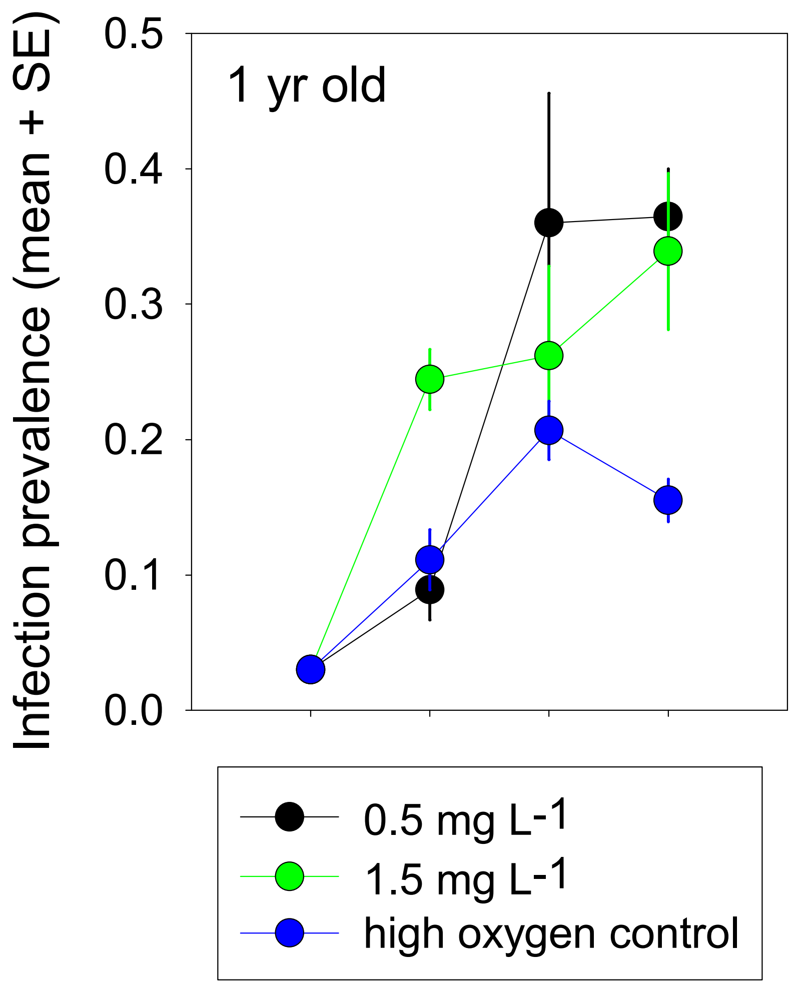
Affects habitat that is important predator refuge for small & juvenile fish

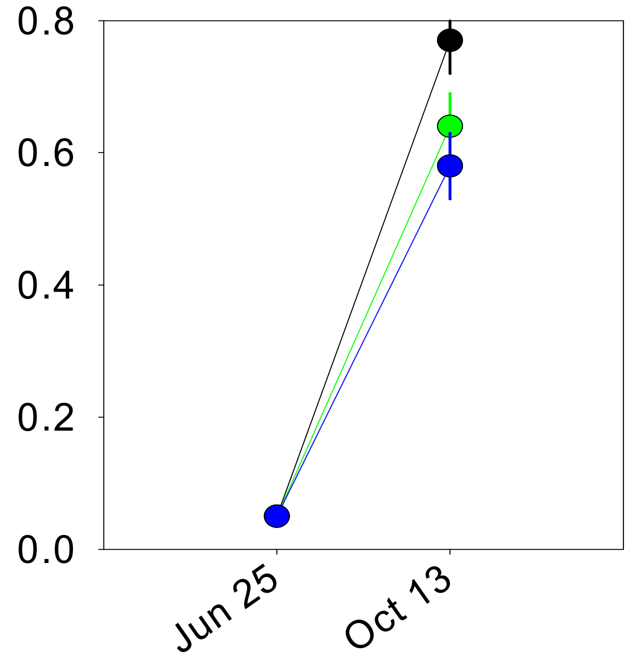
Is oyster susceptibility to disease increased by the hypoxic conditions encountered in shallow water habitats?

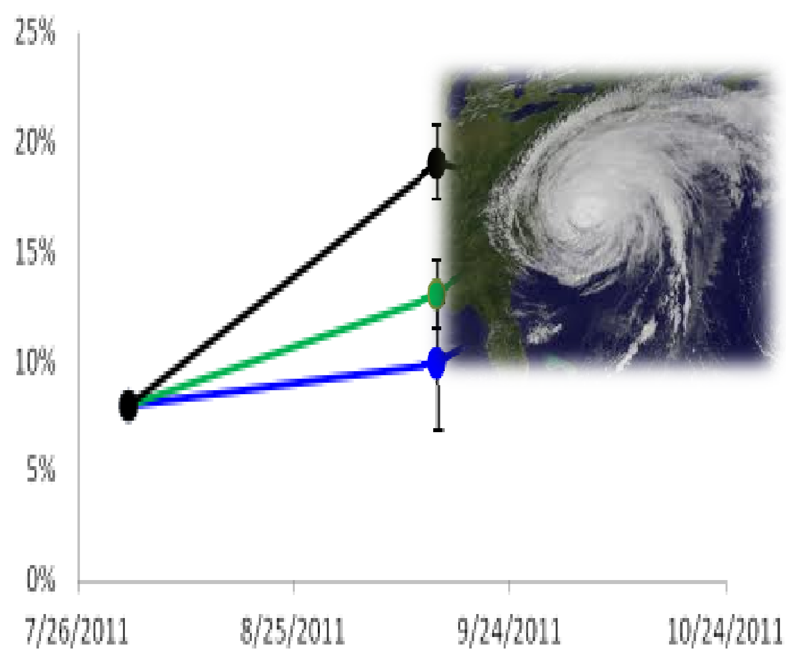


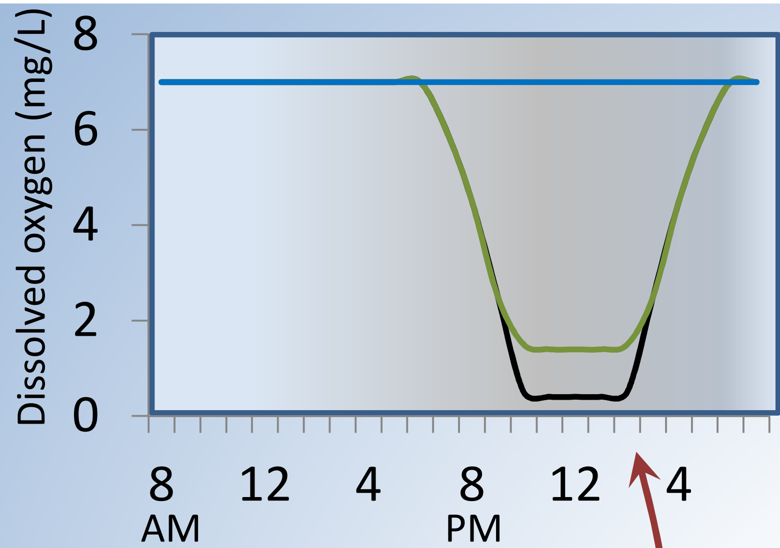
Low oxygen reduces hermocyte function in oysters- Boyd & Burnett

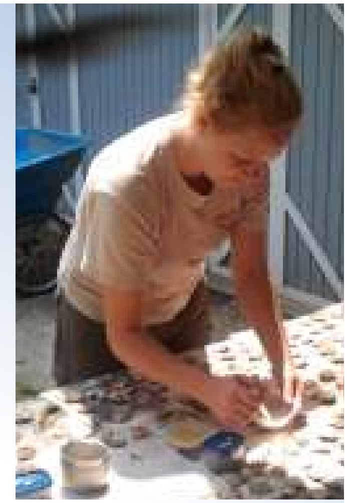
Diel-cycling hypoxia increases acquisition of *P. marinus* infections in experimental oysters





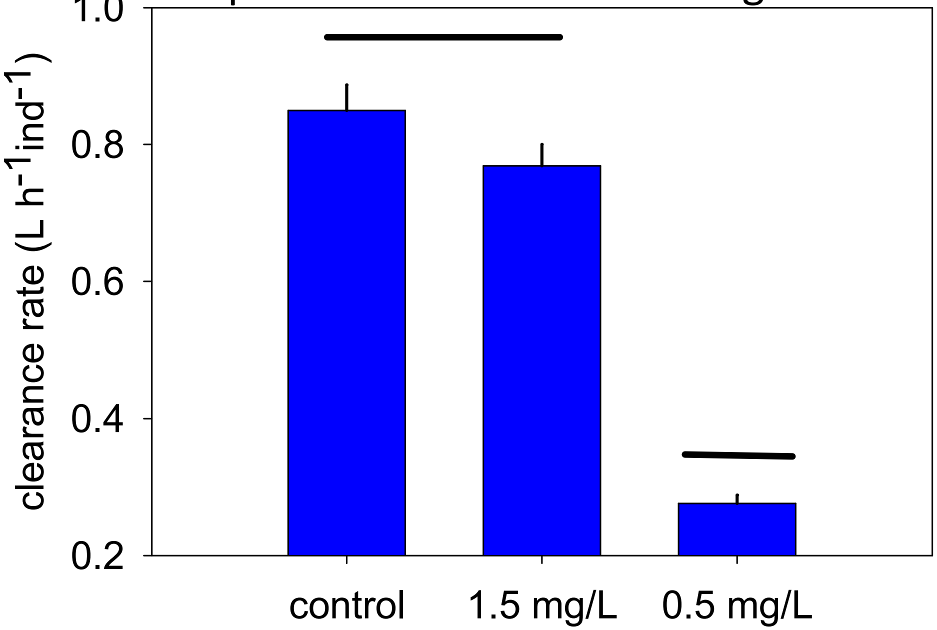


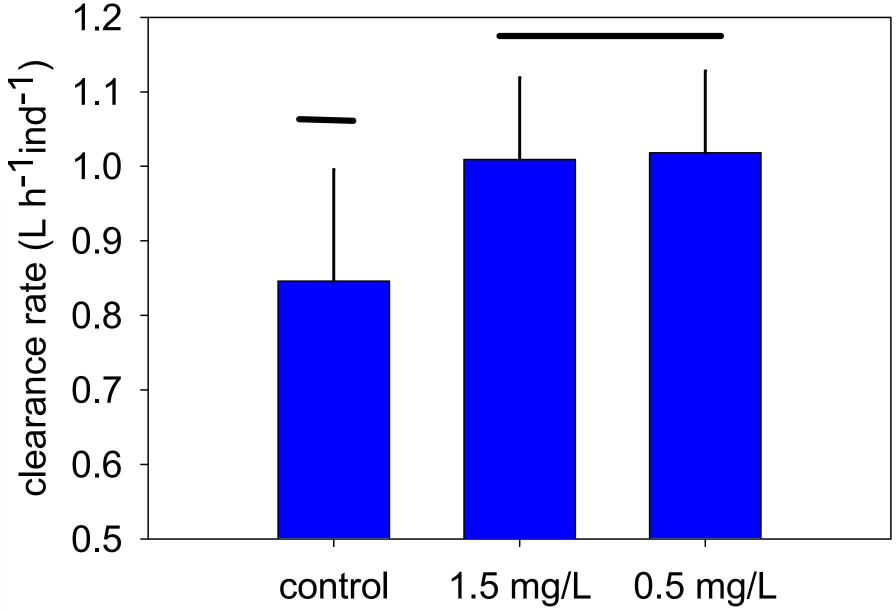




Recovery phase: partial compensation but only by older oysters

Exposure = decreased feeding

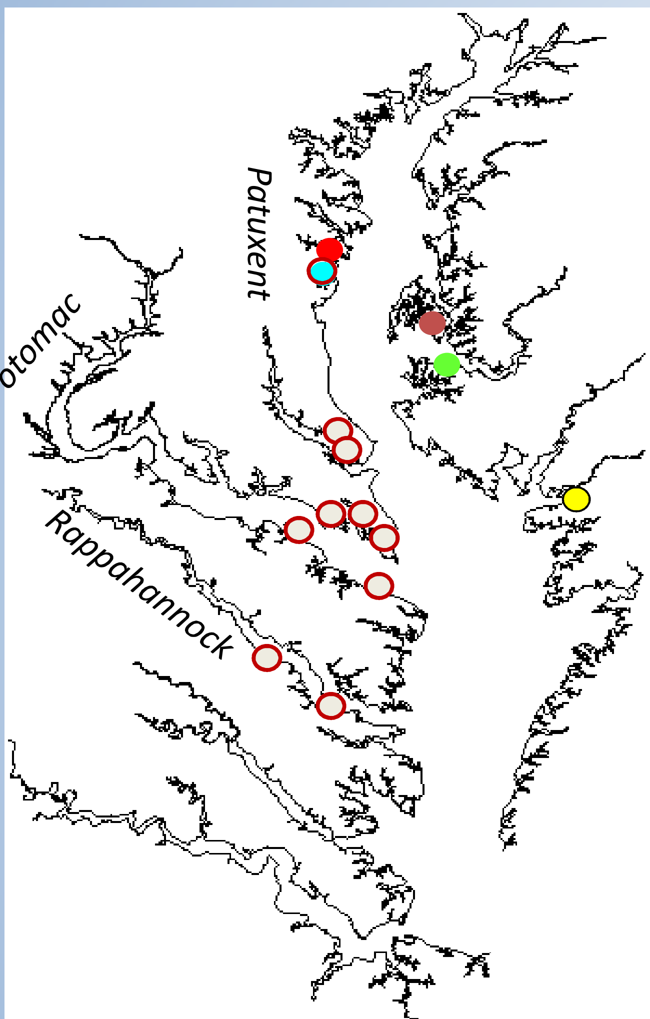




Virginia Clark- in prep

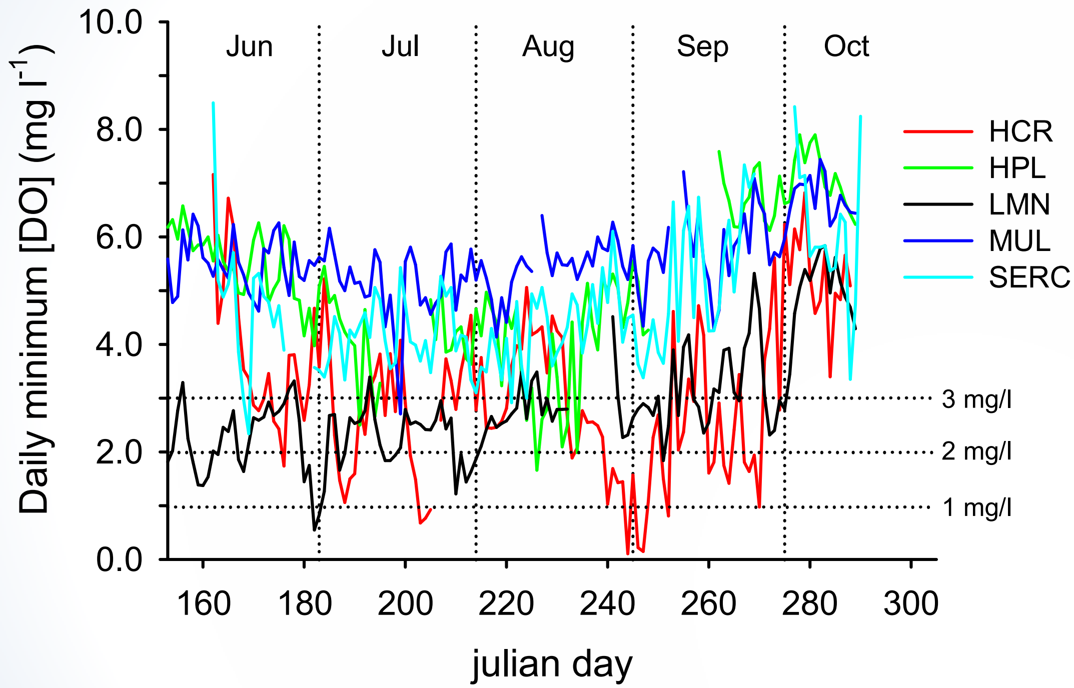
Field experiment (2008-09)

Darryl Hodorp (USGS) , in prep



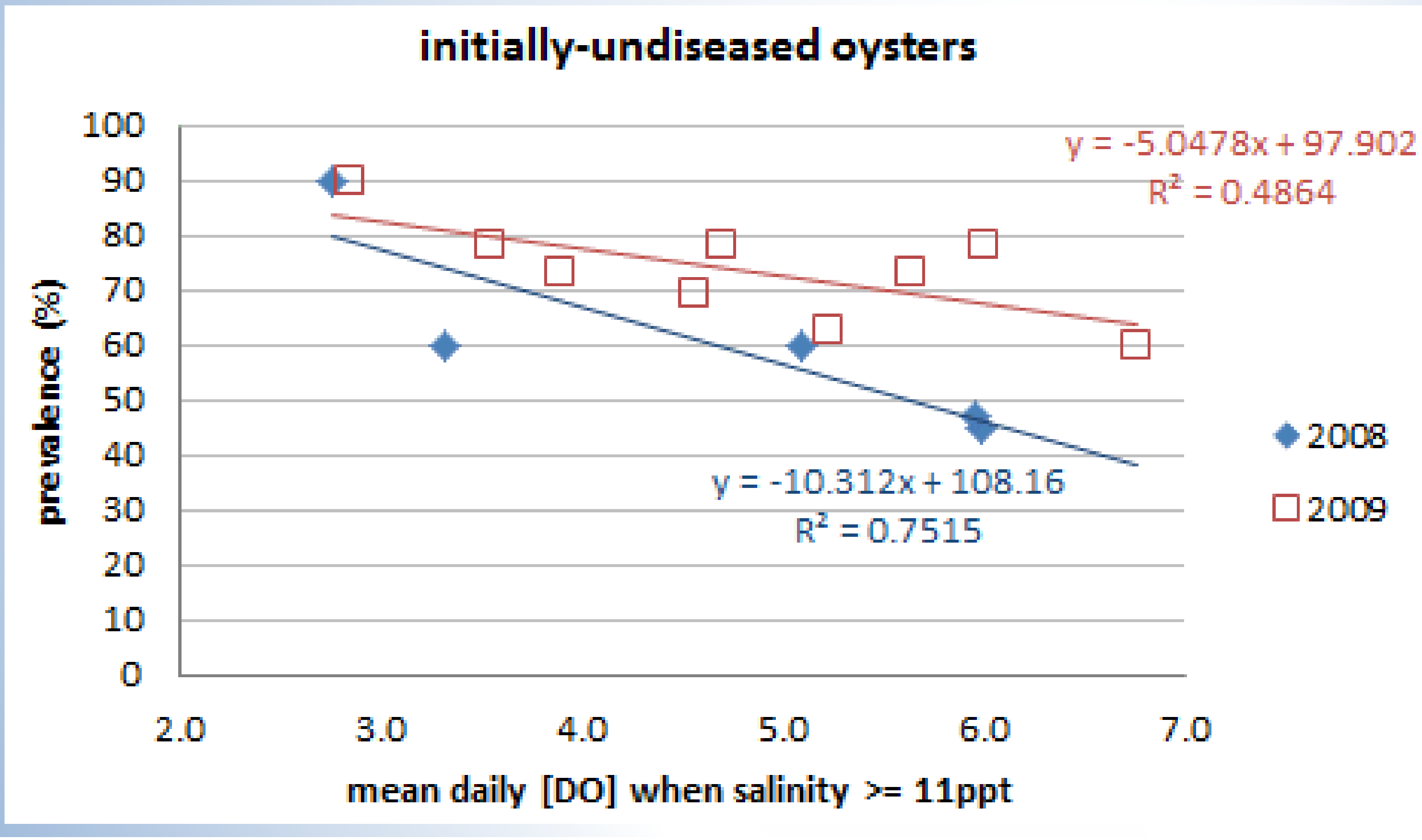
} 2008

2009

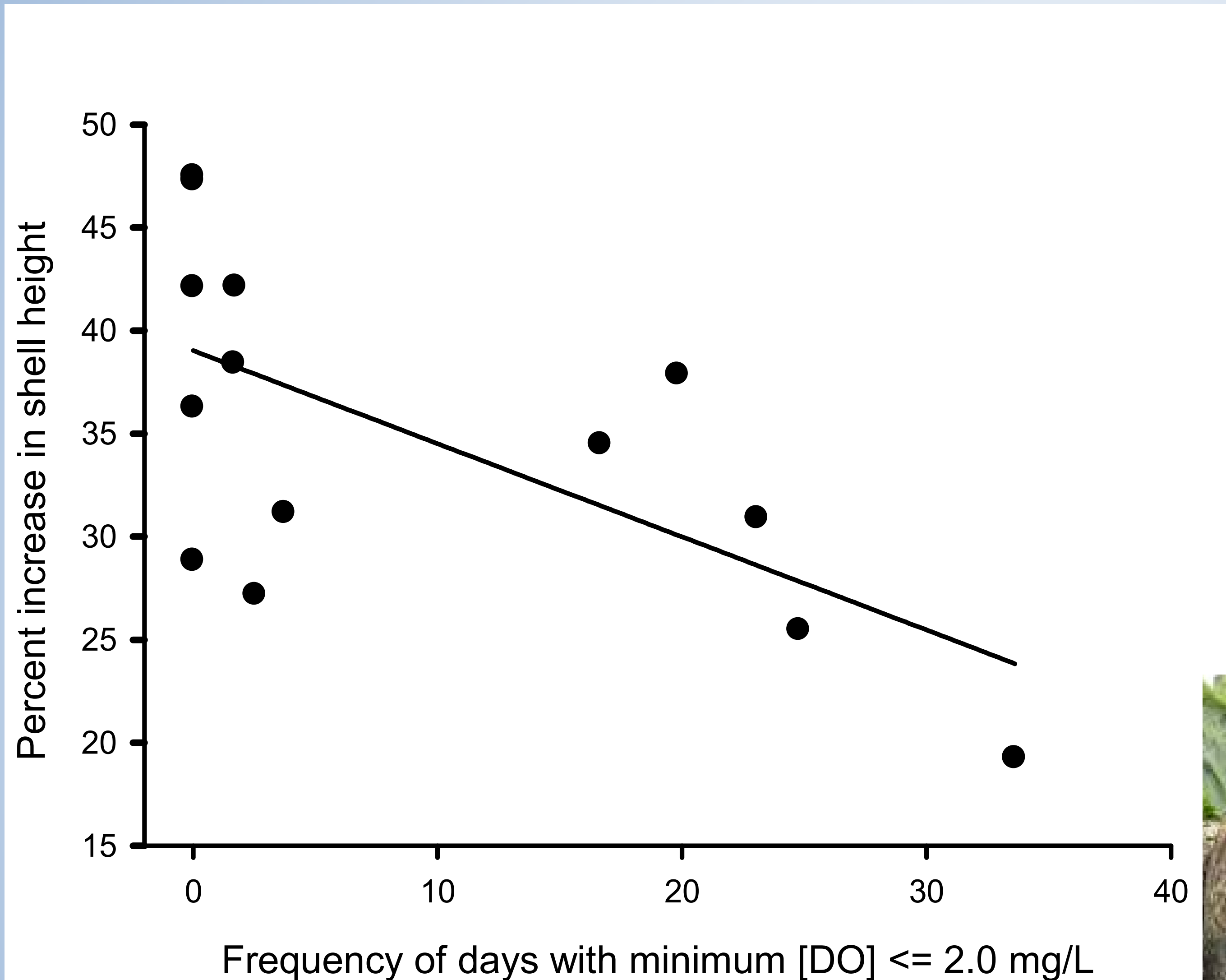


Increased disease Prevalence & intensity

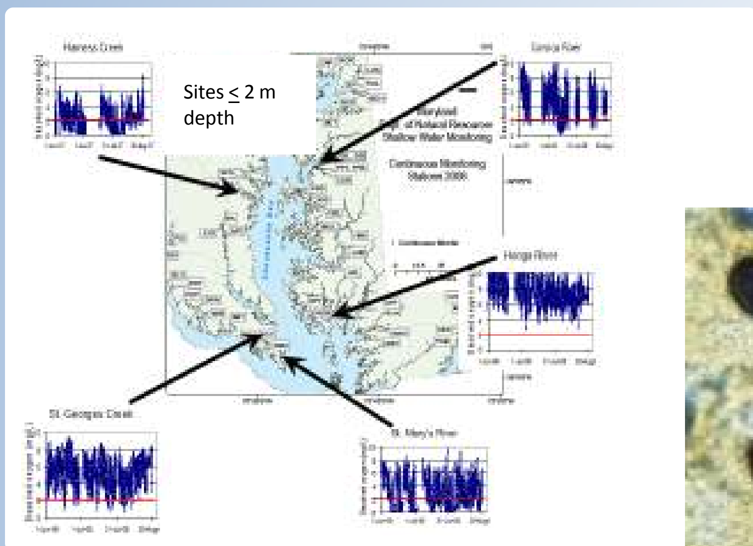
	Prevalence		Intensity	
1 yr olds:	P=	0.009	P=	0.02
	R^2 =	0.53	R^2 =	0.44
2-3 yr olds:		ns	P=	0.014
			R^2 =	0.51

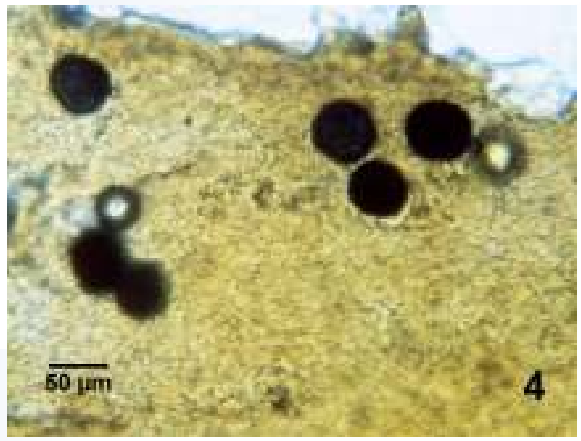


Decreased growth



Diel-cycling hypoxia has the potential to contribute to landscape-level spatial variation in epizootics, ecosystem services provided by oyster restoration, and the success of restoration



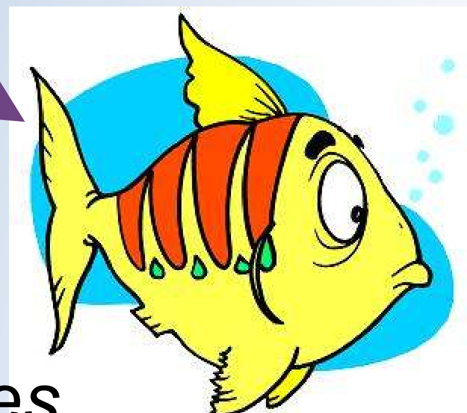


CHRP: Shallow water hypoxia – Tipping the balance for individuals, populations and ecosystems

Denise Breitburg, SERC
Timothy Targett, UDEL
Kenneth Rose, LSU
Howard Townsend, NOAA CBO
Bruce Michaels, MD DNR

Eutrophication → Increased CO_2

nutrients



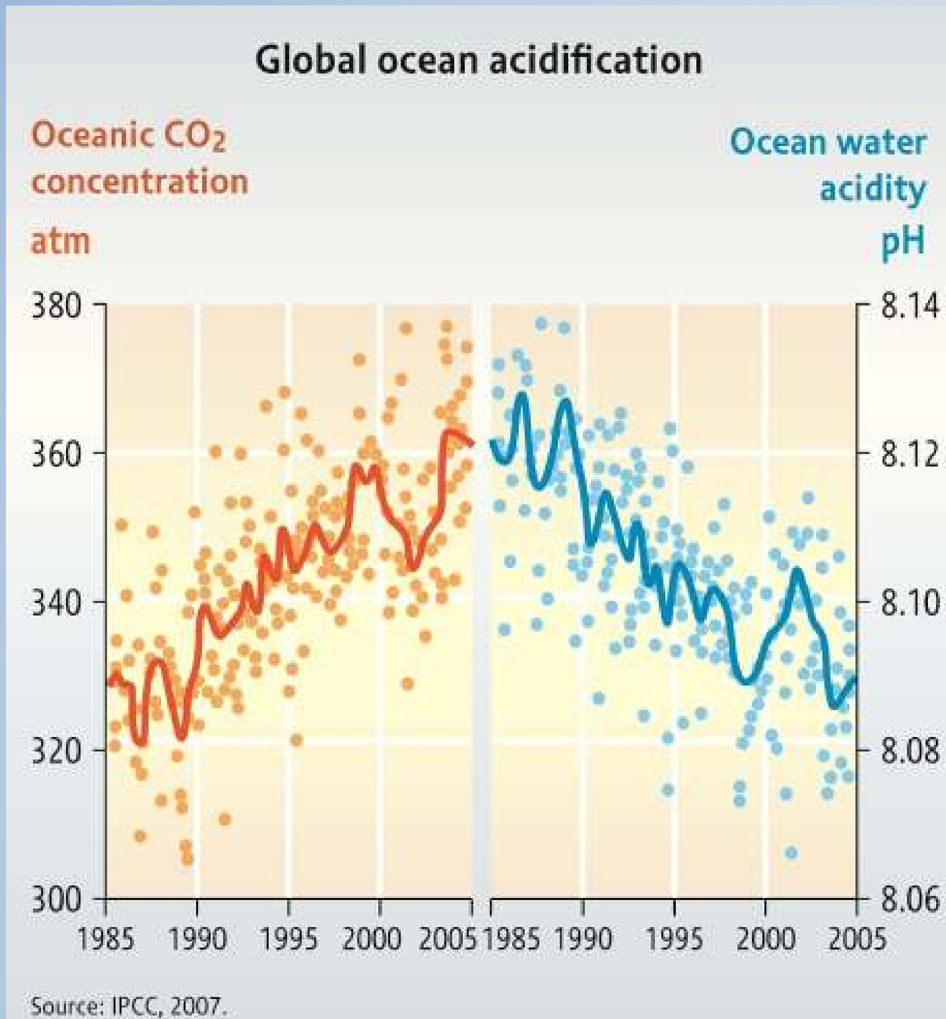
microbes

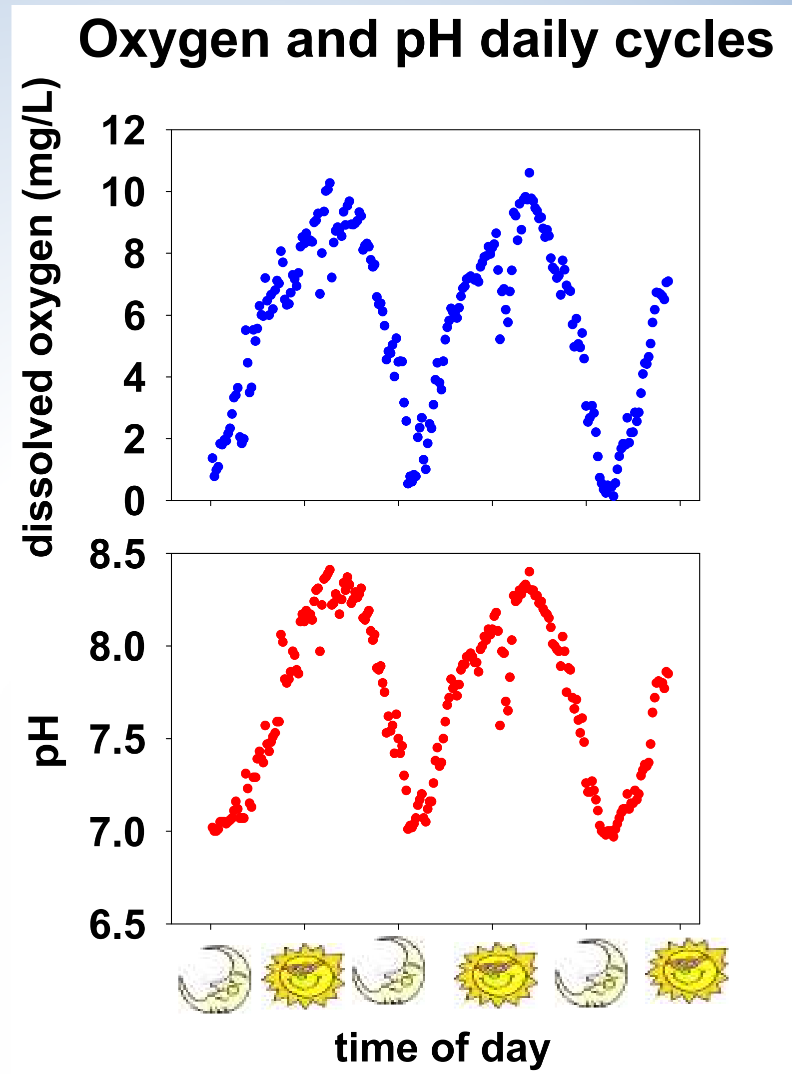
Respiration

$-O_2$ $+CO_2$

Low oxygen

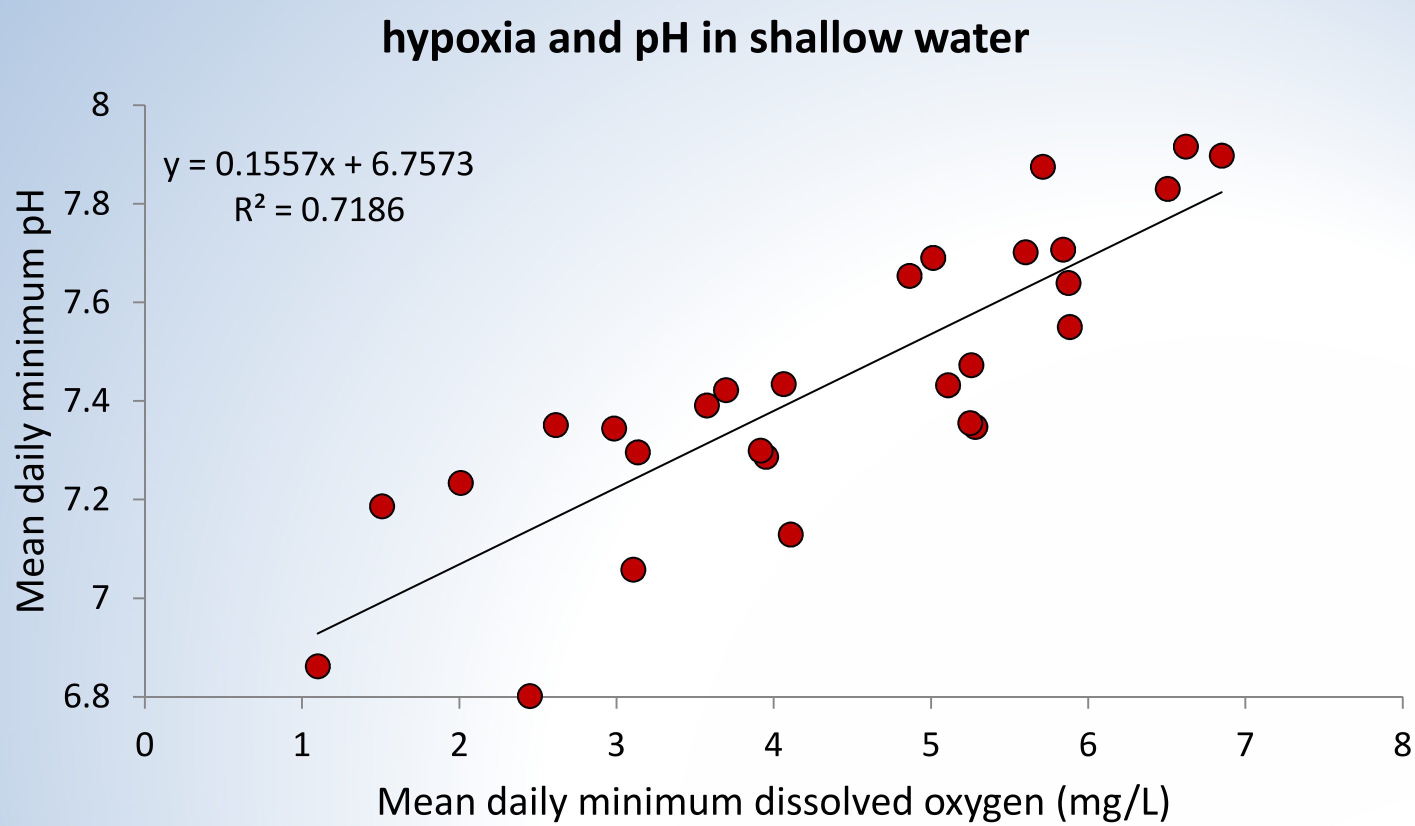
<u>And</u> Low pH





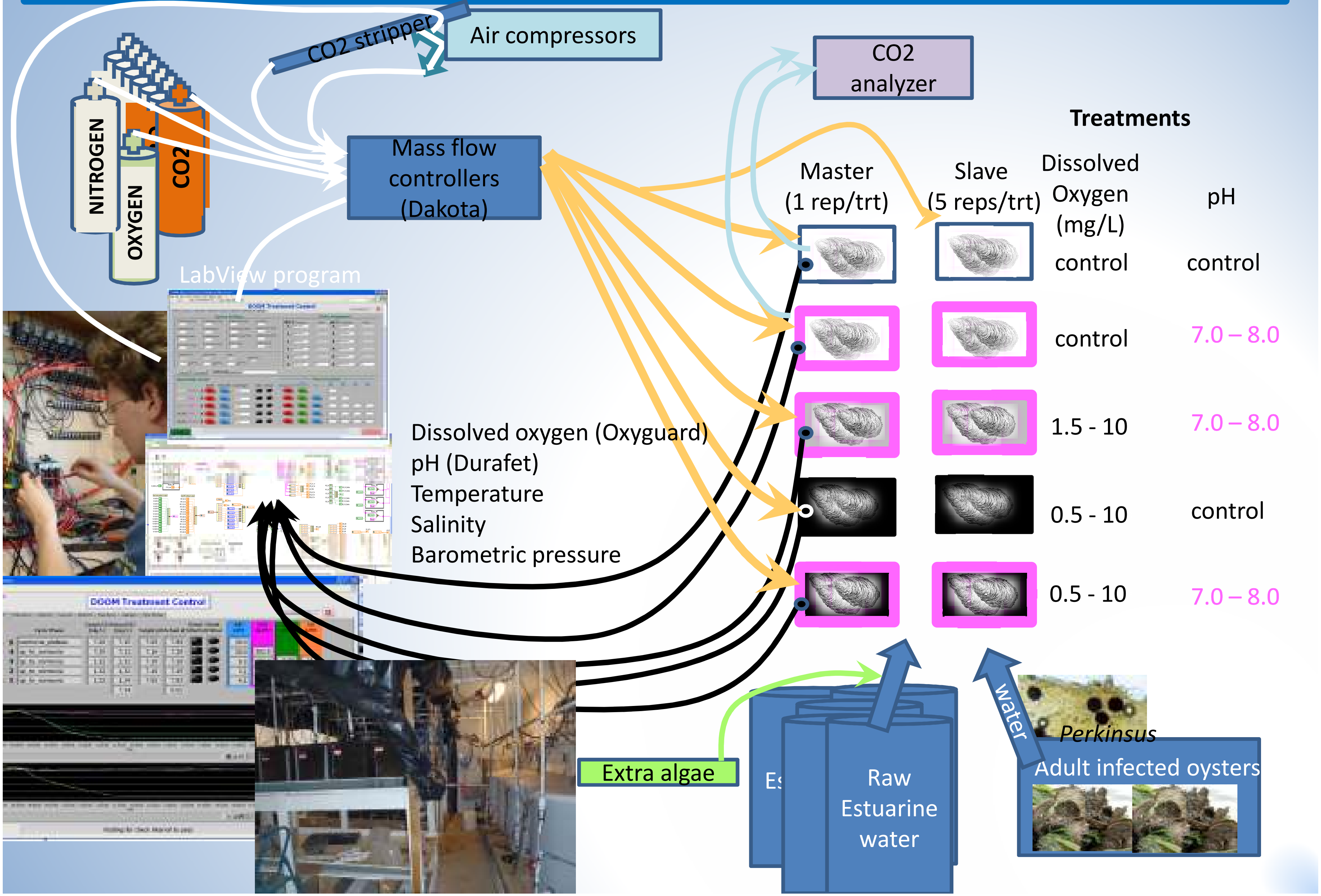
UNEP/GRID-Arendal. Global Ocean Acidification. UNEP/GRID-Arendal Maps and Graphics Library. 2009. Available at: http://maps.grida.no/go/graphic/global-ocean-acidification.

June – August 2004-2009



Data from MD-DNR shallow water monitoring program continuous monitoring sites with mean summer salinity >7.0
eyes on the bay

Experimental set-up for testing effects individual and interactive effects of diel-cycling hypoxia and pH on oyster disease dynamics, growth and filtration

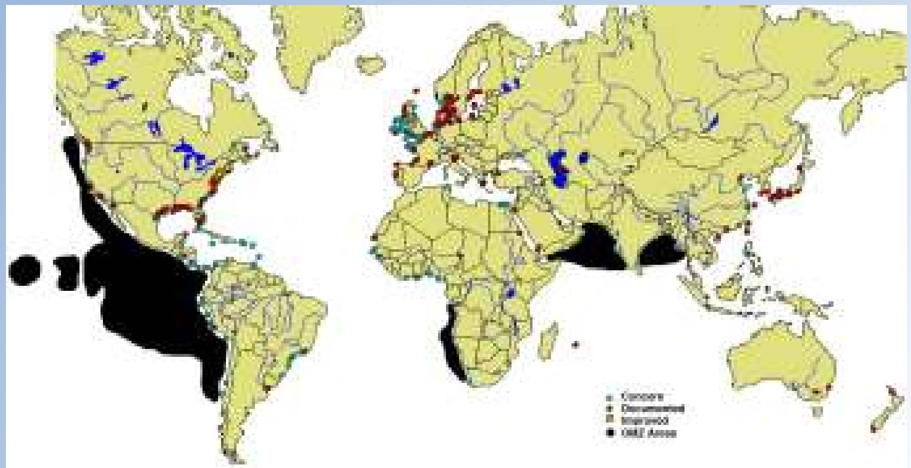


Is oyster susceptibility to disease increased by the hypoxic, acidic conditions encountered in shallow water habitats?

Why focus on shallow water is important?

- •Memory of oysters in knee deep water
- •Shallow water restoration may have largest effect on water quality
- •Shallow water restoration may have largest effect on shoreline protection
- •Shallow water restoration has greatest potential for co-restoration of bivalves & SAV

•Shallow water is a refuge from deep water persistent low oxygen



Major need to consider co-occurring stressors – fisheries, pH, etc. - and develop tools to integrate across time, space and species

Large persistent dead zones are dramatic, but short-lived hypoxia and constantly changing oxygen may have important effects relevant to management & restoration

If we want to improve fisheries and the living resource populations on which fisheries depend:

We may need to manage our fisheries more aggressively to compensate for water quality problems

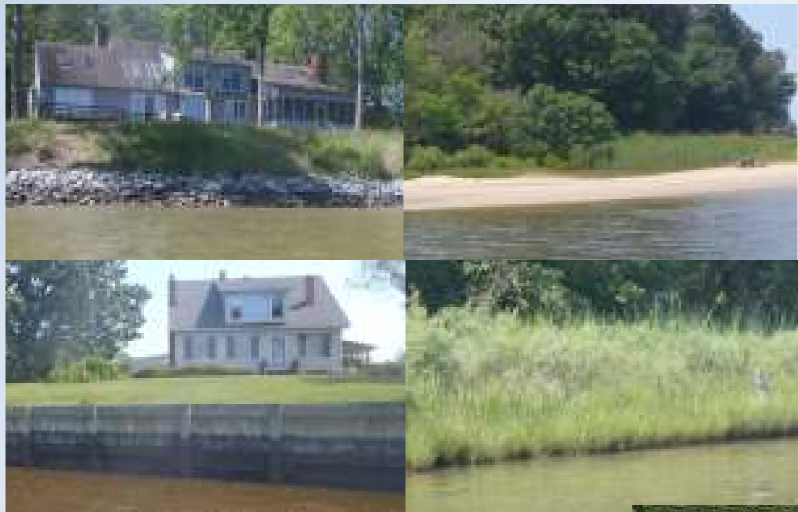
Joint management of nutrients and fisheries critical
- Political feasibility of implementing changes
- Different stressors may be important at high and low points in population cycles

Fisheries management – responsiveness to climate-driven population variability and change

Eutrophication – wholesale destruction of Chesapeake Bay
- No excuse – natural system that inspired poetry & literature has been transformed into a poorly managed protein production facility
- Don’t know consequences
- Dangerous to rest too much case for clean-up on benefit to fisheries species

Relating community composition, abundance, growth, and condition of aquatic macrofauna to watershed land use and shoreline alteration in Chesapeake Bay.

Denise Breitburg
Matthew S. Kornis
Rochelle D. Seitz
Donna M. Bilkovic
Richard Balouskus
Timothy E. Targett
Ryan S. King
Steve Giordano
Jim Uphoff
John M. Jacobs
Lori A. Davias
Keira Heggie
Heather Soulen

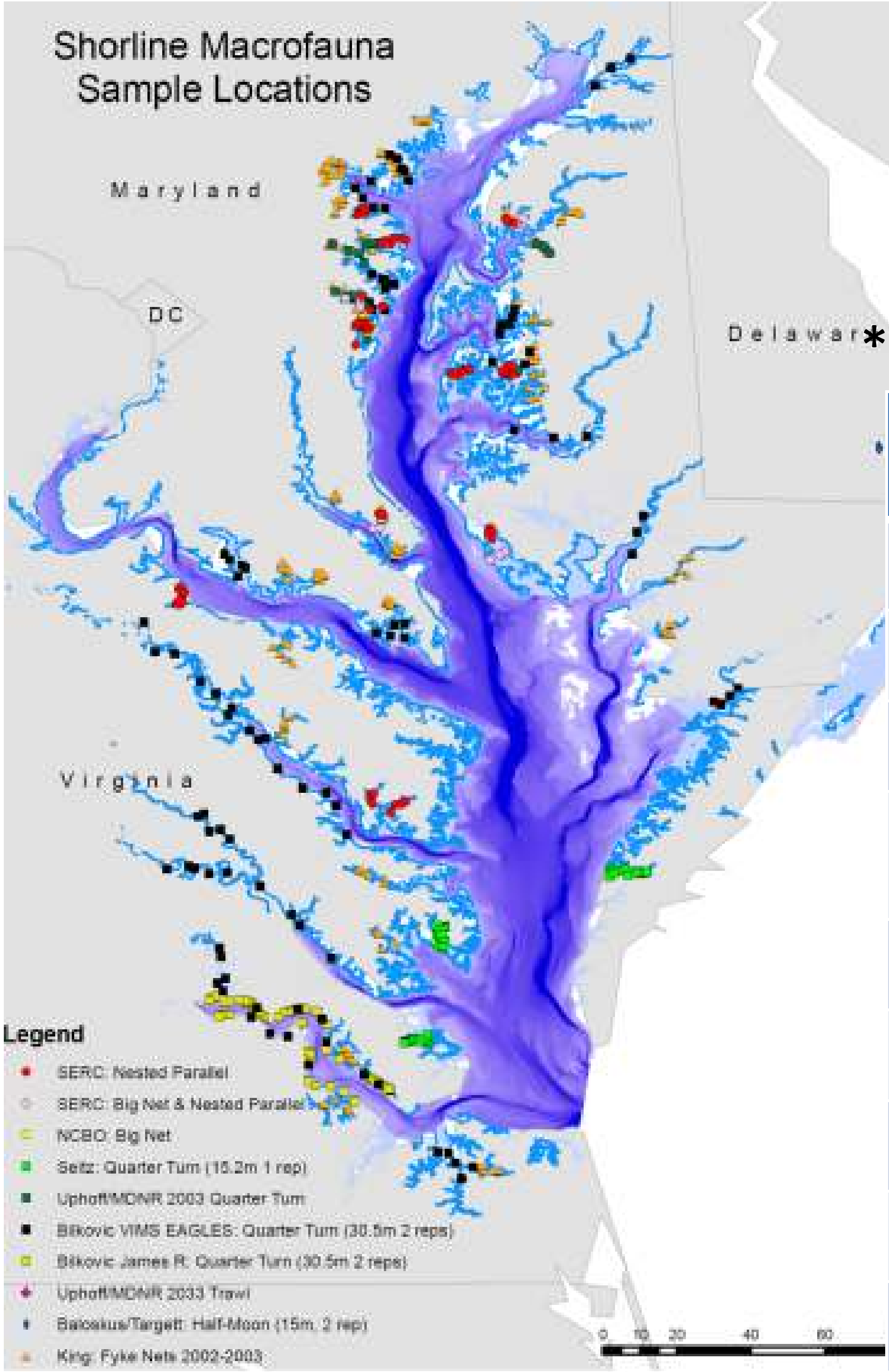


Shoreline alteration

Land use

Part of Jordan et al. mid-Atlantic stressors grant

William & Mary VIMS Virginia Institute of Marine Science School of Marine Science
NOAA
Maryland Department of Natural Resources
Smithsonian Institution
Baylor University



43 Subestuaries
694 samples
730,000 individuals enumerated

PreliminaryMultiple Regression Analysis

Response	Land Use?	Shoreline Habitat?
Fish Richness	X	X
Blue Crab	X	
Mummichog	X	X
Atlantic Silverside	X	X
White Perch	X	
Striped Bass	X	
Grass Shrimp	X	X
Centrachidae	X	X
Menhaden		