



OYSTER RESTORATION, AQUACULTURE AND NITROGEN REMOVAL – A BIOGEOCHEMIST'S PERSPECTIVE

Jeffrey Cornwell, Michael
Owens, Lisa Kellogg

*Thanks to RIE Newell and K
Paynter*



University of Maryland
CENTER FOR ENVIRONMENTAL SCIENCE
HORN POINT LABORATORY



The Promise of Oyster Reef Restoration



Source: Tom Toles (2013) The Washington Post.

Resources

2014 Funding:

- NCBO Funding in Harris Creek MD, nutrient fluxes + benthic community assessment + fish utilization
- TNC funding to examine oyster biomass-driven differences in biogeochemistry
- Just completed: MD Sea Grant/NOAA funded research on aquaculture biogeochemical effects
- Just completed: 2 Virginia studies (bayside/oceanside) on oyster nutrient cycling.

Vol. 480: 1–19, 2013
doi: 10.3354/meps10331

MARINE ECOLOGY PROGRESS SERIES
Mar Ecol Prog Ser

Published April 22



FEATURE ARTICLE

Denitrification and nutrient assimilation on a restored oyster reef

M. Lisa Kellogg^{1,*}, Jeffrey C. Cornwell², Michael S. Owens², Kennedy T. Paynter^{3,4}

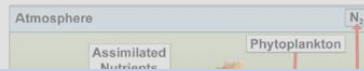
¹Virginia Institute of Marine Science, College of William & Mary, Gloucester Point, Virginia 23062, USA

²University of Maryland Center for Environmental Science, Horn Point Laboratory, Cambridge, Maryland 21613, USA

³Chesapeake Biological Laboratory, University of Maryland Center for Environmental Science, Solomons, Maryland 20688, USA

⁴Department of Biology, University of Maryland, College Park, Maryland 20742, USA

ABSTRACT: At a restored reef site and a control site in the Choptank River, Maryland, USA, we partially quantified the effect of oyster reef resto-



Kellogg, M. L., J. C. Cornwell, M. S. Owens, and K. T. Paynter. 2013. Denitrification and nutrient assimilation on a restored oyster reef. *Marine Ecology Progress Series* **480**:1-19.

Kellogg, M. L., M. W. Luckenbach, B. L. Brown, R. H. Carmichael, J. C. Cornwell, M. F. Piehler, M. S. Owens, D. J. Dalrymple, C. B. Higgins, and A. R. Smyth. 2013. Quantifying nitrogen removal by oysters - workshop report. NOAA Chesapeake Bay Office.

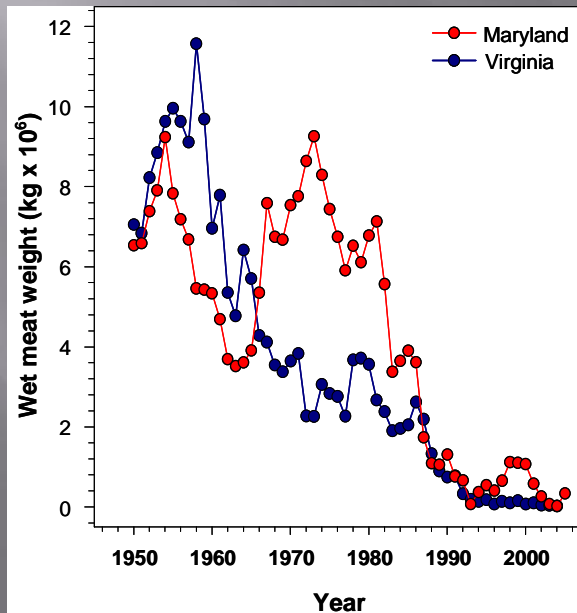
Previous and Ongoing Studies

Outline

- Evolution of measurement approaches
- Prior studies
- Biogeochemical concepts
- Putting flux rates in an environmental context

Data

- Simulation of organic matter additions: Newell et al. 2002; Holyoke 2008
- Aquaculture-related studies: Holyoke 2008; current MDSG work in Chesapeake, Maine; clam work in MD Coastal Bays
- Reef measurements – Kellogg et al. 2013



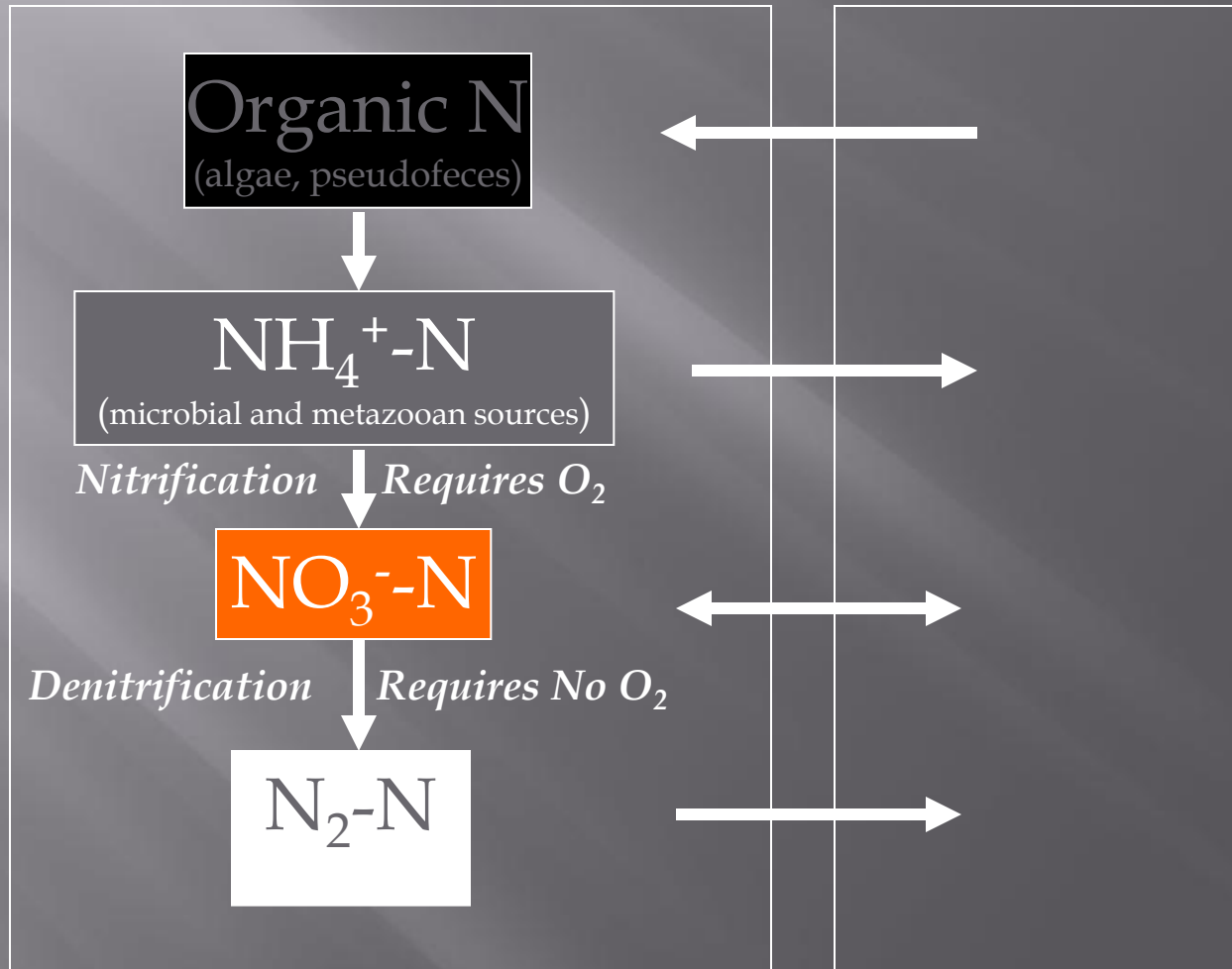
Talk Sections

- ▣ Biogeochemical fundamentals
- ▣ Restoration sites
- ▣ Aquaculture
- ▣ Modeling

Denitrification

Oyster/Clam Community

Water Column



Shallow Water Biogeochemistry

The diagram illustrates the vertical profile of redox potential and nutrient cycling in a shallow water environment, divided into three vertical panels by dashed lines. The top of the diagram shows the water surface with a wavy line representing the water-air interface. A rainbow-colored arrow points down from the surface into the water column, indicating light penetration. A circular arrow with O_2 indicates oxygen production at the surface. A red 'X' is placed over a dashed line with a rainbow arrow, indicating a point where a process is inhibited or not occurring.

The vertical axis represents the depth profile, with the water column at the top and the sediment at the bottom. The sediment is shown in cross-section, with various chemical and biological processes occurring at different depths. The processes are categorized by redox potential, with the most oxidized conditions at the surface and the most reduced conditions at the bottom.

Key Processes and Chemical Species:

- Nitrogen Cycle:** NH_4^+ is converted to NO_3^- (nitrification) and then to N_2 (denitrification). NO_3^- can also be reduced to NH_4^+ (dissimilatory nitrate reduction).
- Phosphorus Cycle:** PO_4^{3-} is shown being released from the sediment into the water column.
- Sulfur Cycle:** S_{redox} is shown as a cycle between oxidized and reduced states, with S_{redox} being the reduced form.
- Iron and Manganese Cycles:** $Fe(III)$ is reduced to $Fe(II)$, and $Mn(IV)$ is reduced to $Mn(II)$.
- Other Species:** O_2 , N_2 , NO_3^- , NH_4^+ , PO_4^{3-} , $Mn(IV)$, $Mn(II)$, $Fe(III)$, and $Fe(II)$ are shown as chemical species involved in the cycles.

The diagram is credited to **Holyoke 2008**.

Shallow Water Biogeochemistry

The diagram illustrates the vertical profile of redox potential and nutrient cycling in a shallow water environment, divided into three vertical panels by dashed lines. The top of the diagram shows the water surface with a wavy line representing the water-air interface. A rainbow-colored arrow points down from the surface into the water column, indicating light penetration. In the top right corner, there is a circular icon with O_2 and a red 'X' over it, suggesting oxygen depletion or a specific redox state.

The vertical axis represents the depth profile, with the water column at the top and the sediment at the bottom. The sediment is shown in cross-section, with various chemical and biological processes occurring at different depths. The processes are categorized by redox potential, with the most oxidized conditions at the surface and the most reduced conditions at the bottom.

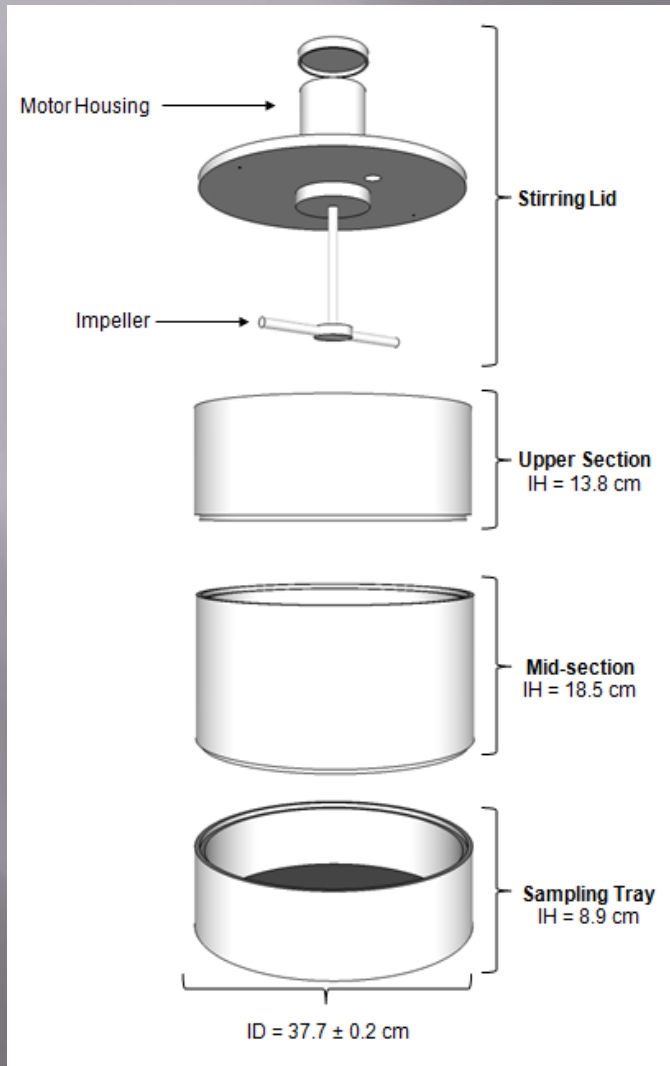
Key Processes and Nutrients:

- Nitrogen (N):** Shown as NH_4^+ and NO_3^- in the water column. In the sediment, NH_4^+ is converted to NO_3^- , which is then denitrified to N_2 gas, shown as a yellow arrow pointing up from the sediment surface.
- Phosphorus (P):** Shown as PO_4^{3-} in the water column. In the sediment, it is converted to NH_4^+ and then to N_2 gas, shown as a yellow arrow pointing up from the sediment surface.
- Iron (Fe):** Shown as $Fe(II)$ and $Fe(III)$ in the sediment. $Fe(III)$ is reduced to $Fe(II)$, which is then oxidized back to $Fe(III)$, shown as a red arrow pointing up from the sediment surface.
- Manganese (Mn):** Shown as $Mn(II)$ and $Mn(IV)$ in the sediment. $Mn(IV)$ is reduced to $Mn(II)$, which is then oxidized back to $Mn(IV)$, shown as a blue arrow pointing up from the sediment surface.
- Sulfur (S):** Shown as S_{redox} in the sediment. S_{redox} is reduced to S_{redox} , which is then oxidized back to S_{redox} , shown as a white arrow pointing up from the sediment surface.

The diagram also shows the presence of various microorganisms, represented by small, stylized figures, which are involved in the biogeochemical processes. The overall process is labeled "Holyoke 2008" at the bottom.

Restoration

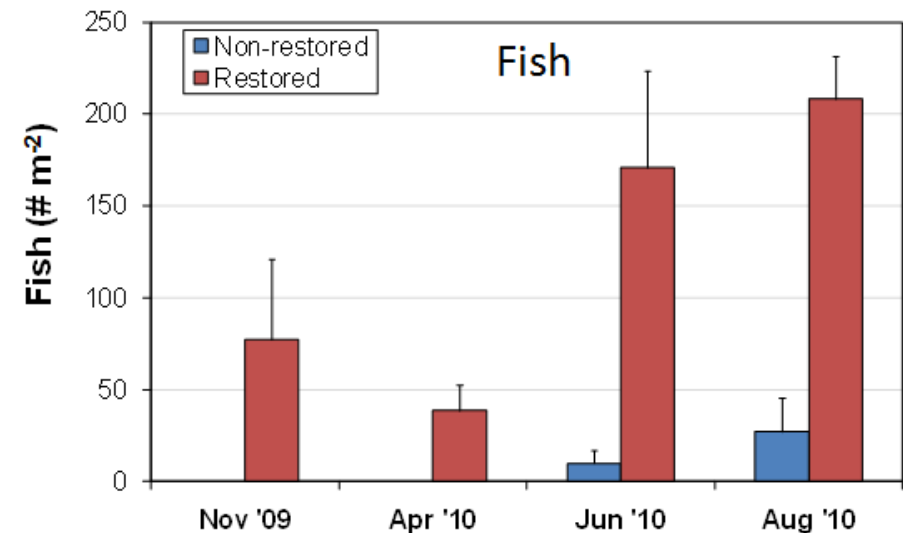
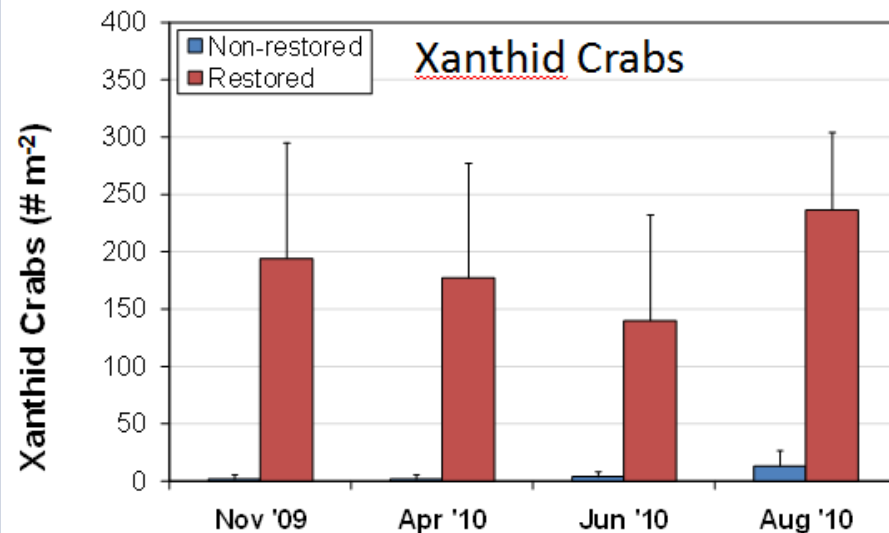
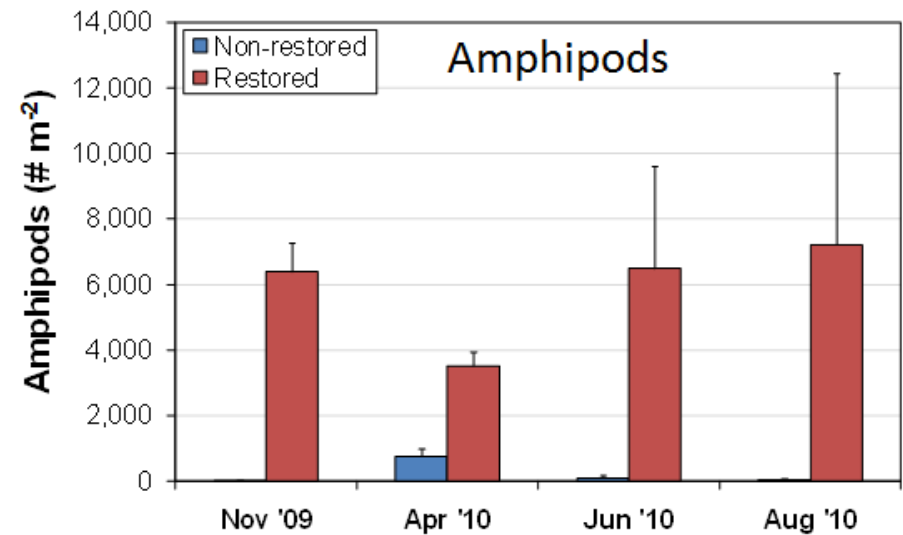
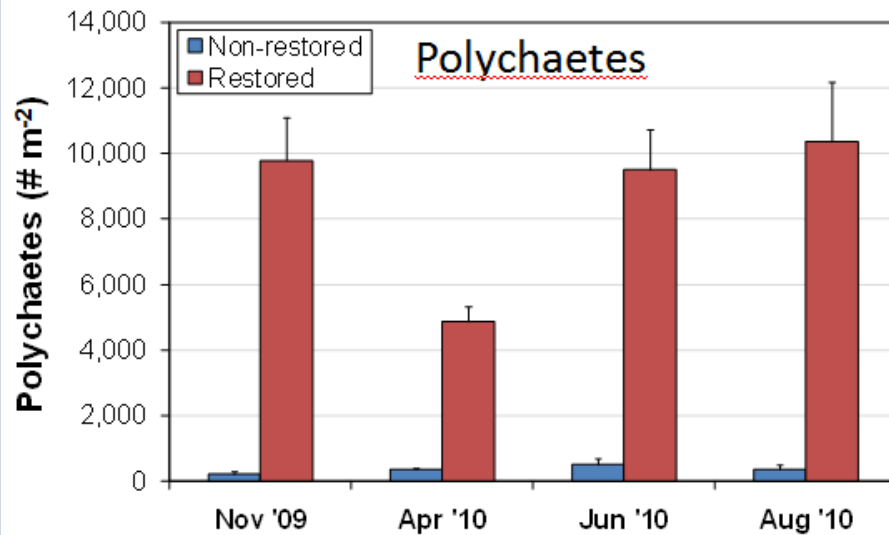
Choptank River Study



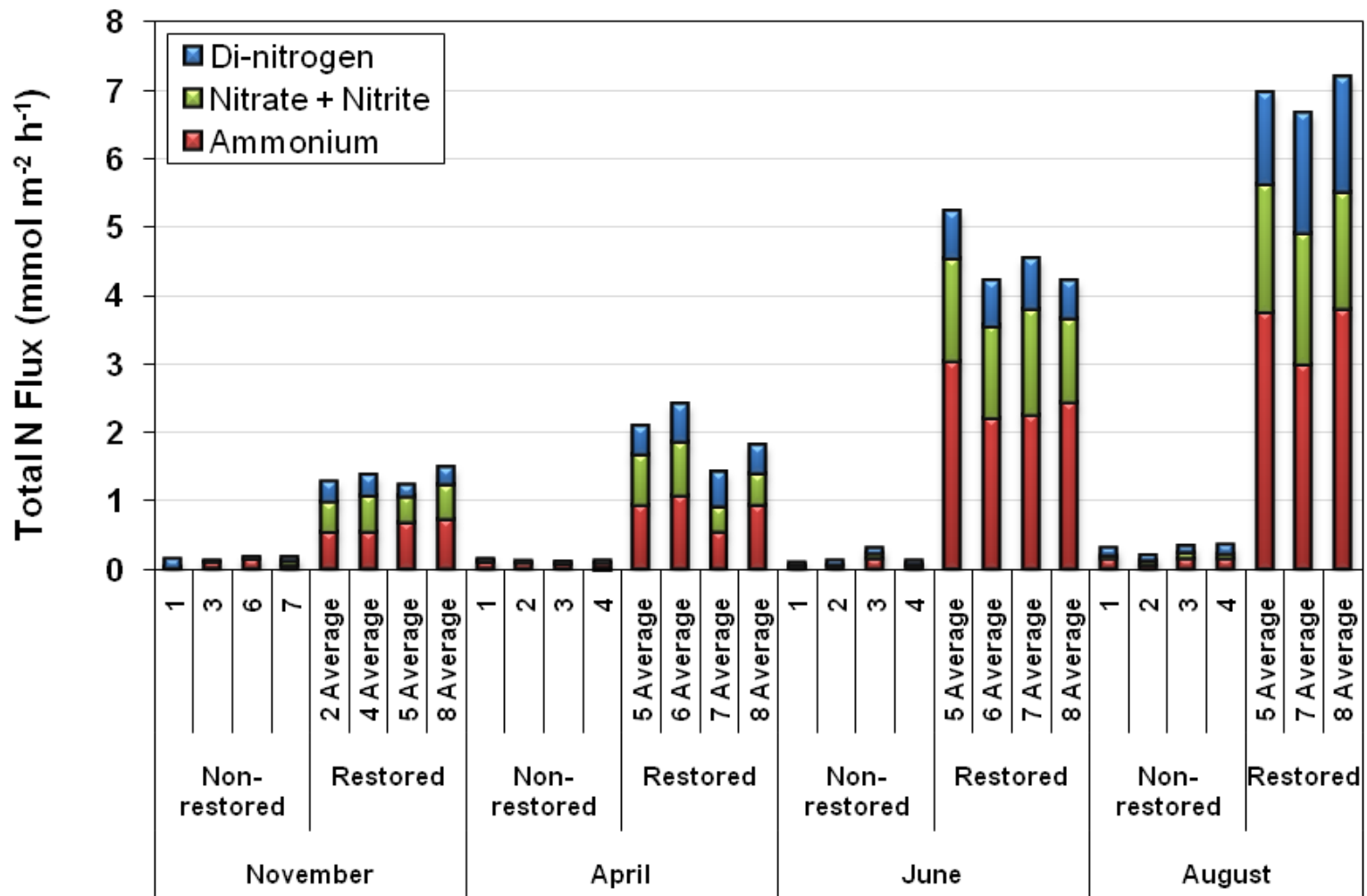
Funding from GenOn Energy with ORP

Faunal Abundance – Choptank River

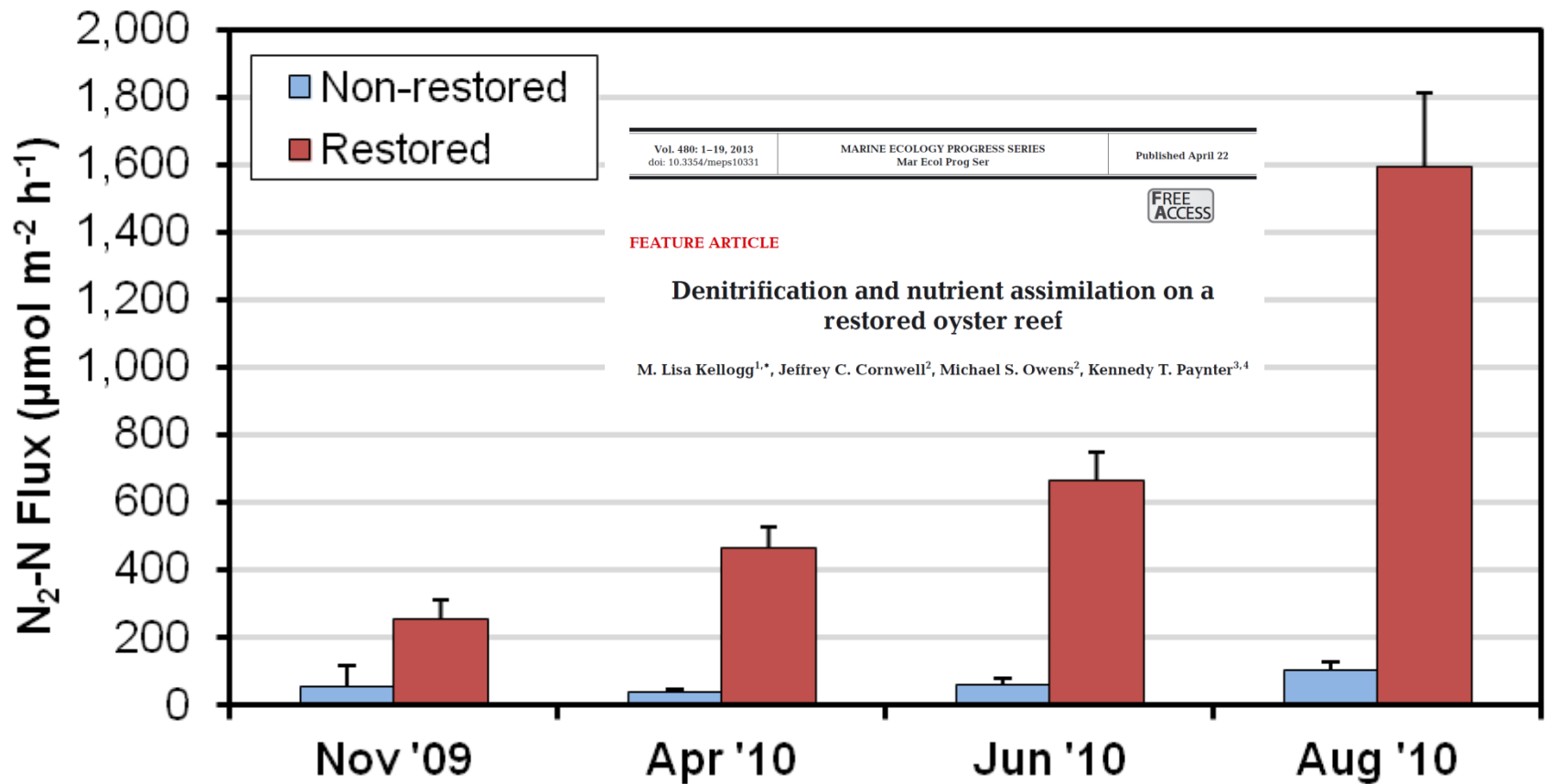
- Higher abundances of most organism types on restored oyster reefs



Small tray to tray variability!



Highest Chesapeake Rates Excluding Waste Water Plants



Impacts on WQ: Choptank River, MD Example

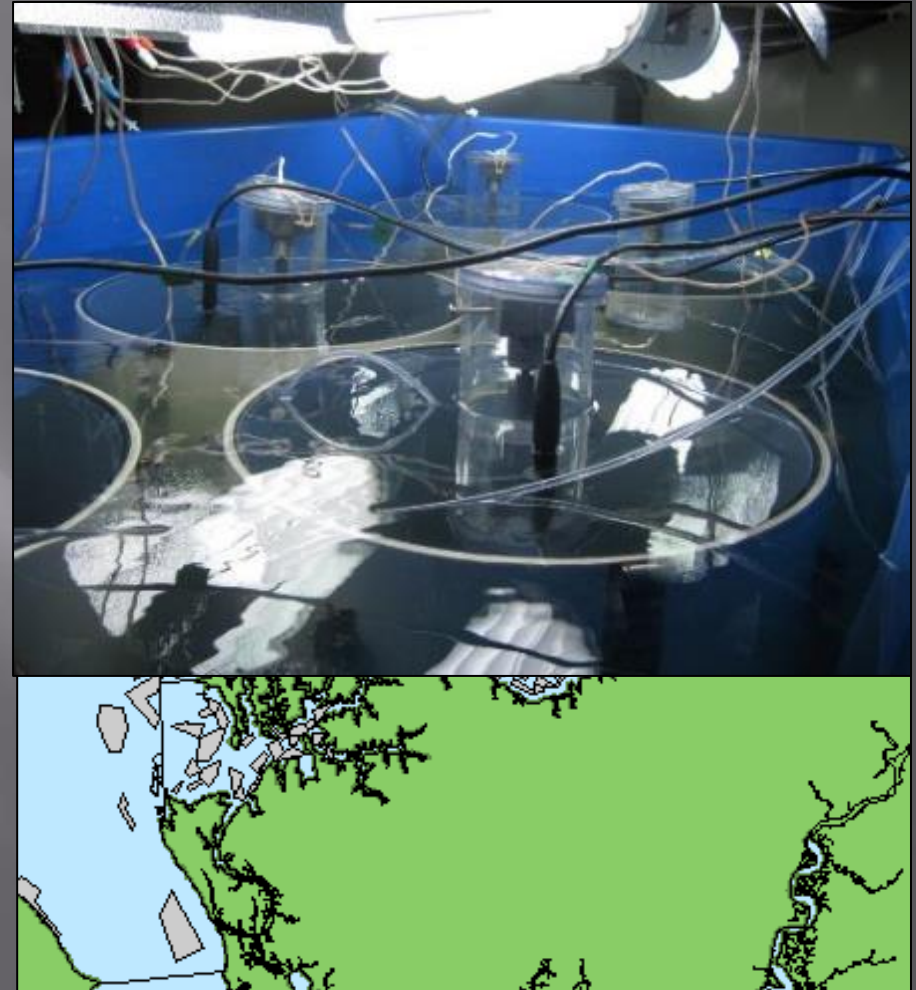
- ▣ Measured denitrification rates for a successfully restored oyster reef
 - Subtidal reef
 - Oysters 3-7 years old
 - High oyster biomass m^{-2}
- ▣ Estimated annual enhancement:
 - $55.6 \text{ g N}_2\text{-N m}^{-2} \text{ y}^{-1}$
(496 lbs. N $\text{acre}^{-1} \text{ y}^{-1}$)

Restoring all suitable bottom:

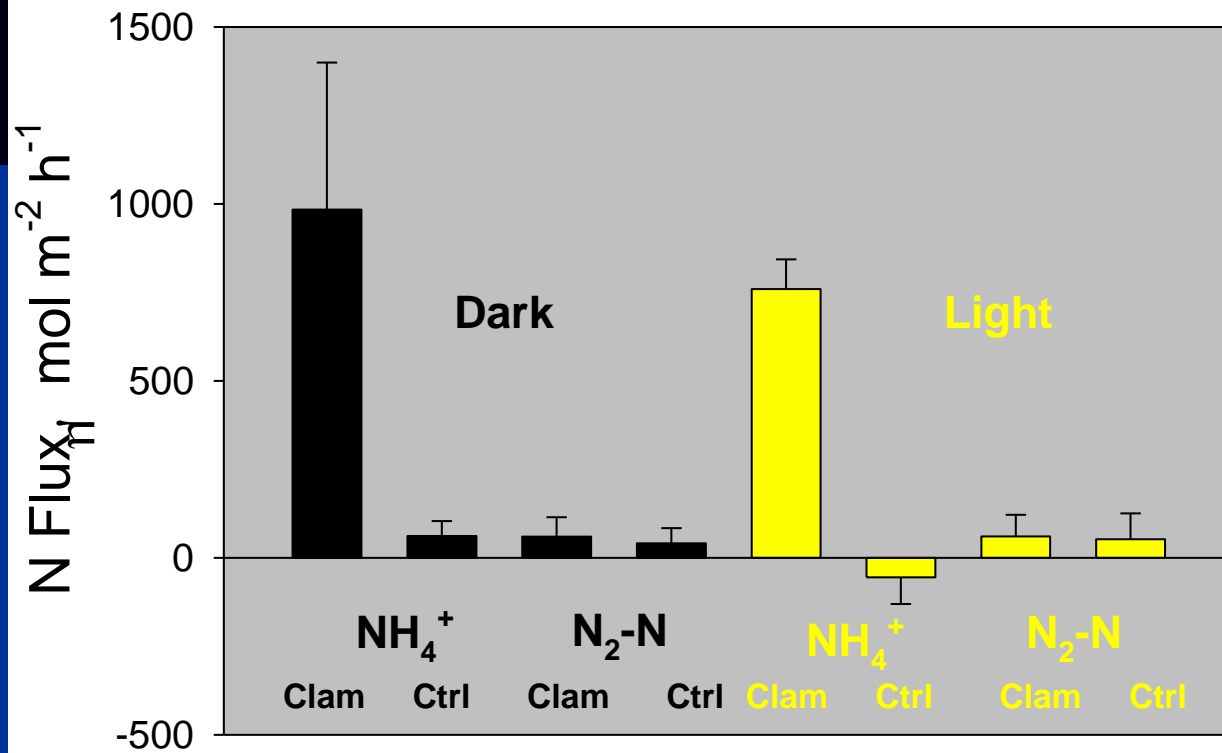
- “Suitable bottom” based on sonar surveys and fine-scale sampling of substratum
- 48% of total external N removed

Restoration needed to meet TMDL requirements:

- 23% of suitable bottom



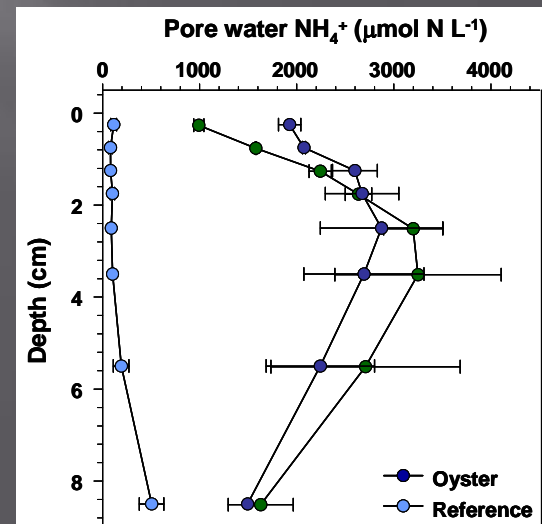
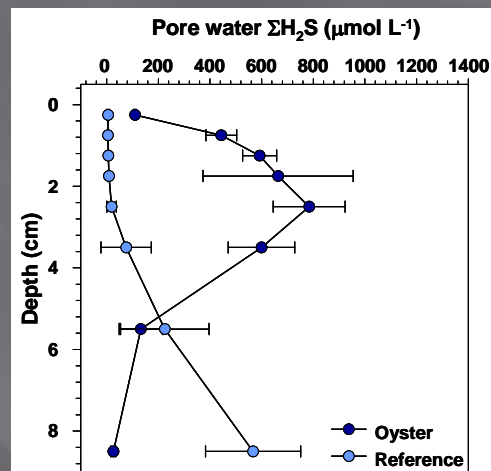
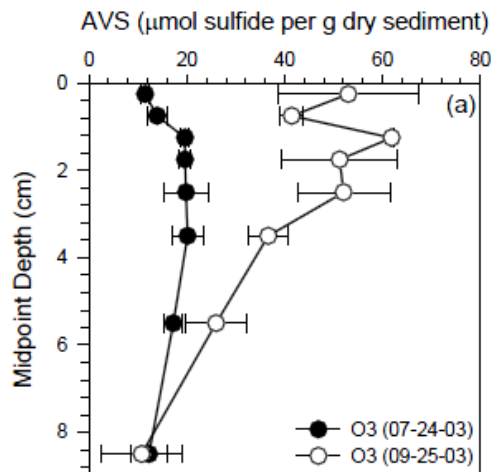
Coastal Bays Clams



Aquaculture

La Trappe Creek Taylor Floats

- Low flow, shallow water turbid system. Large changes in P, Fe, S chemistry, loss of benthic animals.
- Changes in N flux were dramatically attenuated by benthic microalgal uptake of remineralized N
- Denitrification not a big sink for N



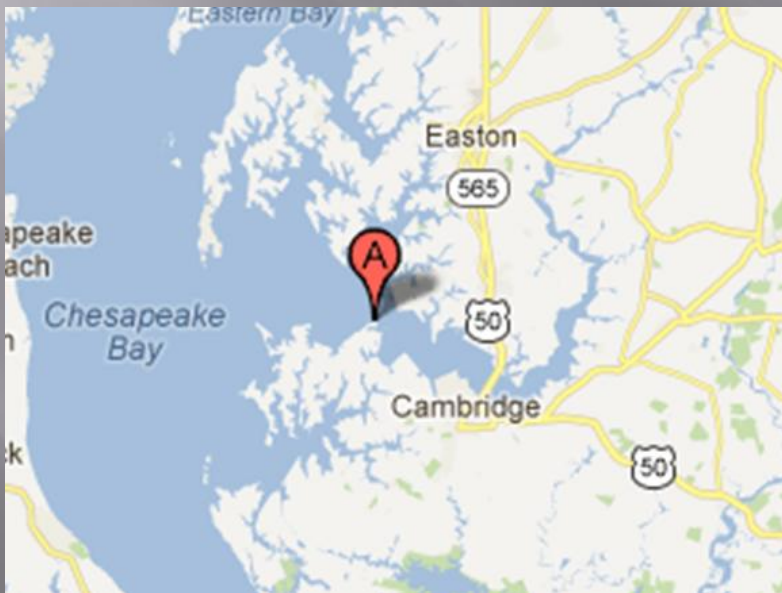
INVESTIGATIONS OF BIVALVE BIODEPOSIT DISPERSAL FROM AQUACULTURE FARMS

Larry Sanford, Roger Newell, Jeff Cornwell, Carter Newell, John Richardson, Jeremy Testa, Damian Brady, Steve Suttles, Abbas Haghshenas, Mike Owens, and Sarah Kwon

Funding from the NOAA National Sea Grant Office is gratefully acknowledged, as is the ready cooperation of Marinetics Oyster Farm (MD) and Mooks Oyster Farm (ME)

Study Sites

We carried out 4 intensive field studies at the Marinetics oyster farm at Castle Haven in the lower Choptank River, MD, during April, June, August, and September 2011, and 2 intensive field studies at a mussel farm and an oyster farm in the Damariscotta River, ME, during July 2012. These studies covered a wide range of temperatures, depths, tidal ranges, tidal currents, food supply, and farm design.





Measurements of sediment biogeochemical fluxes



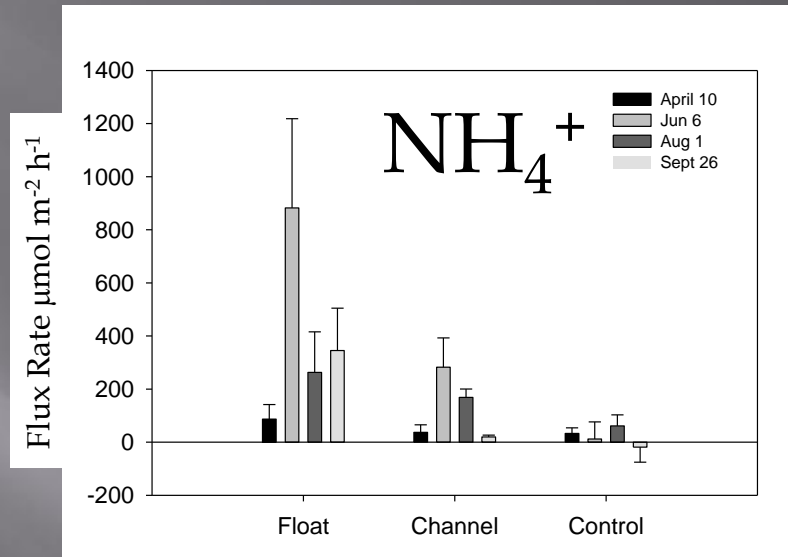
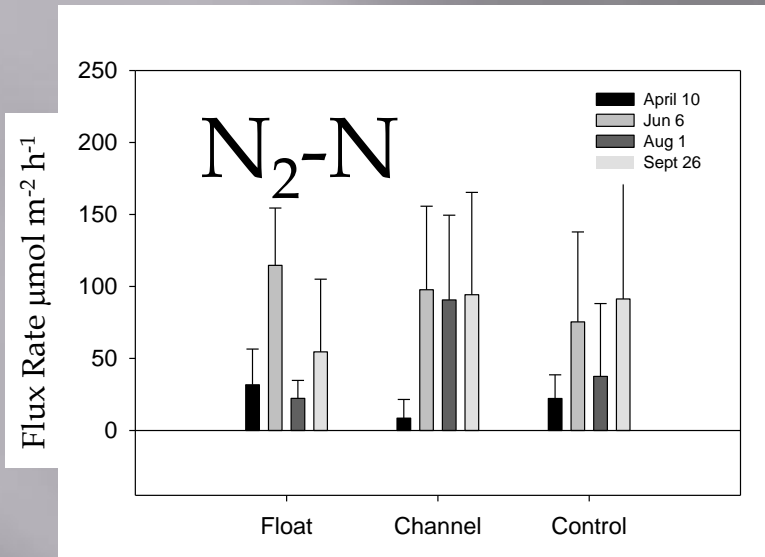
Different oyster aquaculture methods in the
Chesapeake (most photos by David Harp in articles
by Rona Kobell in the Chesapeake Bay Journal)



Measurements of currents, waves, tides, and water properties



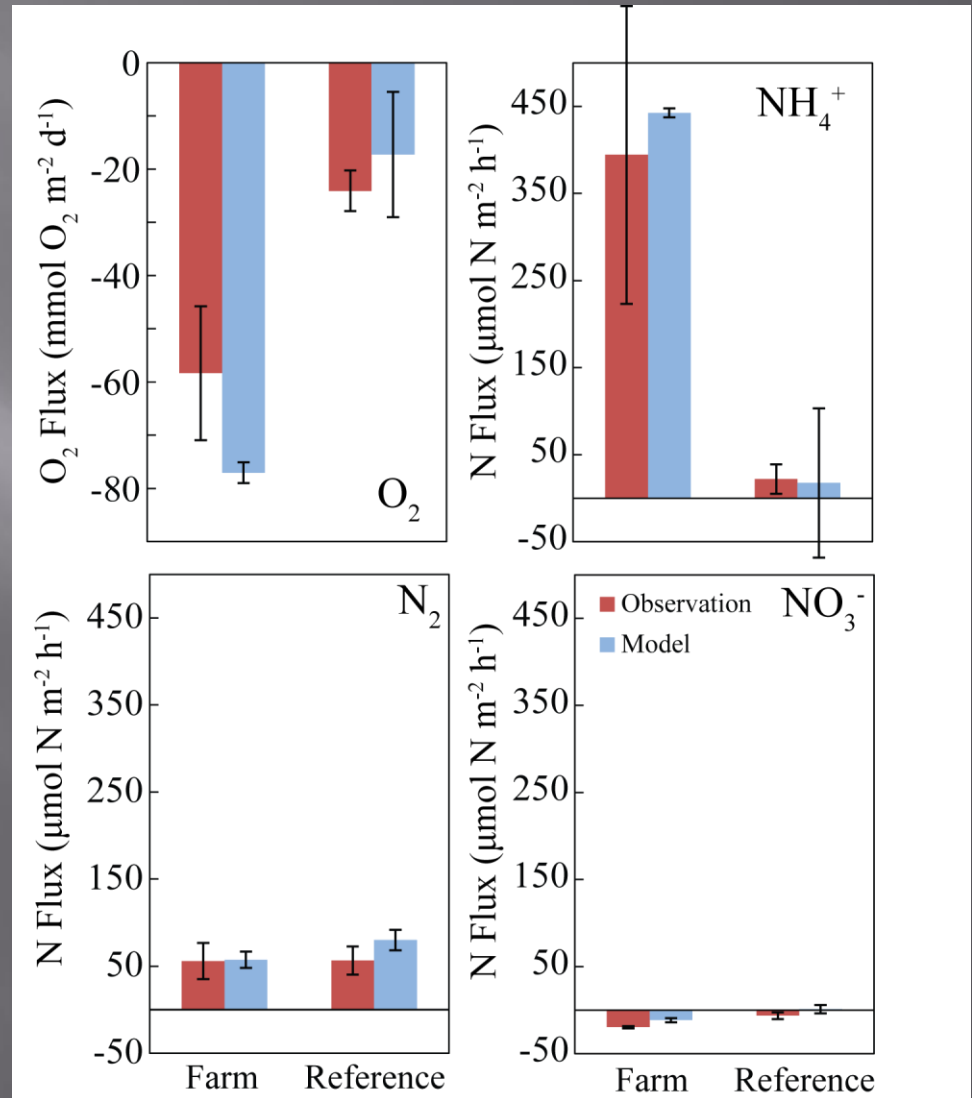
Nitrogen Fluxes



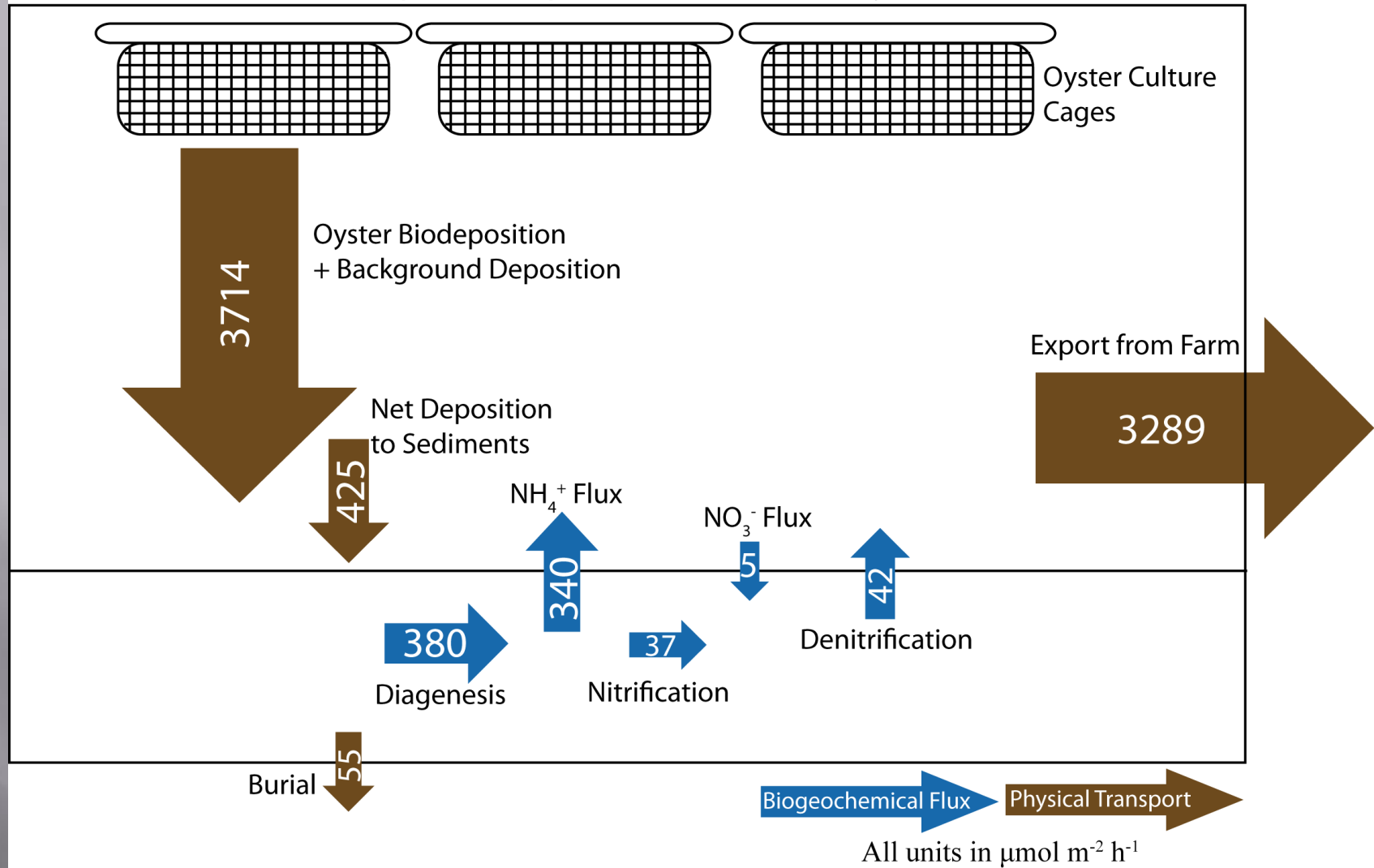
- ❑ High ammonium efflux rates occurred in June; at other times fluxes were higher than controls, but not extreme.
- ❑ Denitrification rates were relatively high at Channel and Control sites, somewhat attenuated at times under the oyster floats.
- ❑ The efficiency of denitrification relative to total N remineralization was 10-20% under the oysters, 20-70% at the other sites

SFM Modeling Results, Marinetics

- < 5% of oyster-generated organic matter was processed beneath the floats in the summer.
- Ammonium and oxygen fluxes are enhanced at farm site
- Denitrification, nitrate, and phosphate flux not enhanced below farm (although the model predicts significant reductions in aerobic layer depth)



Annual Nitrogen Budget at Marinetics Oystem Farm



CHALLENGES IN MODELING THE WATER QUALITY BENEFITS OF OYSTER REEF RESTORATION: HARRIS CREEK, MD

M. Lisa Kellogg, Mark J. Brush and Younjoo Lee*

Harris Creek Model

User inputs for each segment

- Area of reef
 - Upper bound set by total amount of suitable bottom in each segment
- Oyster per unit area
- Mean oyster biomass or length

2. Specify the density of restored oysters (#/acre) in each spatial element.

Restored Oyster Density ▼	
Oyster density[1]	0
Oyster density[2]	0
Oyster density[3]	0
Oyster density[4]	0
Oyster density[5]	0

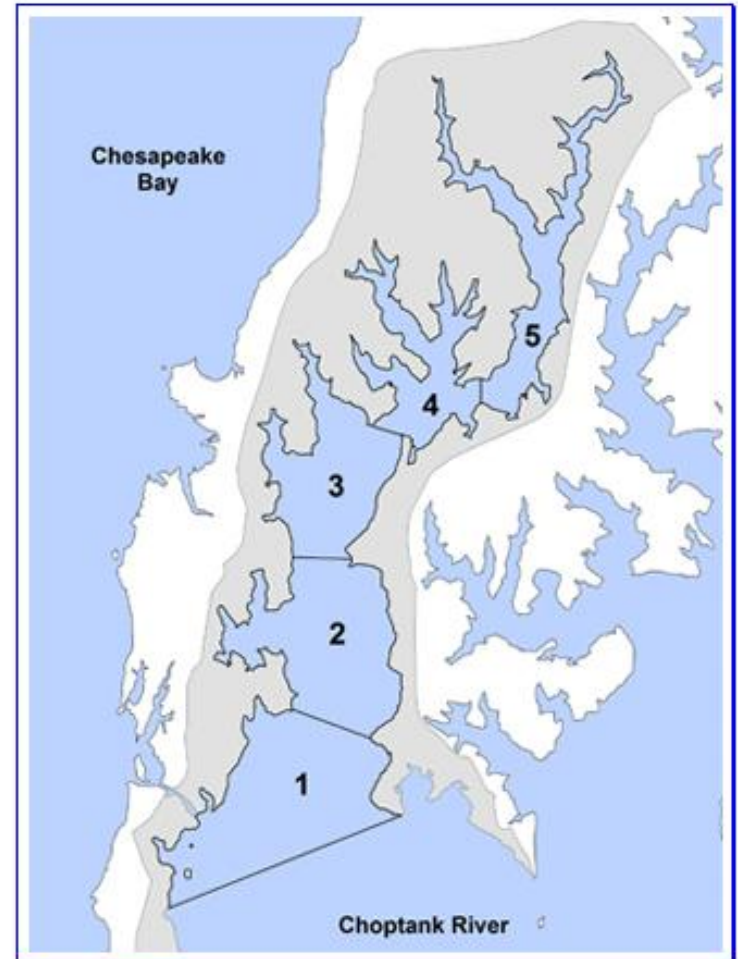
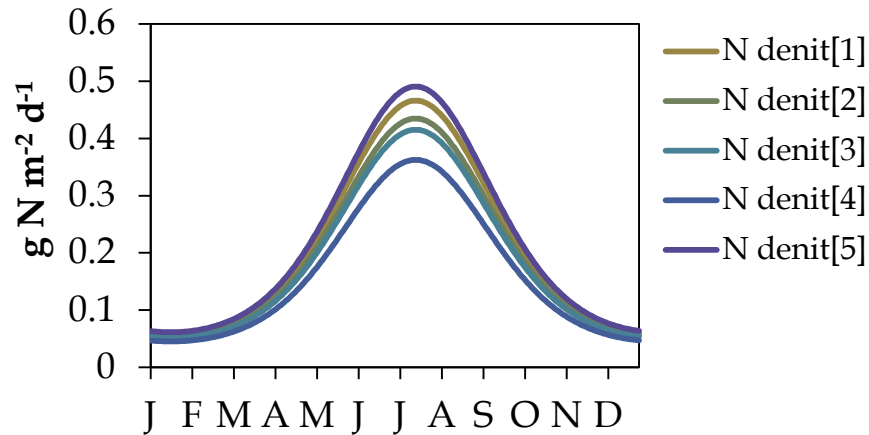


Fig. 1: Spatial elements (1-5) of the Harris Creek model. Watershed boundary is shown in light grey.

Harris Creek Model

Denitrification



N Assimilation

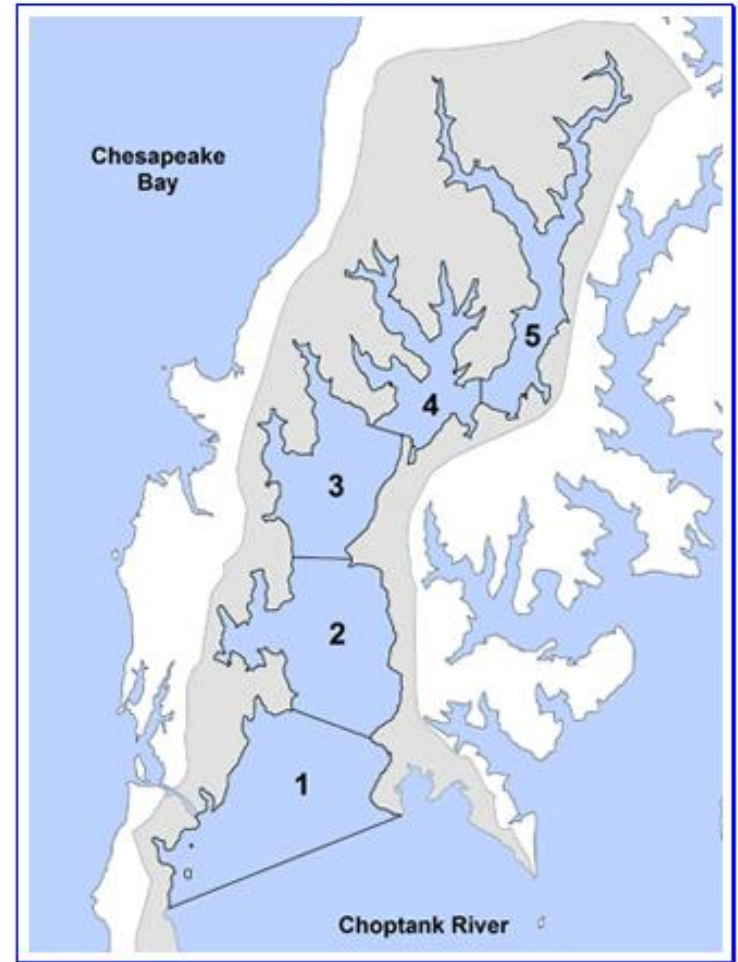
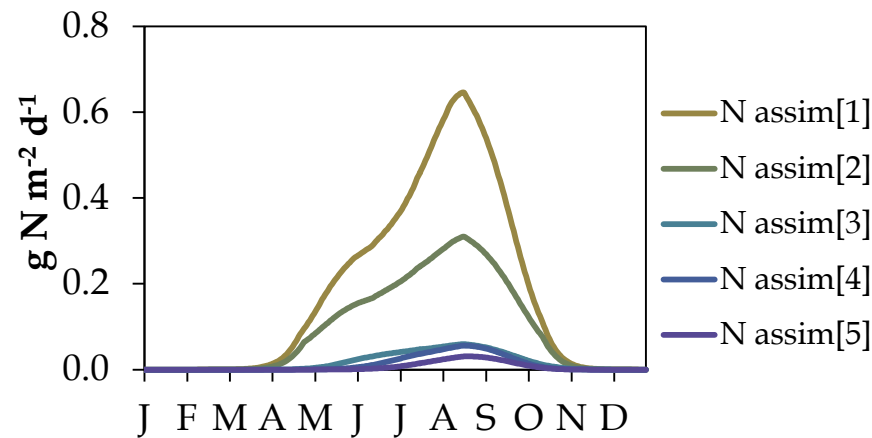
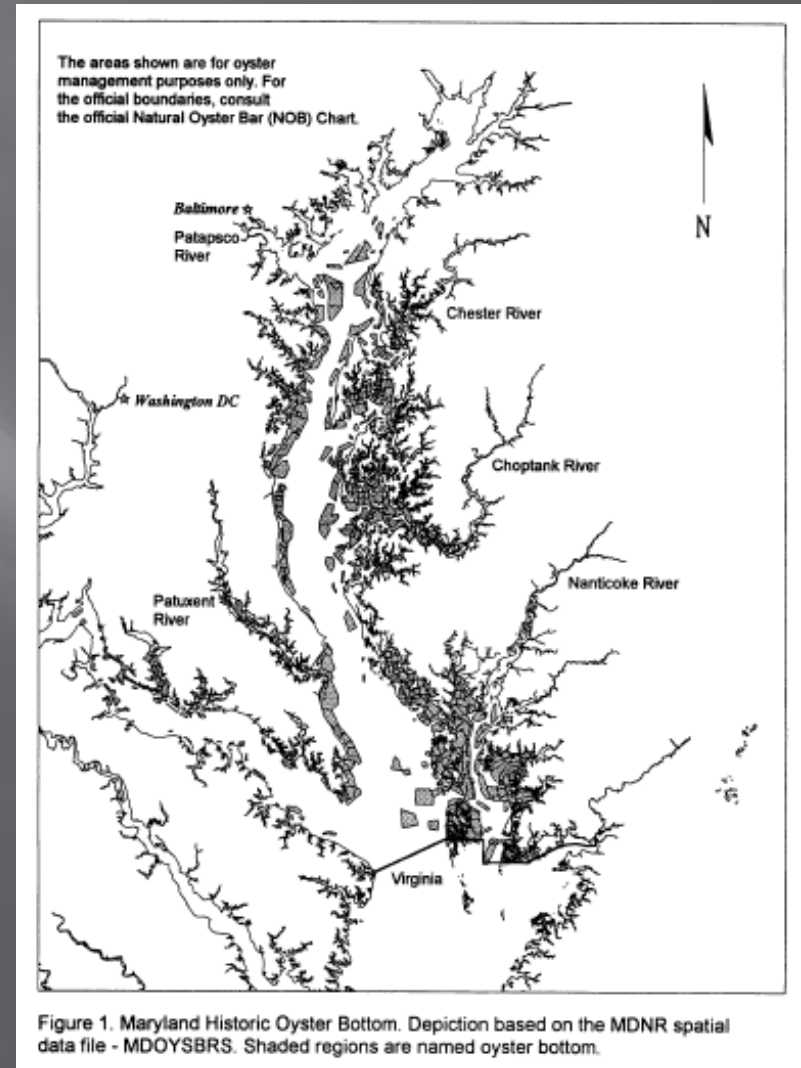
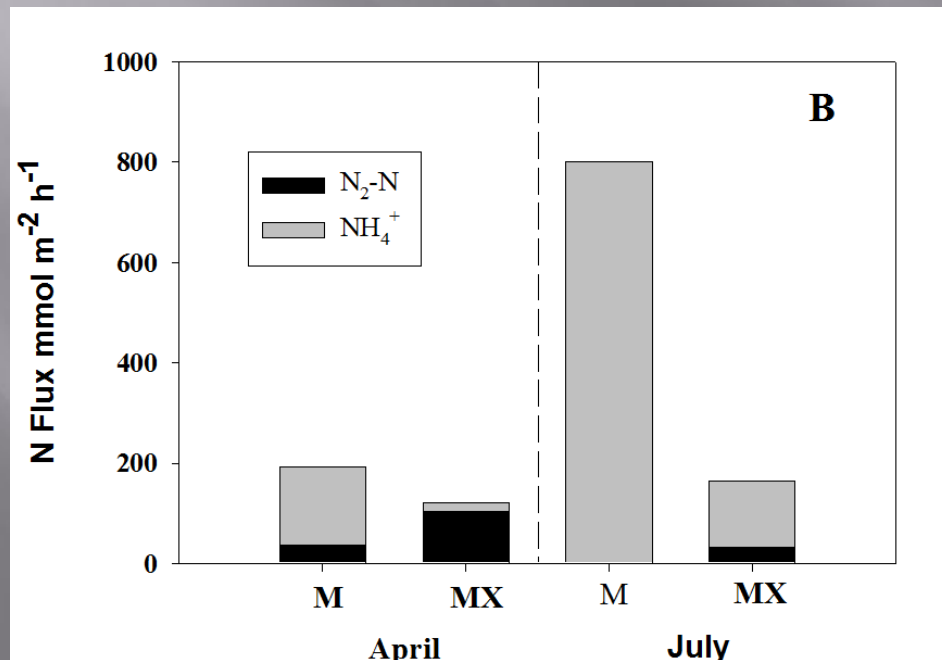


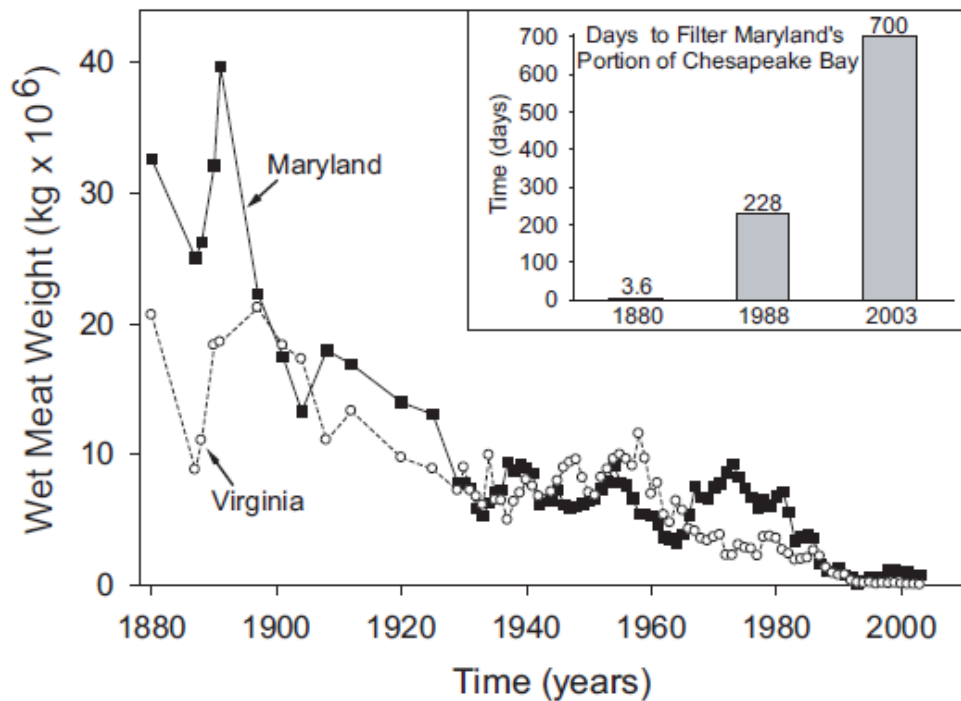
Fig. 1: Spatial elements (1-5) of the Harris Creek model. Watershed boundary is shown in light grey.

Large Scale Changes????

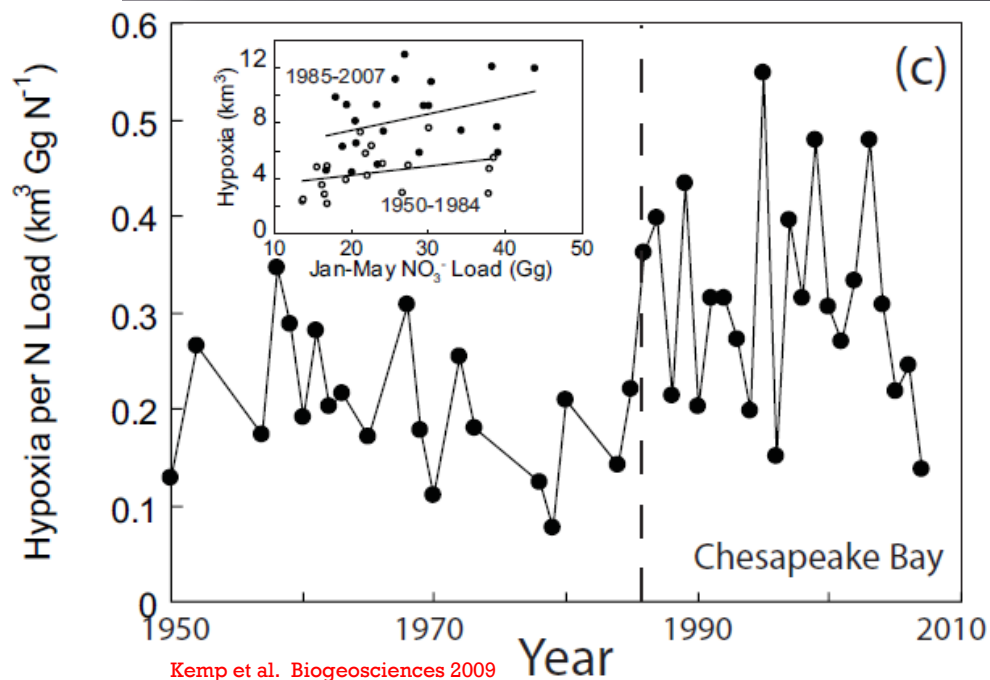
The Simple Case

If the fate of algal N is removal in shallow oyster reefs versus deep, anaerobic sediments, reef denitrification is a true net water quality benefit





Kemp et al. MEPS 2005



Kemp et al. Biogeosciences 2009