Bivalve impacts on water quality: positives, negatives and unknowns

M. Lisa Kellogg

September 7, 2012

VIMS | William & Mary
Virginia Institute of Marine Science

Overview

Focus:

- Chesapeake Bay
- Nitrogen
  - Bioassimilation
  - Burial
  - Denitrification

Bivalve scenarios:

- Unharvested oyster reefs
- Harvested oyster reefs
- Oyster aquaculture
- Clam aquaculture

Phosphorus and Carbon

Phosphorus

- Bioassimilation
  - Easily calculated for standing stocks
  - Rates are more complicated
- Burial
  - More complicated and site-specific than N
    - Fluxes of P from sediments highly variable
    - Dependent on sulfur and iron cycles

Organism	% N	% P
Amphipods	4.53	1.99
Anemones	9.17	1.33
Barnacles	0.99	0.14
Clams - mixed spp.	1.42	0.10
Clams - *Mya* spp.	2.38	0.28
Crabs - gravid	4.15	1.40
Crabs - not gravid	3.98	1.37
Fish - Blennies	10.86	3.84
Fish - Gobies	10.60	3.61
Fish - Skilletfish	9.37	4.59
Fish - Toad fish	11.04	3.66
Mussels - shell	**0.47**	**0.04**
Mussels - tissue	**10.93**	**1.35**
Oyster - shell	**0.21**	**0.04**
Oyster - tissue	**9.27**	**1.26**
Polychaetes worms	6.84	1.07
Shrimp - gravid	8.95	2.44
Shrimp - not gravid	9.35	2.59

Phosphorus and Carbon

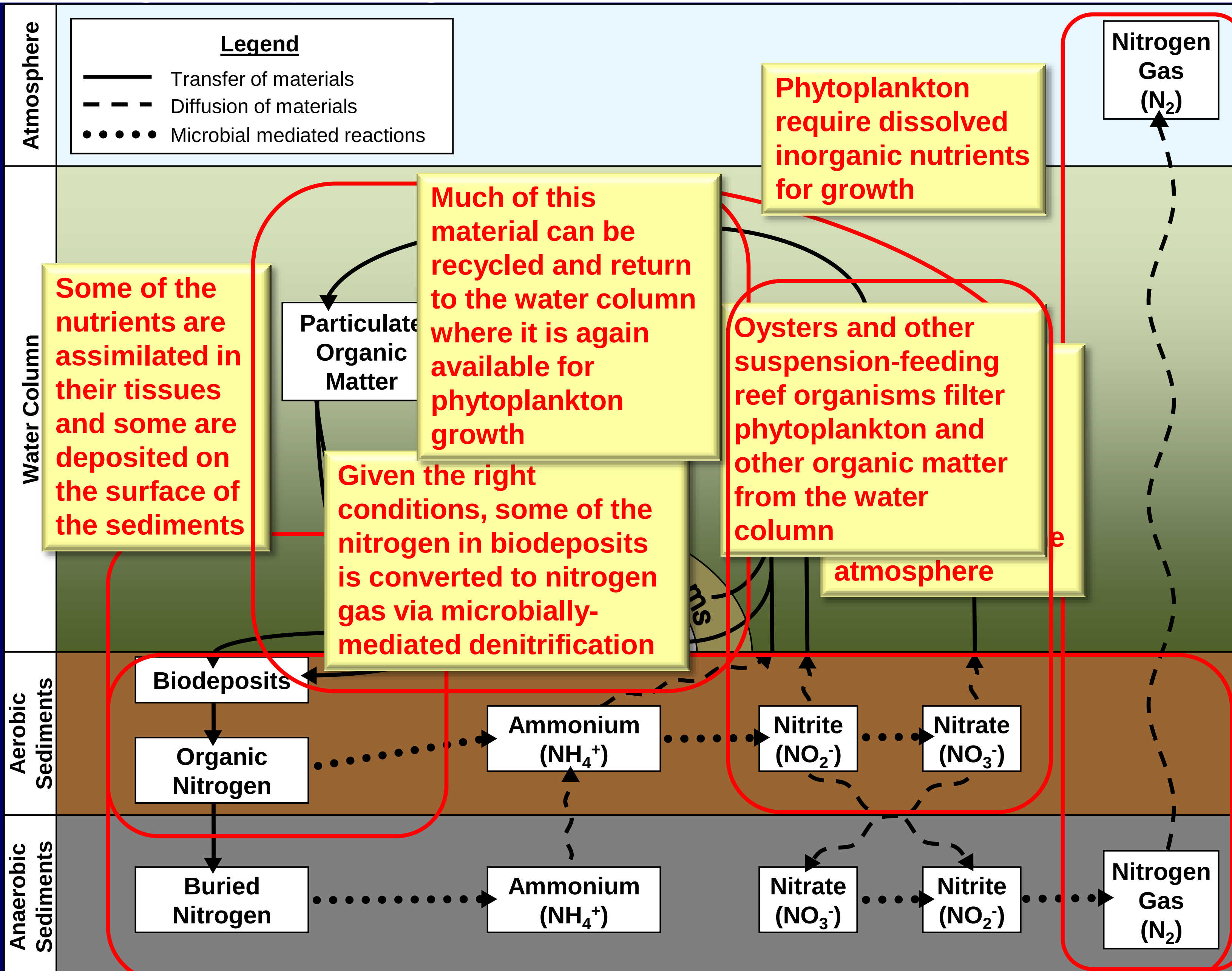
Carbon

- Bioassimilation
  - Not equal to total carbon content
    - Calcium carbonate production releases CO_2
    - Shellfish respire
    - Soft tissues do contain C

Organism	% C	% $CaCO_3$-C
Amphipods	27.73	
Barnacles	14.55	9.24
Clams - *Mya* spp.	19.65	6.95
Crabs	24.55	
Fish - Blennies	43.46	
Fish - Gobies	43.70	
Fish - Skilletfish	43.04	
Fish - Toad fish	40.29	
Mussels - shell	12.95	5.98
Mussels - tissue	46.55	
Oyster - shell	12.29	11.03
Oyster - tissue	48.56	
Polychaetes worms	35.50	

- Burial
  - Might result in carbon sink on natural oyster reefs (Fodrie et al. In prep)
    - Organic burial > inorganic burial
    - Reef accretion without long-term accumulation of shell
      - Intertidal sandflats: 7.1 ± 1.2 Mg C ha^{-1} yr^{-1}
      - Shallow subtidal: -1.0 ± 0.4 Mg C ha^{-1} yr^{-1}
      - Adjacent to salt marshes: -1.3 ± 0.4 Mg C ha^{-1} yr^{-1}

Nitrogen Cycling on Unharvested Oyster Reefs



Adapted from: Newell RIE, Fisher TR, Holyoke RR, Cornwell JC (2005) Influence of eastern oysters on nitrogen and phosphorus regeneration in Chesapeake Bay, USA. In: Dame RF, Olenin S, (eds). The comparative roles of suspension feeders in ecosystems, NATO ASI Sci Ser 4 Earth Environ Sci, Springer-Verlag, Berlin, p 93–120.

Unharvested Oyster Reef

Bioassimilation

- Choptank River, MD (Kellogg et al.)
- Based on average standing stock biomass
  - Restored reef 2 orders of magnitude > bioassimilation than non-restored
  - Non-oyster macrofauna 37% of total N

	Non-restored	Restored
Nitrogen (g m^{-2} ± SD)		
Oysters	0.000 ± 0.000	61.759 ± 6.082
Non-oyster macrofauna	0.254 ± 0.218	35.880 ± 11.093
Total	***0.254 ± 0.218***	***97.639 ± 17.051***

- Nitrogen sequestered, not removed
- Calculations of rates is more complicated

Unharvested Oyster Reef

Burial

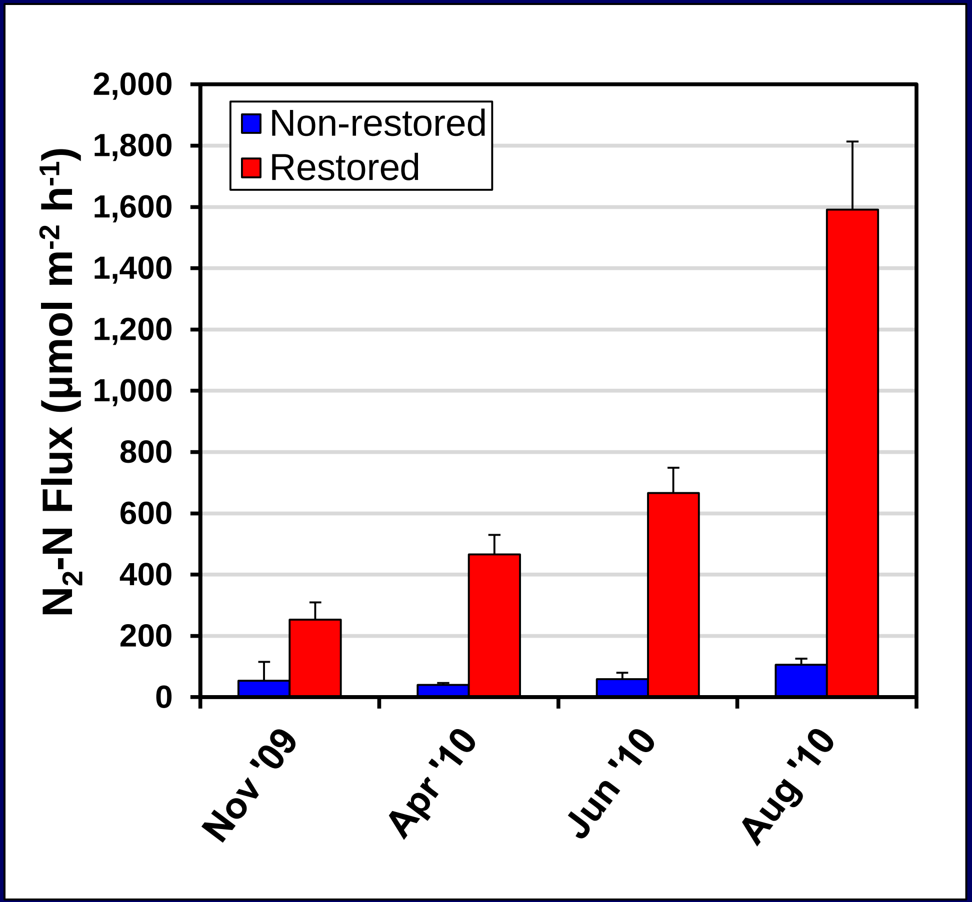
- Newell et al. (2004):
  - 10% burial of PON in biodeposits
    - Based on Boynton et al. (1995)
      - Data for Choptank River sediments, not oyster reefs specifically
- Likely varies by site and with reef characteristics
  - Deposition rates
  - Hydrodynamic patterns
  - Reef structure
  - Position within the landscape (e.g. proximity to salt marsh)

Photos: Mark Luckenbach

Unharvested Oyster Reef

Denitrification

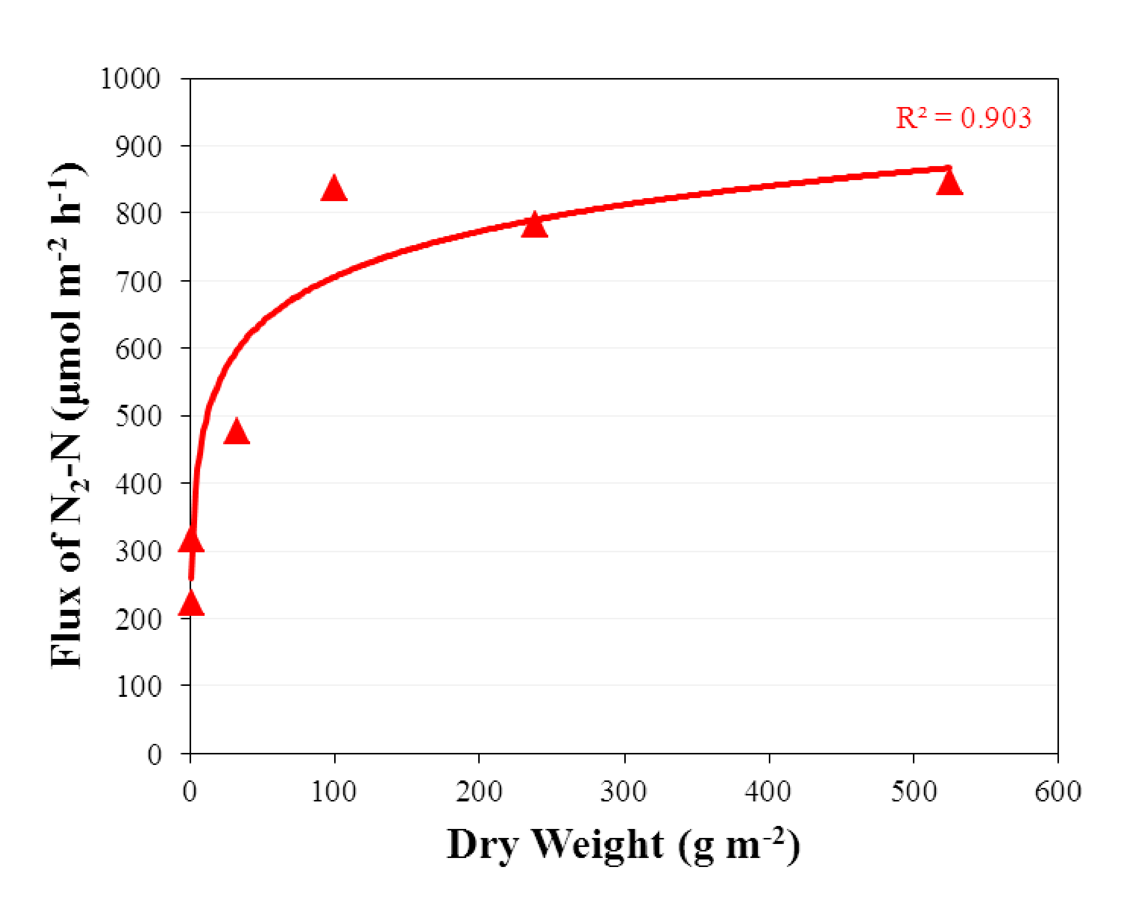
- Restored oyster reef in Choptank River (Kellogg et al.)
  - Below photic zone
  - Rates vary with season
  - August rates high
    - 1592 μmol N m^{-2} h^{-1}
  - Estimated annual removal:
    - 609 kg N ha^{-1} yr^{-1}
    - 543 lbs N $acre^{-1}$ yr^{-1}



Unharvested Oyster Reef

Denitrification

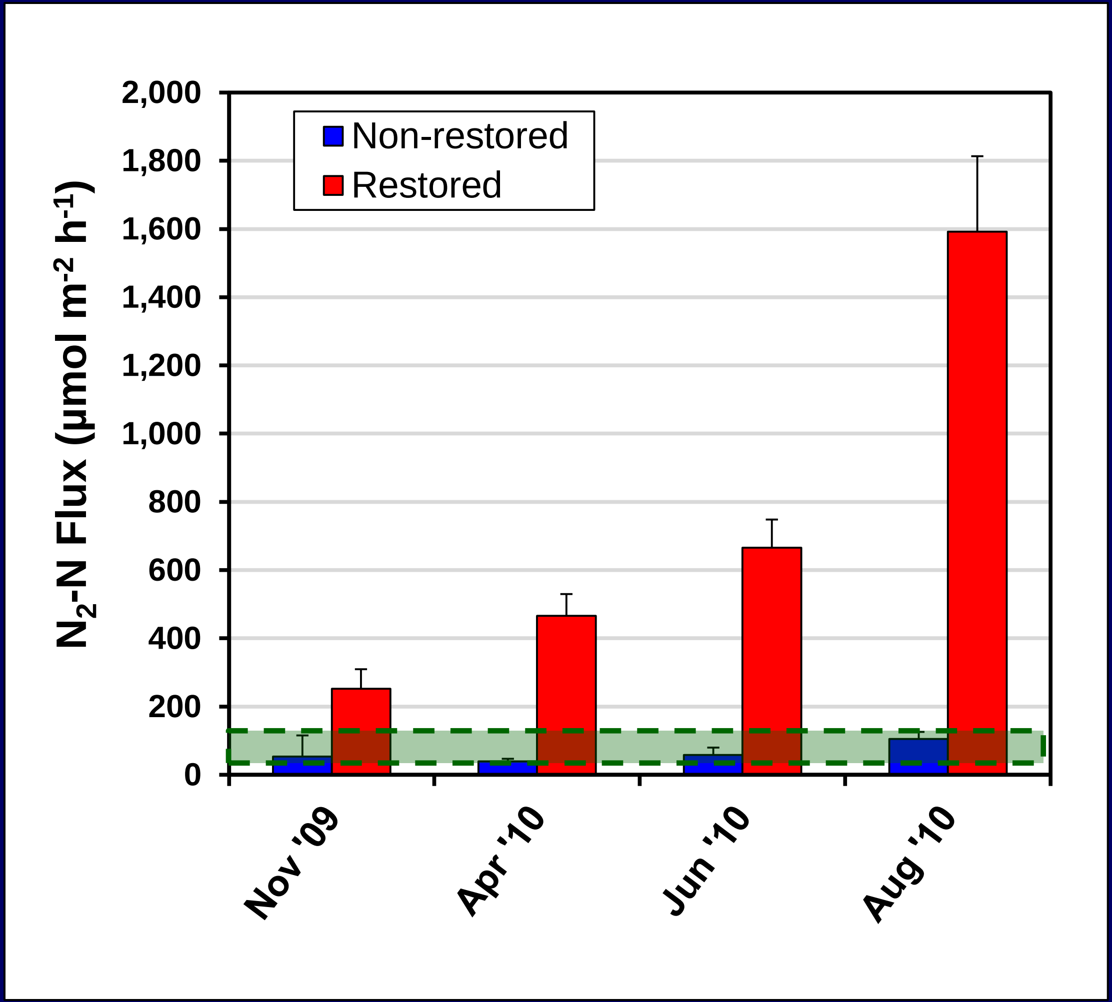
- Experimental reefs in Onancock Creek, VA (Kellogg et al.)
  - April 2012
  - Shallow subtidal
  - Rates vary with oyster density



Unharvested Oyster Reef

Denitrification

- Rates vary widely with location
  - Onancock April rates ~2x Choptank rates for comparable oyster densities
  - Piehler et al. (2011)
    - Oyster reef sediments only
    - Rates much lower than Kellogg et al.



Harvested Oyster Reef

Bioassimilation

- Occurs in oysters and associated macrofauna
- Harvest
  - Removes nutrients in oysters
  - Mortality releases nutrients
    - Some unharvested oysters killed by harvest activities
    - Can be significant mortality of associated macrofauna

Harvested Oyster Reef

Burial

- Harvest impacts:
  - Resuspends buried nutrients
    - Varies with harvest method
  - Degrades reef structure
    - Alters local hydrodynamics and reduces passive deposition
  - Reduces filtration capacity and biodeposition
    - Oysters
    - Associated organisms
      - Mussels
      - Tunicates

Harvested Oyster Reef

Denitrification

- Harvest:
  - Reduces biodeposition
    - Less organic material decomposition
    - Lower potential for denitrification
  - Reduces bioturbation
    - Fewer areas were oxic and anoxic sediments are in close proximity
  - Degrades reef structure
    - Reduced total surface area for microbial growth
    - Reduced complexity reduces areas of adjacent oxic and anoxic sediments
  - Reduces nitrification
    - Surfaces of macrofauna can be sites of nitrification (Welsh et al.)

Oyster Aquaculture

Bioassimilation

- Maintenance
  - Kills macroalgae and macrofauna
  - Releases nutrients
- Harvest removes nutrients
  - Two sites in Potomac River, MD (Higgins et al. 2001)
    - 378 kg N ha^{-1} per 1-2 yr
      - Oyster density = 286 76-mm oysters m^{-2}
      - Assumes no mortality

Photo: Mark Luckenbach

Oyster Aquaculture

Burial

- Site-specific
  - Biodeposition rate
    - Phytoplankton density
    - Oyster density
    - Hydrodynamic regime
    - Type of aquaculture
      - Surface floats
      - Bottom racks

Photos: Mark Luckenbach

Oyster Aquaculture

Denitrification

- Can be enhanced or not
  - Laboratory study (Newell et al. 2002)
    - 20% of biodeposits denitrified if:
      - Sediments were oxygenated
      - No significant microphytobenthic community
    - No denitrification under anoxic conditions
    - Under oxic conditions with sufficient light
      - Microphytobenthic community developed
      - Absorbed inorganic nitrogen
      - Fixed N_2

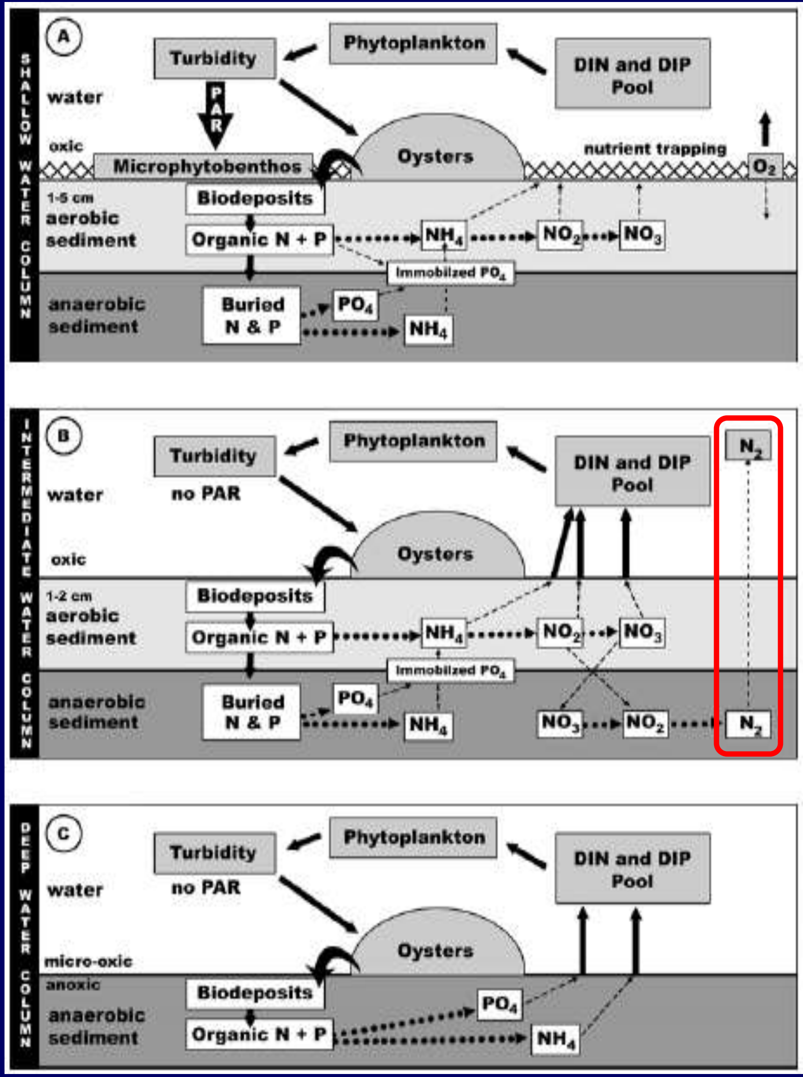


Image: Newell et al. 2002

Nitrogen Cycling and Clam Aquaculture

Differs from oyster reefs

- Infaunal bivalves
  - Less enhancement of associated macrofauna
- Shallow waters in photic zone
- Covered with netting to exclude predators
  - Significant macroalgal growth
- Far higher densities than found naturally

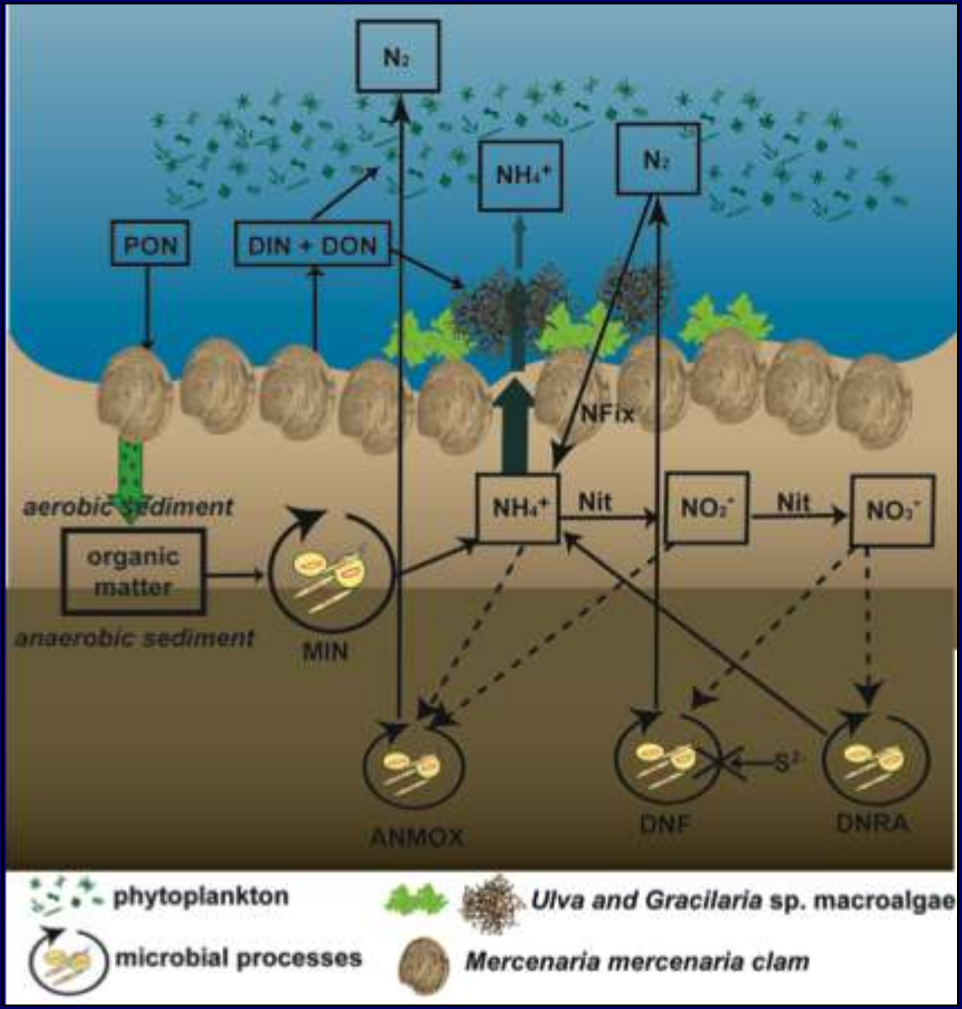
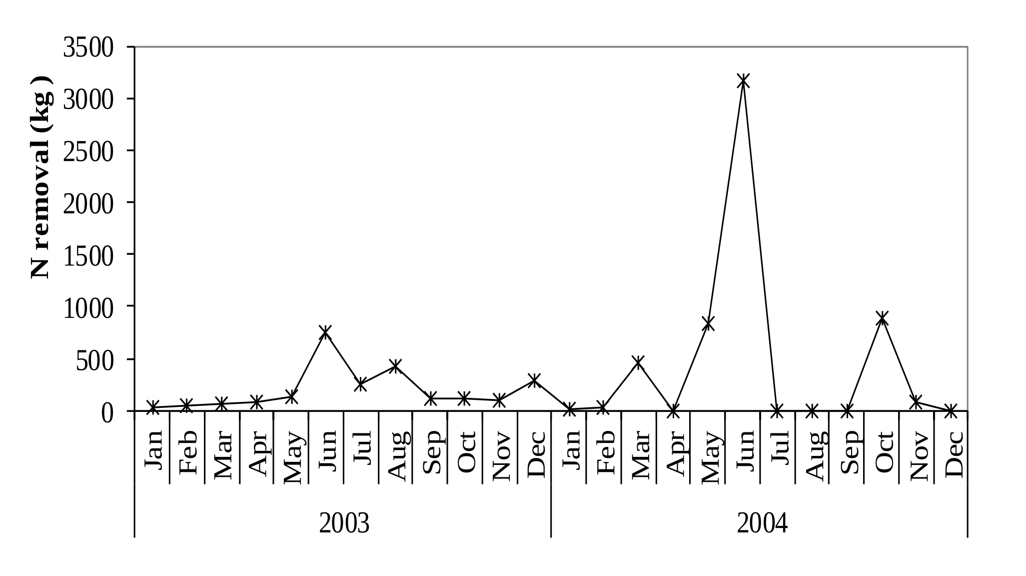


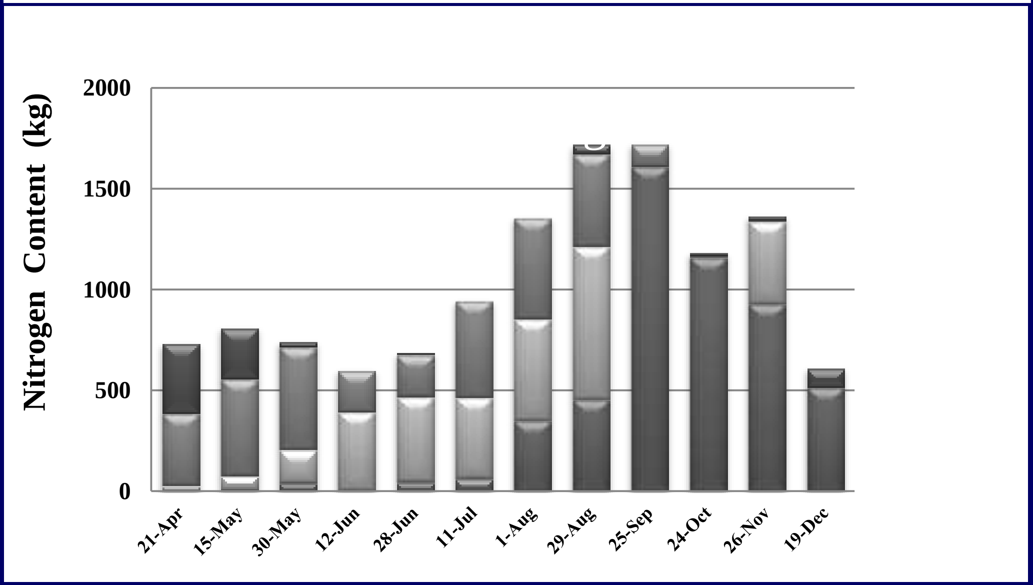
Image: Jen Stanhope

Clam Aquaculture

Bioassimilation

- Cherrystone Creek, VA
- Clams (Condon 2006)
  - Removal of nutrients by clam harvest
- Macroalgae (Luckenbach 2008)
  - Collected data on macroalgae abundance and nutrient content on nets
  - Calculated creek-wide nitrogen bioassimilated in macroalgae





Clam Aquaculture

Burial

- Clams
  - Enhance biodeopsition
    - Varies with season (Murphy et al. ongoing studies)
  - Harvest resuspends deposits
- Macroalgae
  - Can reduce flow and enhance passive deposition
  - Net cleaning resuspends deposits

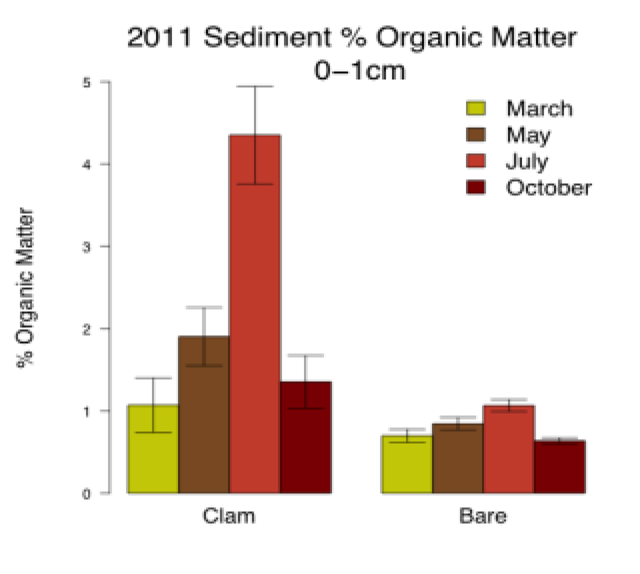
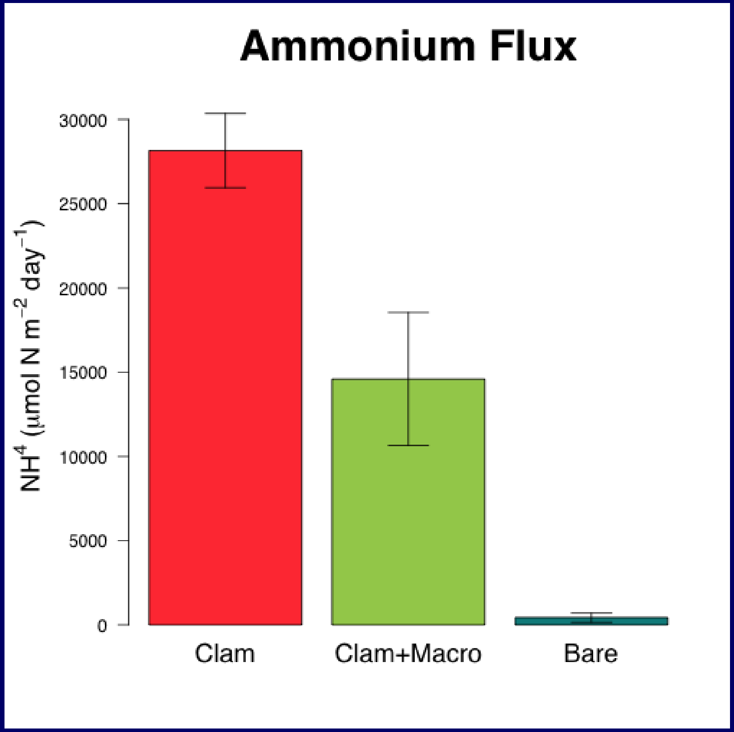


Photo: Mark Luckenbach

Clam Aquaculture

Denitrification

- May be enhanced or reduced
  - Likely depends on season and interactions with macroalgae (Murphy et al. ongoing studies)
    - Denitrification rates not available yet
    - Ammonia fluxes clearly influenced by presence of macroalgae
    - Summer measurements demonstrate periodic anoxia under nets



Points to Remember

1) Filtration ≠ nutrient removal
   - Significant portion of nutrients recycled
2) Calcium carbonates ≠ carbon sequestration
   - CO_2 released during formation
3) Location, density and season matter
   - Rates of nutrient cycling vary in space and time
   - Variances are often greater than the means
4) Extrapolate with caution
   - Commonly-cited values are based on data that may or may not apply to the situation at hand