Understanding Nitrogen Transformations and Removal at Oyster Restoration Sites in the Hudson-Raritan Estuary

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Ray Grizzle, U. of New Hampshire

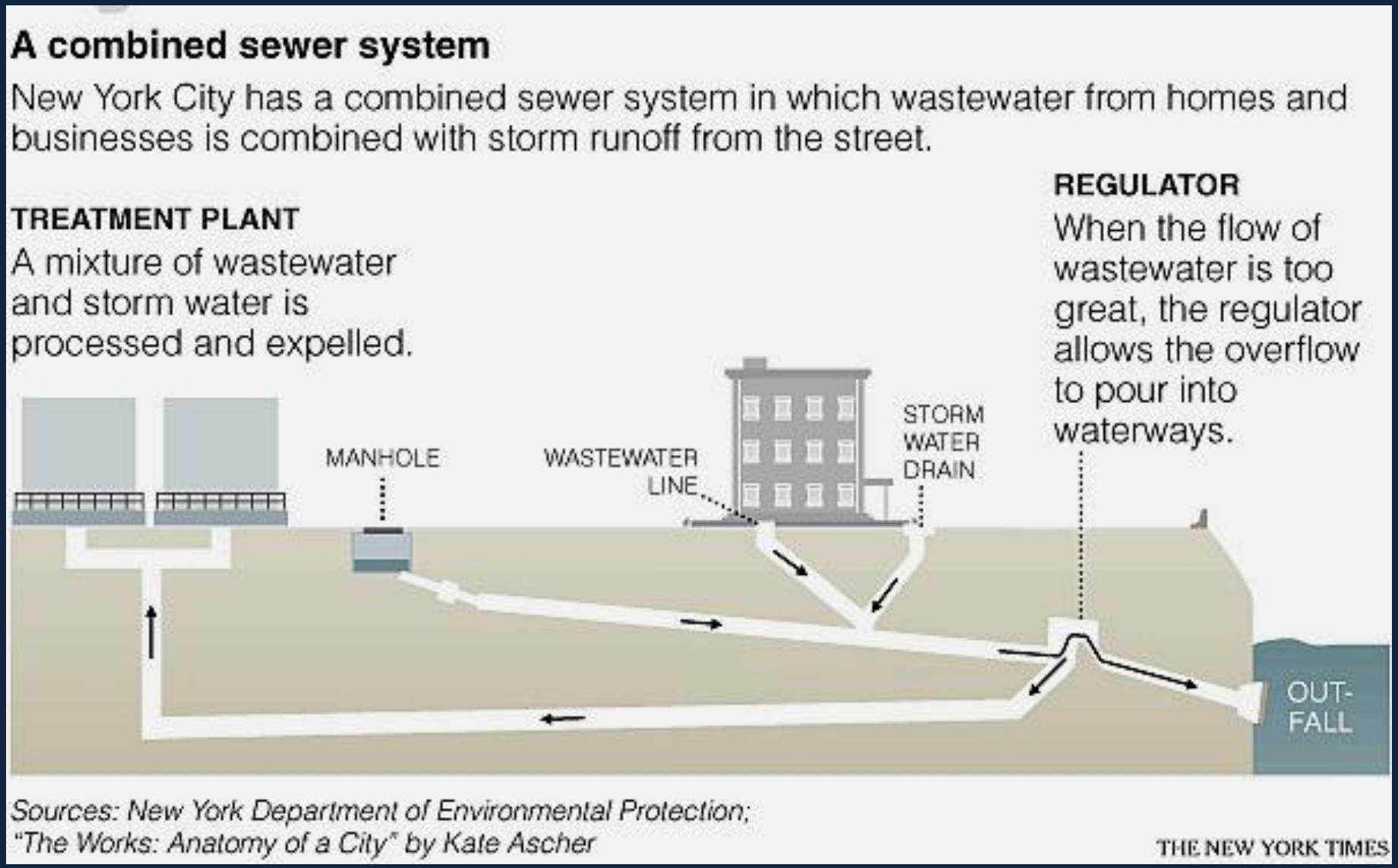
Eutrophication is a major environmental concern

- Common in estuaries globally
  (Kennish 2002)
- Coastal ecosystems are typically N-limited
  (Howarth and Marino 2006)
- Hudson River estuary among highest N load in the world
  (Howarth et al. 2006)

N load to various estuaries	(g N $m^{-2}yr^{-1}$)
Hudson River estuary	290
Scheldt River estuary	190
Boston Harbor (pre-diversion)	130
Ochlockonee Bay	84
N. Gulf of Mexico ("dead zone")	32
Narragansett Bay	28
Delaware Bay	27
San Francisco Bay	25
Long Island Sound	17
Chesapeake Bay	14
Baltic Sea	3

(Howarth et al. 2006)

NYC Sewer System



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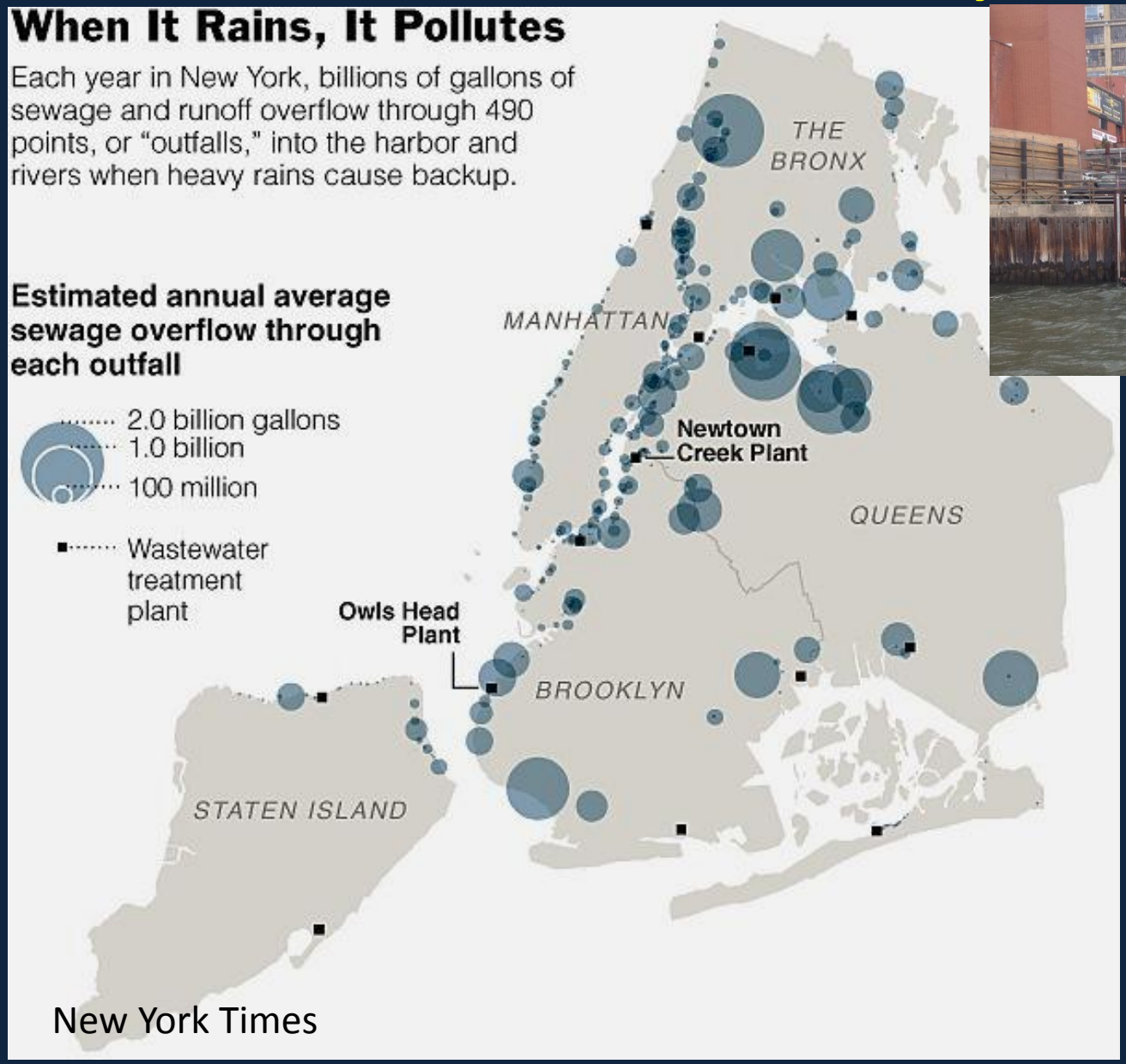

New York Times

Impacts of nitrogen loading

Impacts of nitrogen loading

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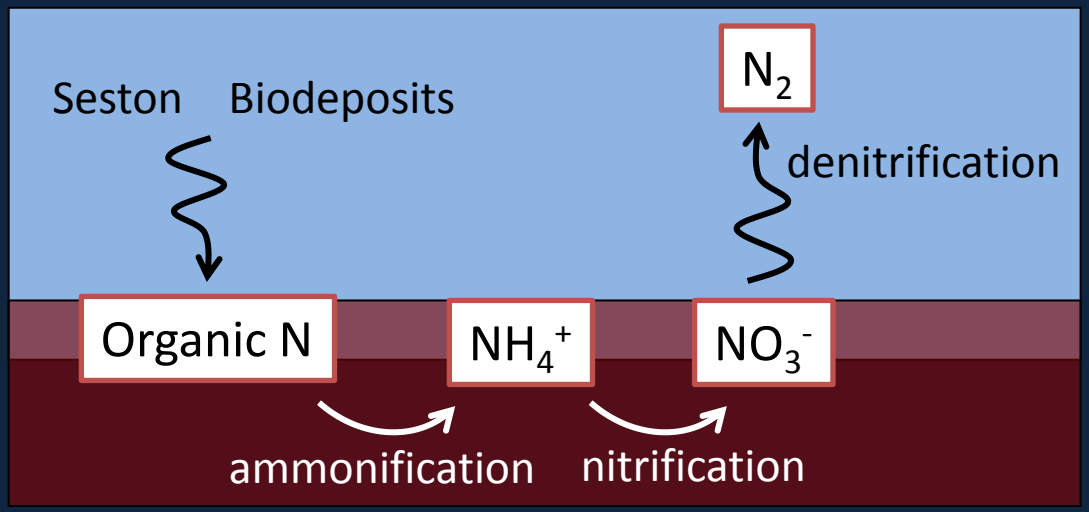
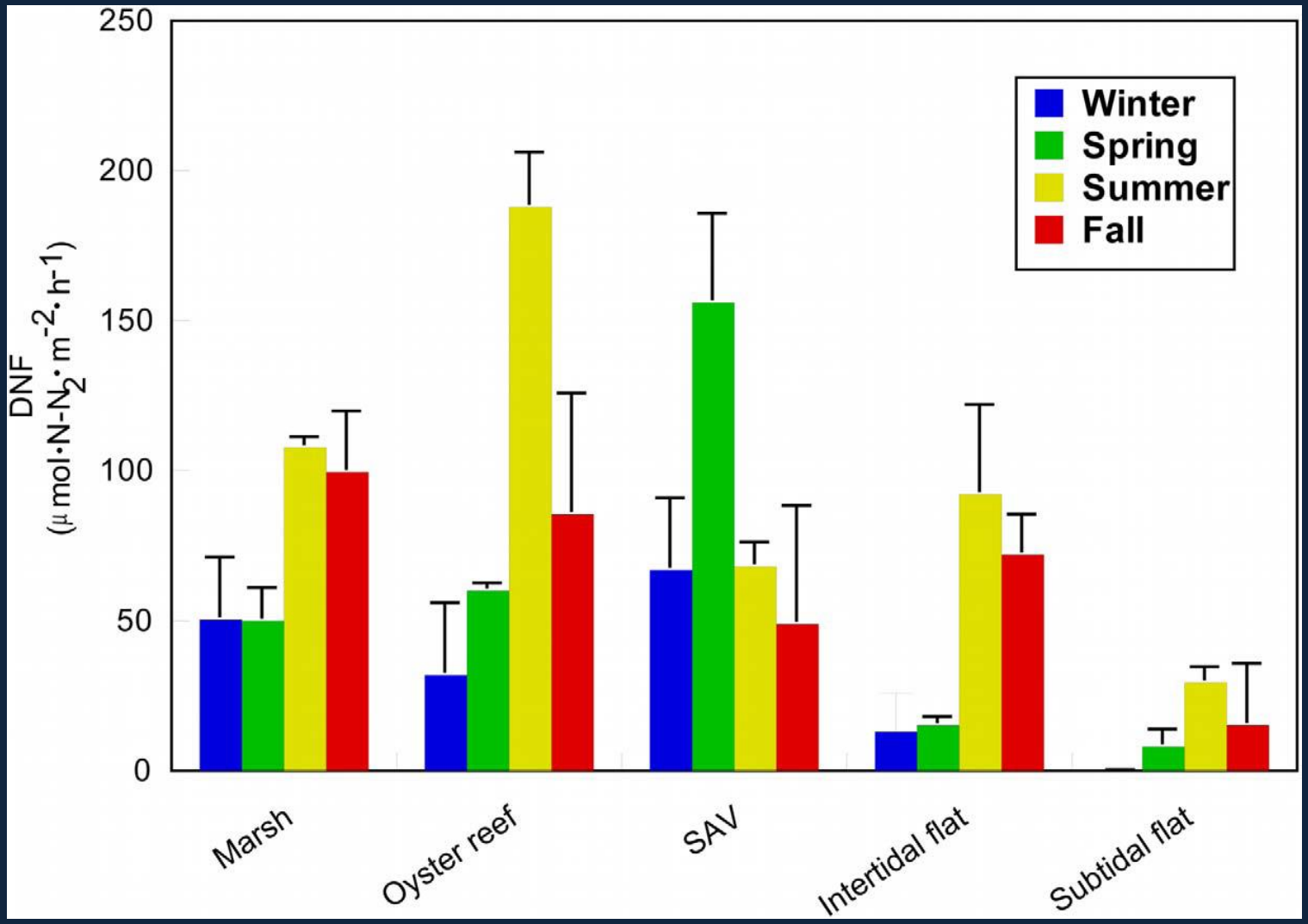
Oysters and Water Quality

- Benthic-Pelagic Coupling
  - Enhance coupled nitrification-denitrification?

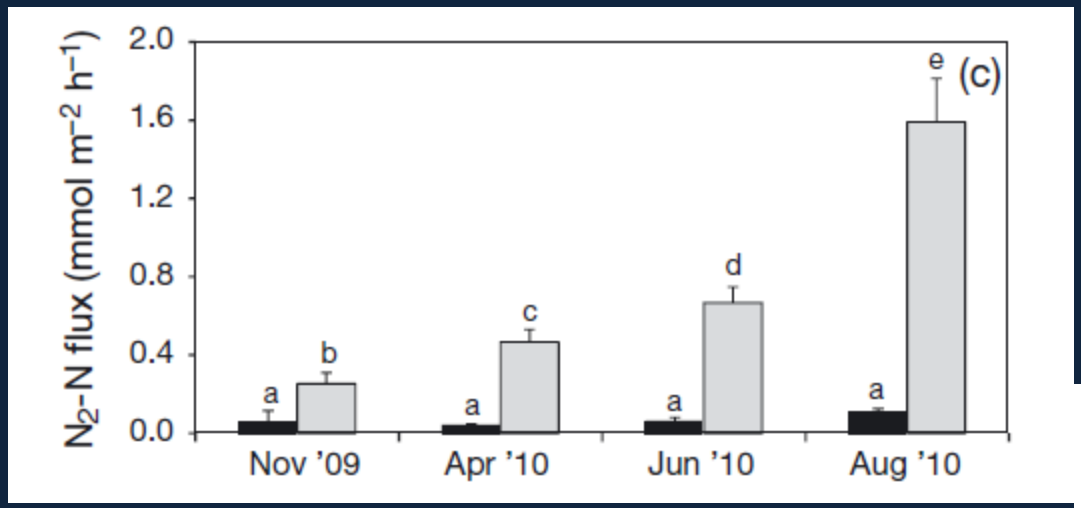


Rates of Denitrification by Habitat

Piehler and Smyth 2011

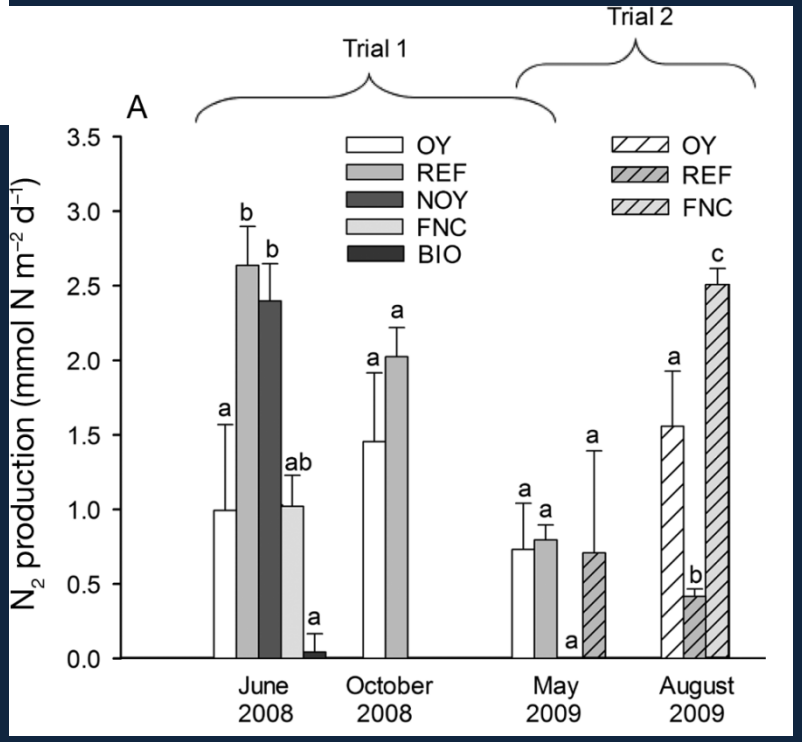


Effects of oysters on denitrification are mixed

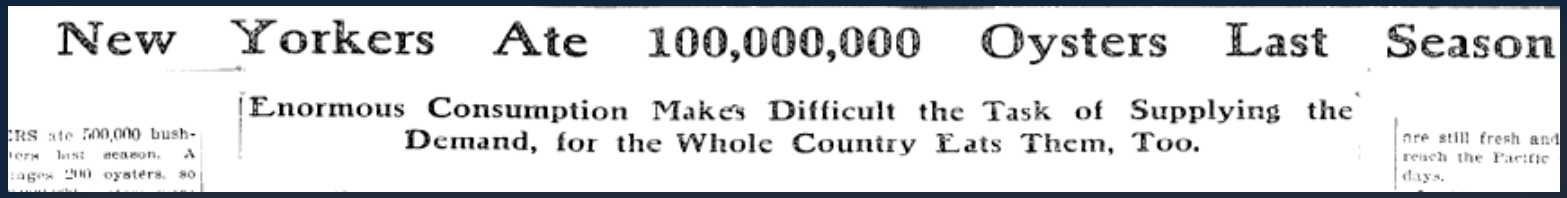


Kellogg et al. 2013 found higher rates of denitrification on restored oyster reefs

Higgins et al. 2013 found no effect of oysters on denitrification



Decline of oysters in NY harbor


New Yorkers Ate 100,000,000 Oysters Last Season

Enormous Consumption Makes Difficult the Task of Supplying the Demand, for the Whole Country Eats Them, Too.

- Fishery gone by 1920s
  - Overfishing
  - Habitat loss
    - Dredge and fill
    - Hydrological modifications
  - Pollution
    - Eutrophication and oxygen minima (sewage)

Oyster companies under Manhattan Bridge

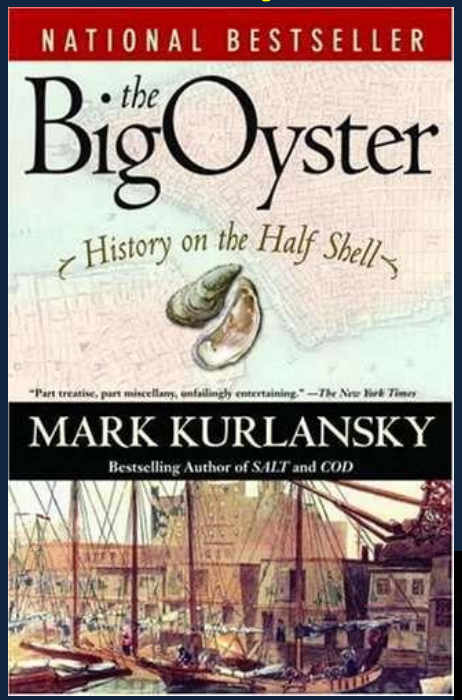
Gov't agencies now promote oyster restoration

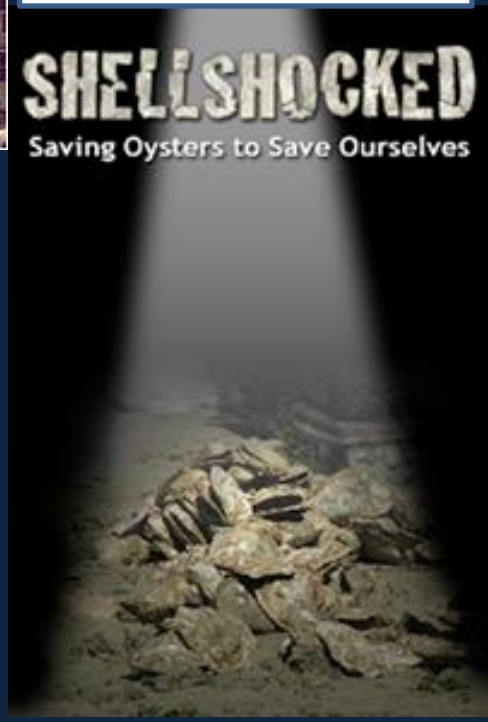
- Studies on oyster growth, reproduction, and survival

(Levinton et al. 2011, Zarnoch and Schreibman 2012, Levinton et al. 2013, Mass-Fitzgerald 2013)

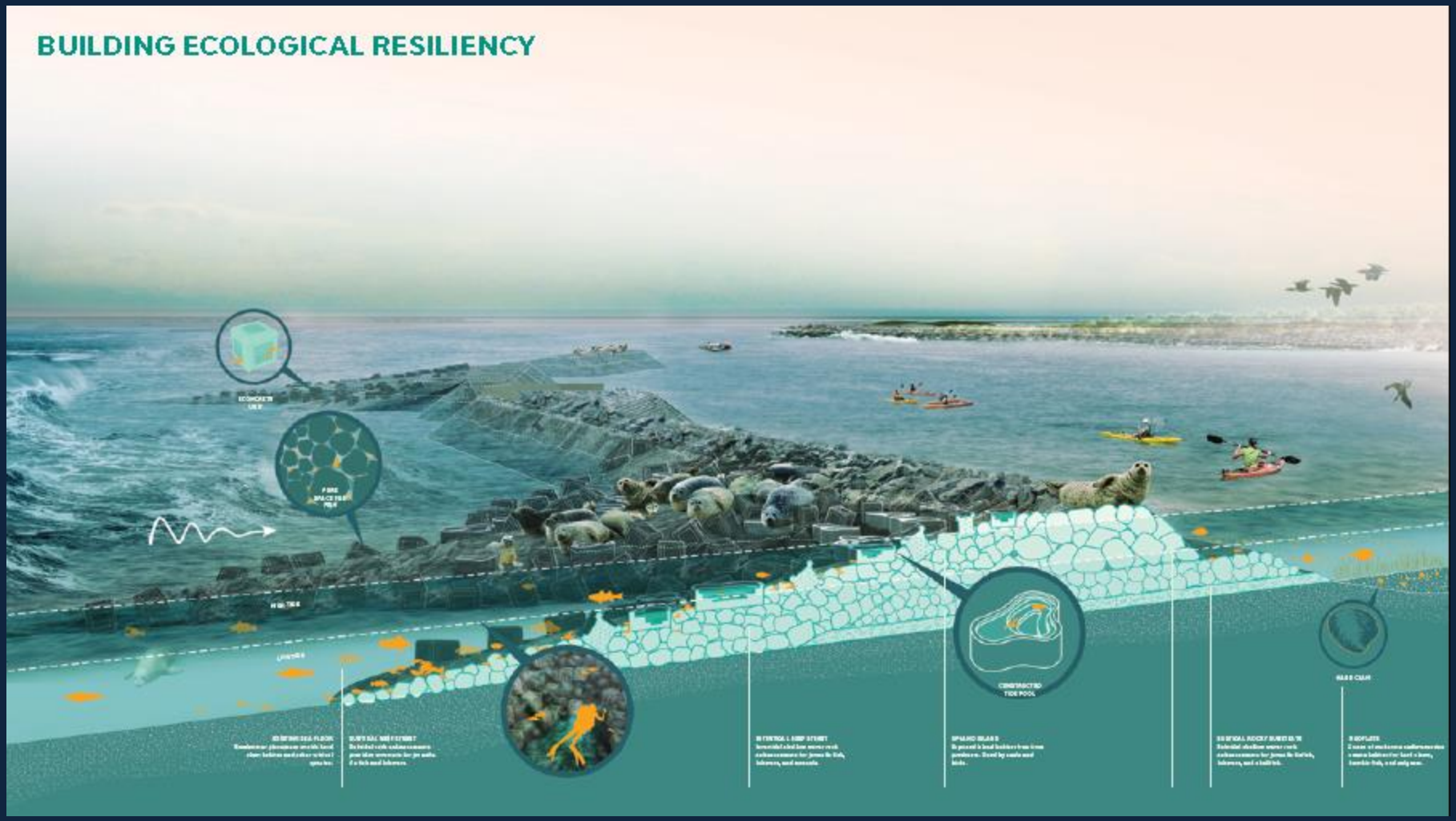
- Current management plans include oyster restoration
  - 500 acres of oyster reefs by 2015 and 5,000 acres by 2050

- **Oyster Restoration Research Project** to determine feasibility of oyster restoration.
  - Over 30 partner institutions





Rebuild by Design
“Living Breakwaters”



Oysters and Water Quality

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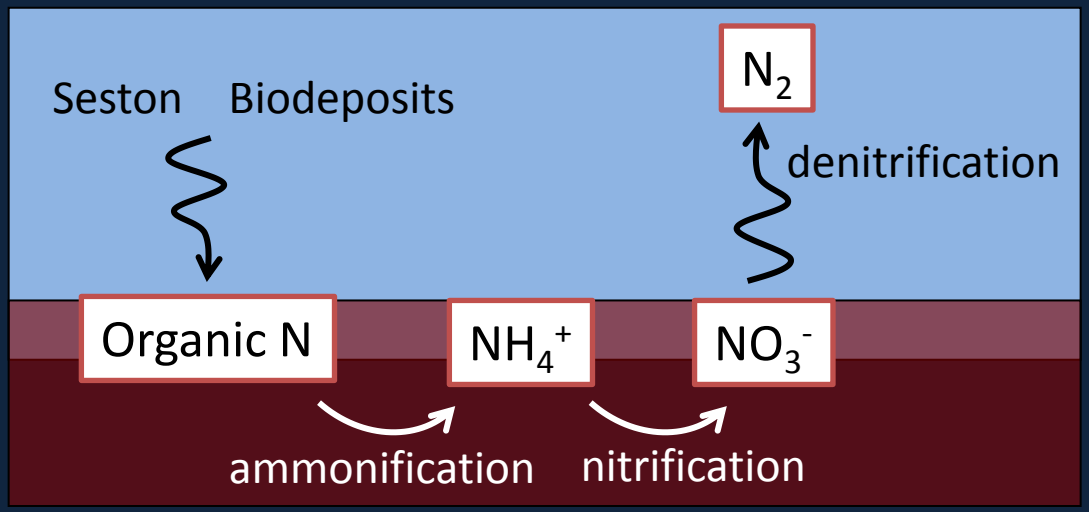


Research Questions

<u>Overarching question</u>:
What is the influence of oysters on sediment N cycling in an urban estuary?

Q_1: Does the influence of oysters on N cycling change across a gradient of <u>N loading</u>?

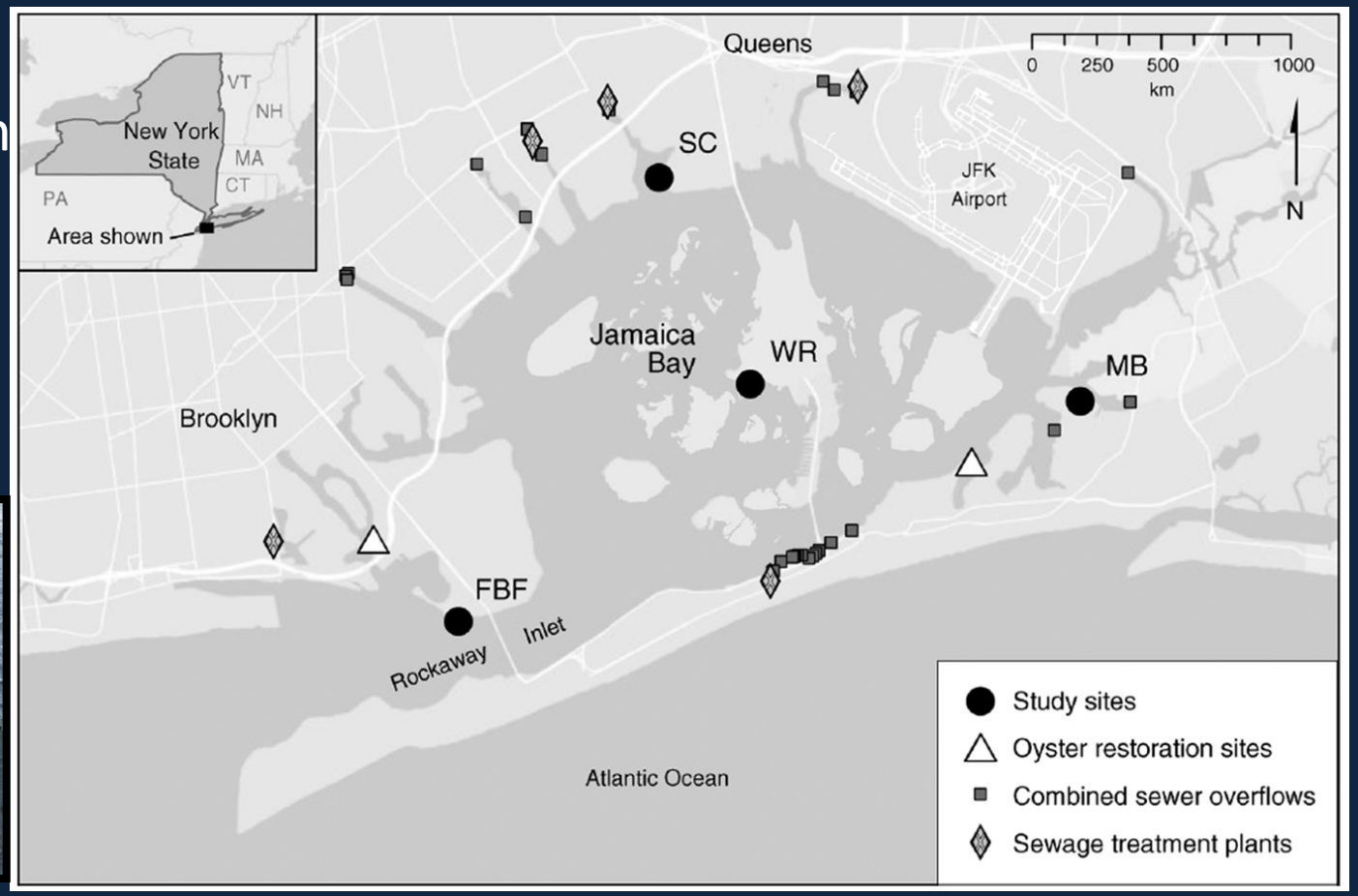
Q_2: Does the influence of oysters on N cycling change across a gradient of <u>oyster density</u>?

Management implications:

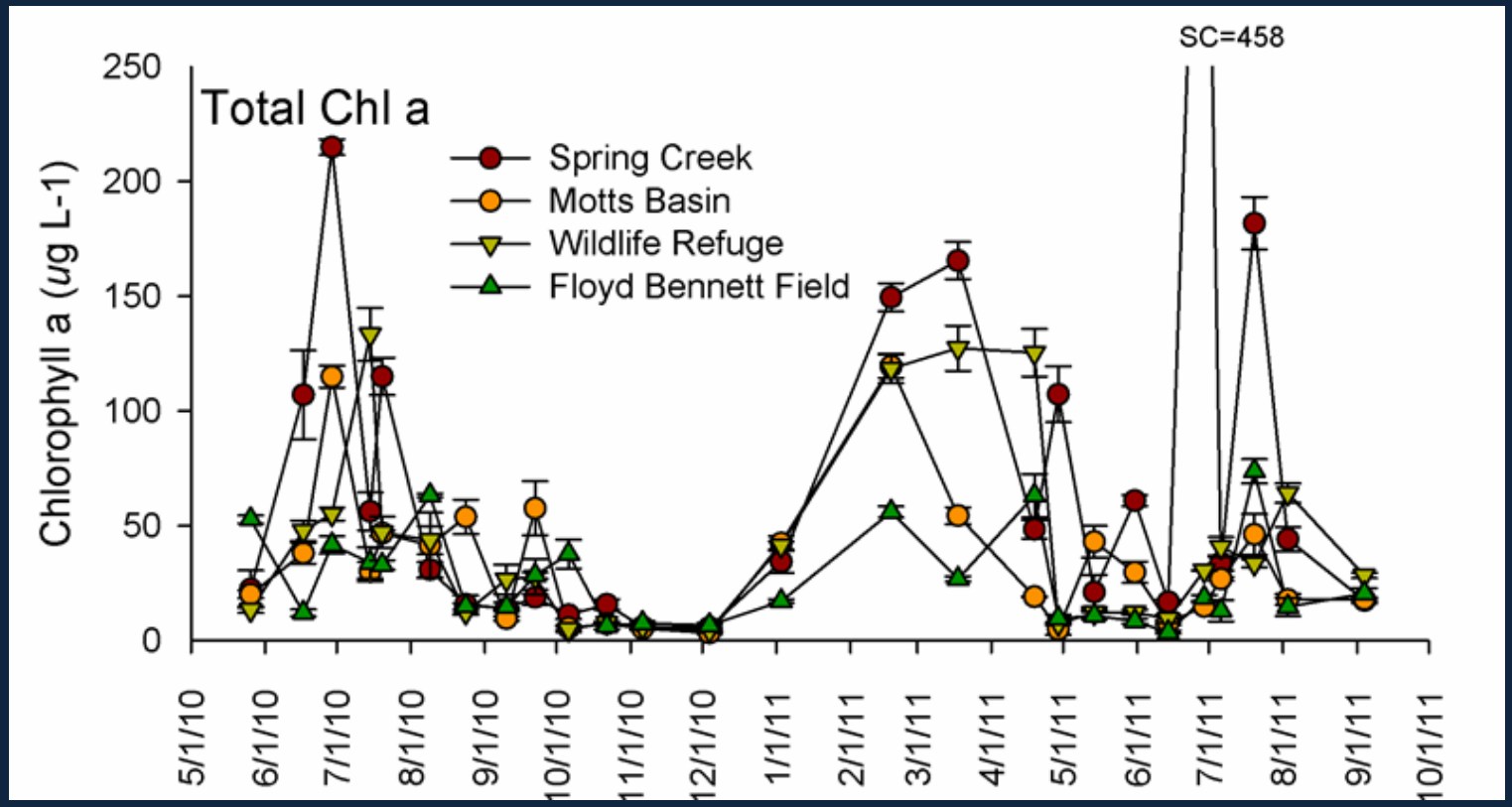
At what locations and densities within an urban estuary could oysters most effectively alleviate N pollution?

Jamaica Bay: eutrophic coastal environment in NYC

- 4 major WWTP, many CSOs
  - 15,800 kg d^{-1} total N
  - 99% of the freshwater to the bay
  - 92% N load
- Mean depth 5m

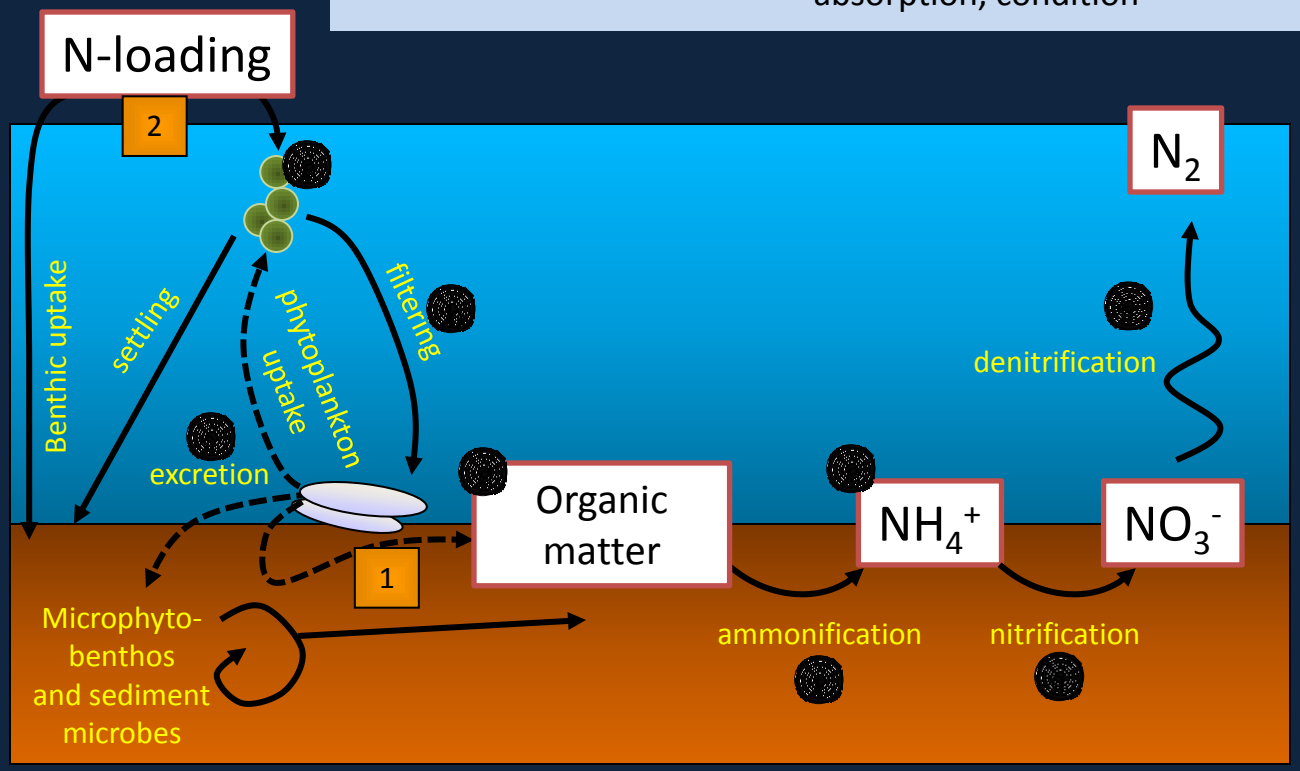


Phytoplankton Abundance Jamaica Bay 2010-2011



Monthly (except winter) July '10-Sept '11

- Phytoplankton: TPM, Chl a, C:N
- Oyster feeding: filtration, ingestion, absorption, condition
- Oyster biodeposition feces, pseudofeces, C:N



Bi-monthly (winter incl.)

- Sediment AFDM, C:N
- Exchangeable NH_4^+
- Net ammonification
- Nitrification rate (nitrapyrin inhibition)
- Denitrification enzyme activity (DEA) (chloram-phenicol amended, acetylene block)

Experimental factors

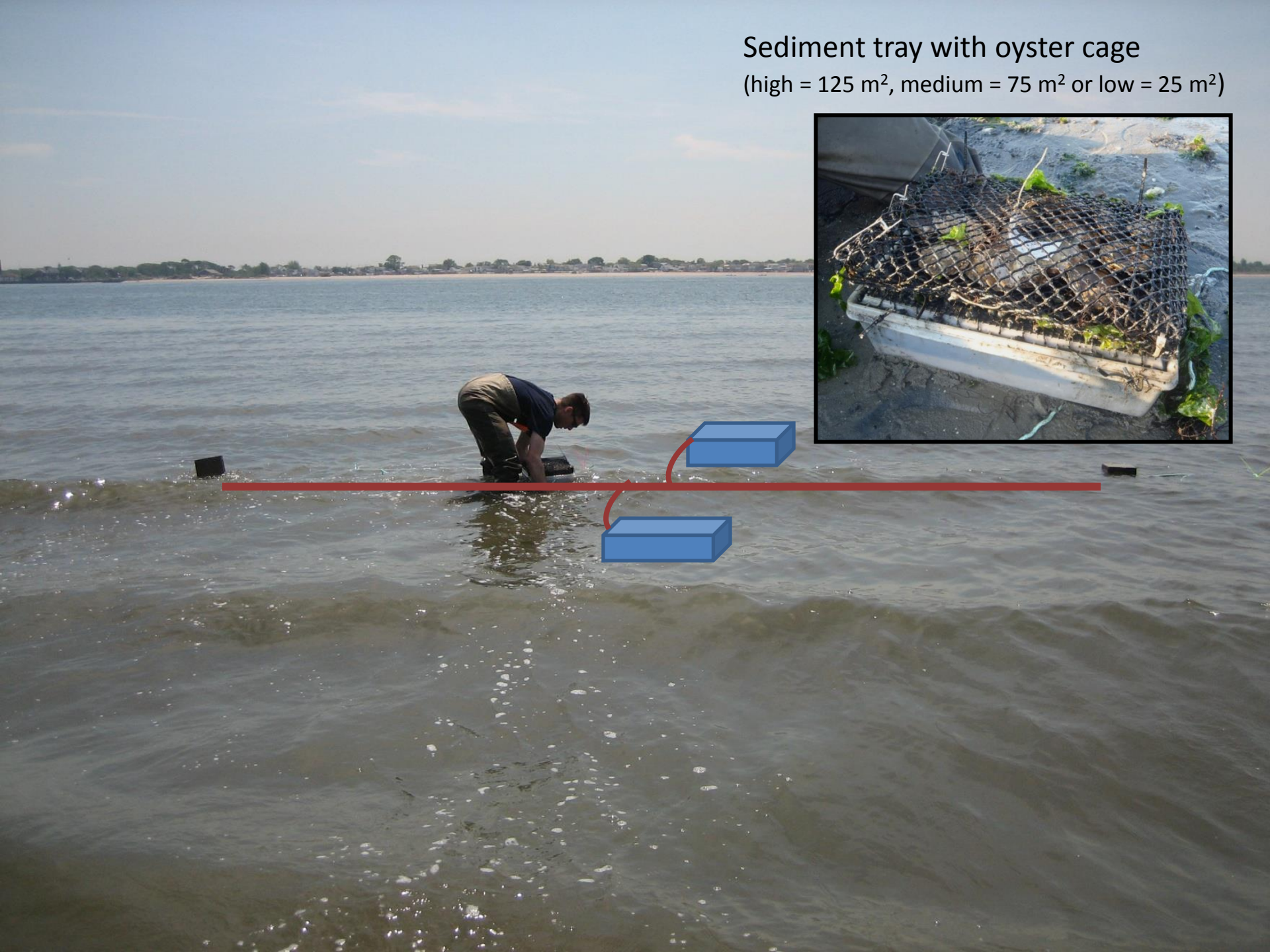
- 1 Oyster density (ctl, low, med, high)
- 2 Nutrient gradient (N= 4 locations)

Objective is to explain <u>mechanisms!</u>

Adapted from: Newell 2004

Sediment tray with oyster cage

(high = 125 m^2, medium = 75 m^2 or low = 25 m^2)



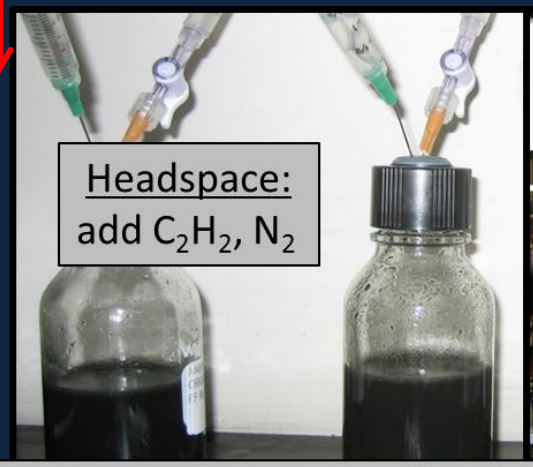
Response Variables – Sediment N cycling

Sediment nitrogen cycling

Sediment AFDM & C:N

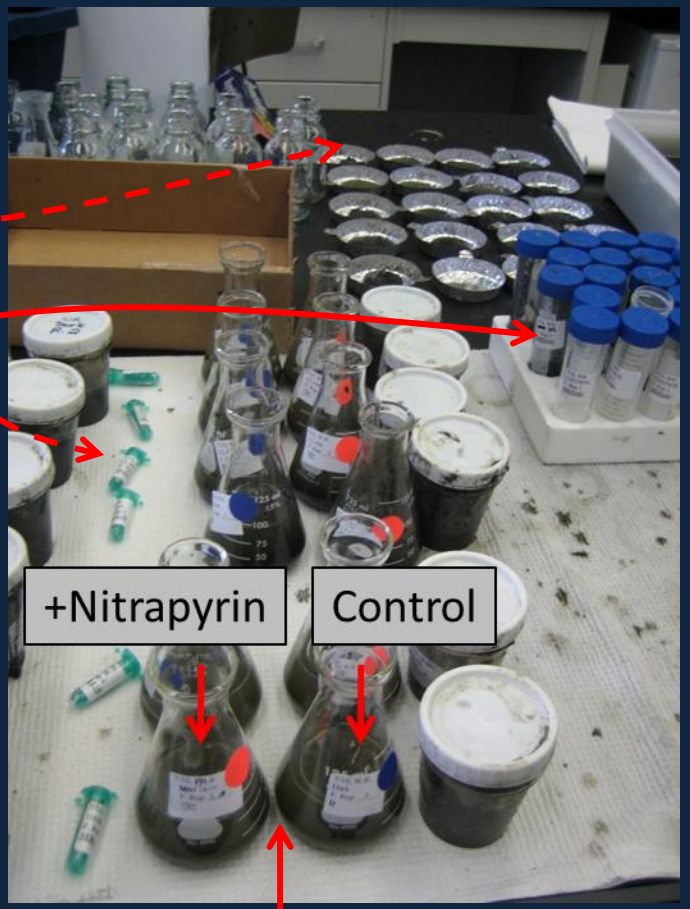
Exchangeable NH_4^+

Denitrification Enzyme Activity



Headspace:
add C_2H_2, N_2

Sediment:
add NO_3^-, glucose, chloramphenicol



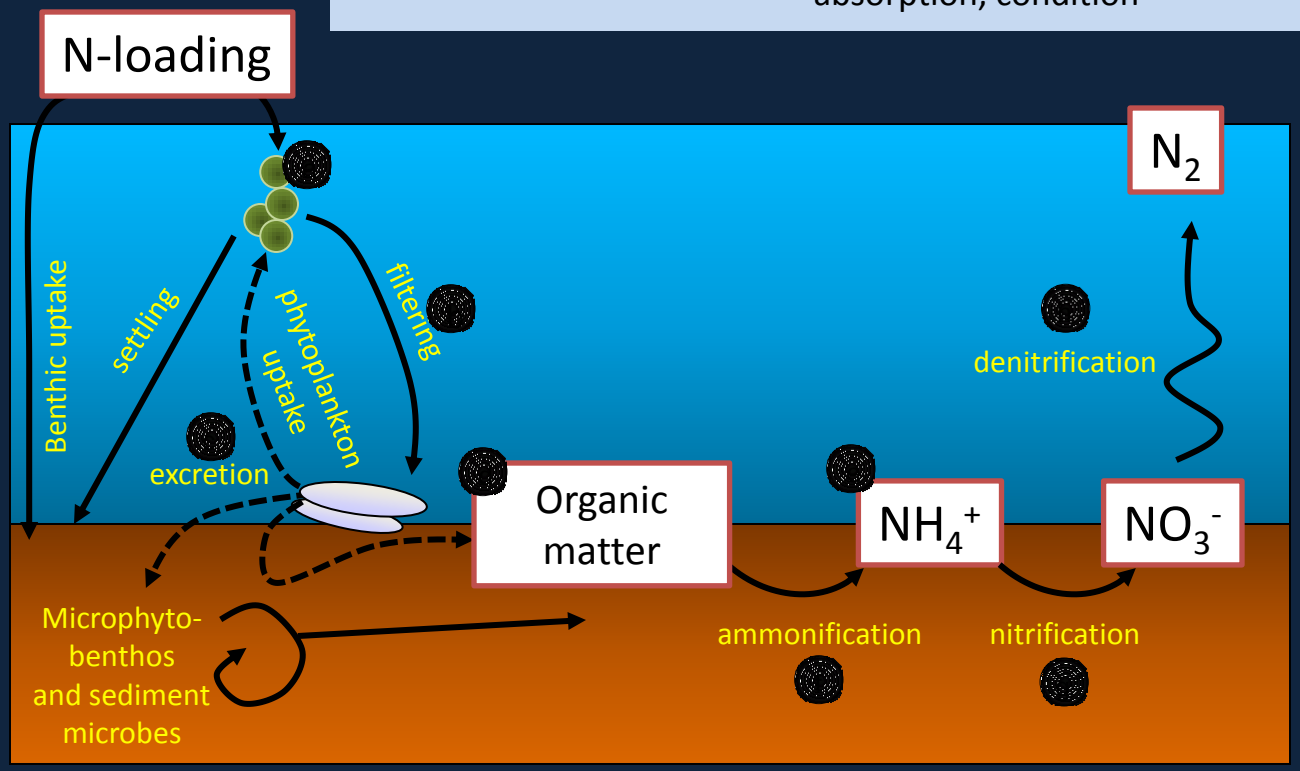
+Nitrapyrin

Control

Nitrification

Monthly (except winter) July '10-Sept'11

- Phytoplankton: Mass, Chl a, C:N
- Oyster feeding: filtration, ingestion, absorption, condition
- Oyster biodeposition feces, pseudofeces, C:N



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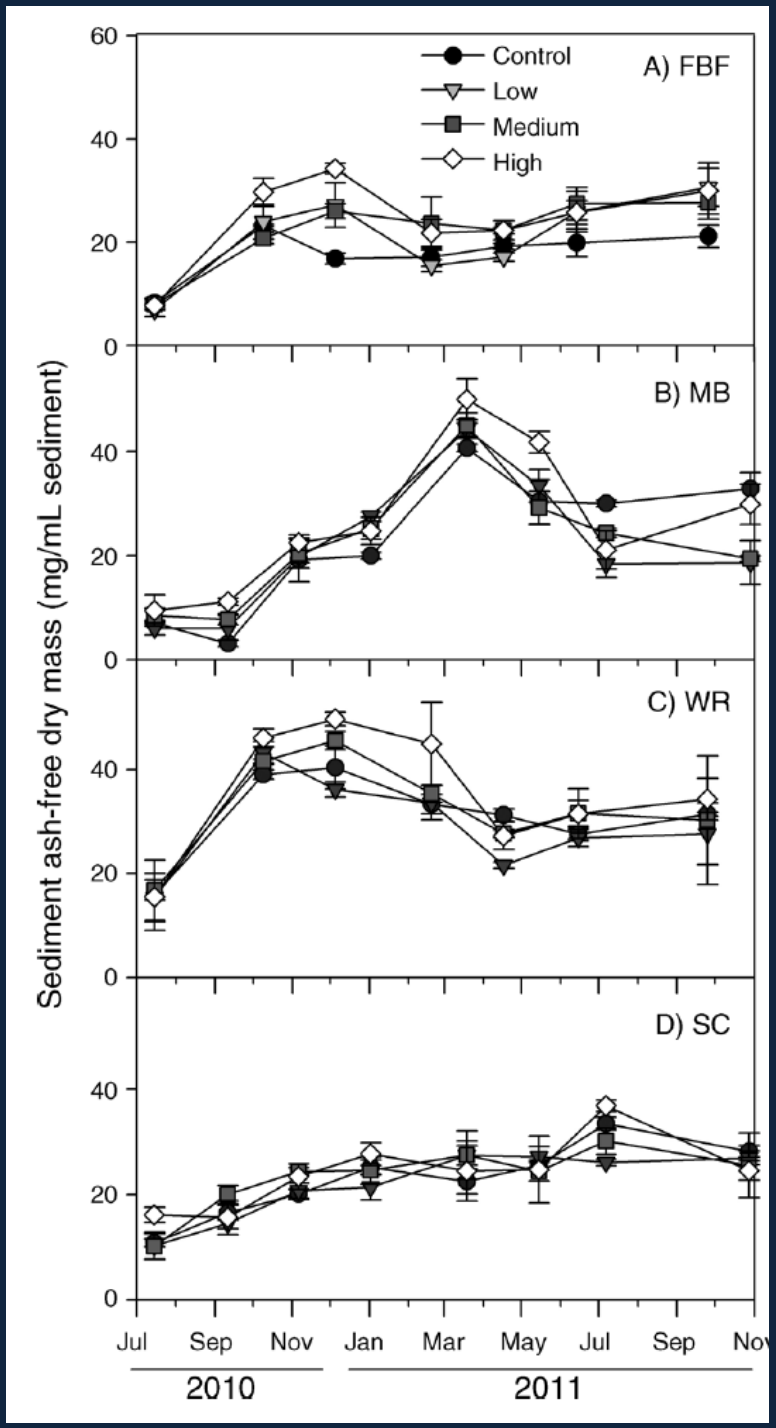
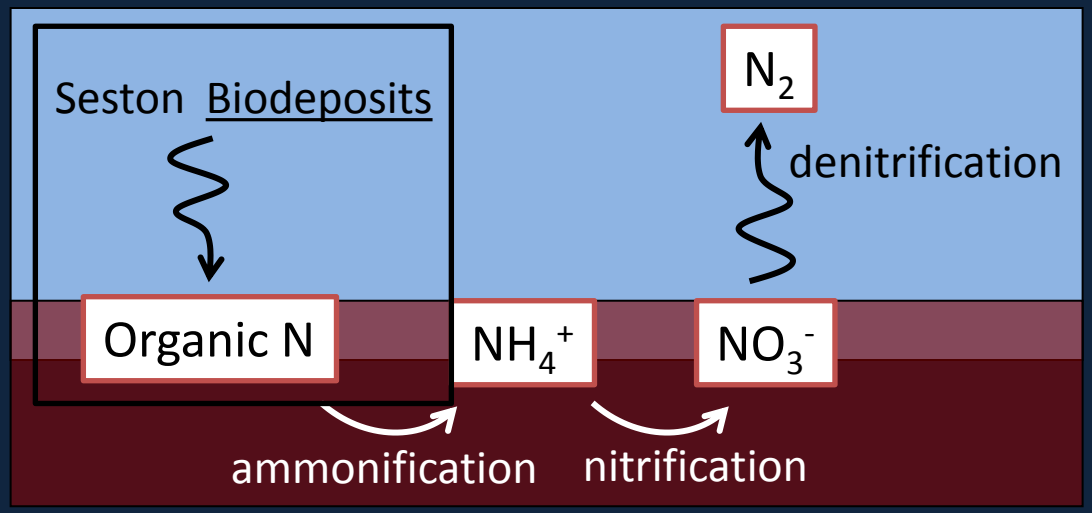


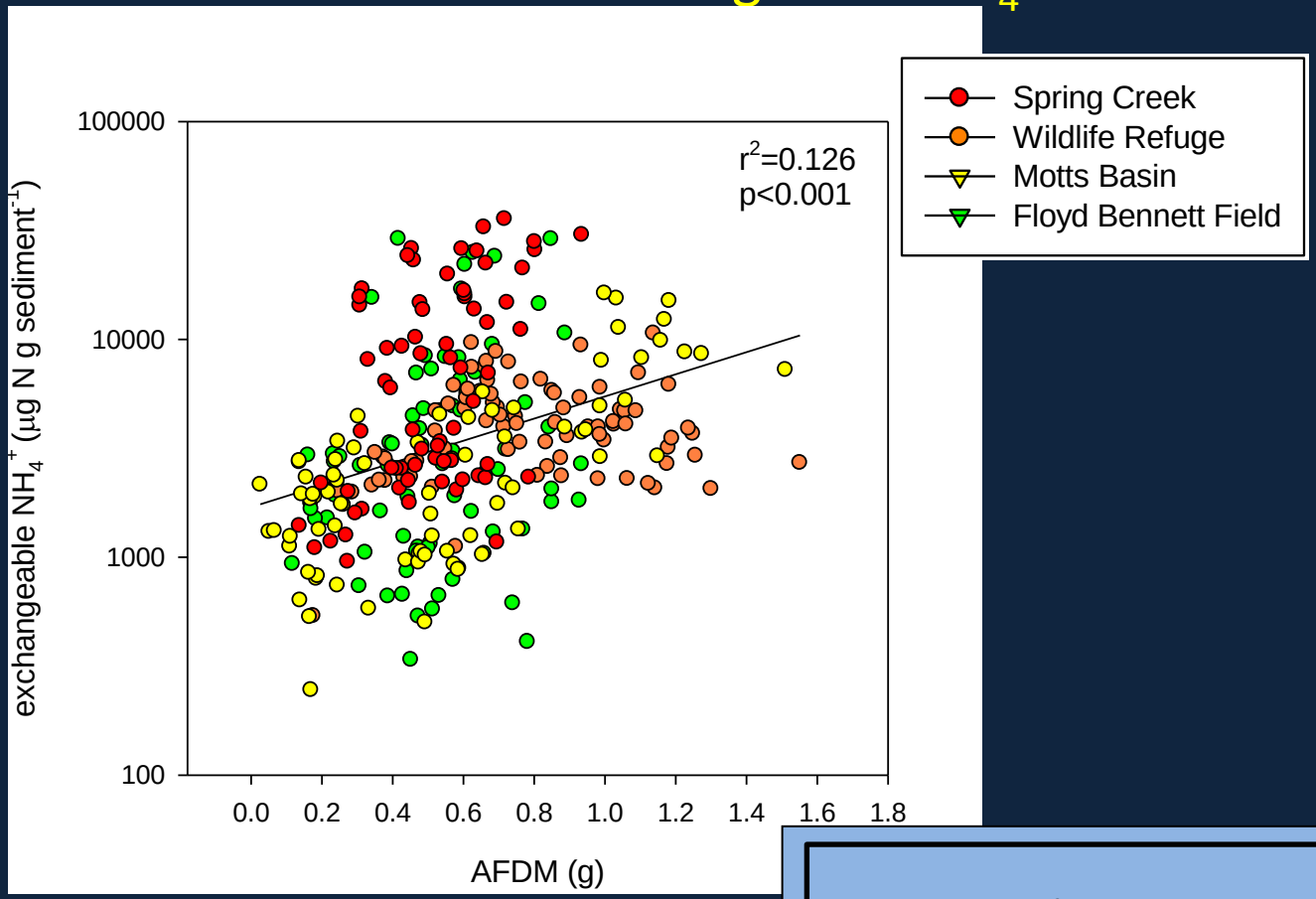
Sediment AFDM

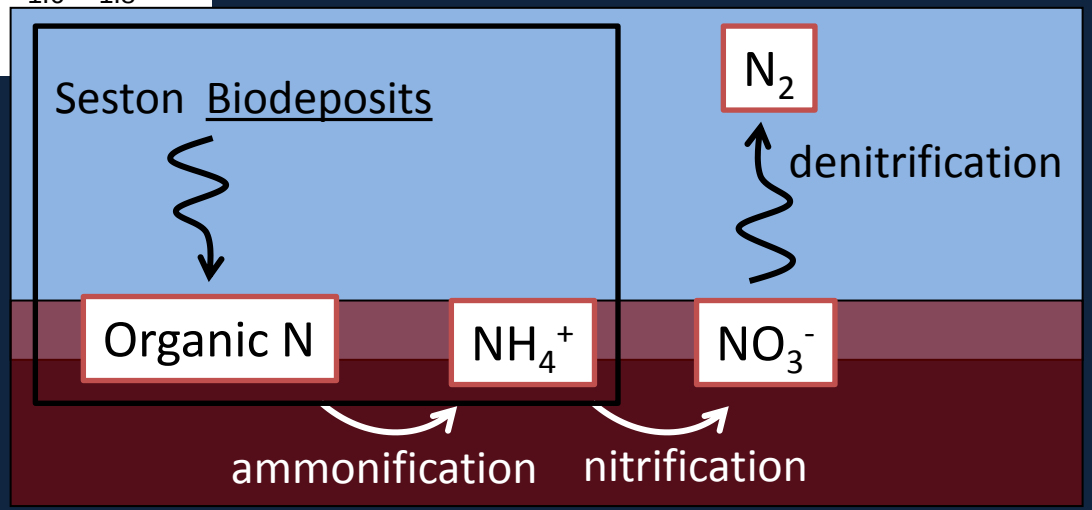
- Date effect all sites
- Treatment effect as predicted (except at Mott's Basin)



Hoellein and Zarnoch, Ecol. Appl. 2014

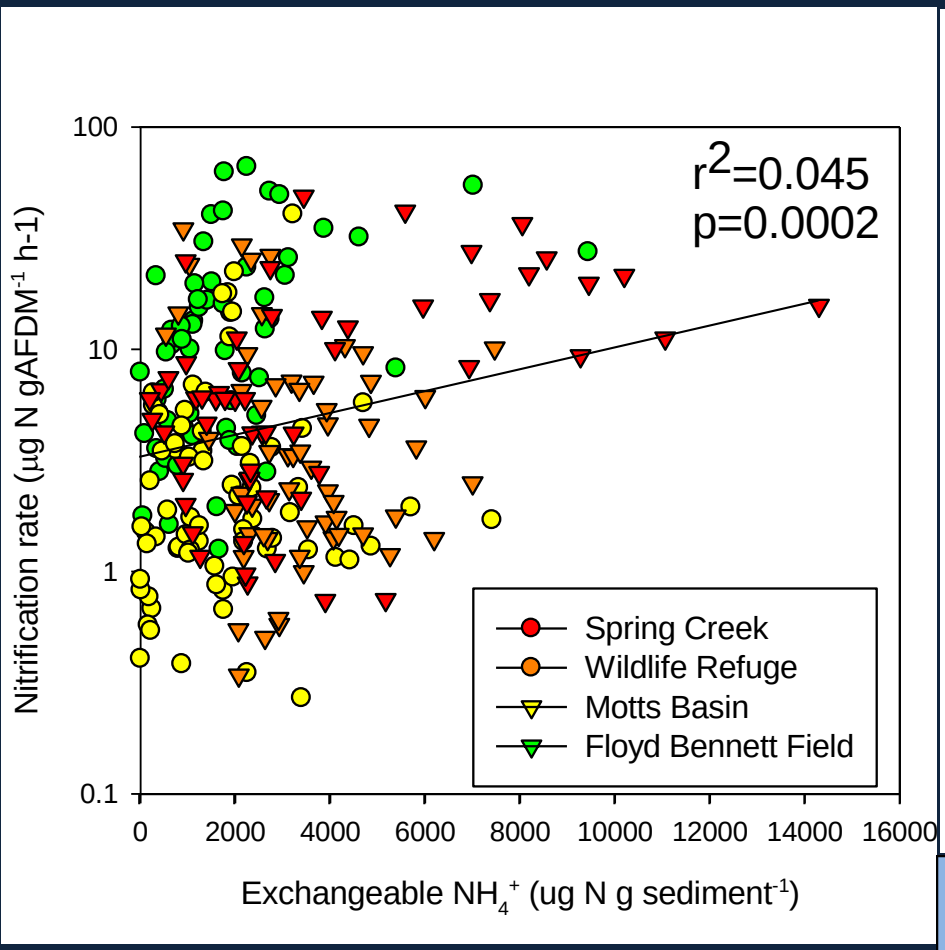
Sediment AFDM and exchangeable NH_4^+ related across sites and seasons

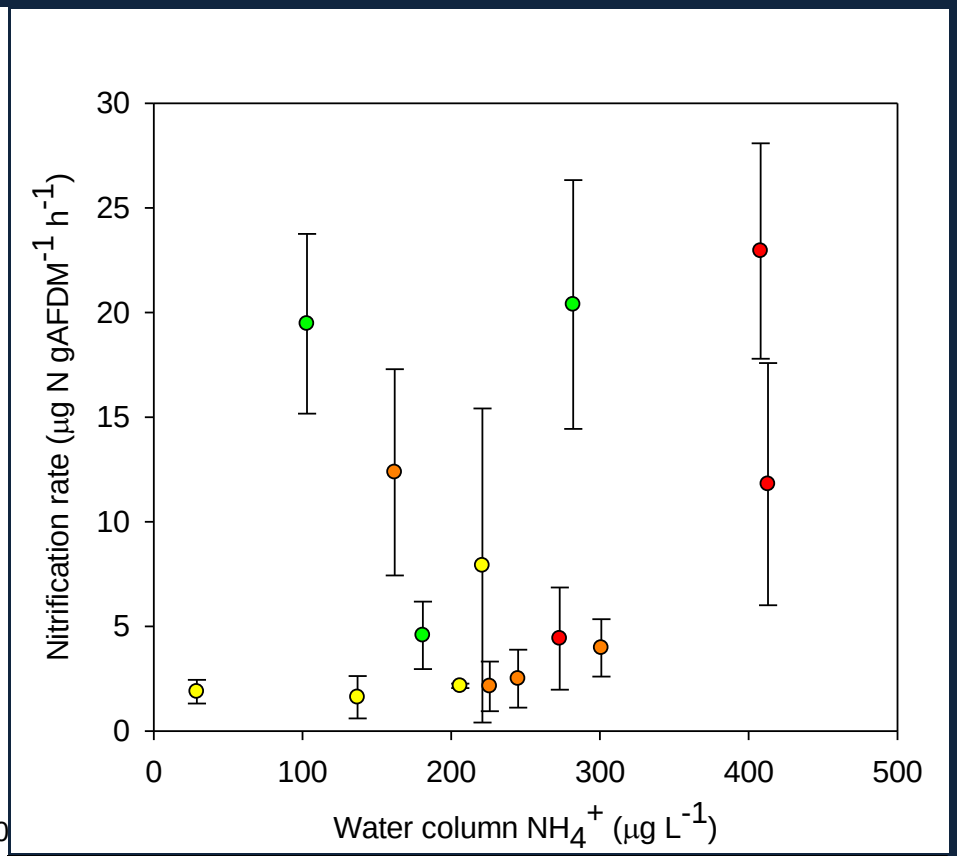


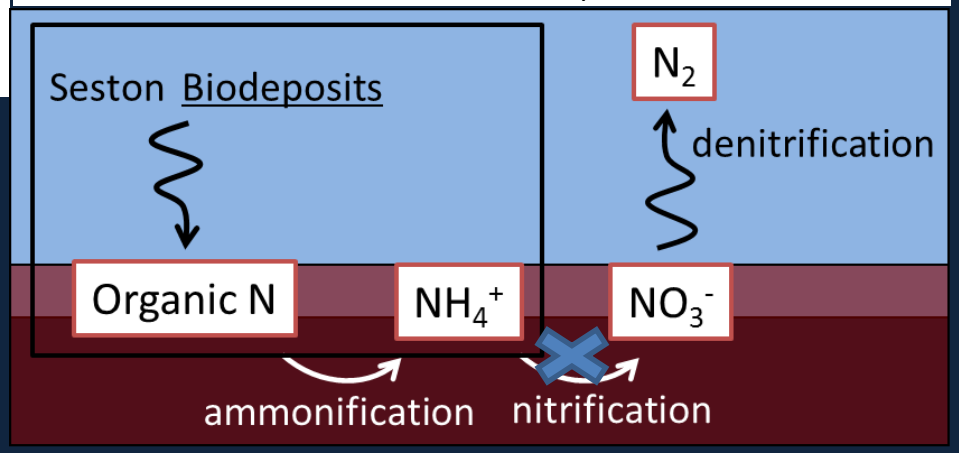


Hoellein and Zarnoch, Ecol. Appl. 2014

Nitrification and NH_4^+ were not related

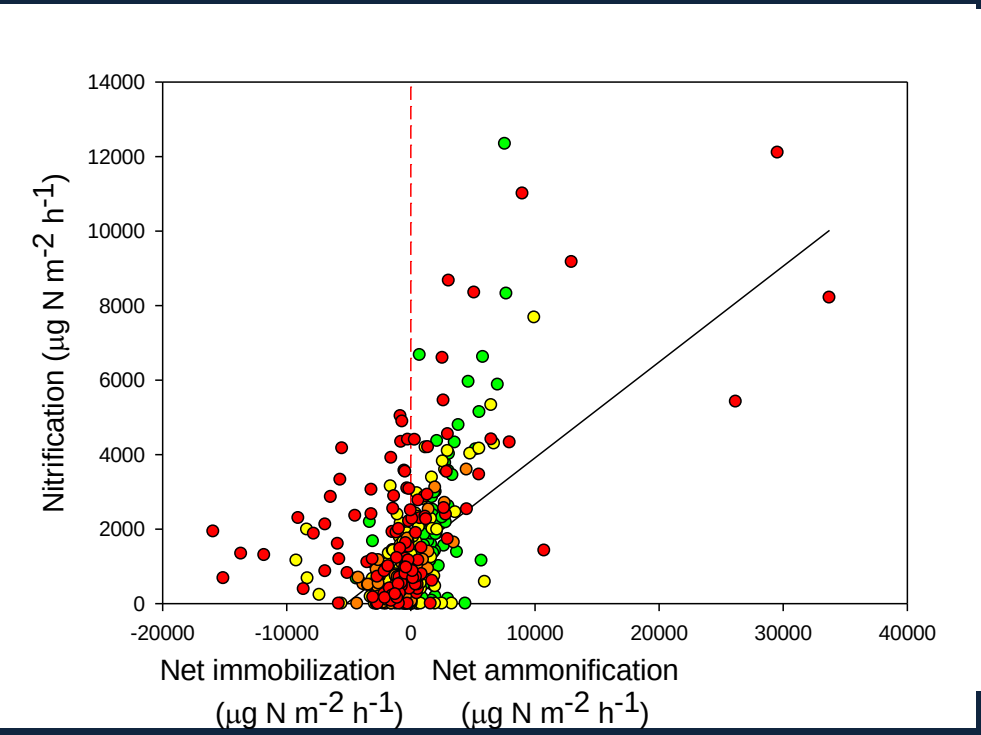


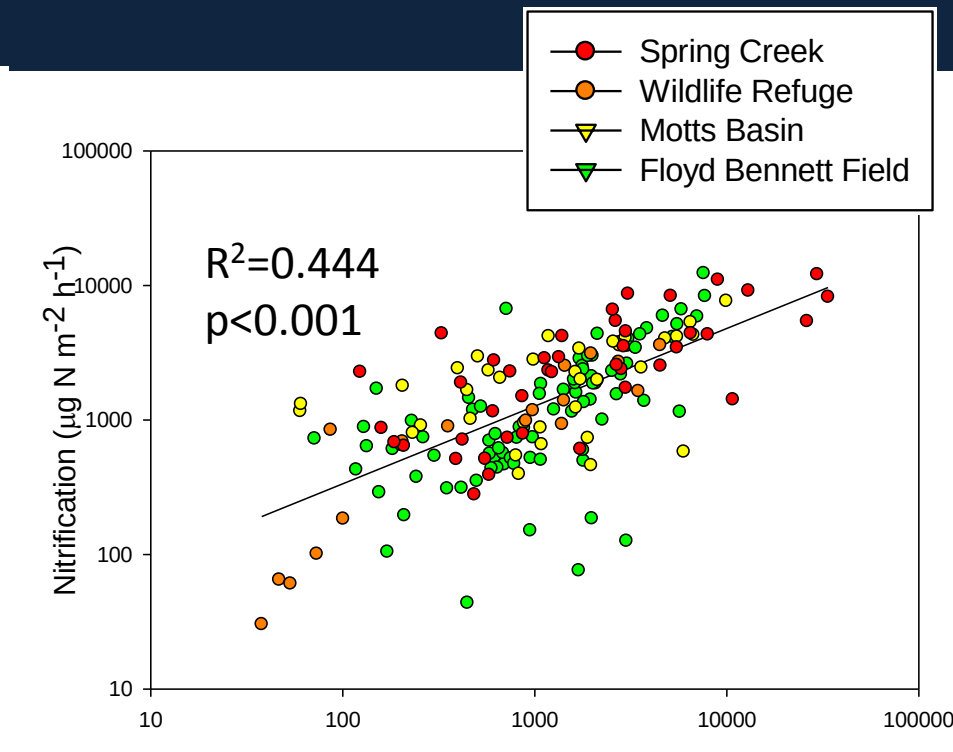


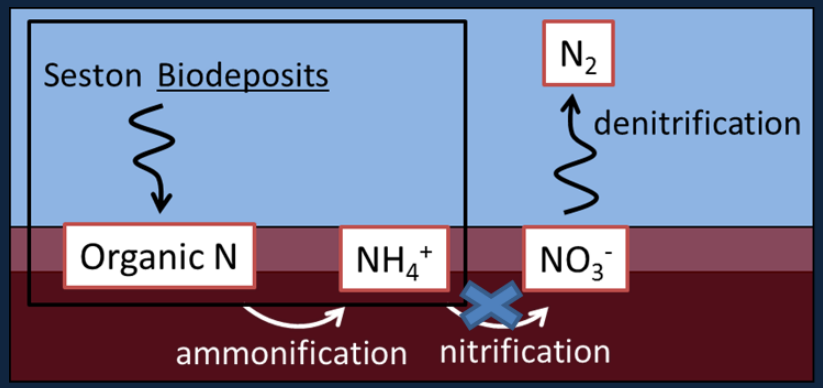


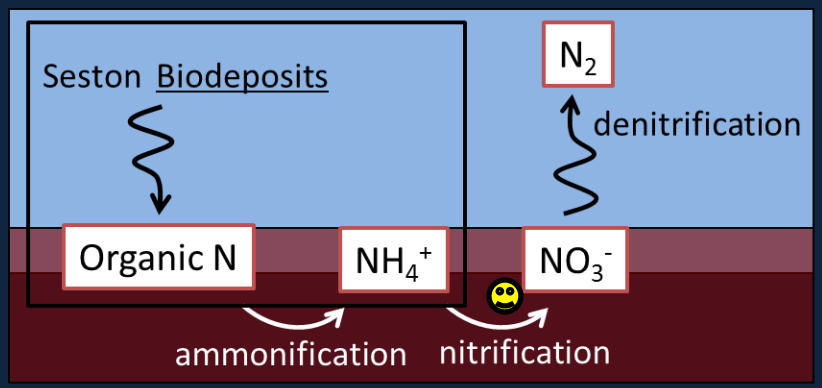
Hoellein and Zarnoch, Ecol. Appl. 2014

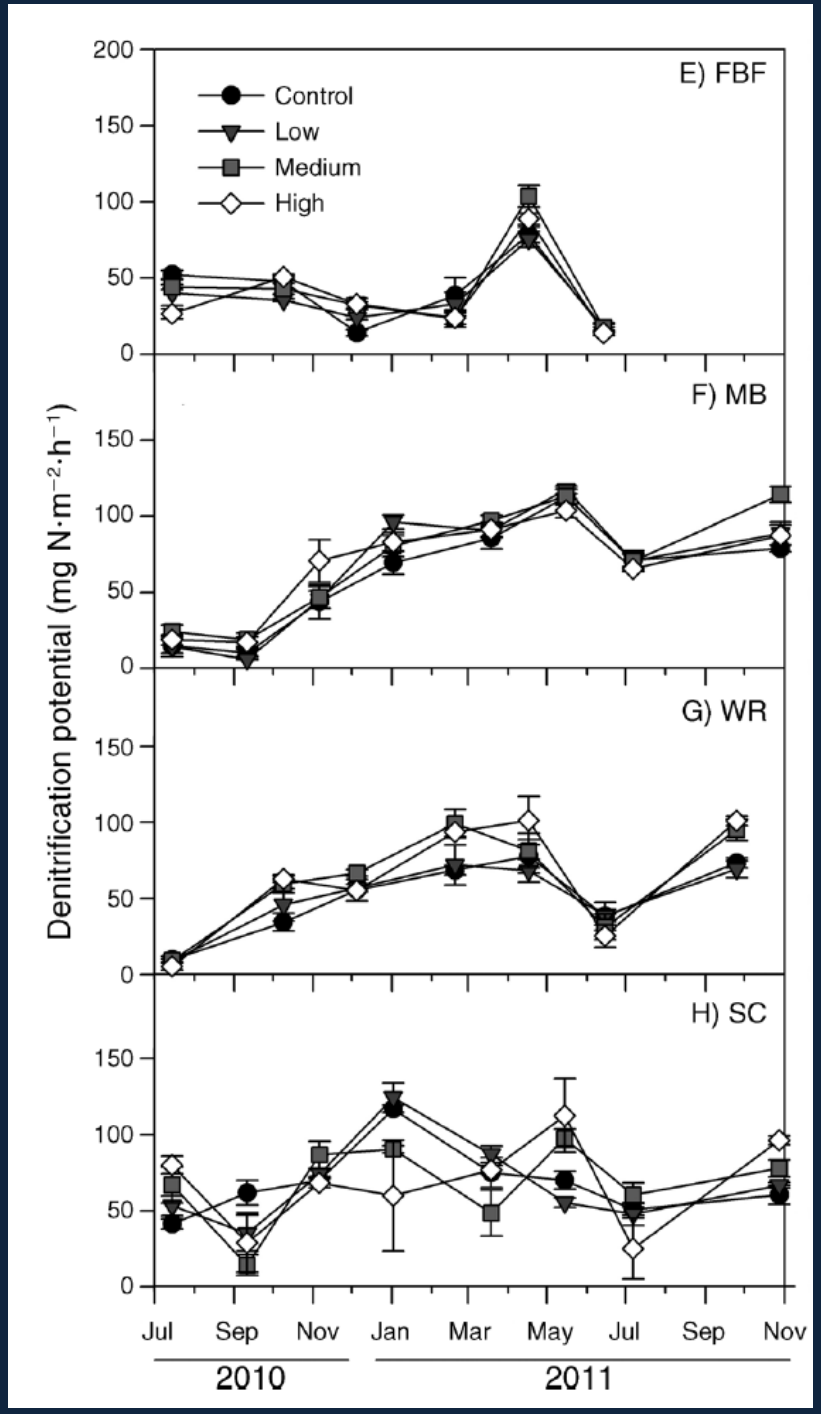
Nitrification strongly related to ammonification





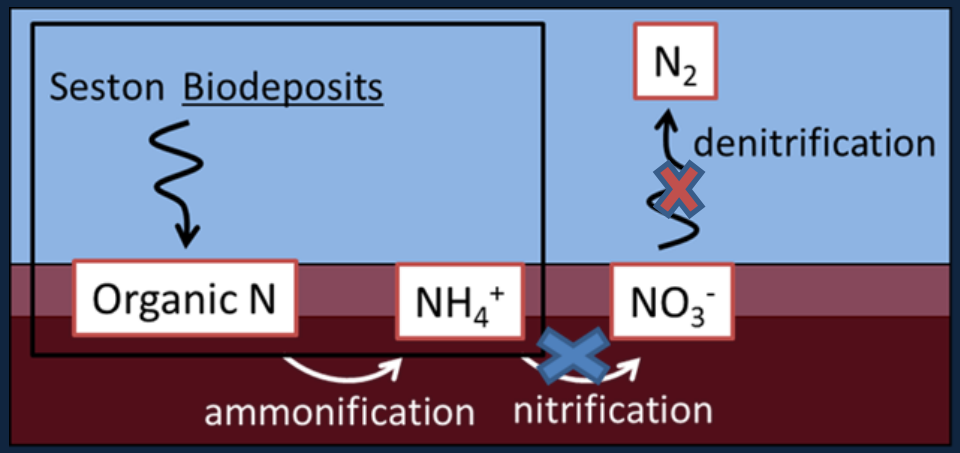






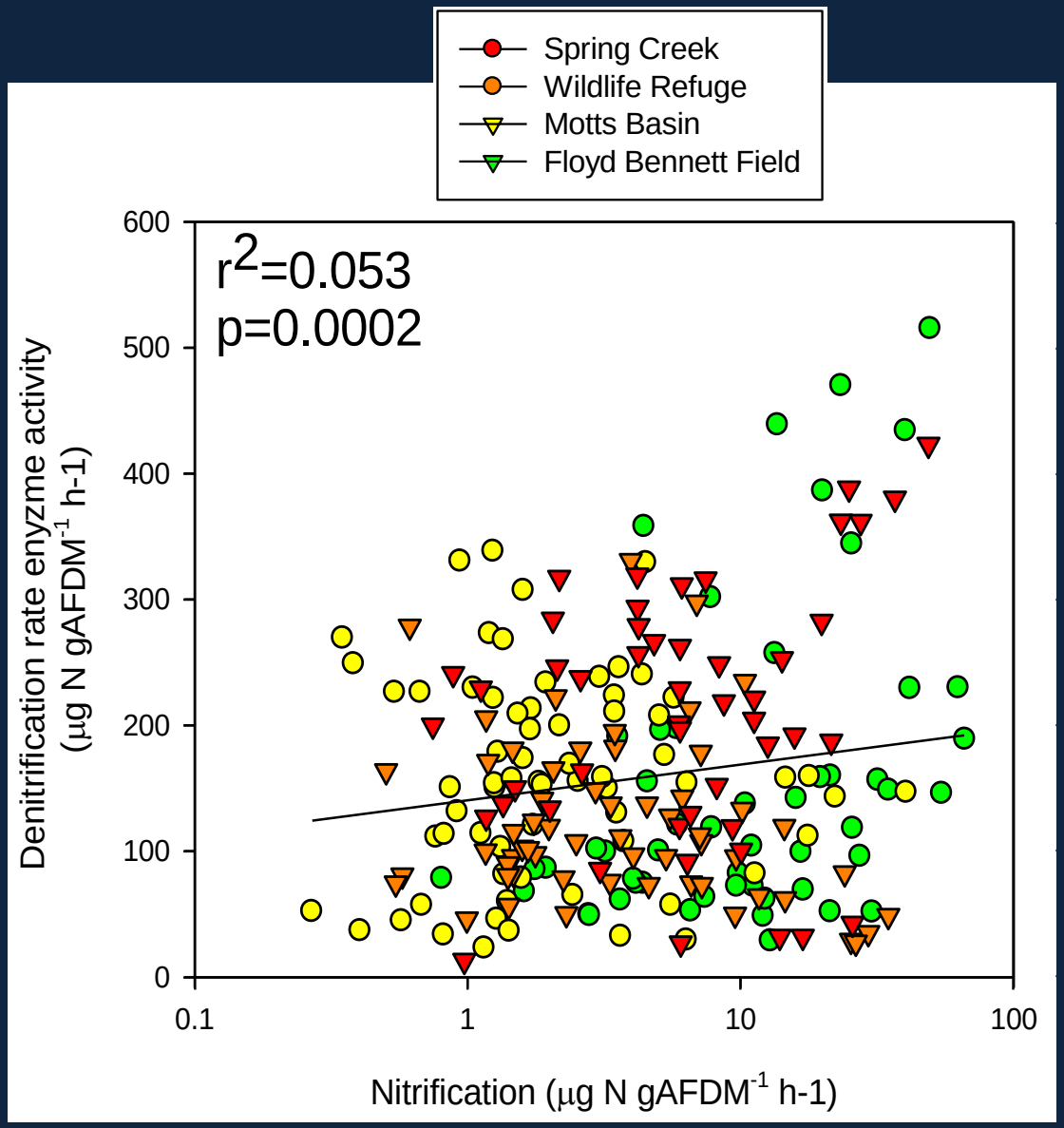
Denitrification enzyme activity

- Date effect all sites
- No treatment effects



Hoellein and Zarnoch, Ecol. Appl. 2014

DEA and nitrification weakly related



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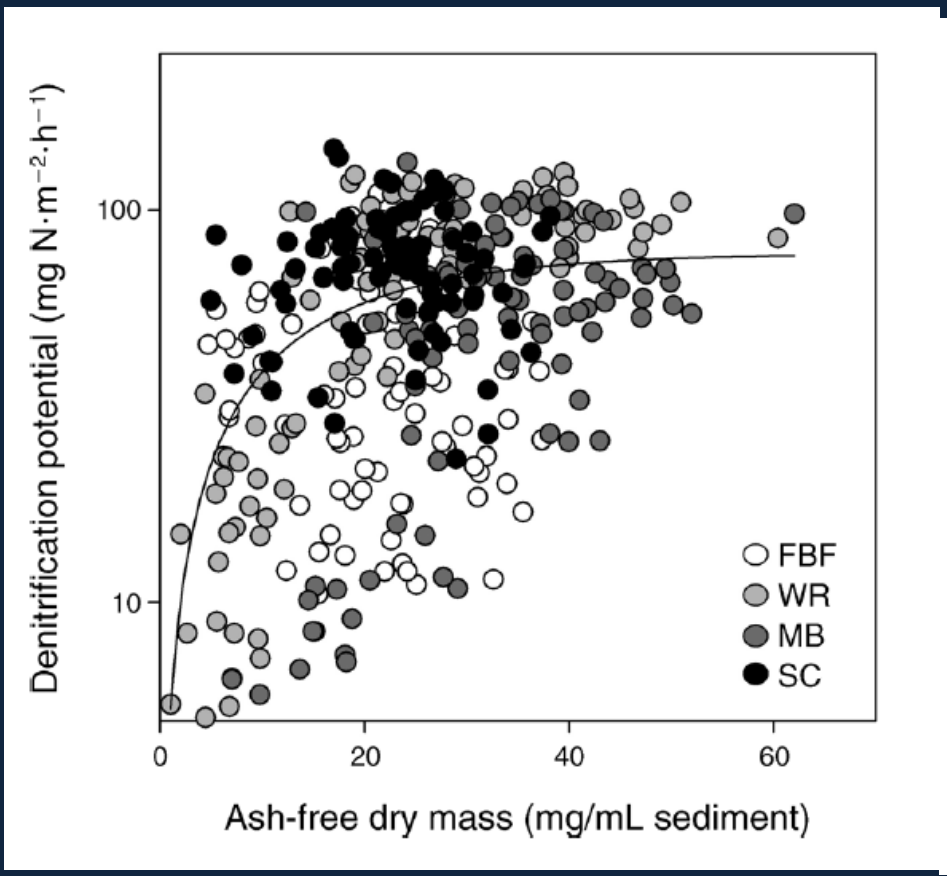
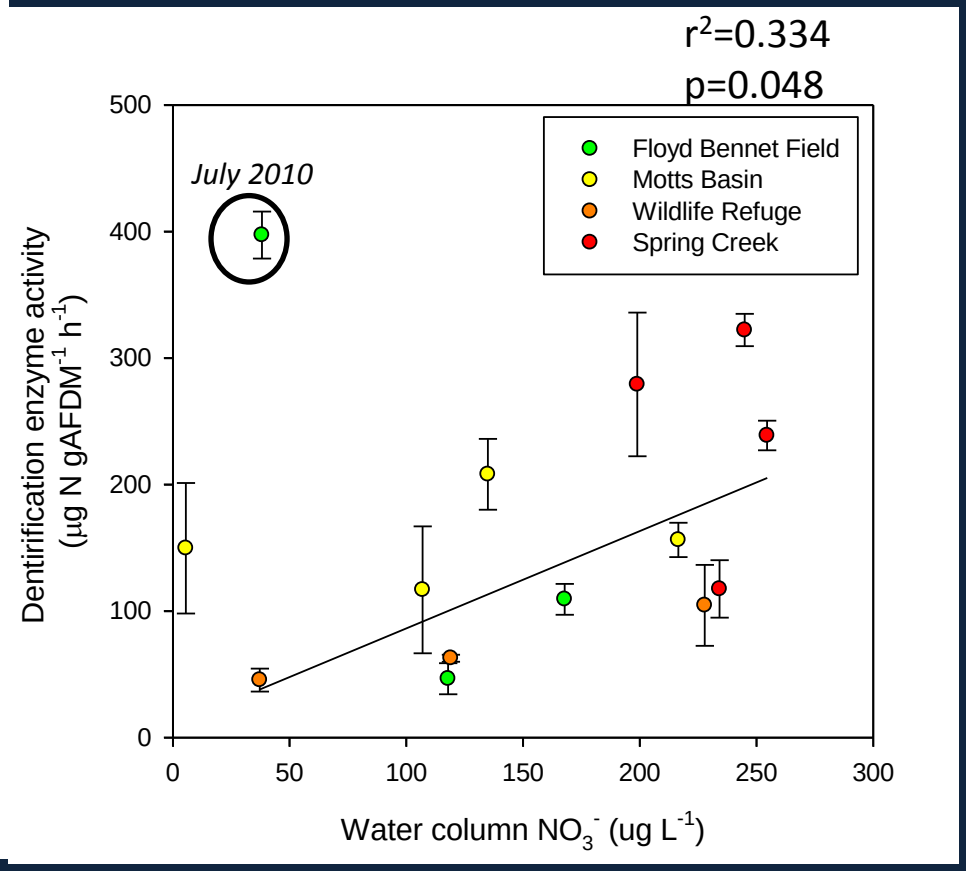
DEA related to organic matter and water column nitrate





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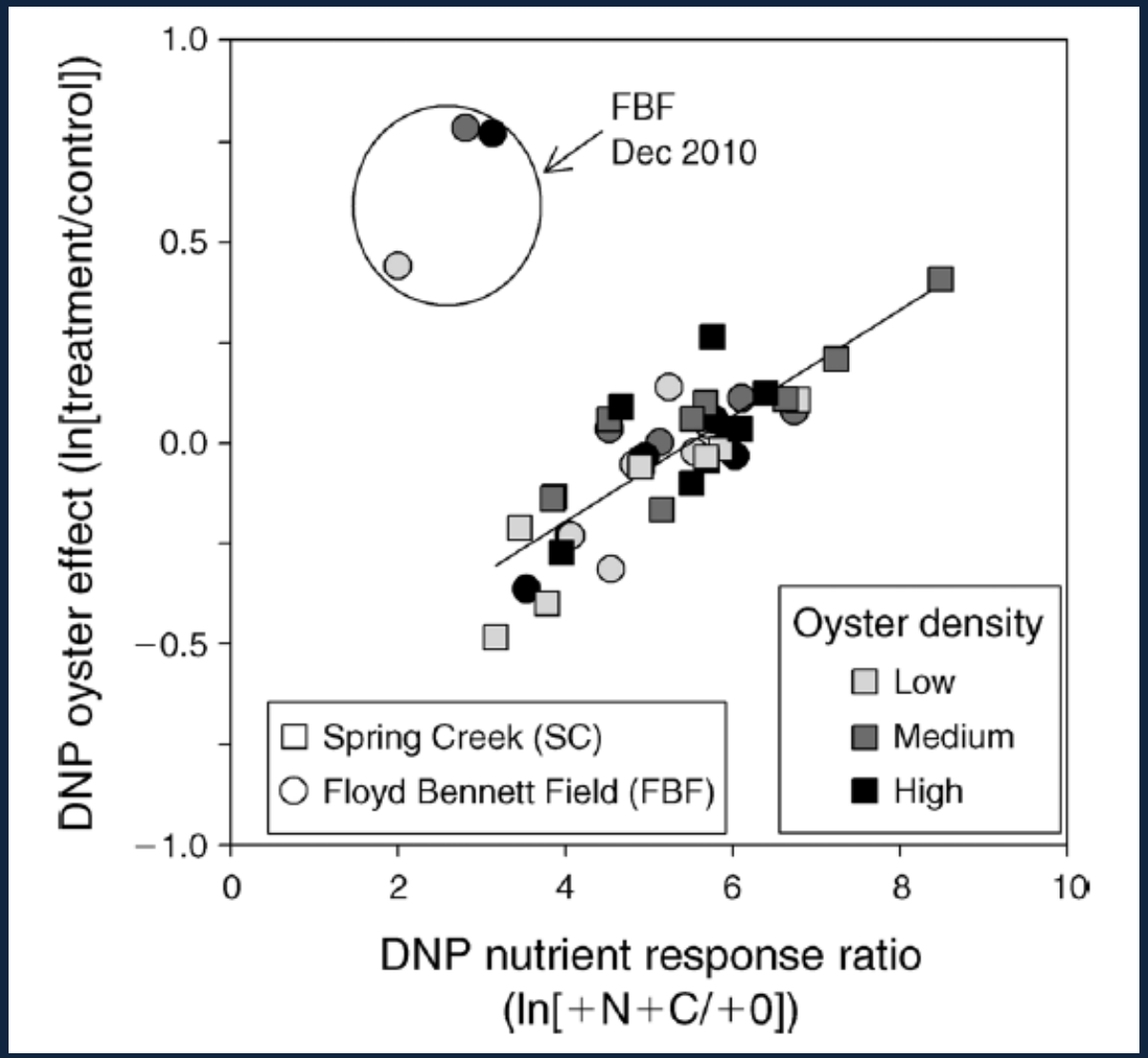
Oyster effect when sediment most nutrient limited



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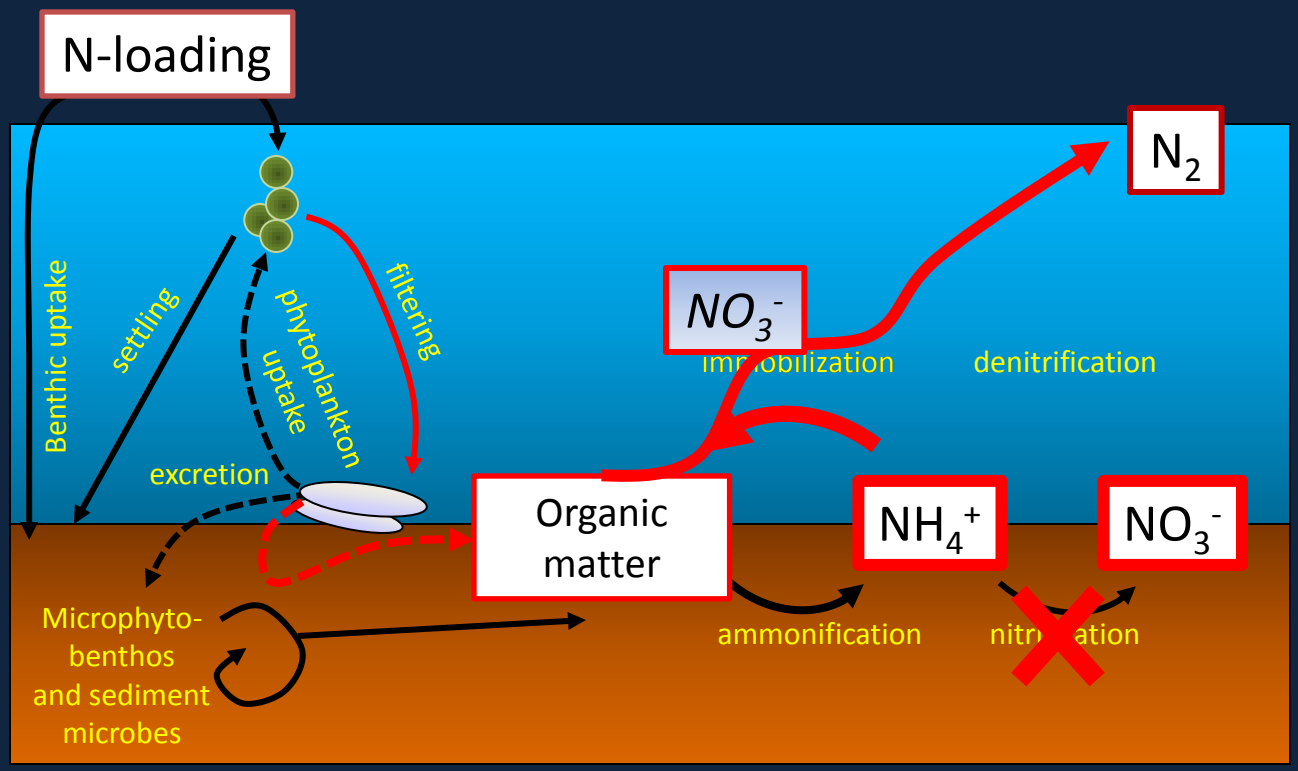
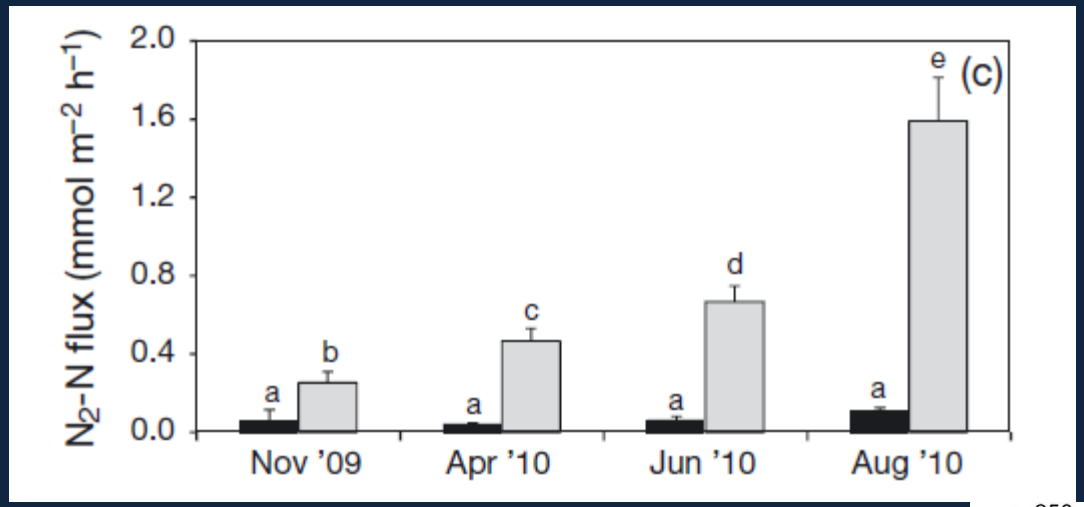


To connect oyster waste N denitrification

- Promote coupled ammonification - nitrification – denitrification
- Our results suggest oysters increase organic matter
- Then, see internal NH_4^+ uptake favored over nitrification
- Potential use of water column NO_3^-, rather than nitrification derived NO_3^-, for denitrification

Effects of oysters on denitrification



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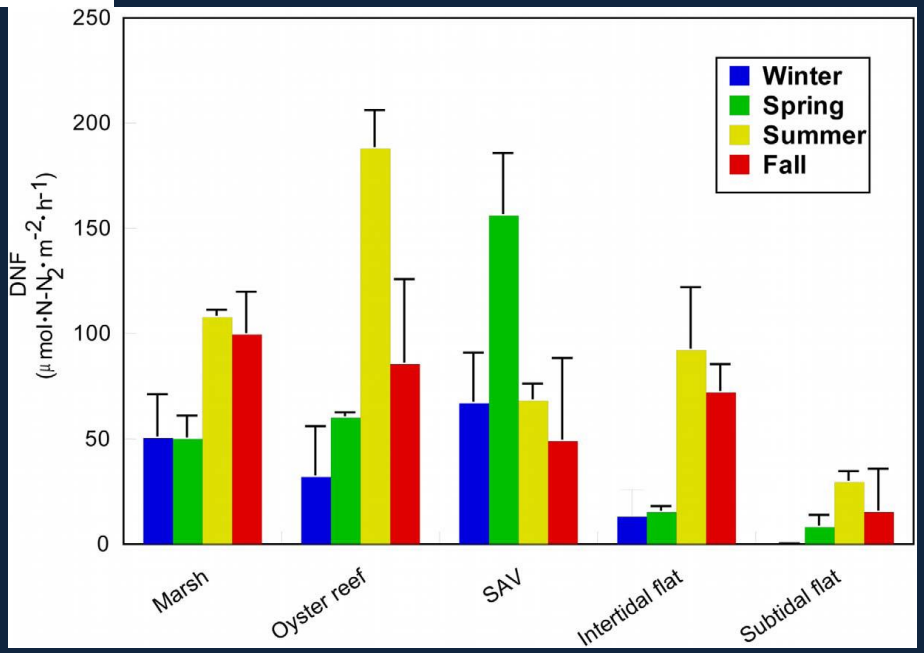
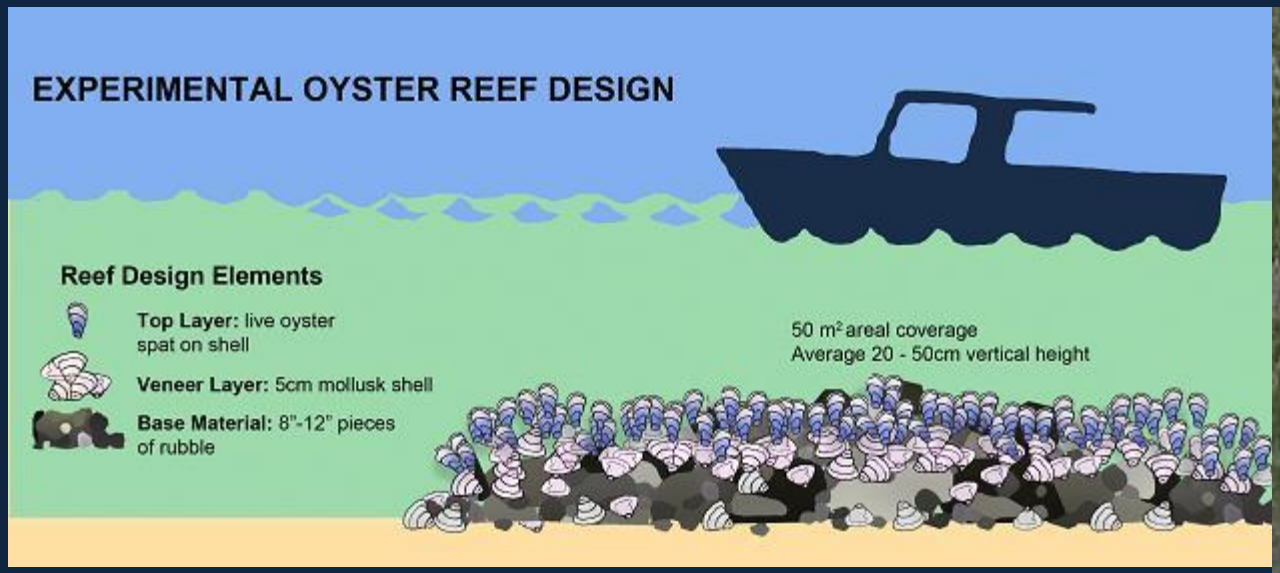
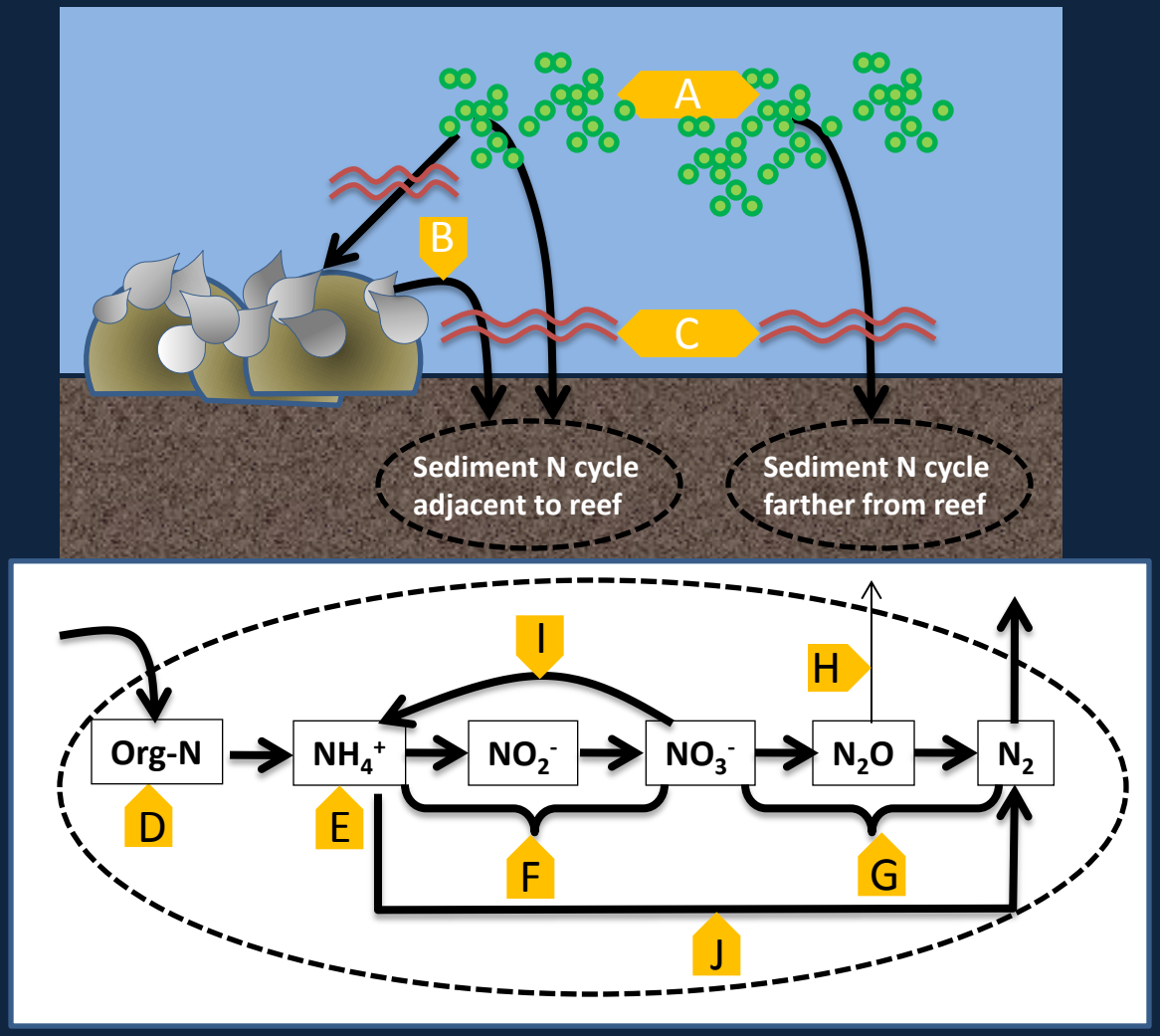


Oyster Restoration Research Project

Hudson River Foundation and > 30 other partner groups



The influence of oyster reef restoration on nitrogen cycling in the Hudson-Raritan estuary



A: Phytoplankton primary production, community respiration, and C:N

B: Oyster excretion

C: Hydrology

D: Sediment organic matter

E: Porewater ammonium

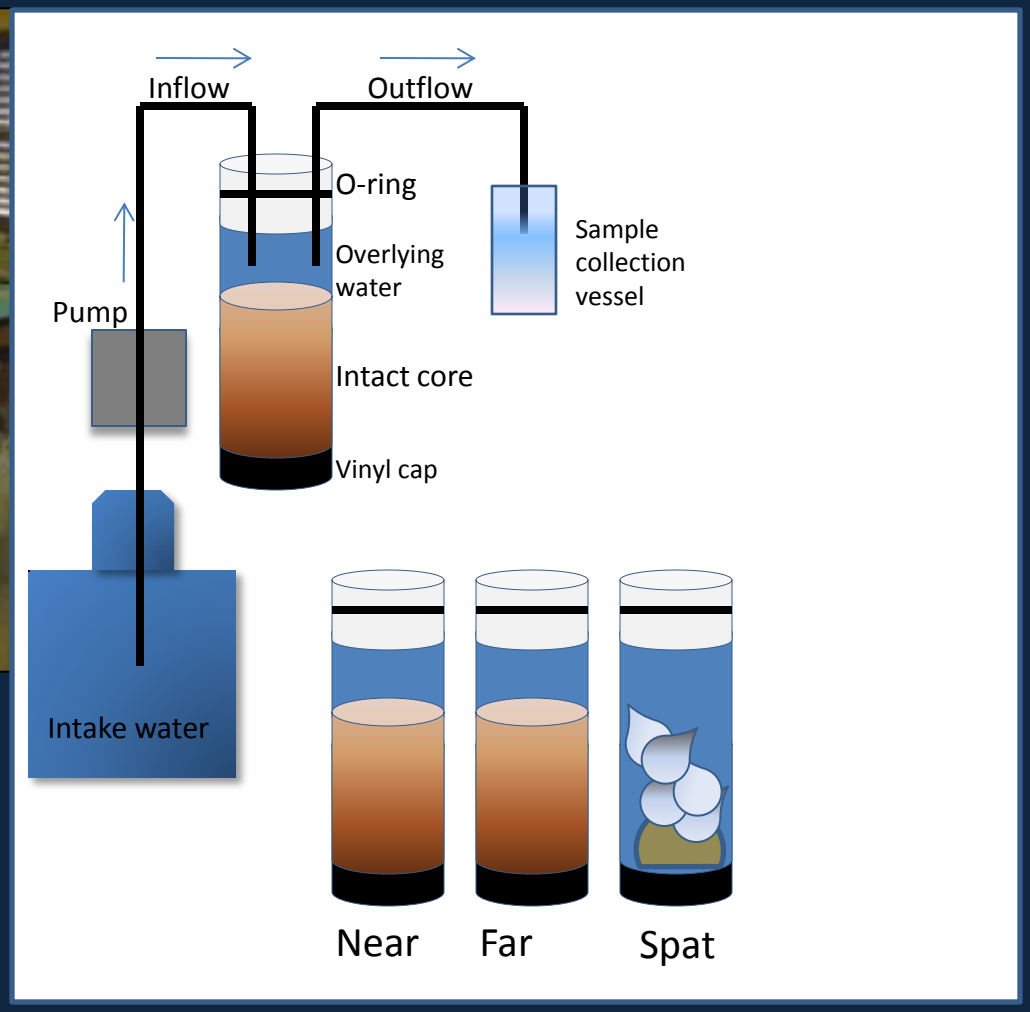
F: Nitrification

G: Denitrification

H: N_2O emission

I: Dissimilatory nitrate reduction to ammonium (DNRA)

J: Ammonium oxidation (Annamox)



CAN Method

Control = no isotope added; to measure net N_2 flux

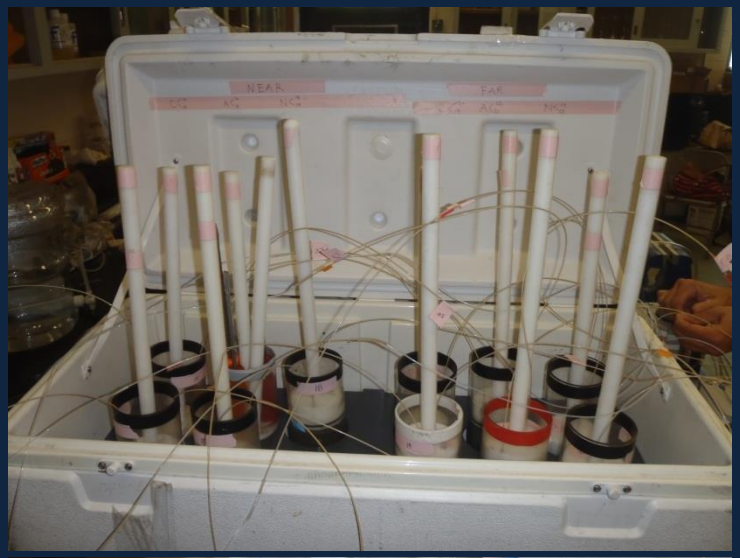
Ammonium = +10 µM $^{15}NH_4^+$; to measure annamox

Nitrate = +10 µM $^{15}NO_3^-$; to measure DN, DNRA, and NO_3^- source for denitrification

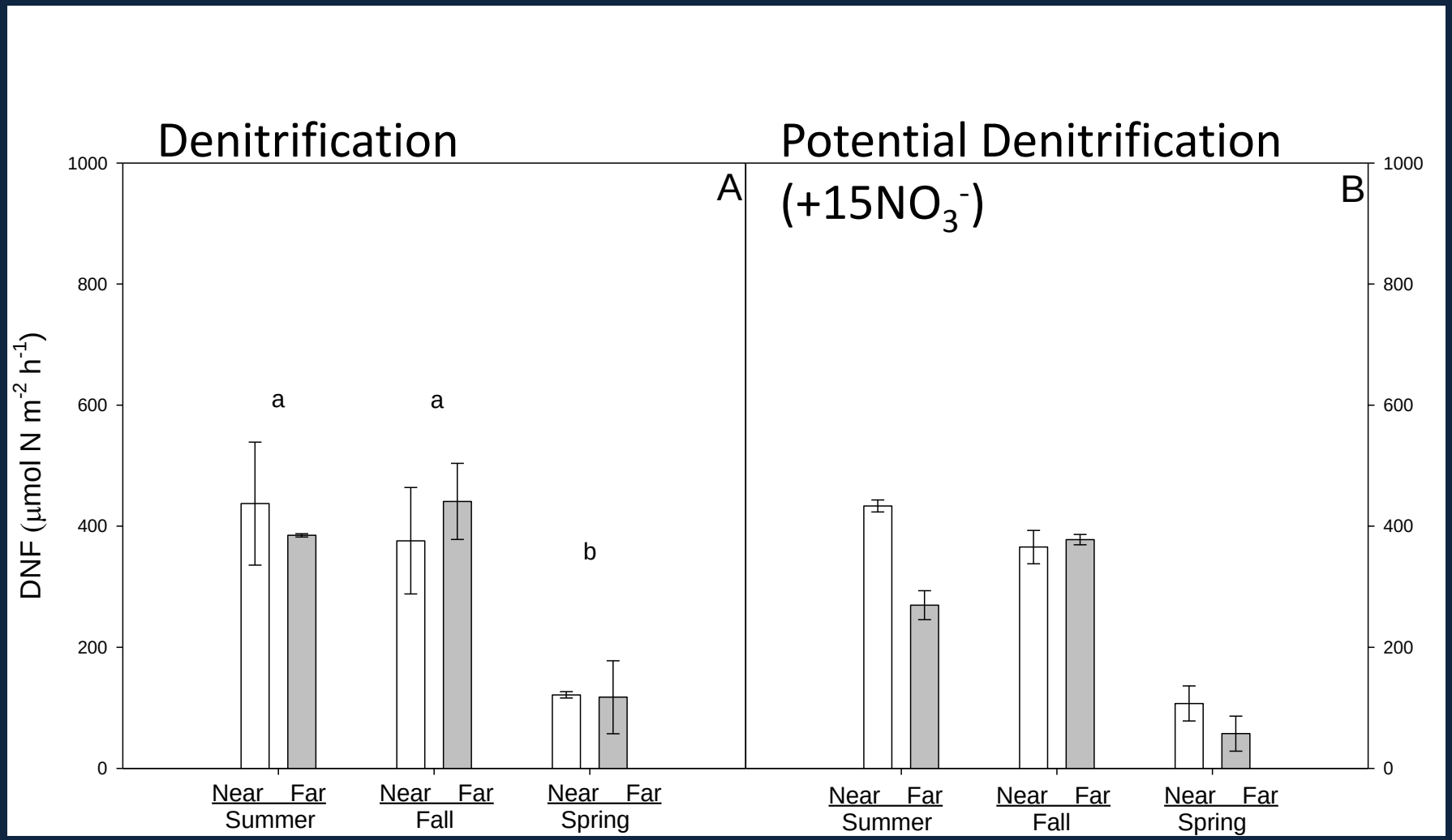
Objective is to explain mechanisms!

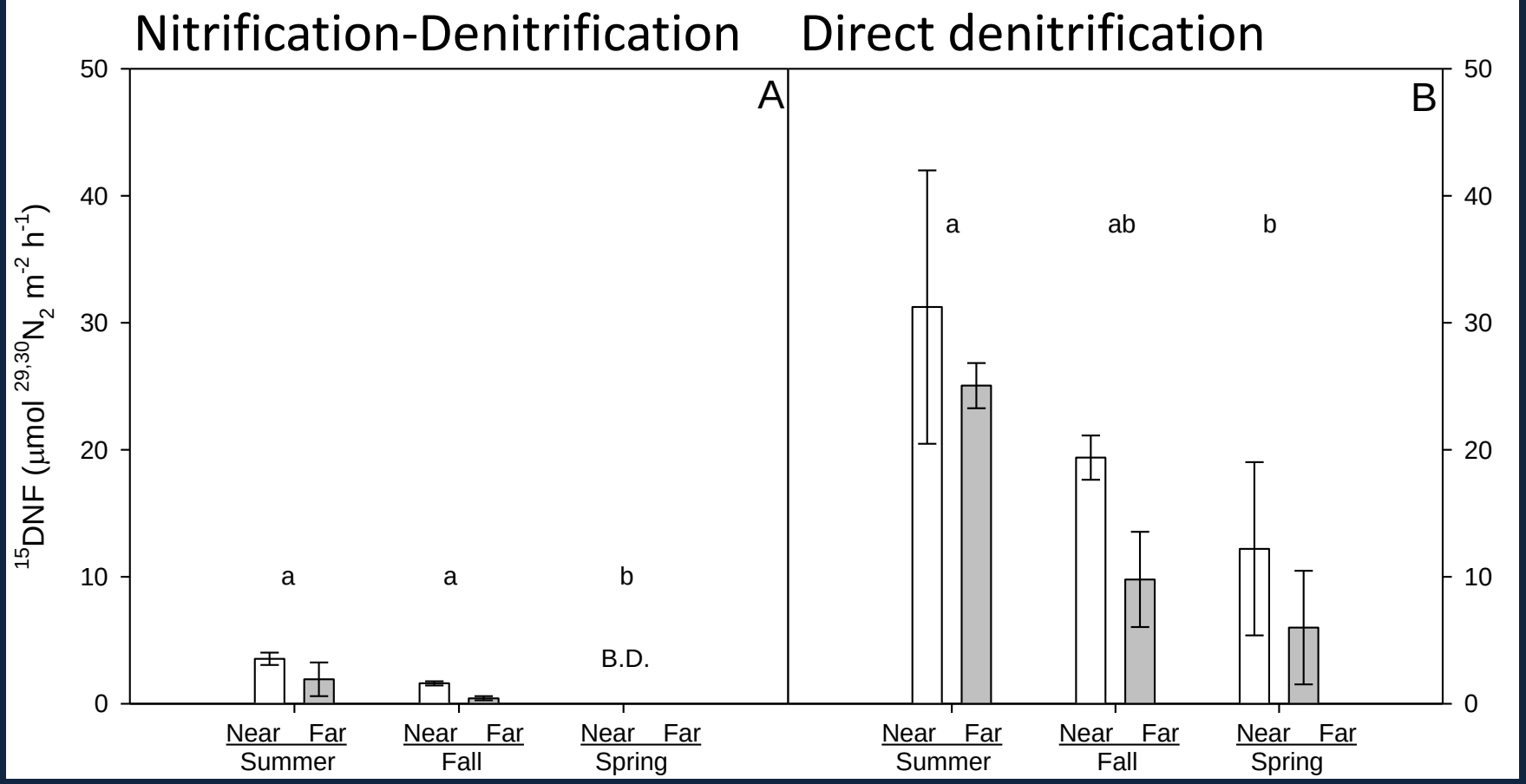
Soundview Reef

Sediment and Reef Core Incubations
CAN method

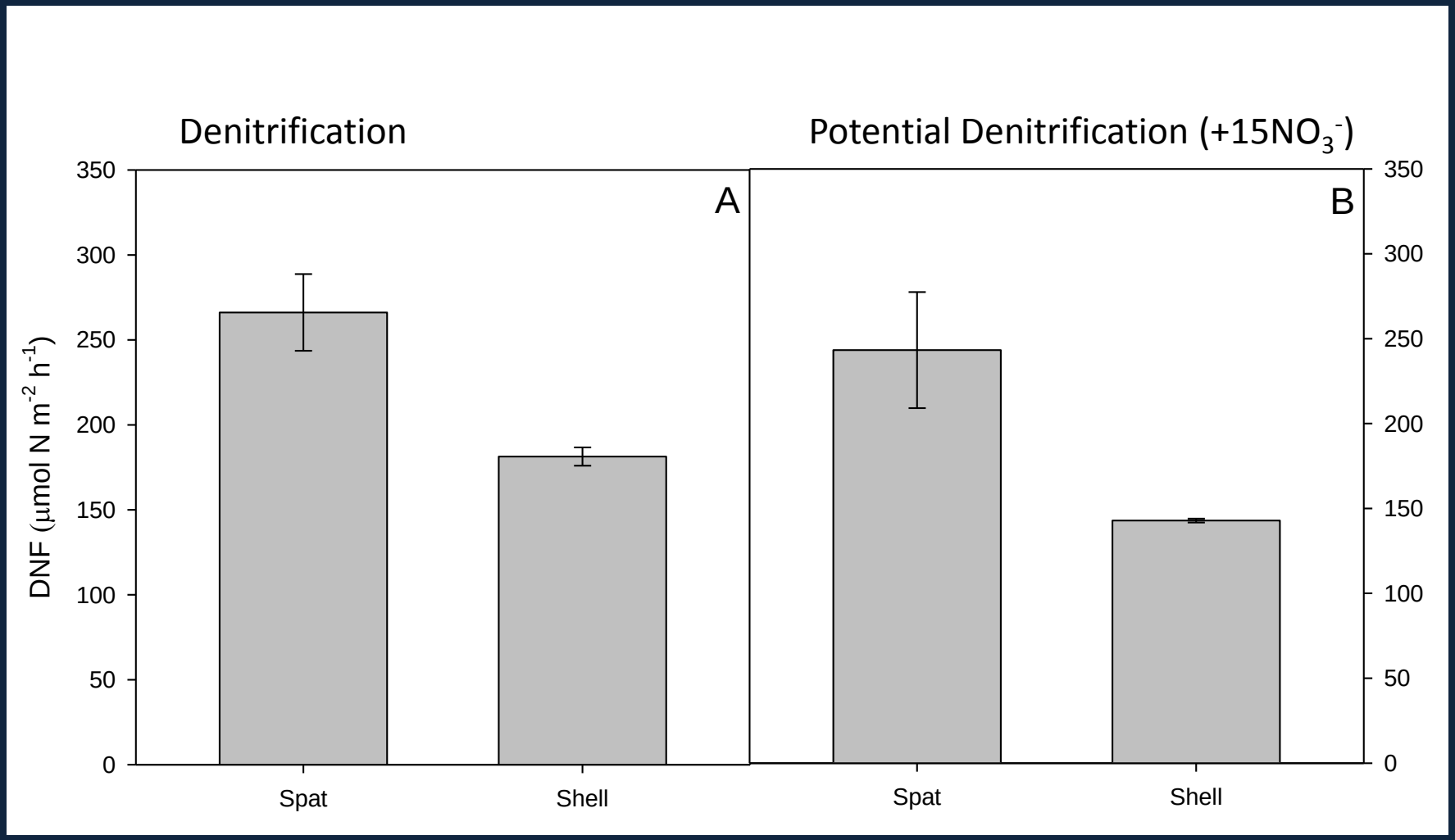


Sediment Denitrification at Soundview




Nitrification-Denitrification
Direct denitrification
A
B
^{15}DNF (µmol $^{29,30}N_2$ m^{-2} h^{-1})
50
40
30
20
10
0
a
a
b
B.D.
a
ab
b
Near Far
Summer
Near Far
Fall
Near Far
Spring
Near Far
Summer
Near Far
Fall
Near Far
Spring

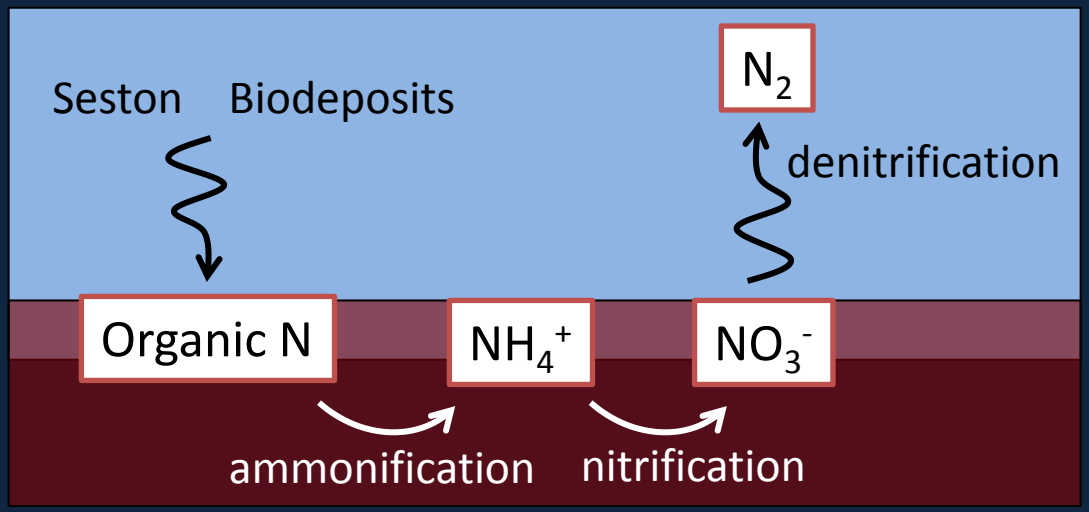
Reef Denitrification at Soundview



Carbon limitation?

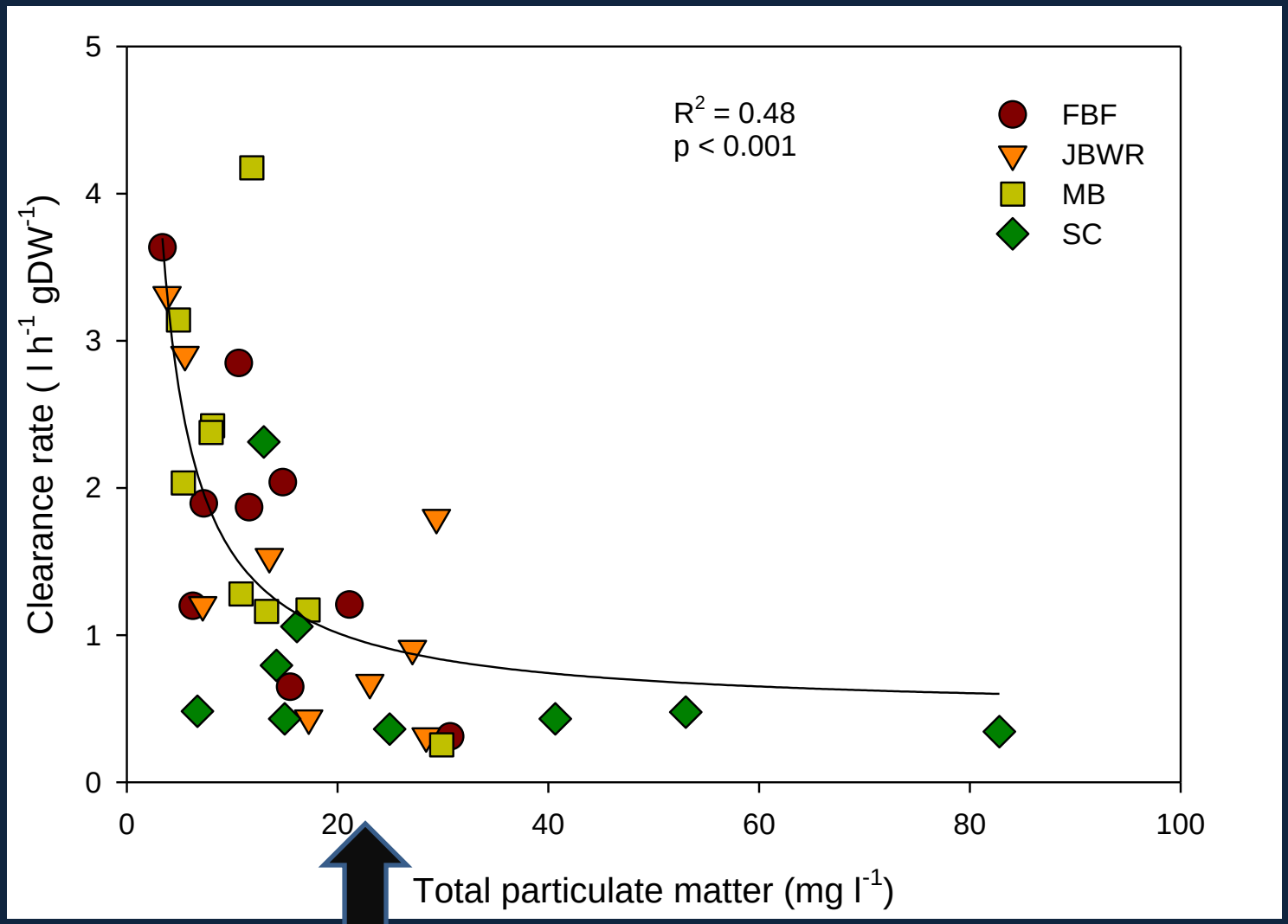
Oysters and Water Quality

- Benthic-Pelagic Coupling
  - Enhance coupled nitrification-denitrification?

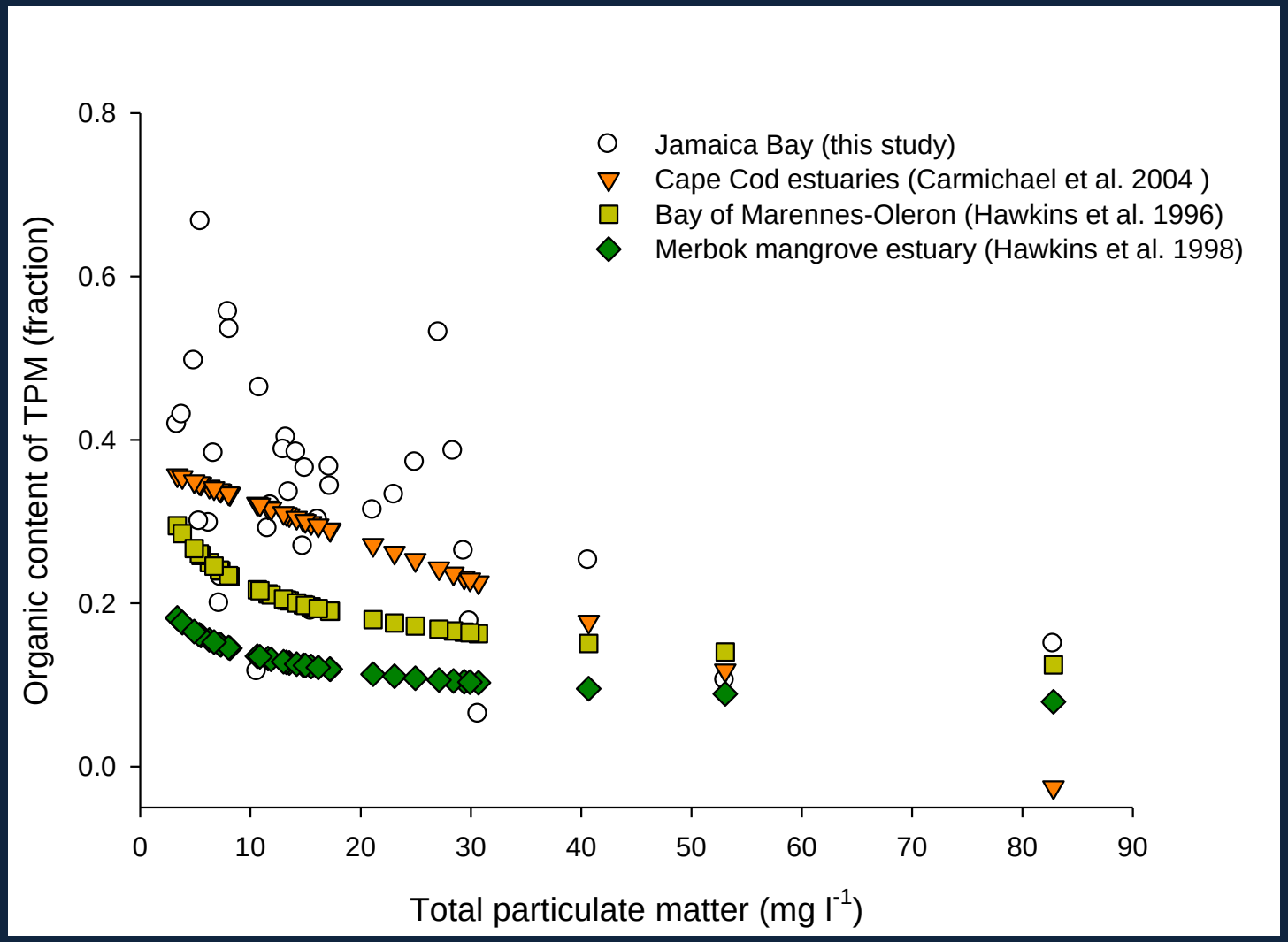


Response Variables – Oyster Feeding

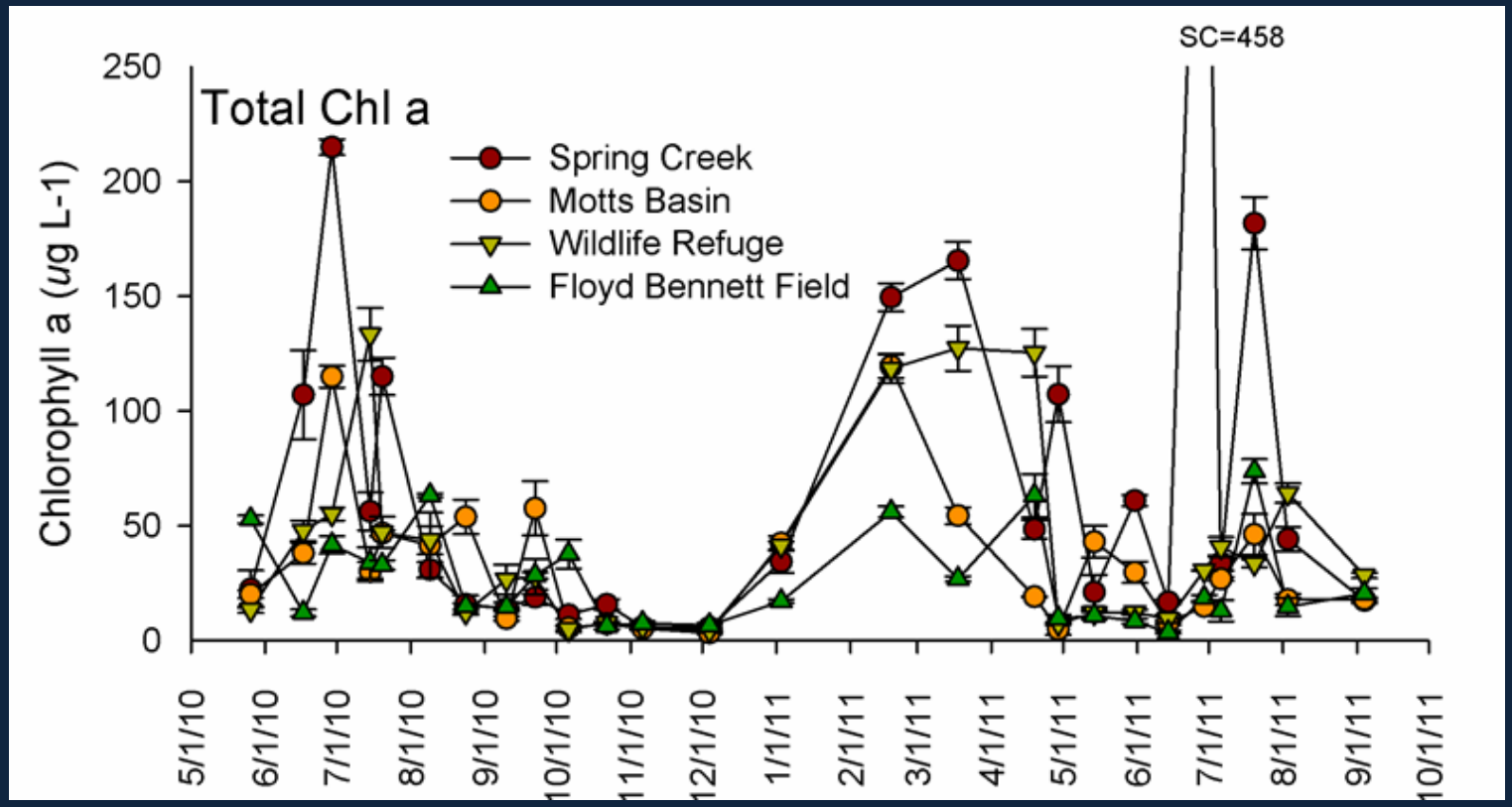
Clearance rates in Jamaica Bay 2010-2011



High organic matter in seston

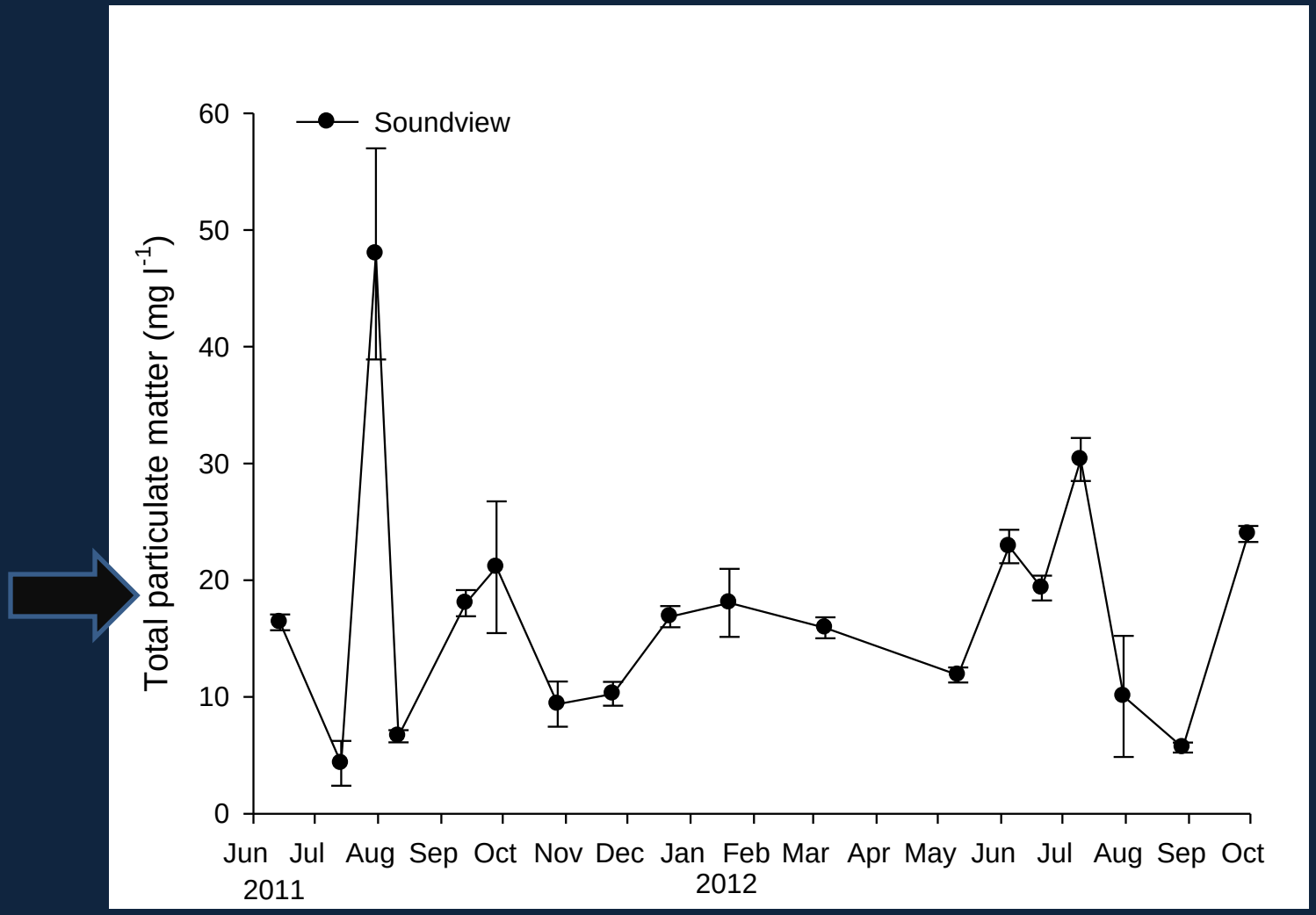


Phytoplankton Abundance Jamaica Bay 2010-2011

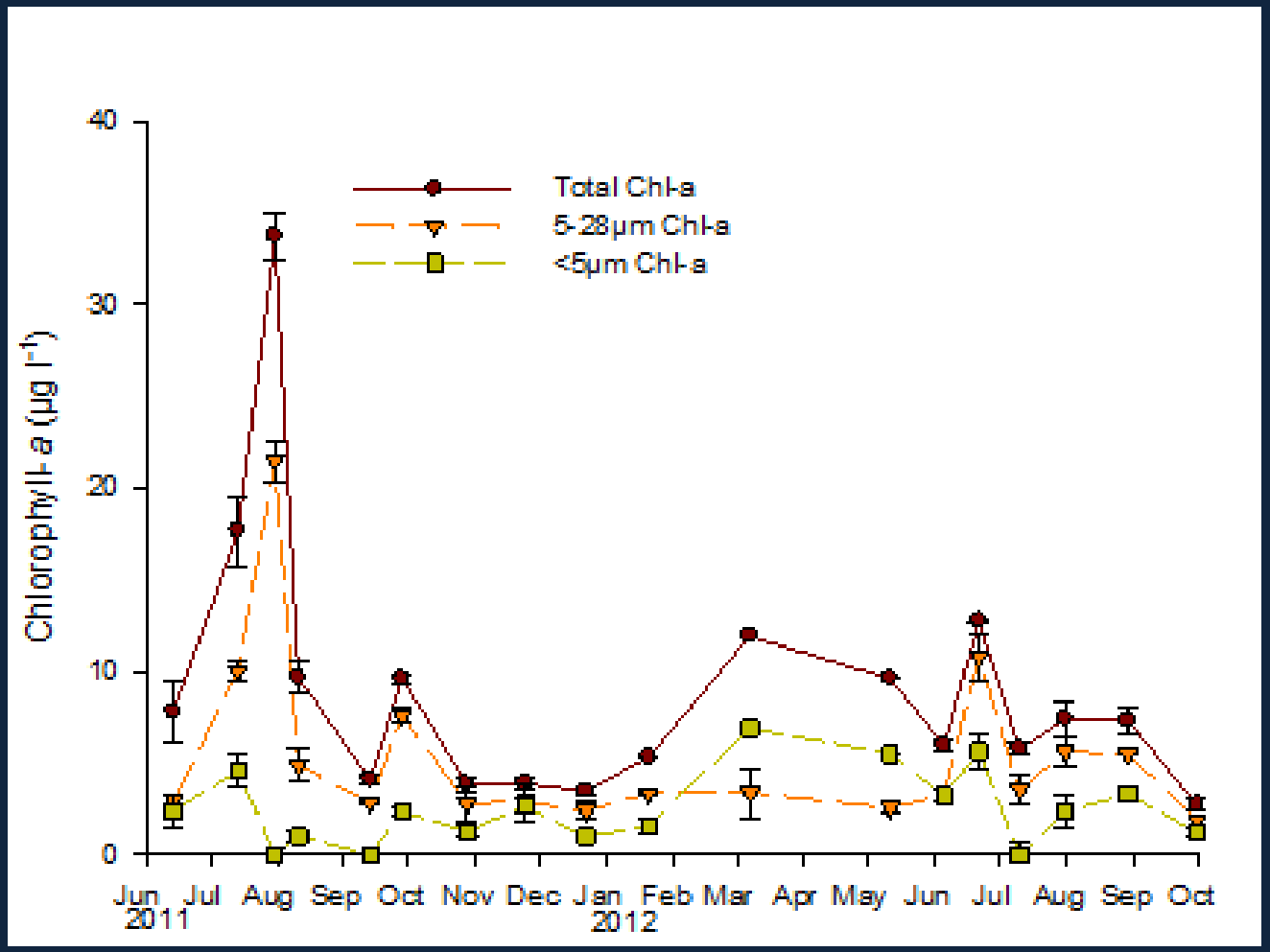


Soundview Reef

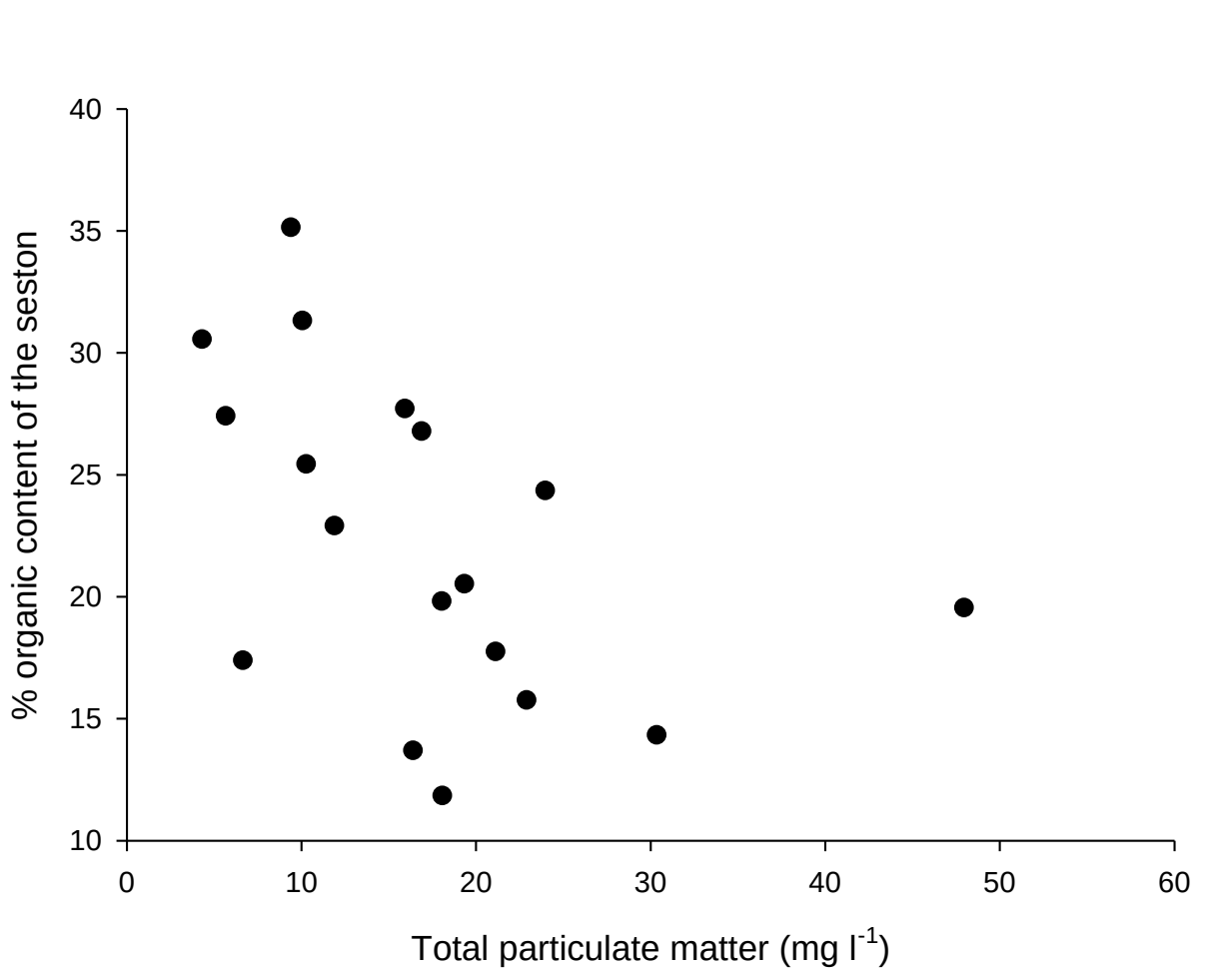
Soundview Seston



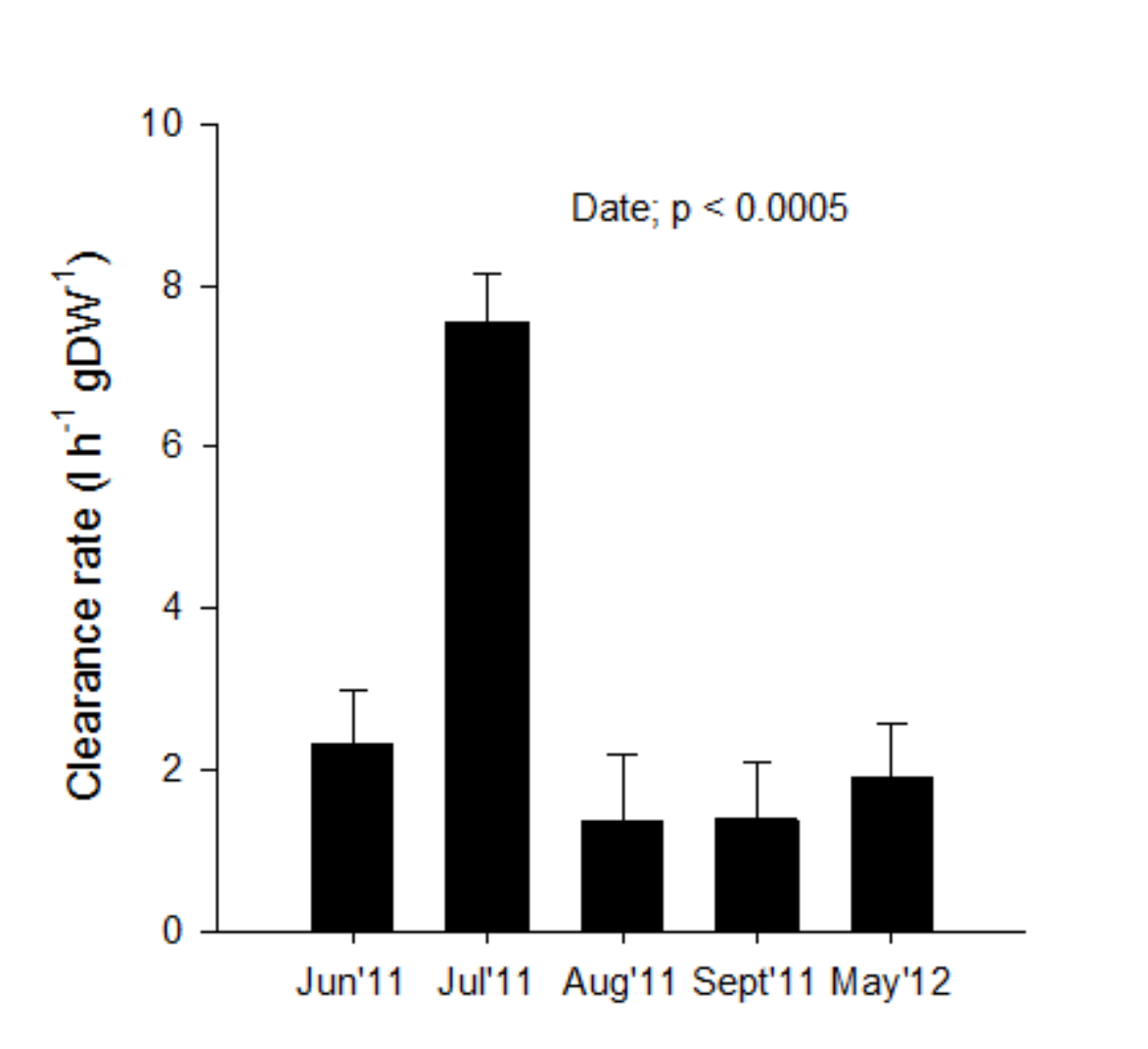
Phytoplankton Abundance Soundview 2011-2012



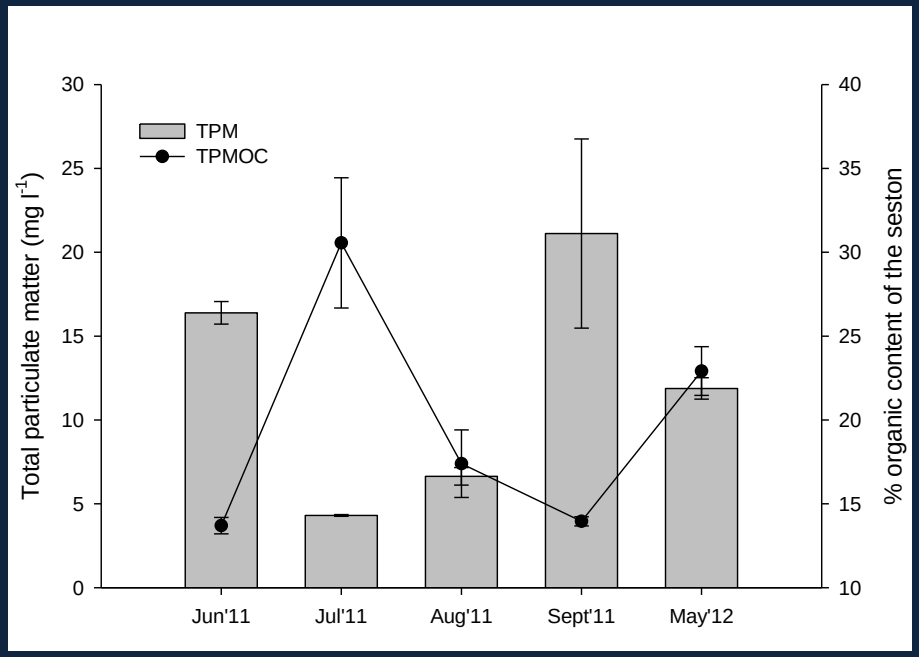
Low organic content in seston

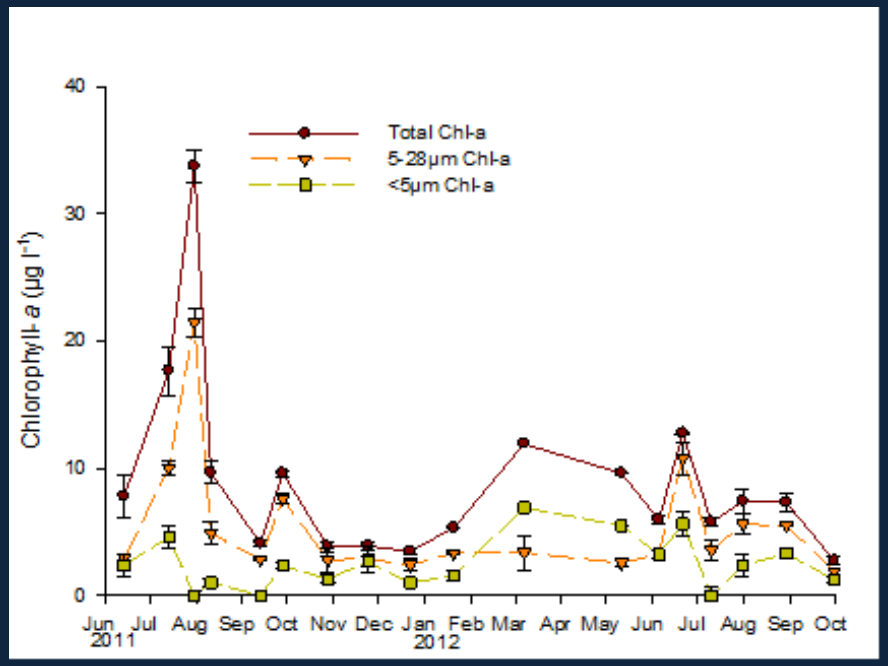


Oyster Feeding Rates at Soundview

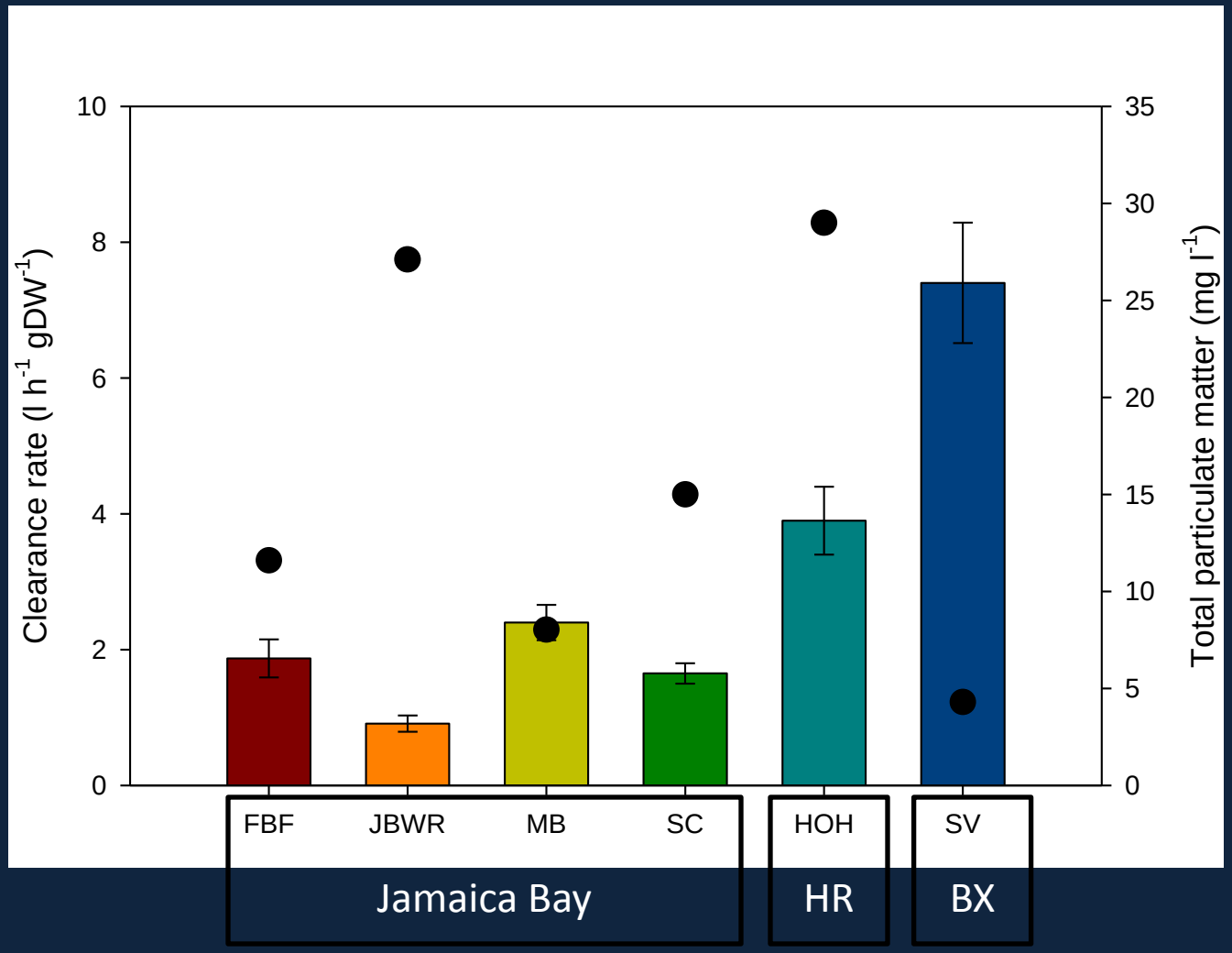


Seston characteristics explain high clearance rates





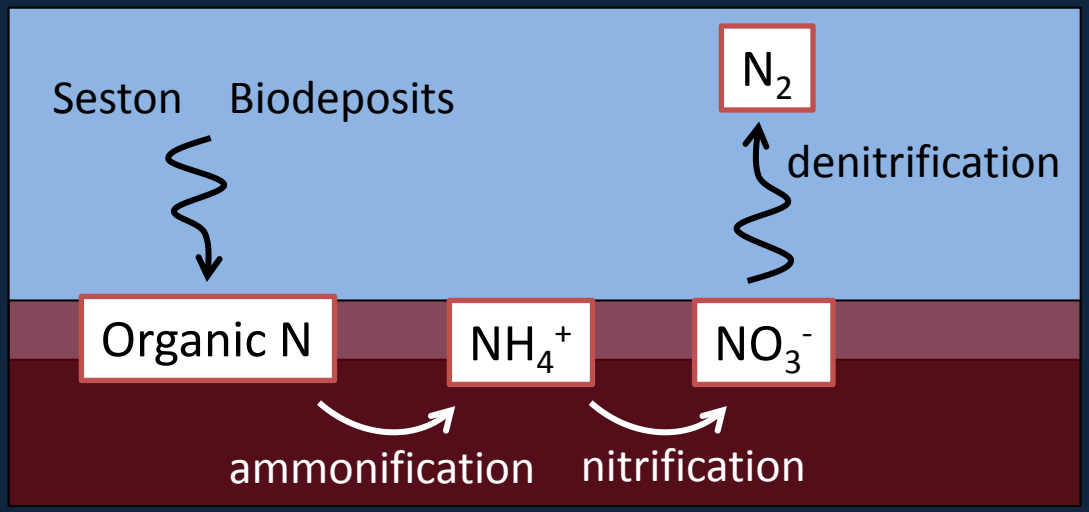
Clearance rates – July'11



* Temporal and spatial replication of feeding physiology is required due to seston dynamics

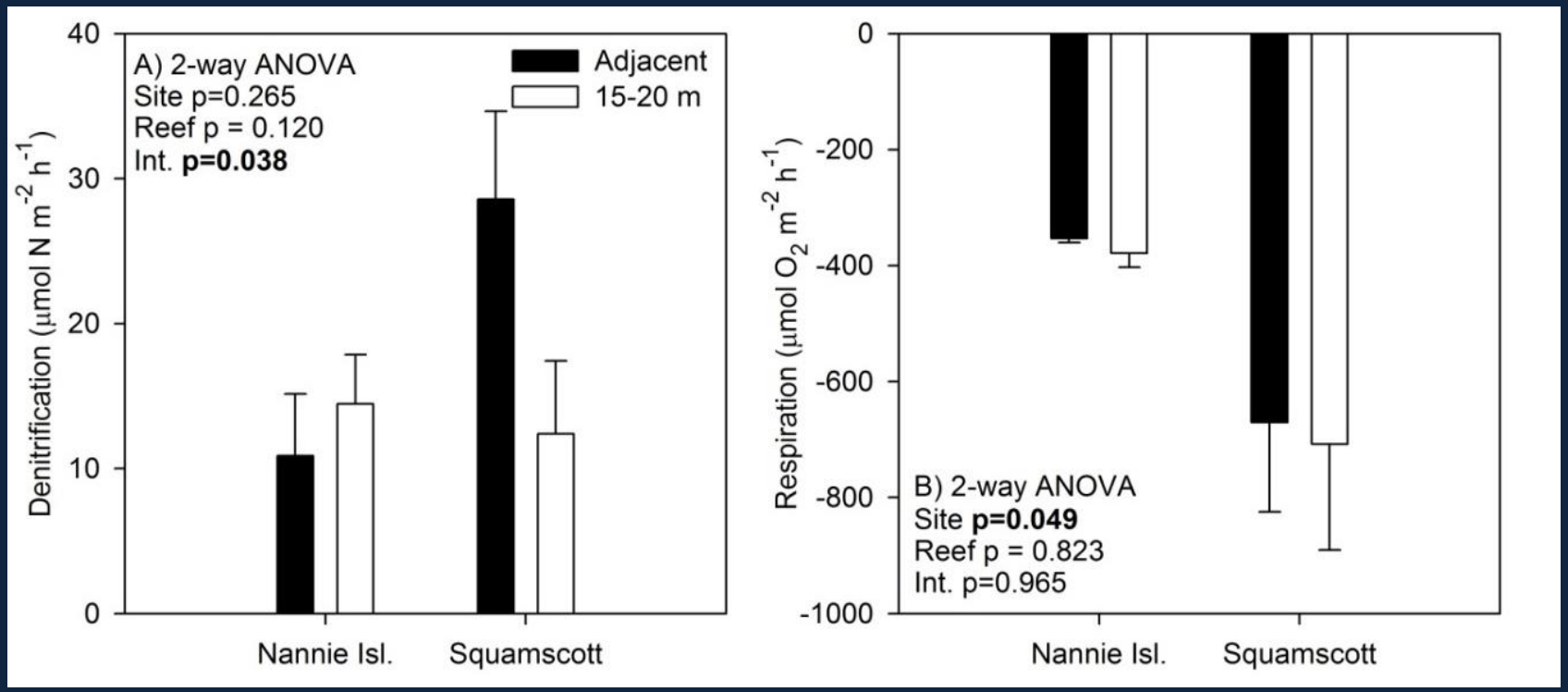
Oysters and Water Quality

- Benthic-Pelagic Coupling
  - Enhance coupled nitrification-denitrification?



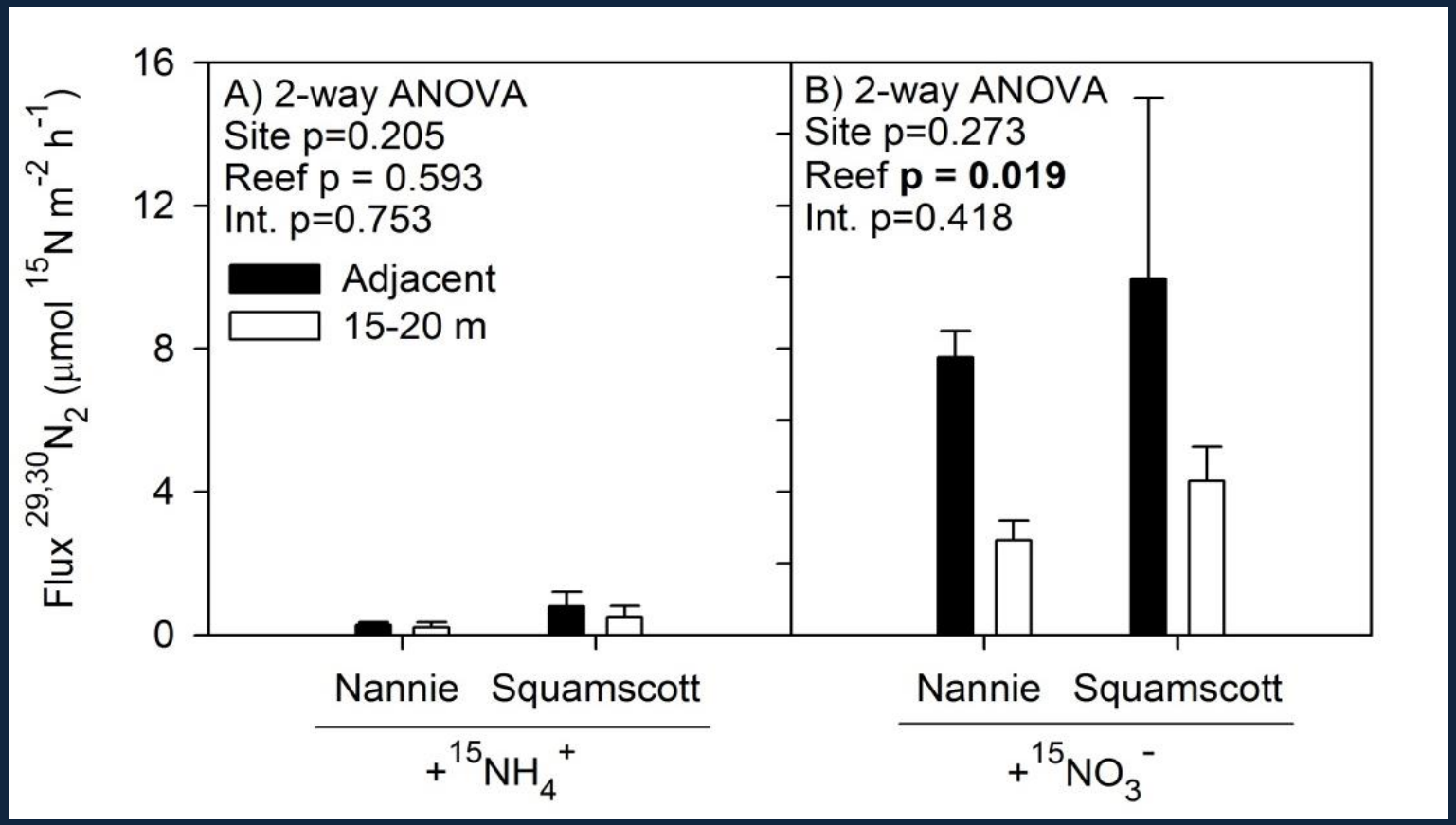
Eastern oyster (*Crassostrea virginica*) filtration, biodeposition, and sediment nitrogen cycling at two oyster reefs with contrasting water quality in Great Bay Estuary(New Hampshire, USA)

Denitrification higher at eutrophic oyster reef



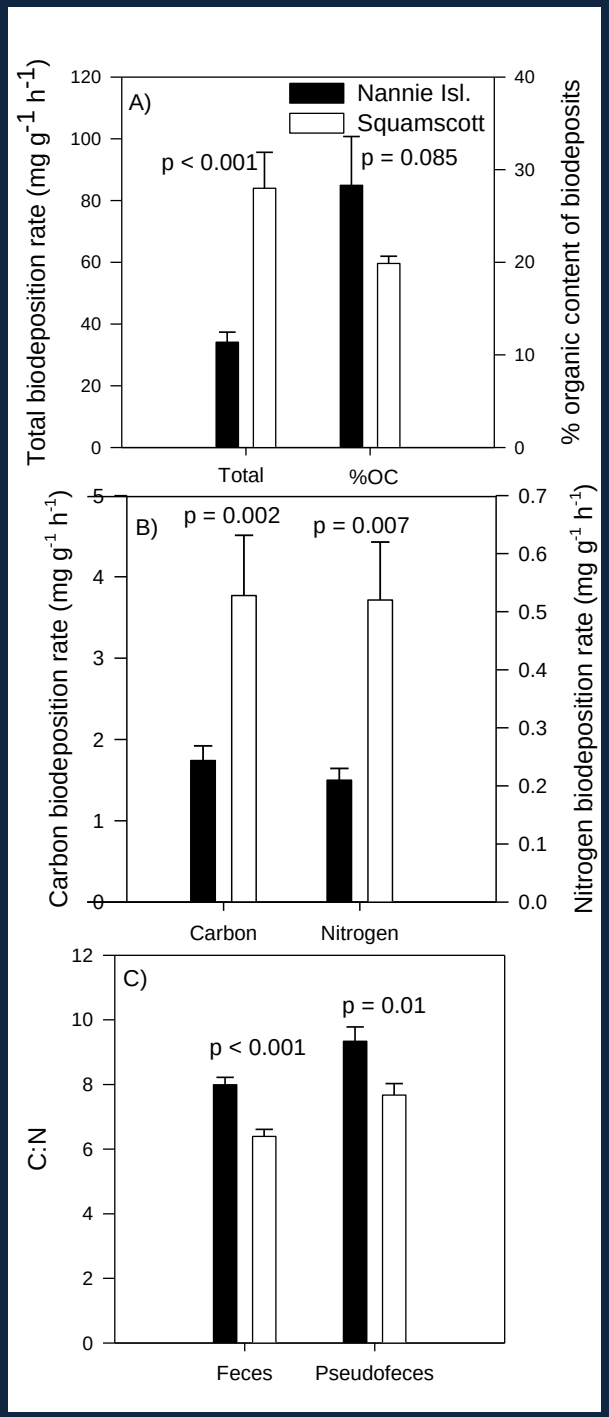
Hoellein , Zarnoch, Grizzle, Biogeochemistry, In Press

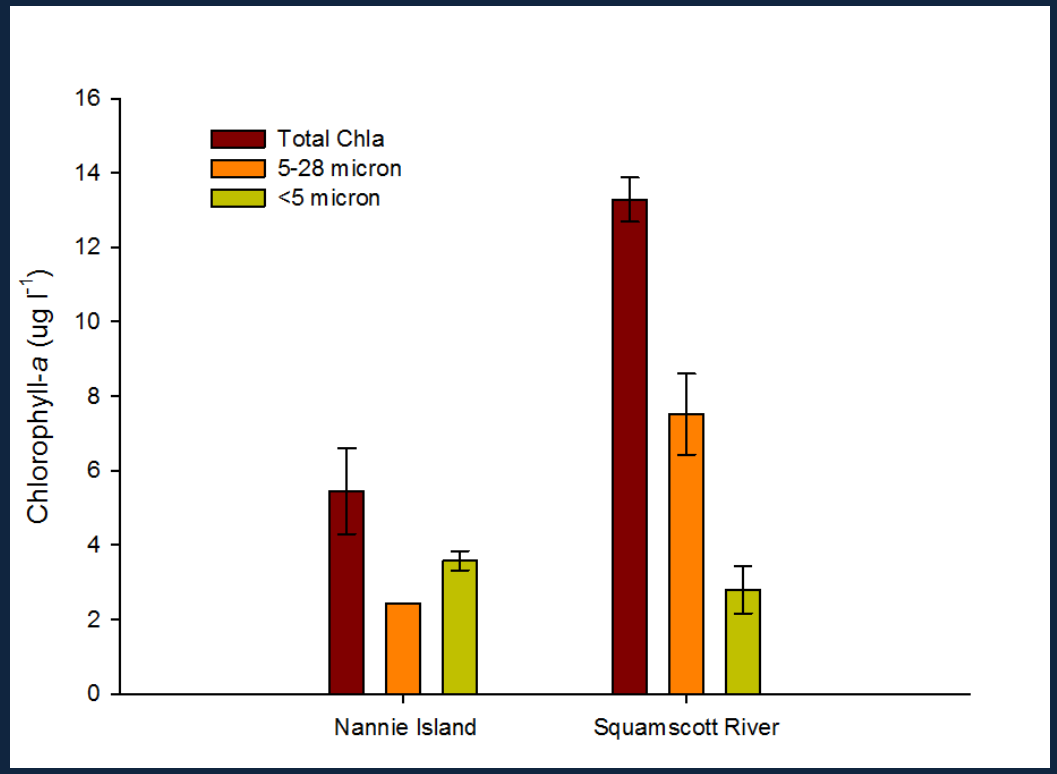
Direct denitrification favored over coupled nitrification-denitrification



Hoellein , Zarnoch, Grizzle, Biogeochemistry, In Press

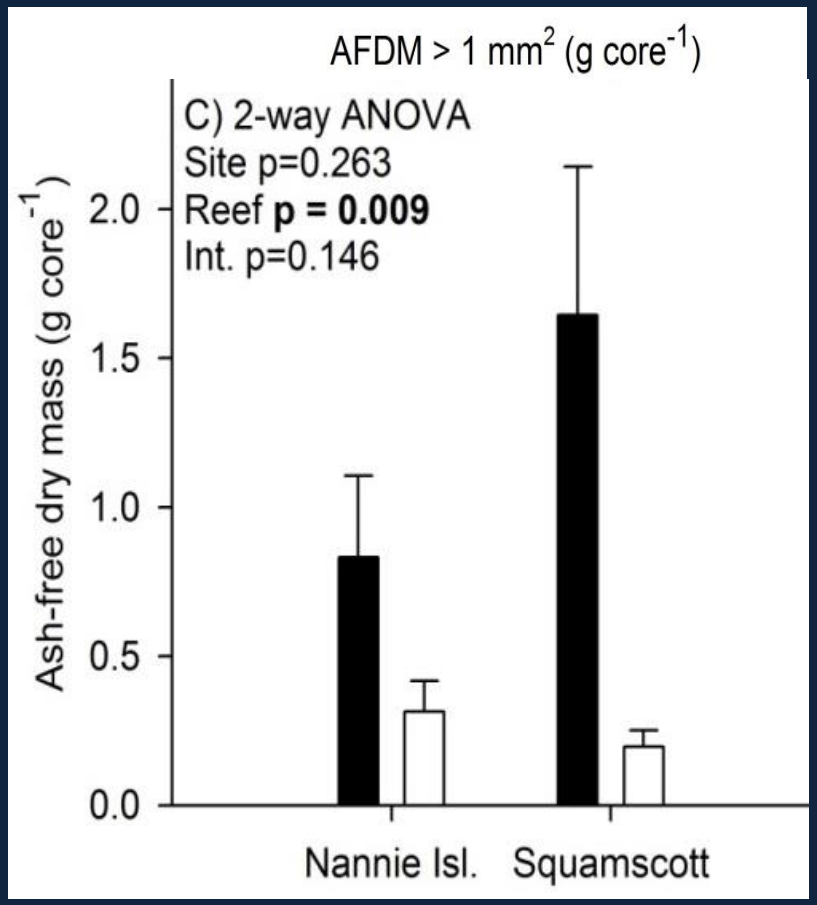
1) Why was denitrification enhanced at the eutrophic site and not at the oligotrophic site?

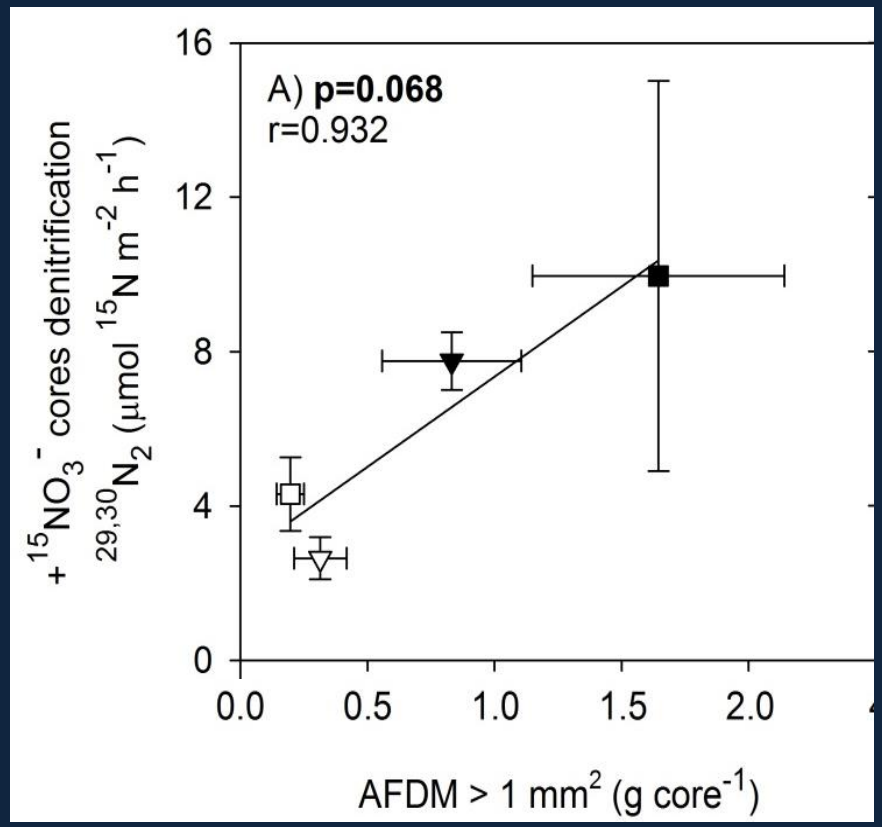




Hoellein , Zarnoch, Grizzle, Biogeochemistry, In Press

2) How do we explain the oyster reef effect on denitrification potential?

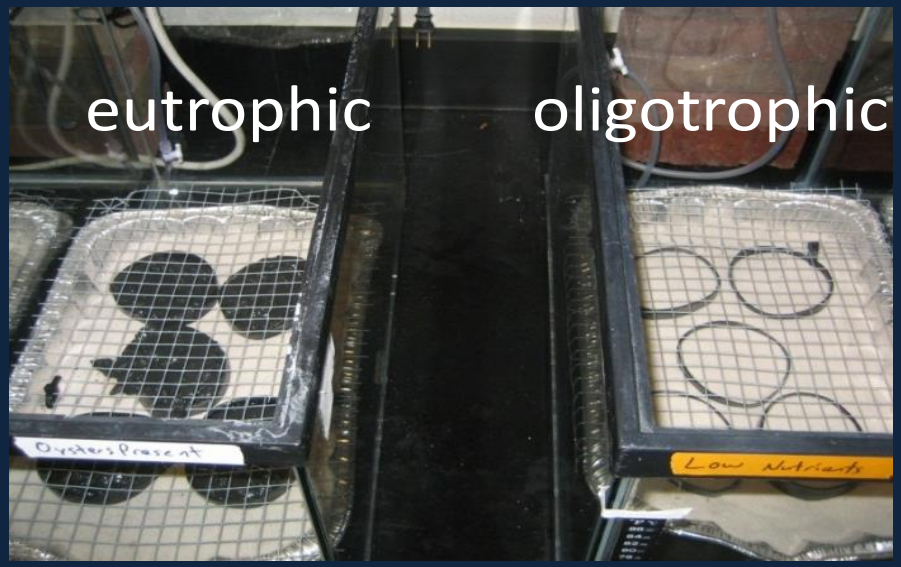


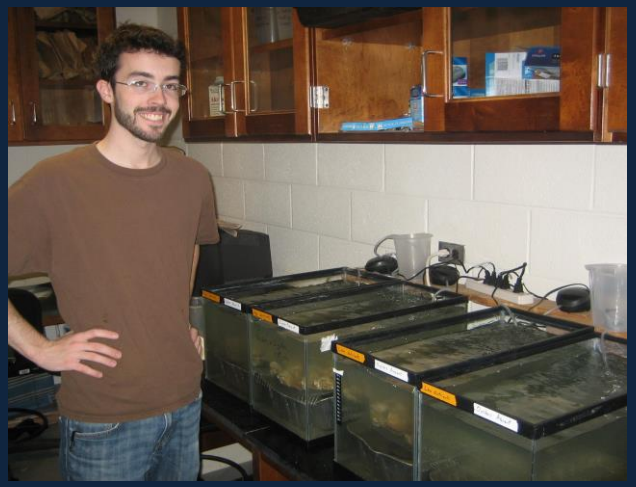


Denitrification potential correlated with larger sediment particles

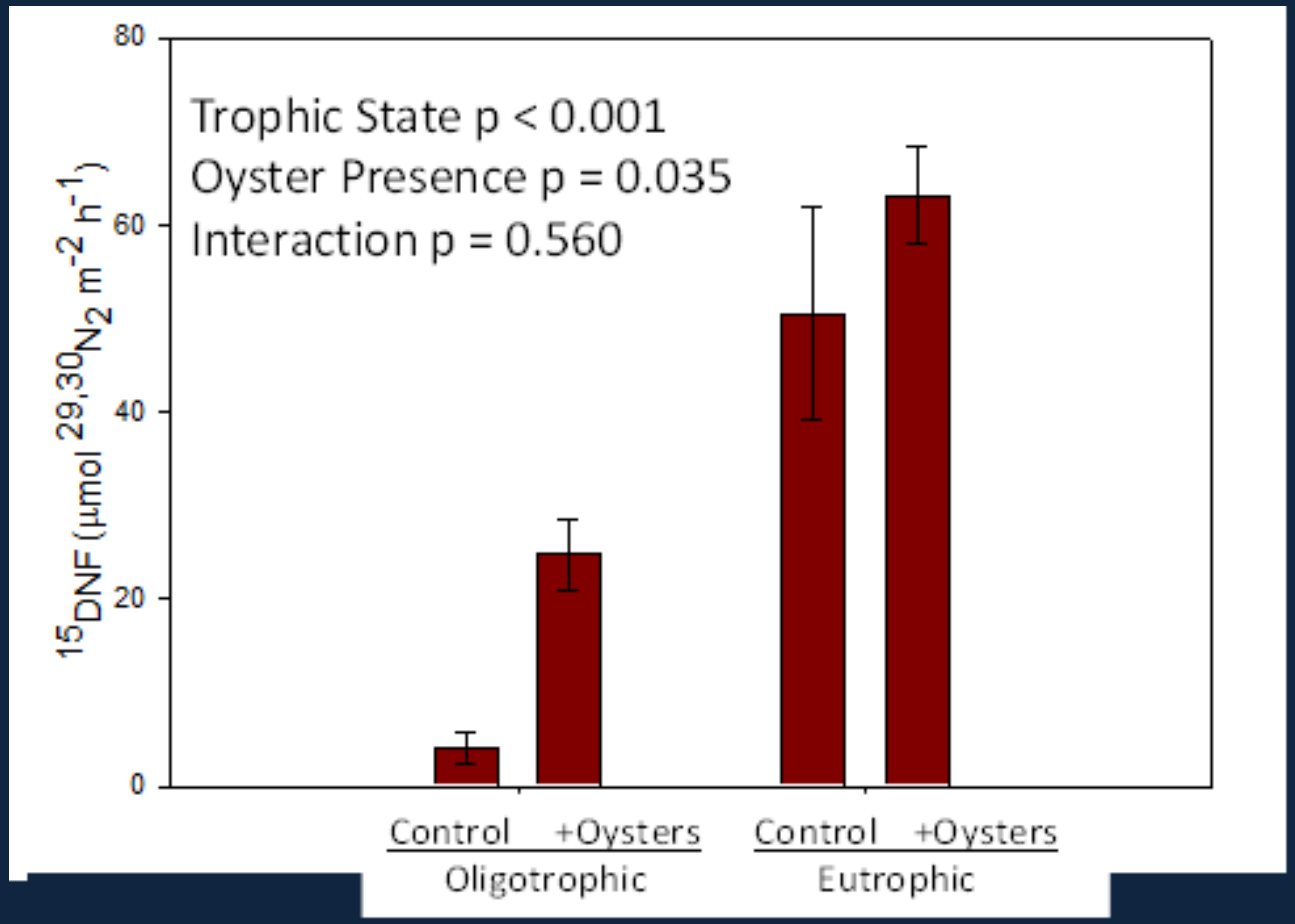
Organic C substrate and enhanced NO_3^- diffusion

Lab experiments – Oysters x Trophic status

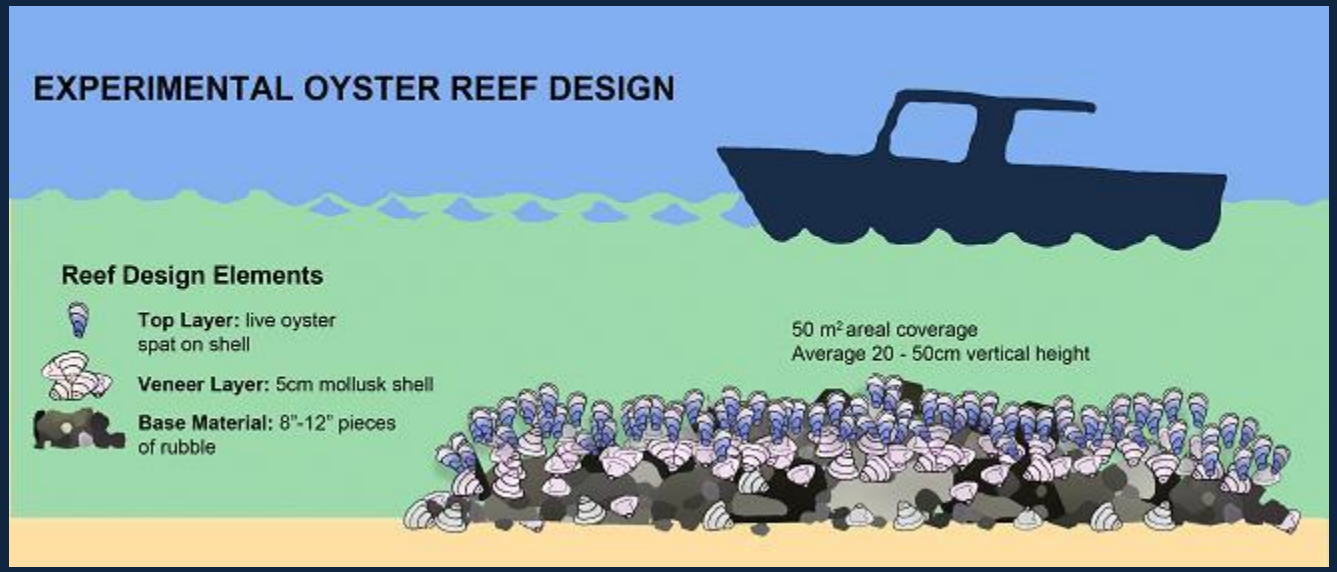


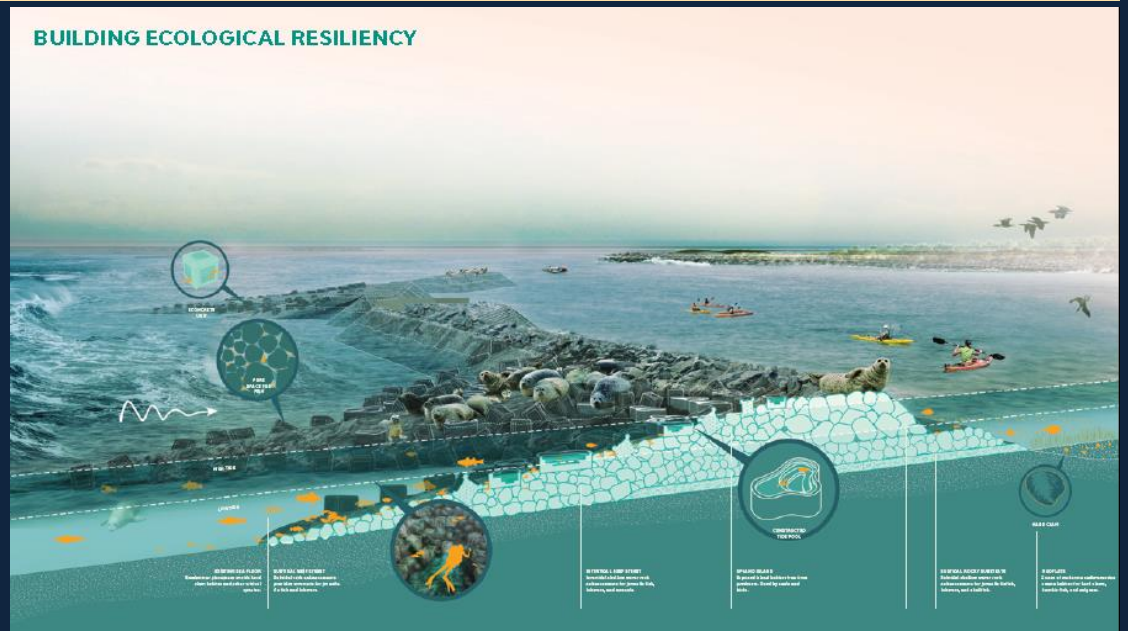


Denitrification potential is enhanced by oysters under oligotrophic conditions



Implications for NYC Restoration





Implications for NYC Restoration

1. Oyster filtration most effective at less turbid sites. Long term monitoring required.
2. Mechanism for oyster mediated denitrification will likely be through enhanced C biodeposition where C is limited.
3. Sediments around reef/breakwater structures may have enhanced NO_3^- diffusion.
4. Measurements of intact living structures using isotopes is needed to understand site-specific <u>mechanisms</u>.

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- National Science Foundation Awards: DEB-0918952 & MRI 0959876
- **Hudson River Foundation**
- CUNY

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- Gateway National Recreation Area
- NYS Department of Environmental Conservation
- New York City Parks – NRG
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Students:

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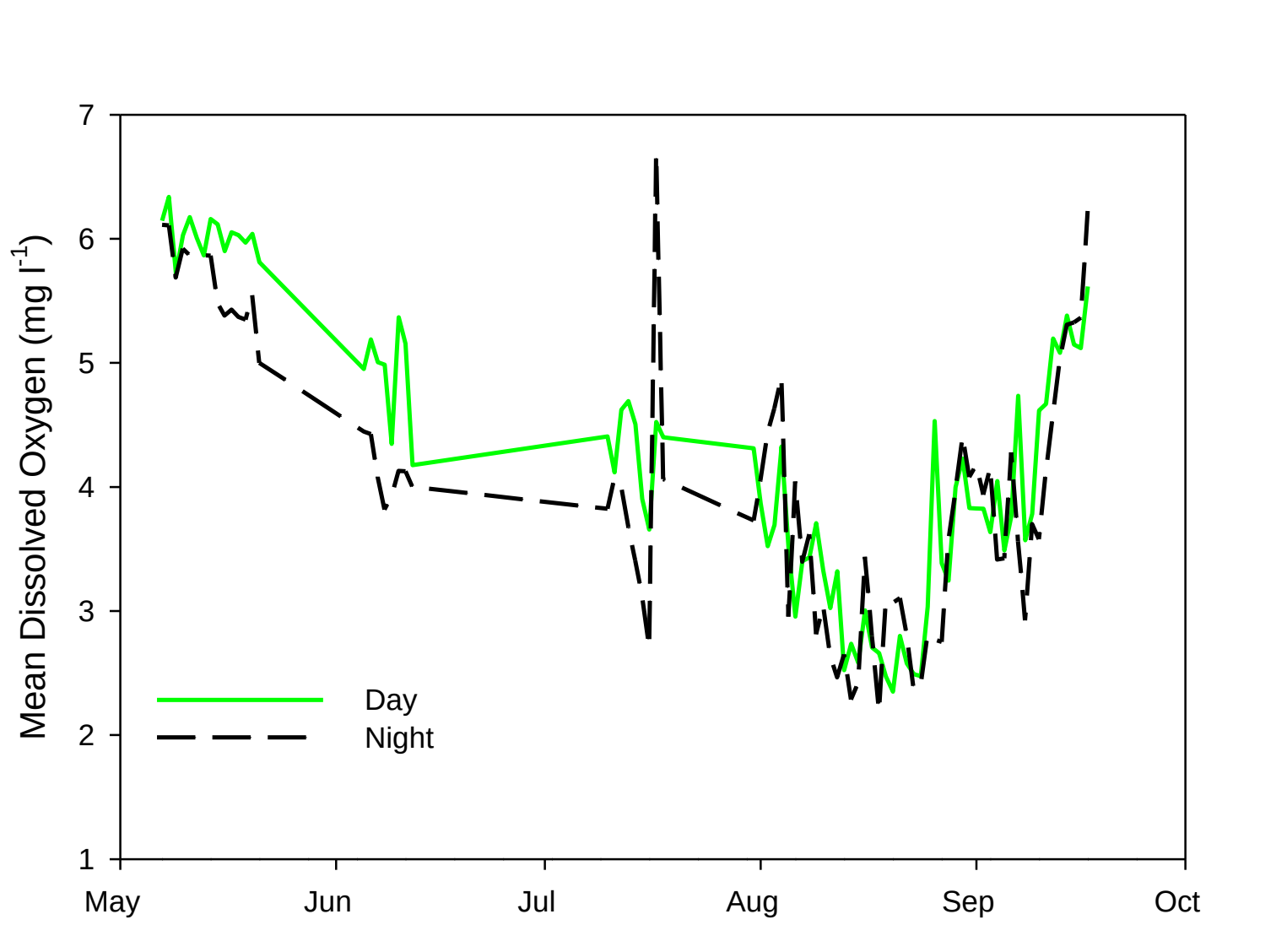
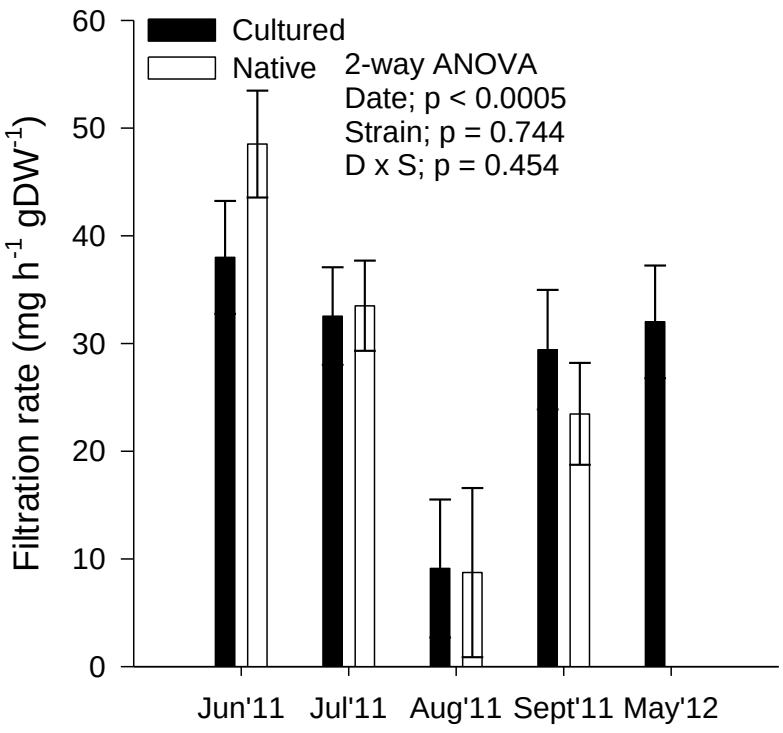
Narendra Paramanand – Baruch College
Doris Law – Baruch College
Swathi Mummini- Hunter College
Gena Israel – Hunter College
Angela David – Loyola University Chicago
S Morgan – Loyola University Chicago
Steve Polaskey – Loyola University Chicago
Vitaly Zaharov – Baruch College
Hanen Yan – Baruch College
Kevin Kucher – Penn State University
Damien Christopher – NY Harbor School
Jemi Jacob – Hunter College
Sanne Lynham – Baruch College
Corinna Singleman – CUNY Graduate Center

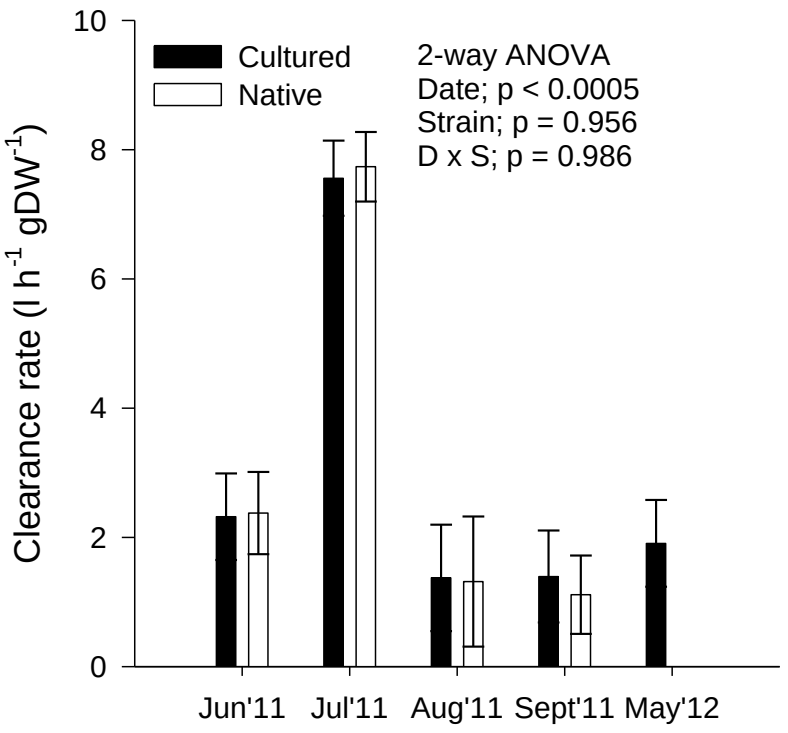
Summer 2012 Soundview

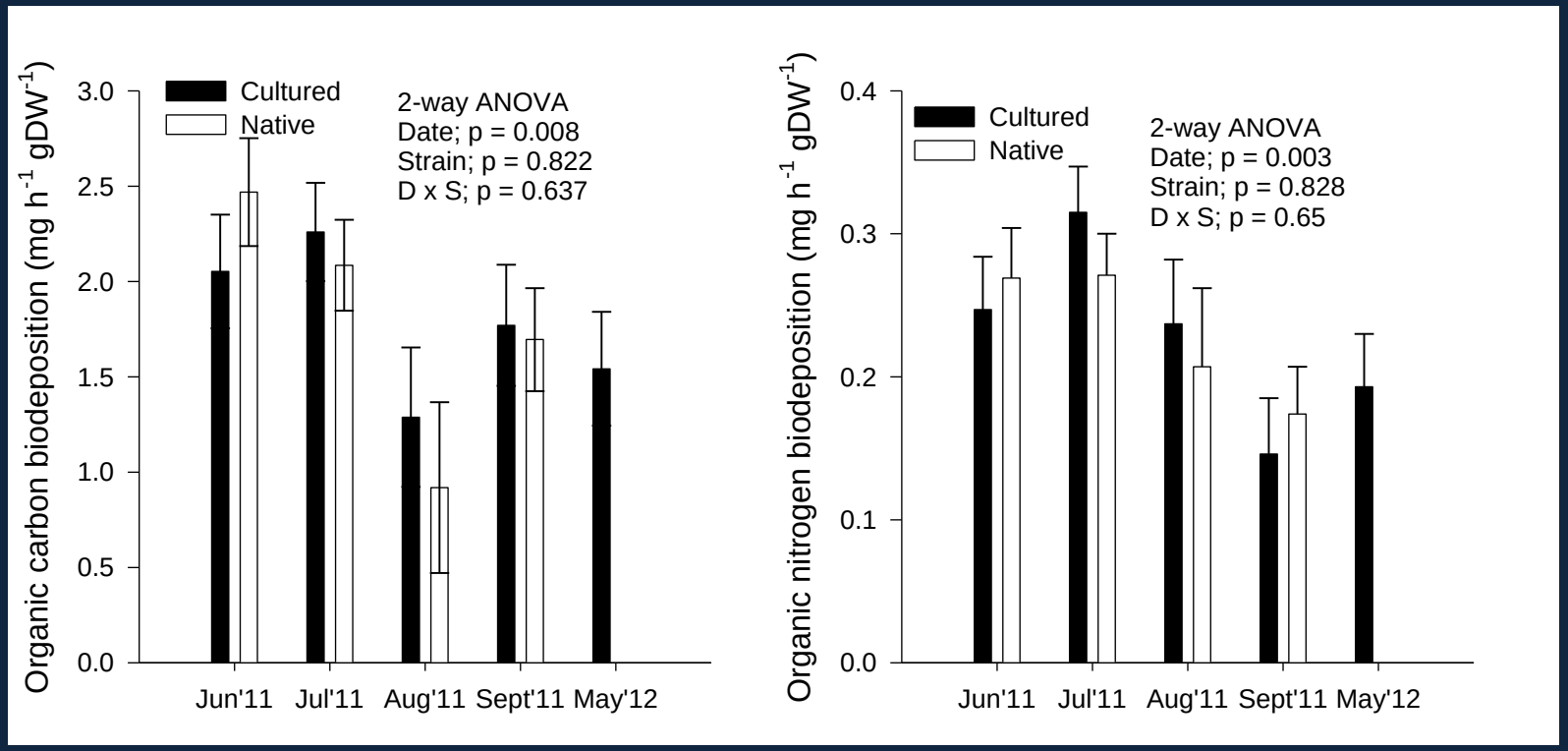


Summary

CHESAPEAKE
NITROGEN-FILTERING OYSTERS
Sunken Treasure
THE GOOD KIND.—
5-10-13


Cultured
Native
2-way ANOVA
Date; p < 0.0005
Strain; p = 0.744
D x S; p = 0.454
Filtration rate (mg h-1 gDW-1)
0
10
20
30
40
50
60
Jun'11
Jul'11
Aug'11
Sept'11
May'12


Cultured
Native
2-way ANOVA
Date; p < 0.0005
Strain; p = 0.956
D x S; p = 0.986
Clearance rate (l h-1 gDW-1)
0
2
4
6
8
10
Jun'11
Jul'11
Aug'11
Sept'11
May'12


Organic carbon biodeposition (mg h-1 gDW-1)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Cultured
Native
2-way ANOVA
Date; p = 0.008
Strain; p = 0.822
D x S; p = 0.637
Jun'11
Jul'11
Aug'11
Sept'11
May'12
Organic nitrogen biodeposition (mg h-1 gDW-1)
0.4
0.3
0.2
0.1
0.0
Cultured
Native
2-way ANOVA
Date; p = 0.003
Strain; p = 0.828
D x S; p = 0.65
Jun'11
Jul'11
Aug'11
Sept'11
May'12