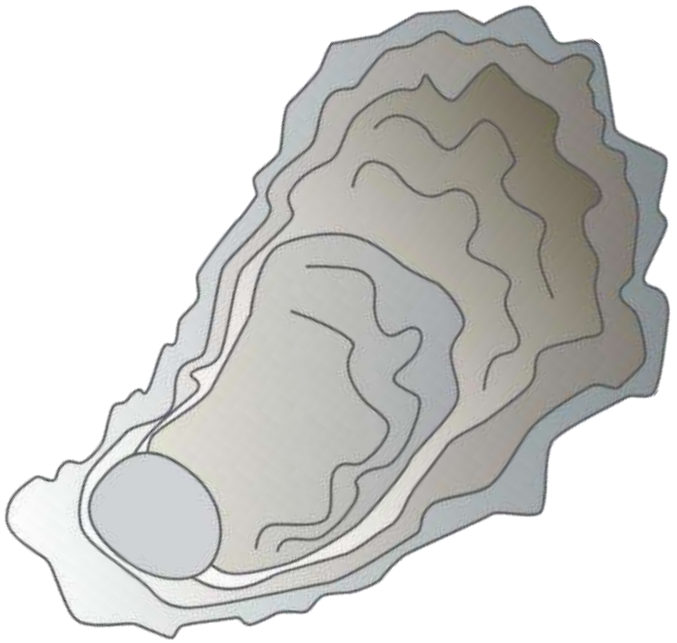
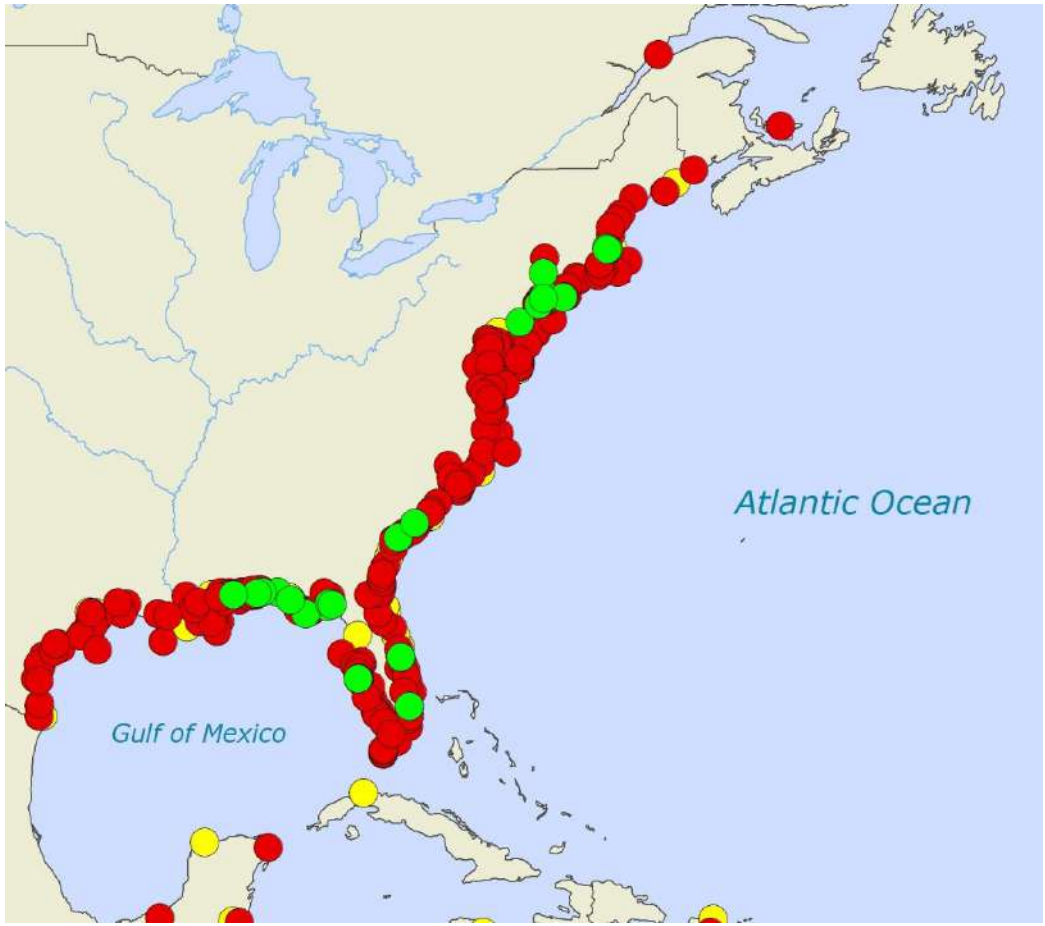
Oyster Farming as a Tool for Removing Excess Nitrogen in Coastal Ecosystems



Nicholas Ray
School of Marine Science & Policy
University of Delaware

CIB STAC Meeting
February 6, 2026

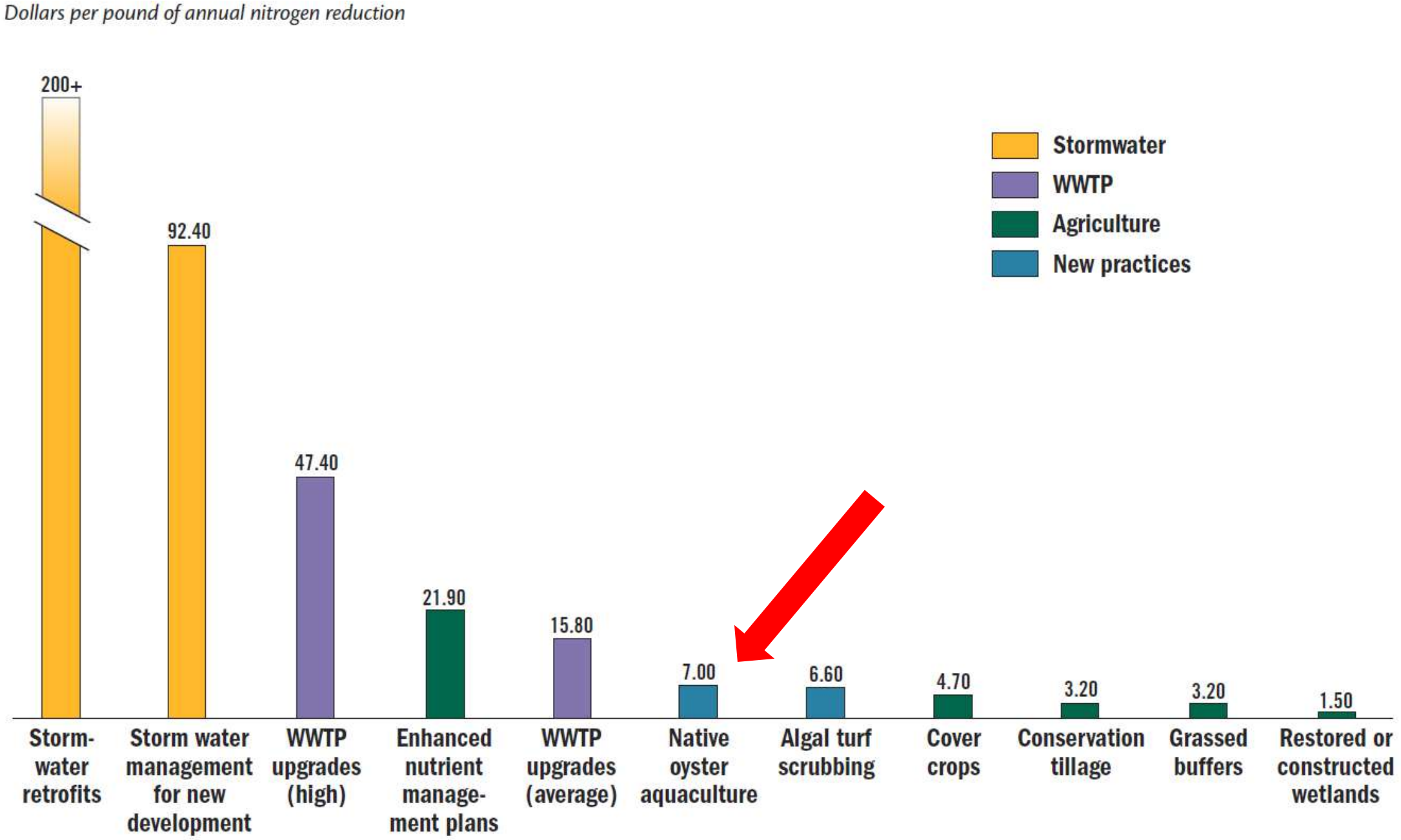
Why Do We Need to Think About This?



CHAPTER	STATUS & TREND	OVERVIEW
WATERSHED CONDITION	Fair; Degrading	Rapid population growth is driving many changes, including significant habitat loss. Conversion of farms and forest to development adds to urban pollution sources and stresses natural habitats. Sea-level rise and shoreline erosion threaten tidal wetlands.
MANAGING NUTRIENT POLLUTION	Fair; No Trend	All major point sources of nutrient pollution have been removed from the Inland Bays. However, nonpoint source inputs of nitrogen pollution remain far above healthy limits in all Bays. Conversion of septic systems to central sewer has surpassed previously set goals, while much work remains to reach goals for agricultural nutrient management practices and stormwater retrofits.
WATER QUALITY	Fair to Poor; No Trend	Nitrogen concentrations in most tributaries are extremely high. Water quality in Little Assawoman Bay continues to improve; however, conditions in the Indian River are degrading. Large summer algal blooms, driven by nutrient pollution, often lead to extended periods of very low dissolved oxygen in bay tributaries and canals.

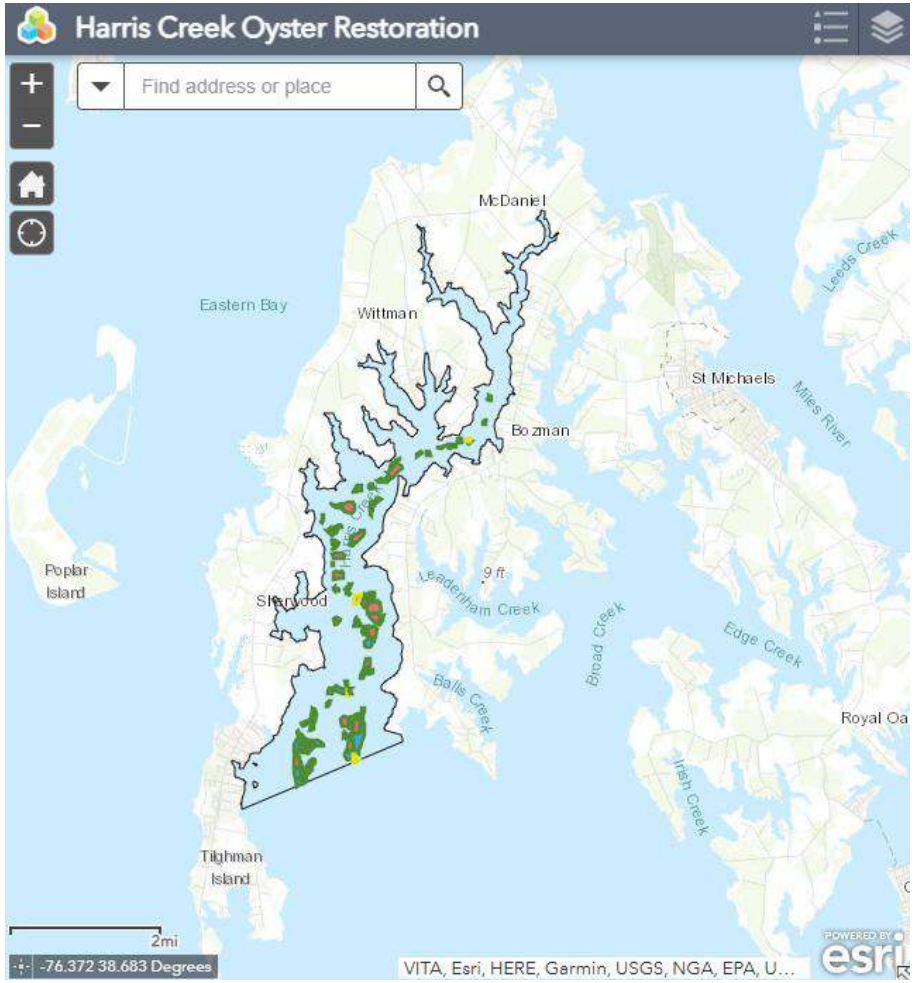
- Eutrophic
- Hypoxic
- Systems in Recovery

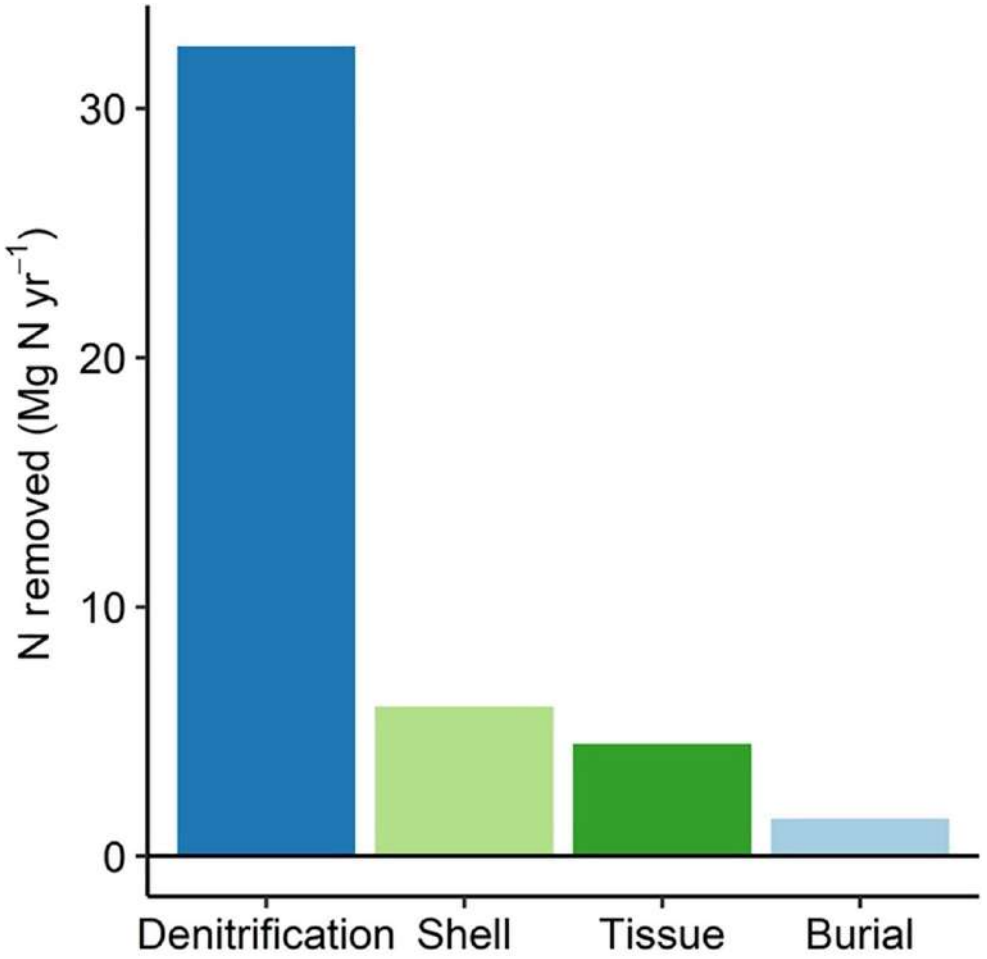
Oysters Offer an “In-System” Remediation Opportunity



Jones et al. (2010) World Resources Institute

Denitrification is Most Important N Removal Mechanism



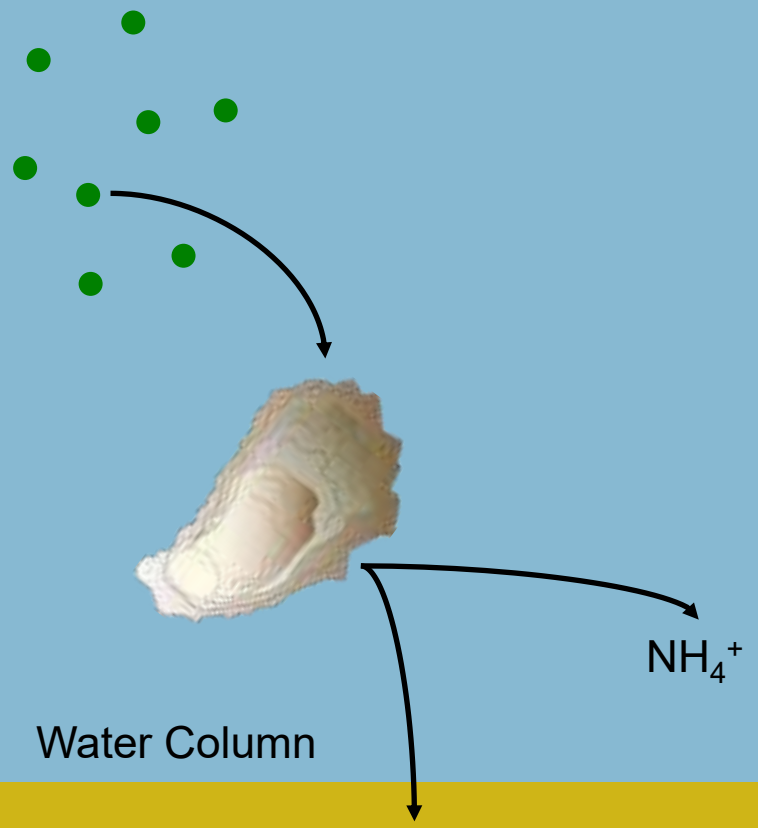


- ~ 2.5 billion spat-on-shell oysters planted (2011-2020)
- 348 acres of reef
- $29 million cost

Oyster-mediated N removal in Harris Creek MD

Kellogg et al. (2018) report to *TNC*

Oysters and Benthic-Pelagic Coupling



Oysters and Benthic-Pelagic Coupling

NH_4^+

Water Column

Organic N

NH_4^+

Oxic Sediment

Organic N

NH_4^+

Anoxic Sediment

Oysters and Benthic-Pelagic Coupling

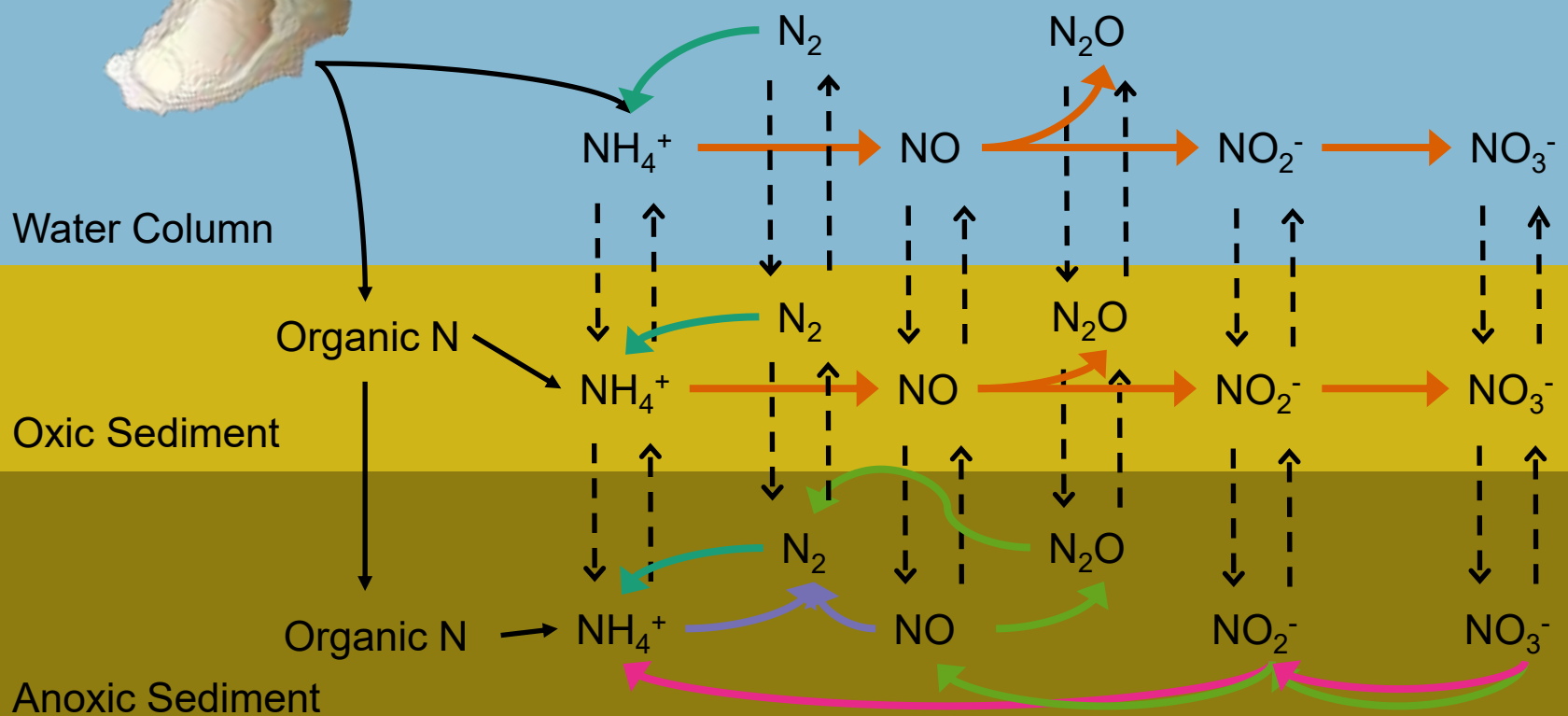
Nitrogen fixation: $N_2 \rightarrow NH_4^+$

Nitrification: $NH_4^+ \rightarrow NO \rightarrow NO_2^- \rightarrow NO_3^-$

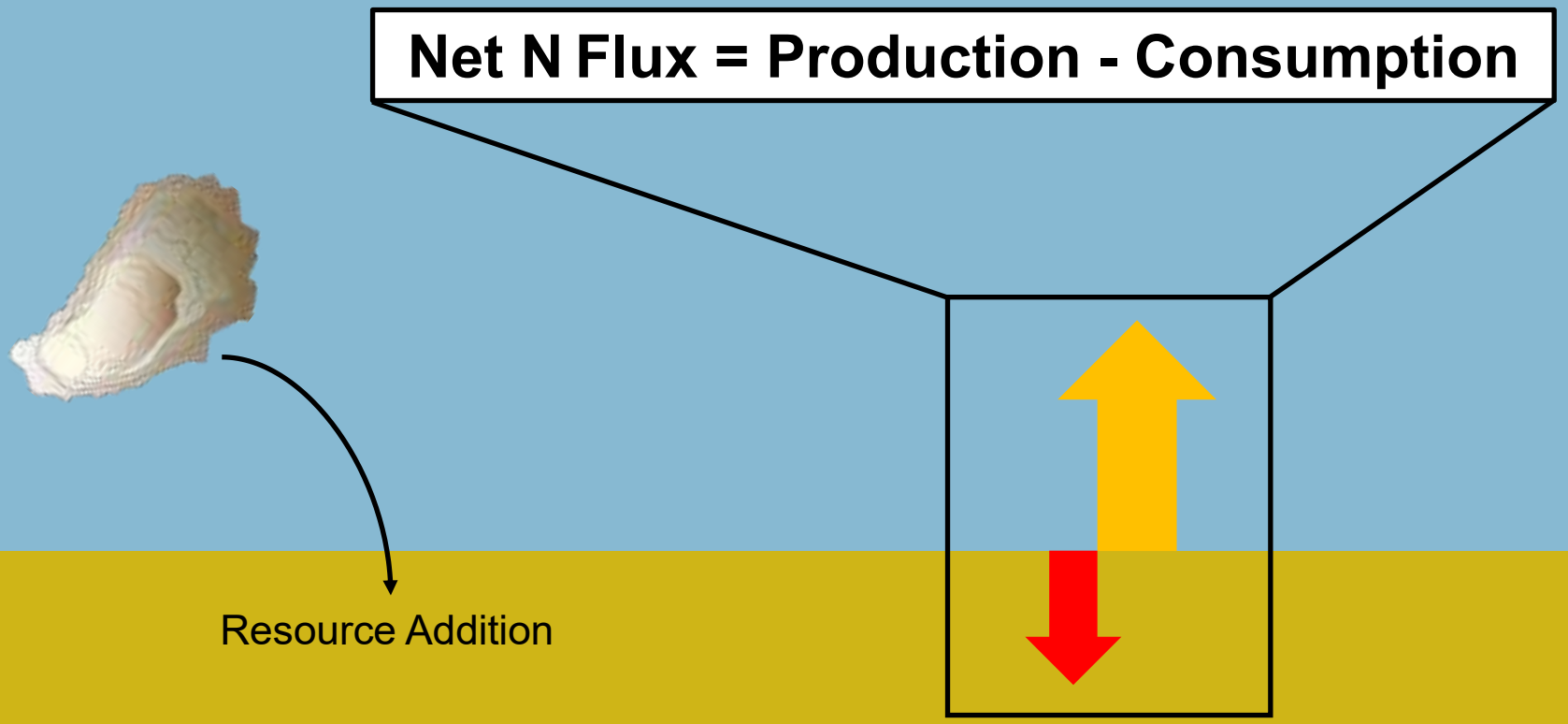
Anammox: $NO_2^- \rightarrow NO + NH_4^+ \rightarrow N_2$

Dissimilatory Nitrate Reduction to Ammonium (DNRA): $NO_3^- \rightarrow NO_2^- \rightarrow NH_4$

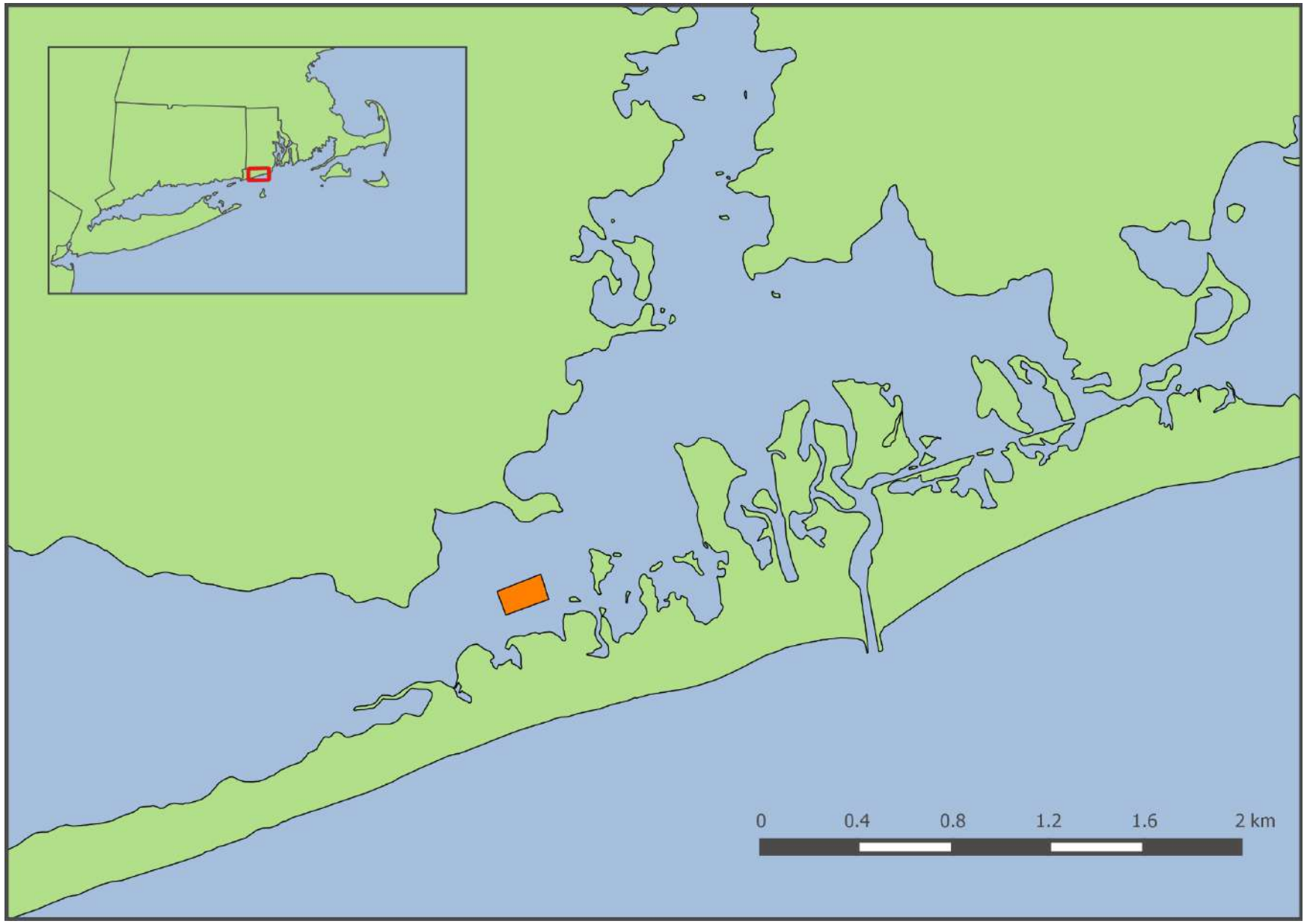
Denitrification: $NO_3^- \rightarrow NO_2^- \rightarrow NO \rightarrow N_2O \rightarrow N_2$



Oysters and Benthic-Pelagic Coupling



How Do We Sample Sediment Denitrification? Example in Ninigret Pond, RI

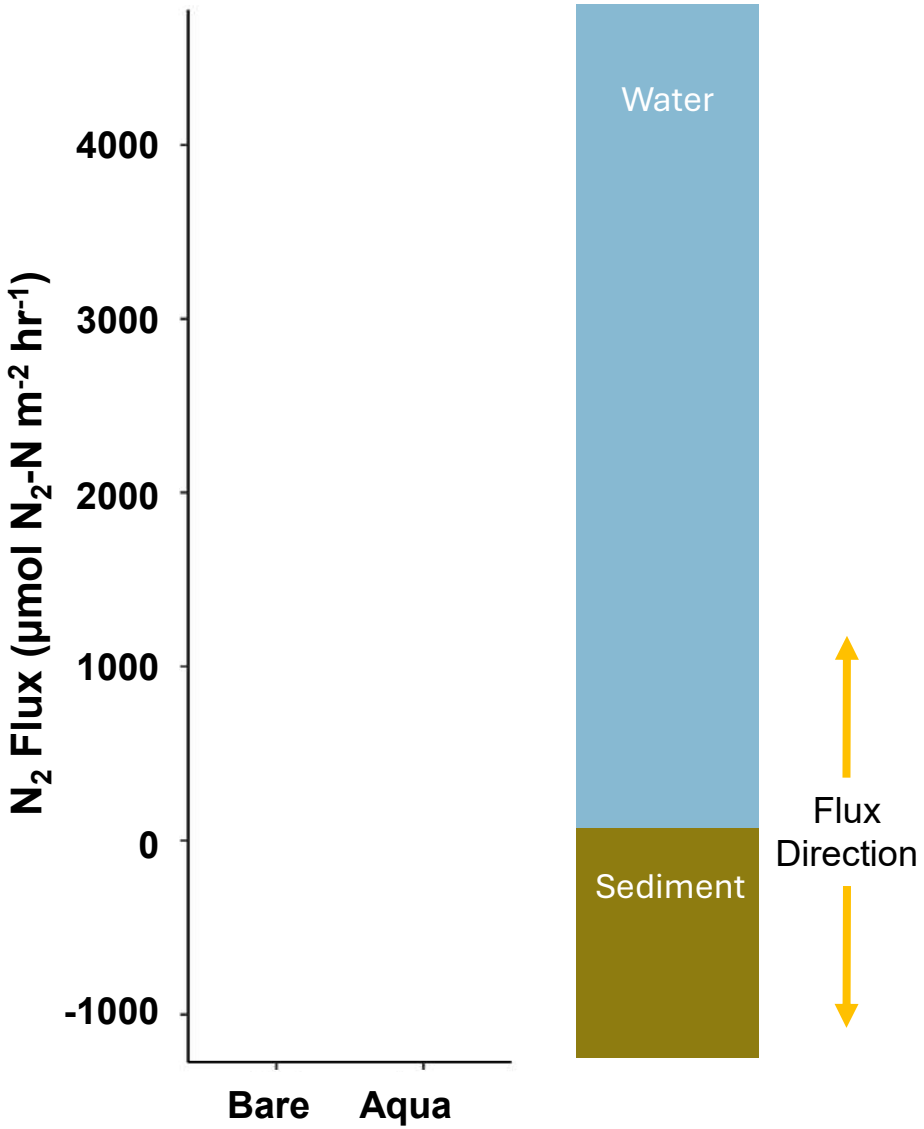


Oyster Farm in Potter Pond; from www.seagrant.gso.uri.edu

These Incubations Can Also be Made by Bringing Sediments to the Lab

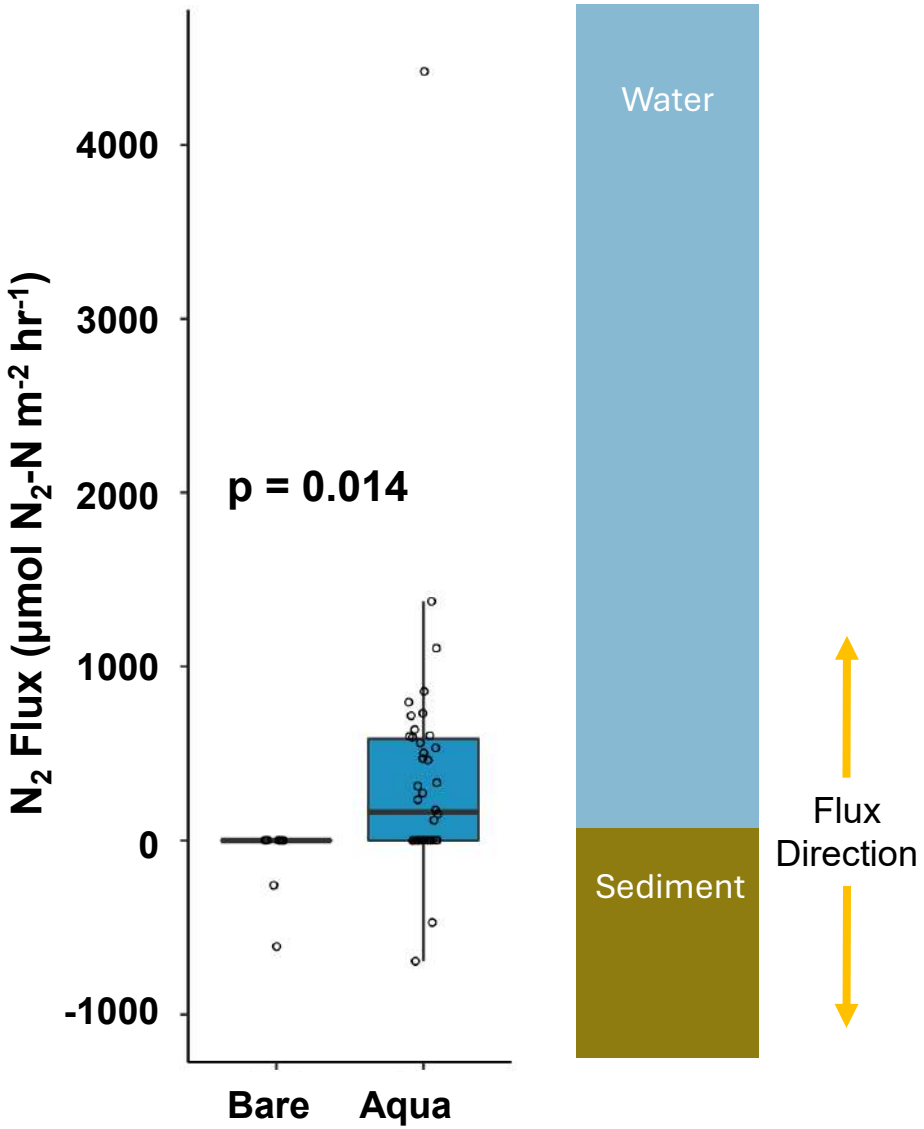
Analyzing the Samples Requires Specialized Equipment

Change in Denitrification Over Time



Ray et al. (2020) *Marine Ecology Progress Series*

Change in Denitrification Over Time



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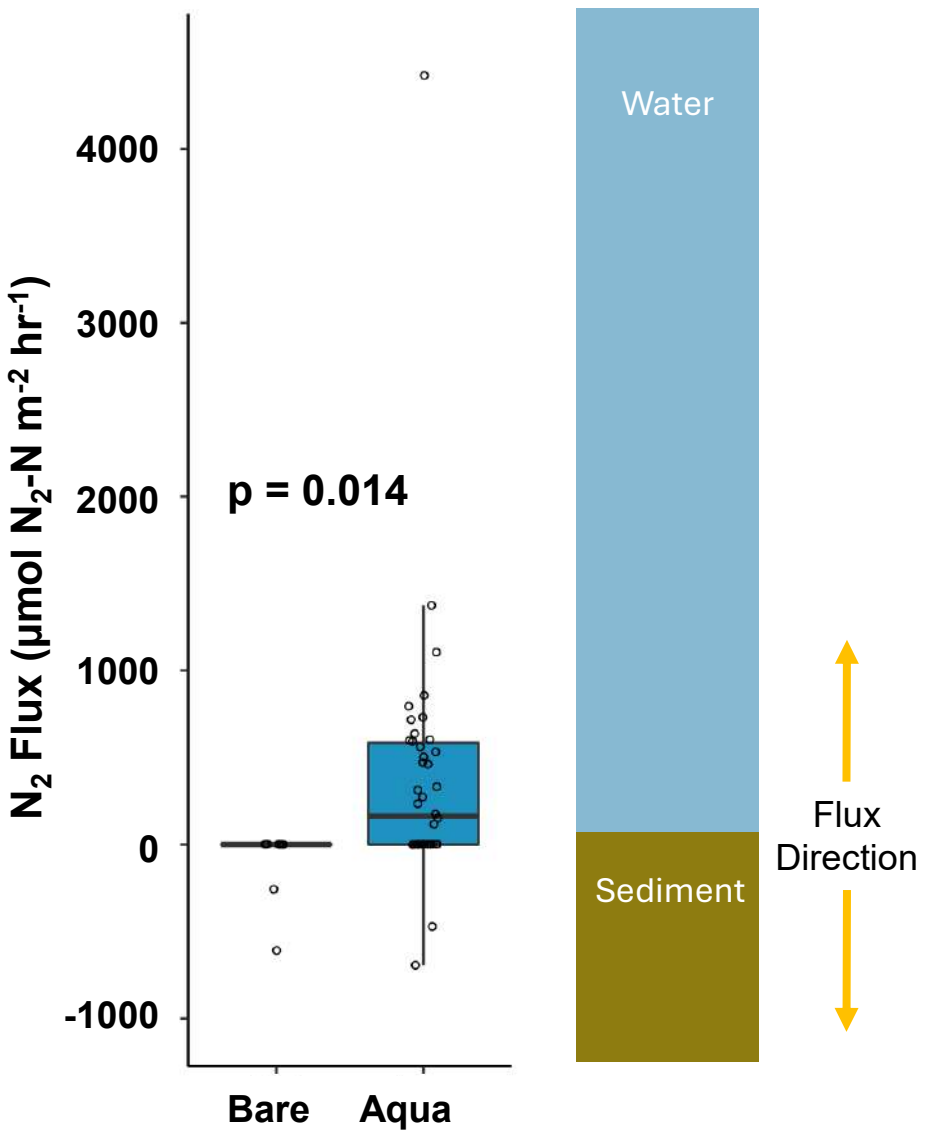
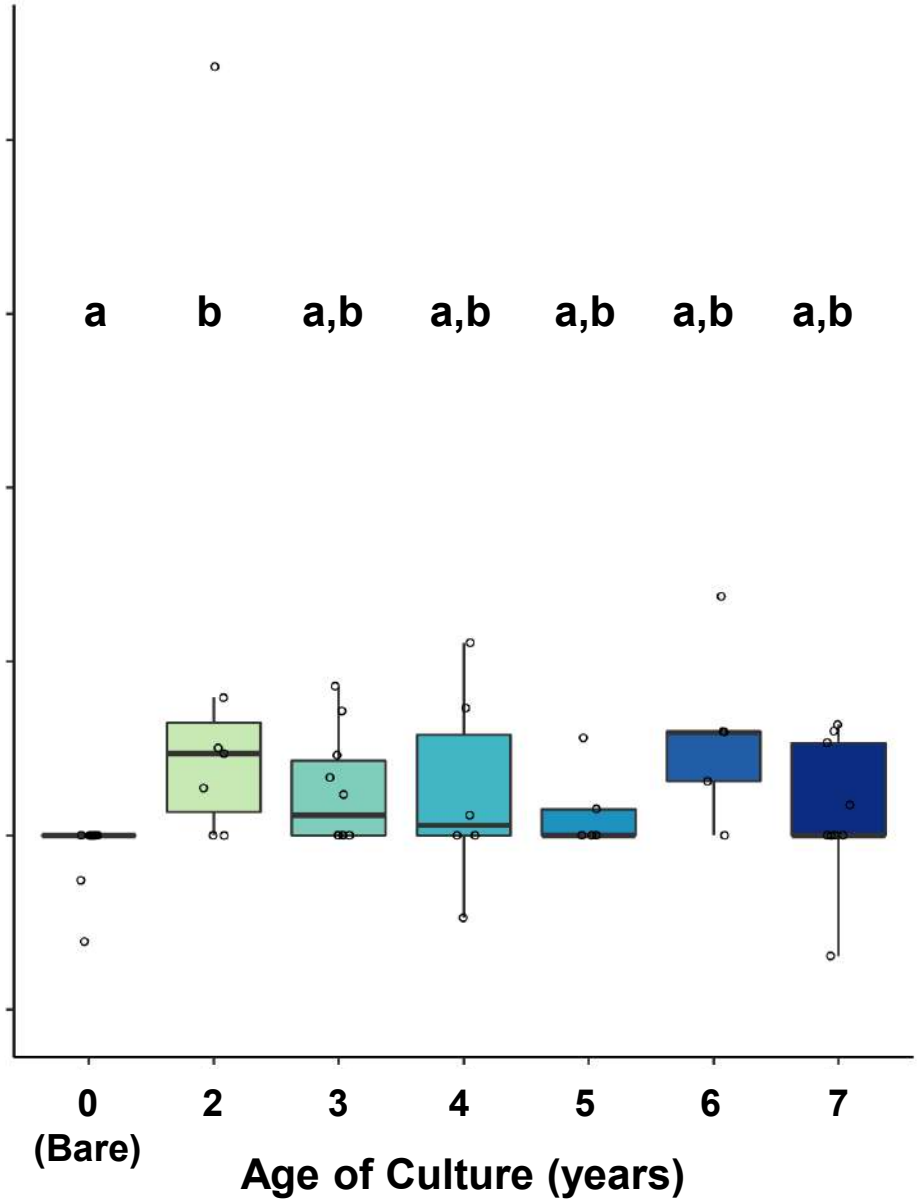
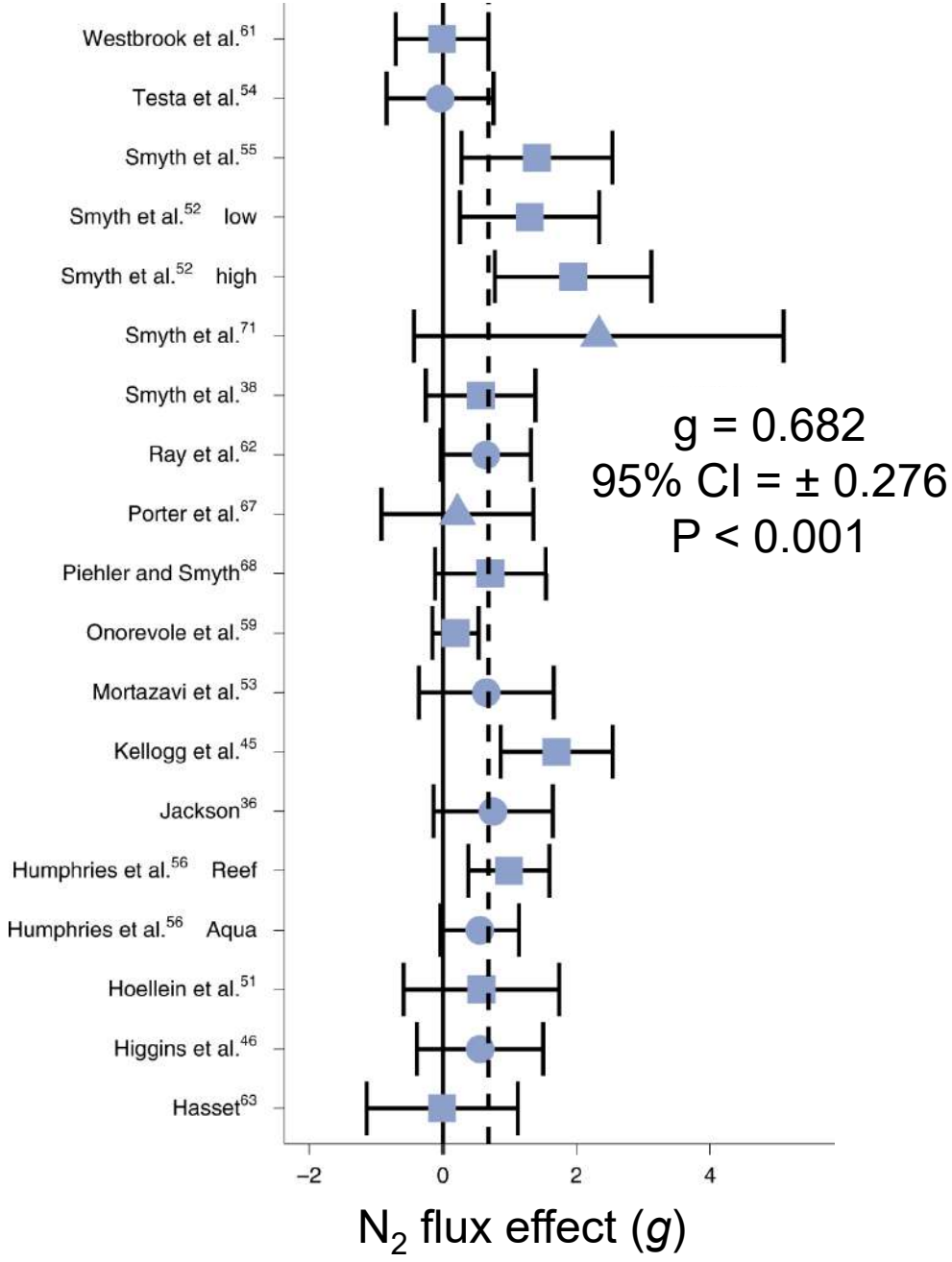




Ray et al. (2020) *Marine Ecology Progress Series*

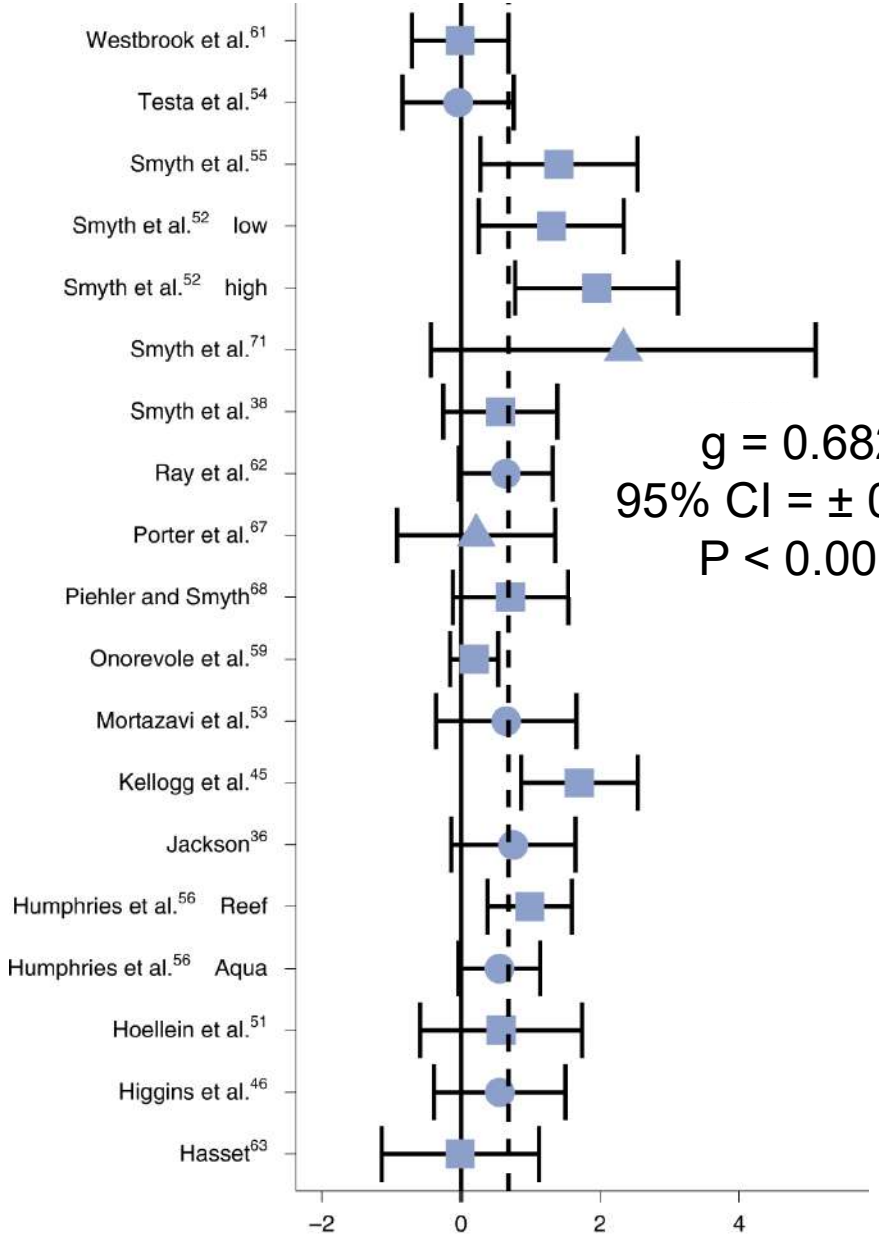
Across Studies, Oysters Clearly Promote Sediment Denitrification – but Variable!



g = 0.682
95% CI = ± 0.276
P < 0.001

Ray & Fulweiler (2021) *Nature Sustainability*

Across Studies, Oysters Clearly Promote Sediment Denitrification – but Variable!



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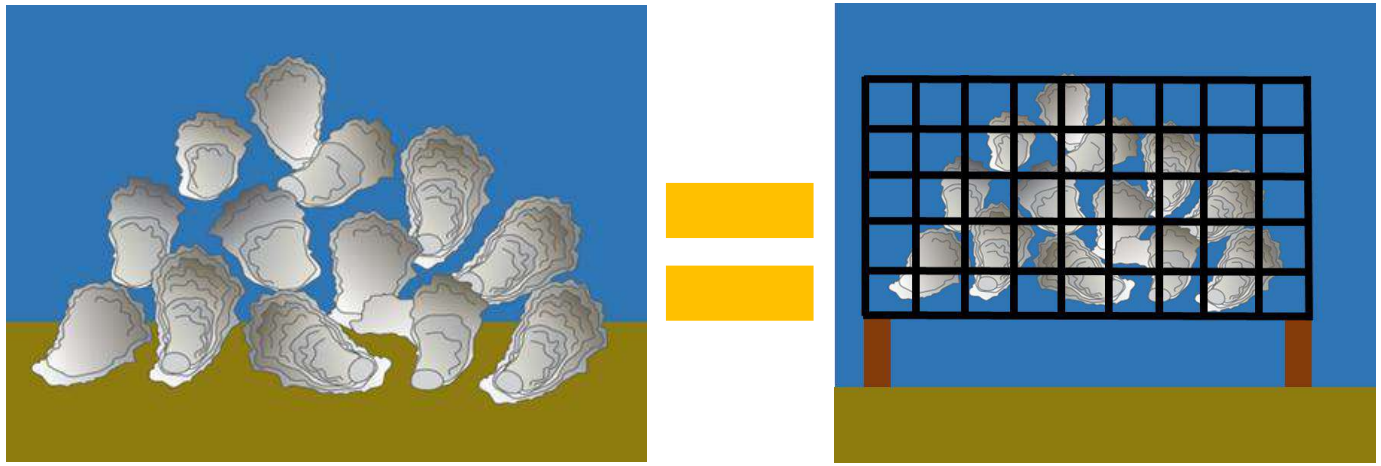

Reefs and aquaculture effect denitrification similarly!

Ray & Fulweiler (2021) *Nature Sustainability*

So Why Aren't We Using Bivalve Aquaculture to Remediate N Pollution?

Westport, MA
June 2016

11. Is there any data on oyster farms and whether or not they are helping?

MassDEP Response: The science regarding nitrogen uptake through aquiculture is very complicated and there is still a lot of research that needs to be done. There are a number of pilot studies going on, including some in Falmouth and Westport. Aquiculture has some promise to assist with nitrogen removal but it cannot address all of the nitrogen entering the estuaries. See MassDEP Response question #34 below in General FAQ's.

34. How about using shellfish to remediate and reduce nitrogen concentrations?

MassDEP Response: The use of shellfish to remediate and reduce nitrogen concentrations is an alternative approach that has been utilized and is being evaluated in some areas of Long Island Sound (LIS), Wellfleet, and Chesapeake Bays. More recently, some Cape communities have been evaluating this method, including Falmouth, Mashpee and Orleans, as well as, the Town of Westport on Buzzards Bay. While this approach has demonstrated promise for reducing nitrogen concentrations, there remain questions regarding the effectiveness and circumstances where it can be successfully utilized. MassDEP recommends communities considering this option discuss such plans with the Department, and evaluate the results from ongoing efforts on the Cape and on other states.

Falmouth, MA
September 2017

So Why Aren't We Using Bivalve Aquaculture to Remediate N Pollution?

Modeling sediment denitrification is challenging!

Adding in oysters makes it even more difficult…

Need to consider:
- Gear type
- Stocking density
- Oyster age
- Background denitrification rate
  - Temperature
  - Salinity
  - Suspended particulates
  - Sediment properties
  - Sediment disturbance
  - The list goes on…

Ecological Applications, 16(6), 2006, pp. 2091–2122

METHODS FOR MEASURING DENITRIFICATION: DIVERSE APPROACHES TO A DIFFICULT PROBLEM

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[7]*Marine Biological Laboratory, The Ecosystems Center, 7 MBL Street, Woods Hole, Massachusetts 02543 USA*
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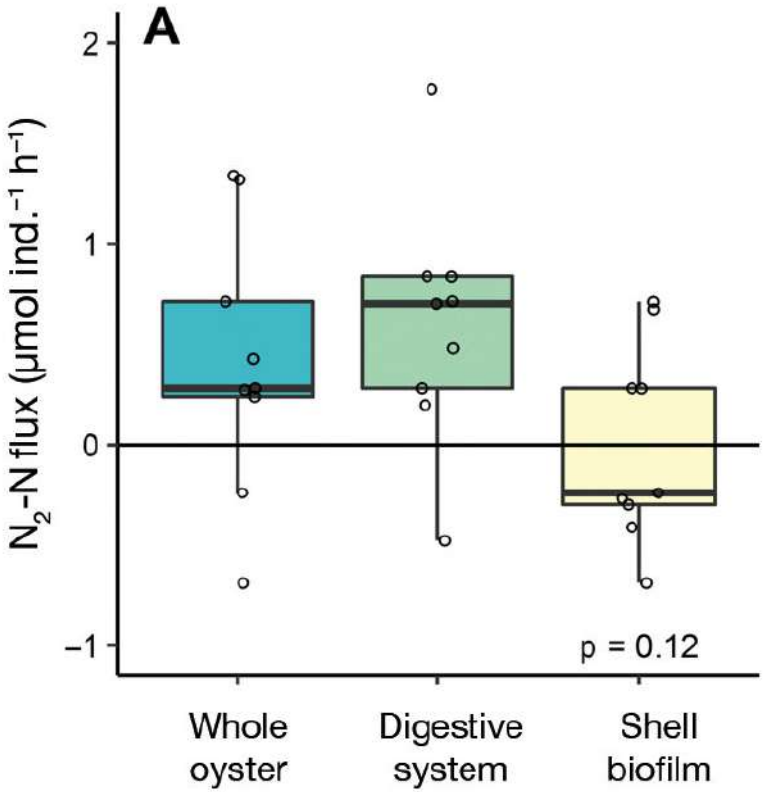
[9]*Department of Microbial Ecology, Institute of Biology, University of Aarhus, Ny Munkegade, Building 540, DK-8000 Aarhus C, Denmark*

There is Also Denitrification in the Oyster Digestive System



Model denitrification by the oyster itself – less challenging…
- Don’t need to account for “background rates”
- Fewer variables to consider
- Should be transferable across locations

Put in proposal to DE SeaGrant in spring 2025
- Good reviews, but not funded
- Main critique was a lack of evidence of need

Ray et al. (2019) *Marine Ecology Progress Series*

Can Oysters Help With N in Coastal Delaware? A Back-of-the-Envelope Guess

How many km^2 of oyster farm to remove all excess N in Rehoboth Bay?

Can Oysters Help With N in Coastal Delaware? A Back-of-the-Envelope Guess

How many km^2 of oyster farm to remove all excess N in Rehoboth Bay? It depends on assumptions

- ***If 2,000 kg excess N → 0.2 km^2 of oyster farm, or 1% of Rehoboth Bay area***
- ***If 252,000 kg excess N → 25 km^2 of oyster farm or the whole area of Rehoboth Bay…***

- ***26 acres leased, 176 acres available (according to DNREC website)***
  - ***Current leased area removing ~1,000 kg N***
  - ***If filled, available leases could remove ~6,800 kg N***

Assumptions about Rehoboth Bay:

- Area: ~21 km^2
- Annual N load 110,000 kg (SEMP Nitrogen Loading Model, 2015) or ~360,000 kg (Volk et al 2006)
- Assume sediment denitrification of ~0.5 mmol N m^{-2} d^{-1} → so ~108,000 kg N removed each year?
- Assume N export is negligible due to long water residence time
- Depending on N load and background denitrification estimates, leaves 2,000-252,000 kg N to deal with…

Assumptions about oysters:

- For oysters, assume N removal of 4.4 mmol ind^{-1} y^{-1} → ~16,000 oysters for 1 kg of N removal
- If an oyster farm has ~150 oysters per m^{-2}, 1 kg N removed by denitrification in the oyster per 100 m^2

These estimates do not consider enhancement of sediment denitrification! Or extraction!
(And also require better N cycling estimates)