Assessing the influence of breakwaters on salt marsh denitrification ecosystem services

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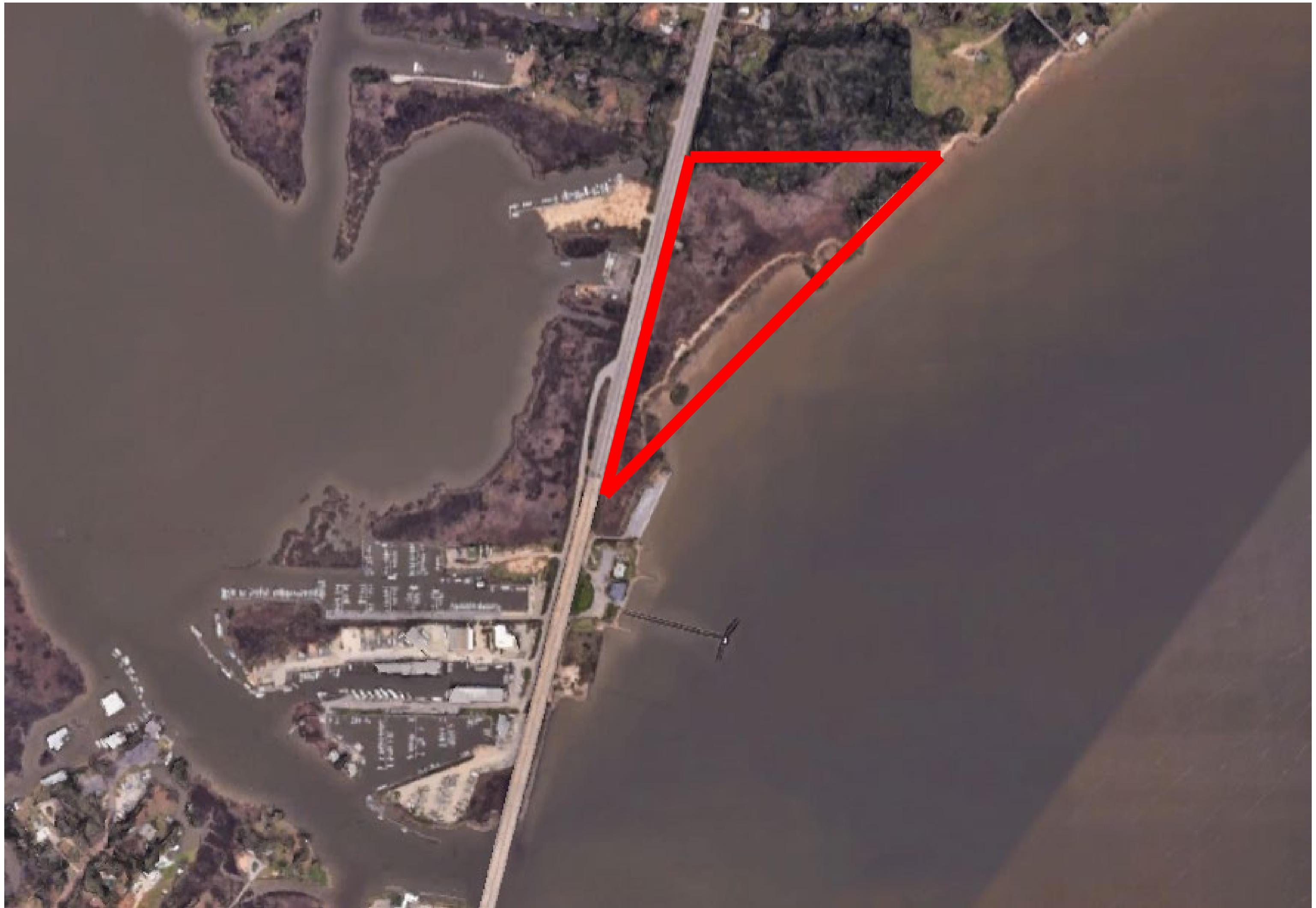
Wetland degradation and loss is occurring rapidly

- Over 50% of coastal wetlands have been lost globally
- Wetlands threatened by multiple natural and anthropogenic stressors
    - Wave energy
    - Land use conversion
    - Eutrophication
    - Decreased sediment
    - Sea level rise
    - Boat wake

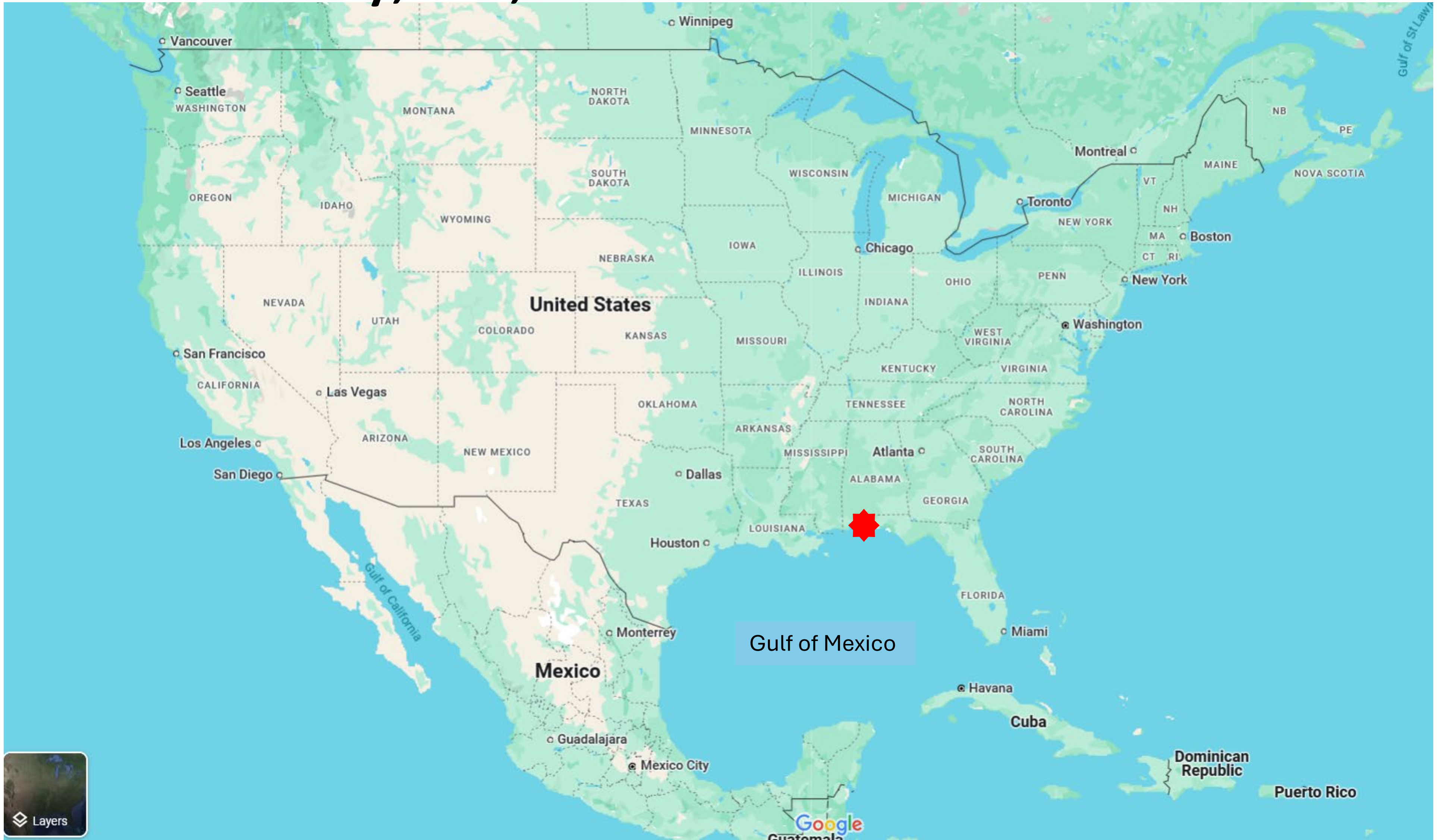
Lotze et al. 2006

Salt marshes prone to “coastal squeeze”



Breakwaters are increasingly used for marsh protection

Breakwaters are being implemented throughout Mobile Bay, AL, to decrease marsh erosion



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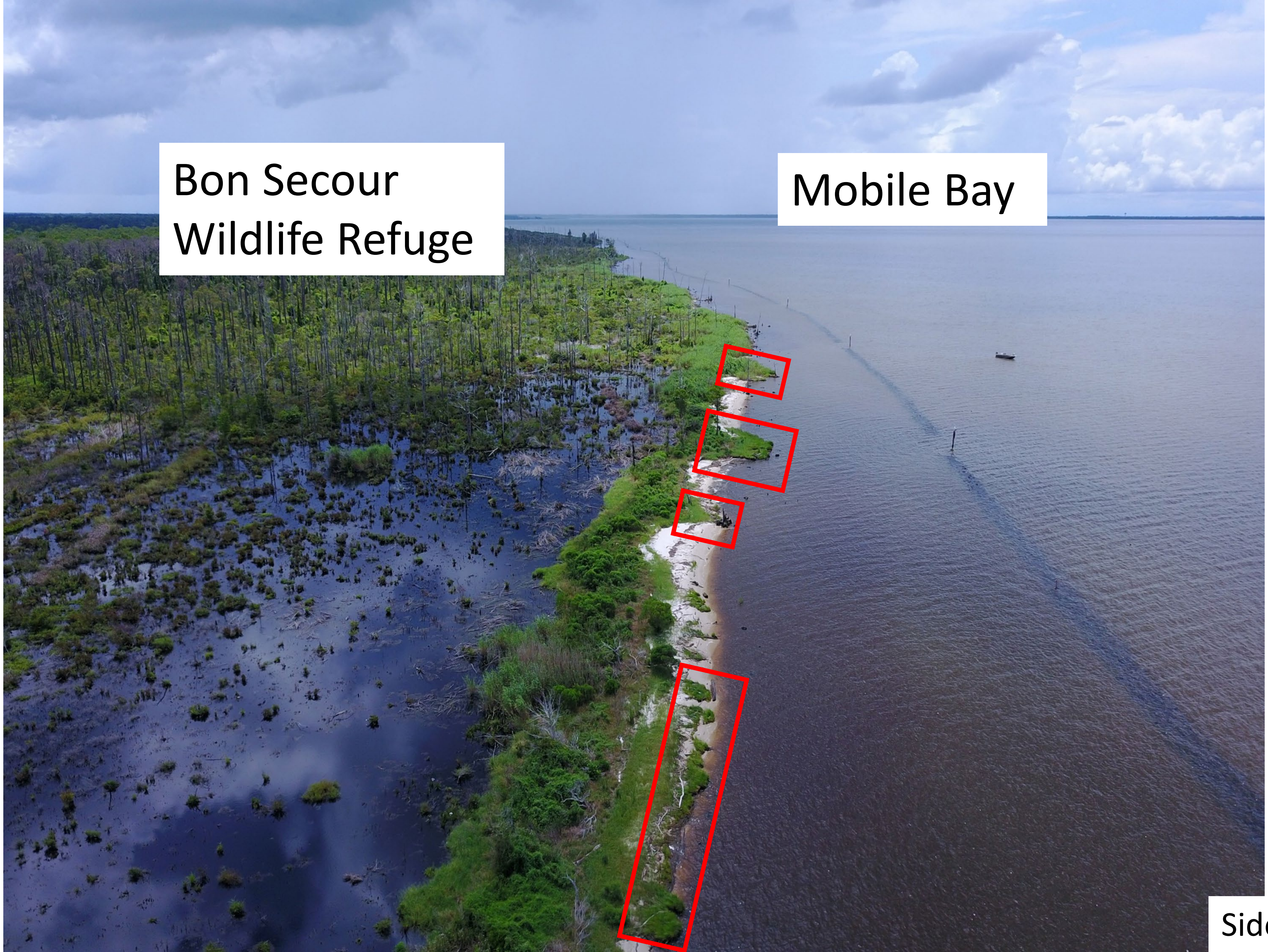
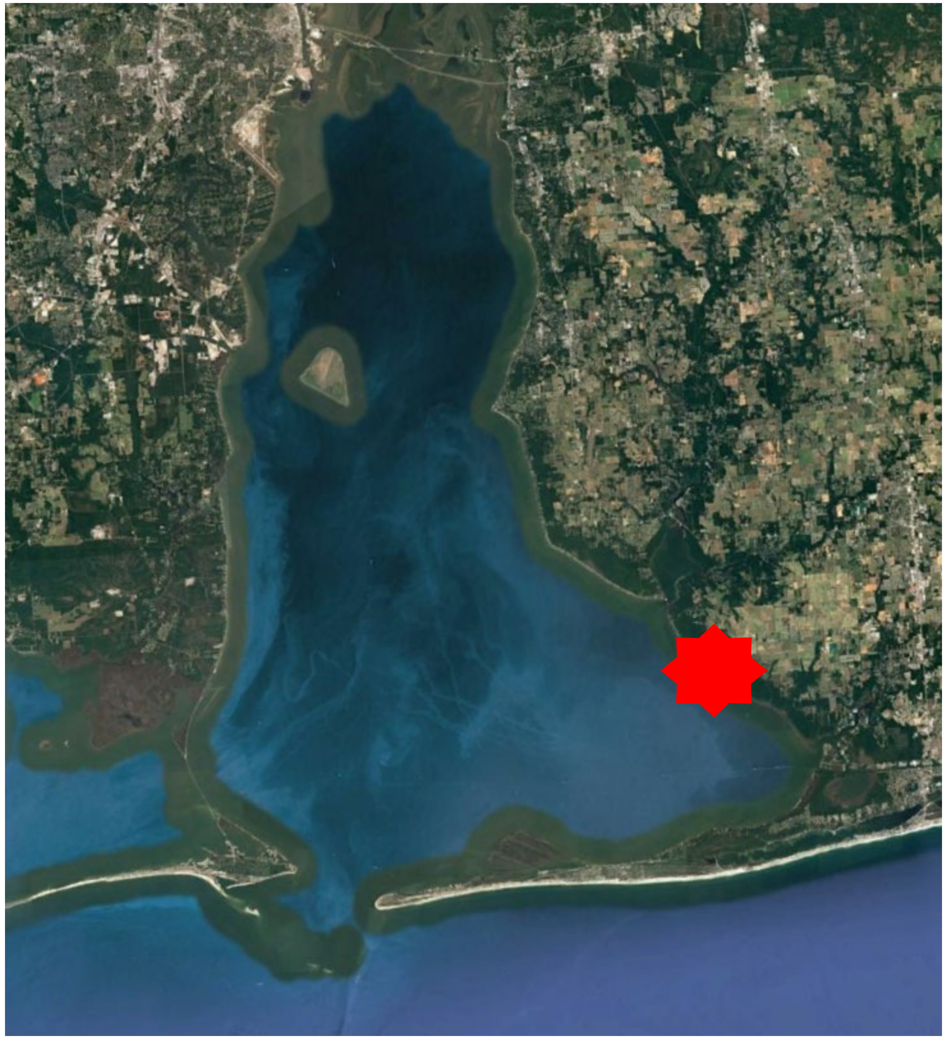
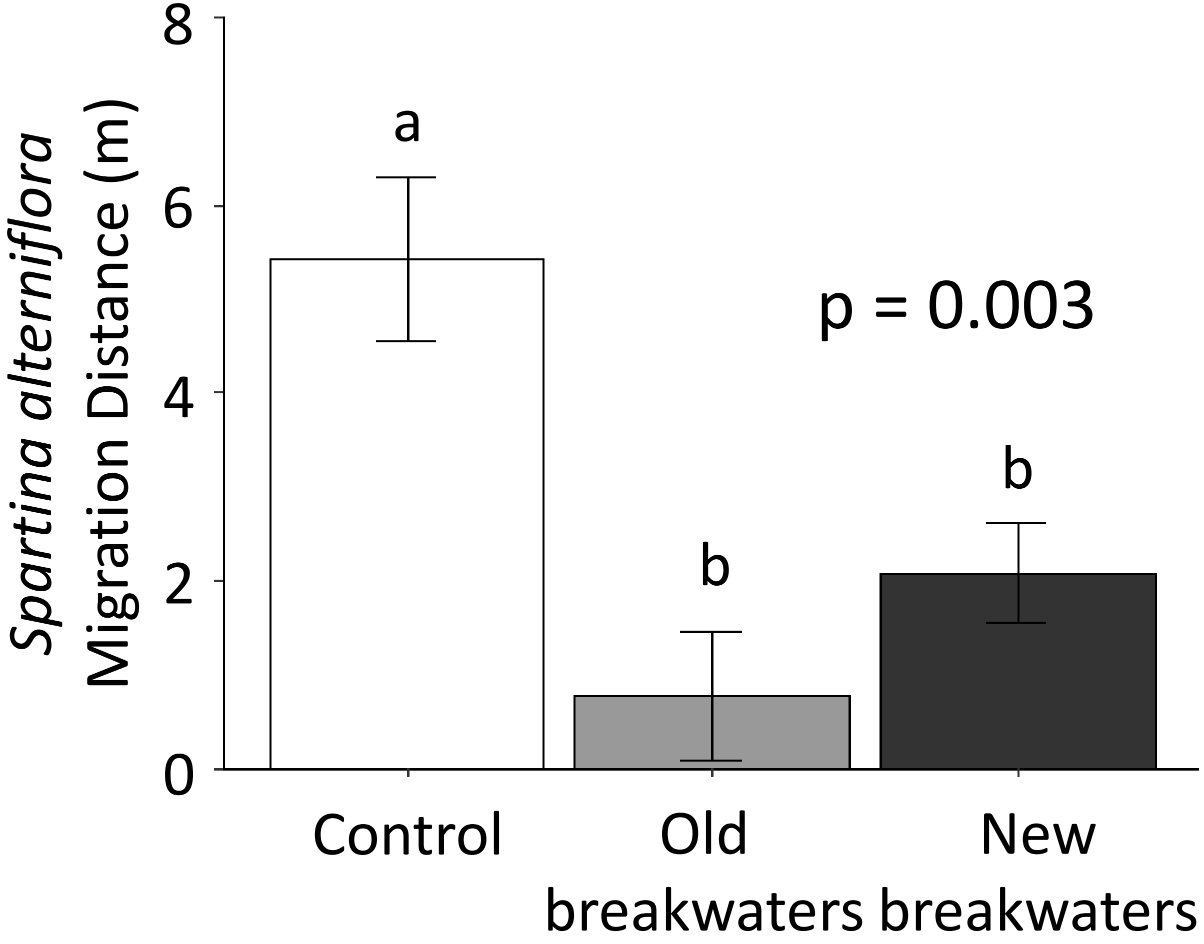


Siders et al. 2025

Some evidence that breakwaters decrease erosion relative to control sites





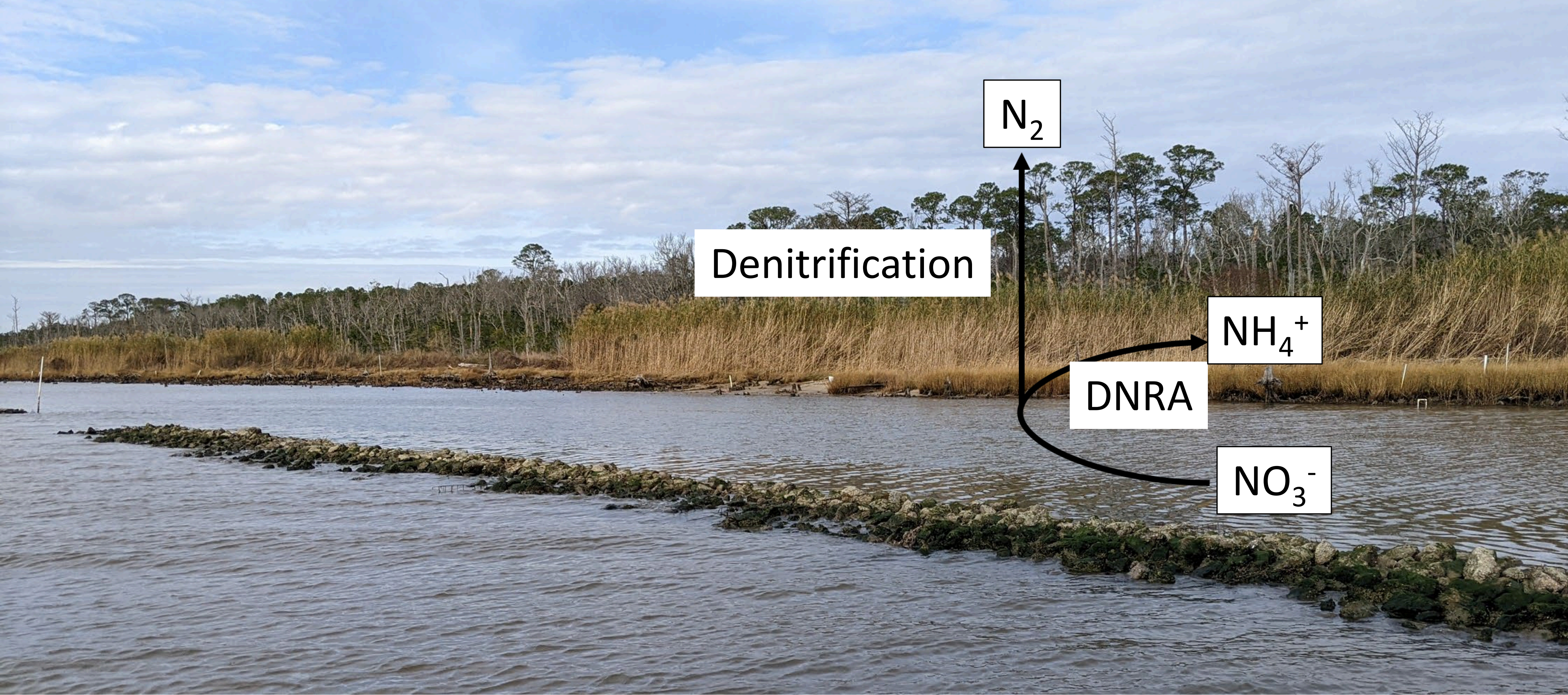
Siders et al. 2025

Breakwaters may affect physical and biological environment

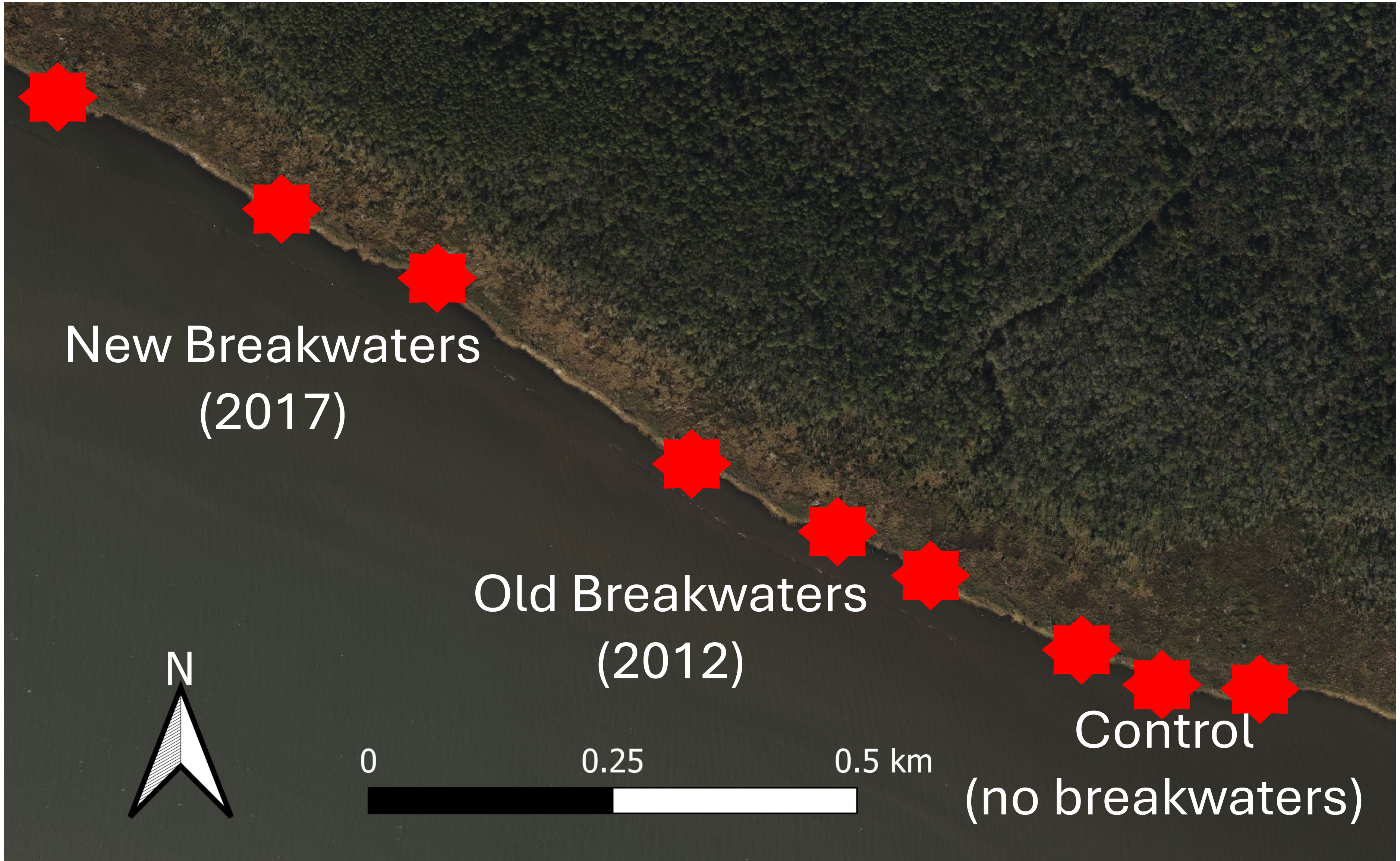
- Sediment size
- Dissolved oxygen availability
- Hydrogen sulfide concentrations
- Vegetation distribution

Any changes in these factors has the potential to affect ecosystem services, such as NO_3^- removal via denitrification

How do breakwaters affect salt marsh potential nitrate reduction rates?

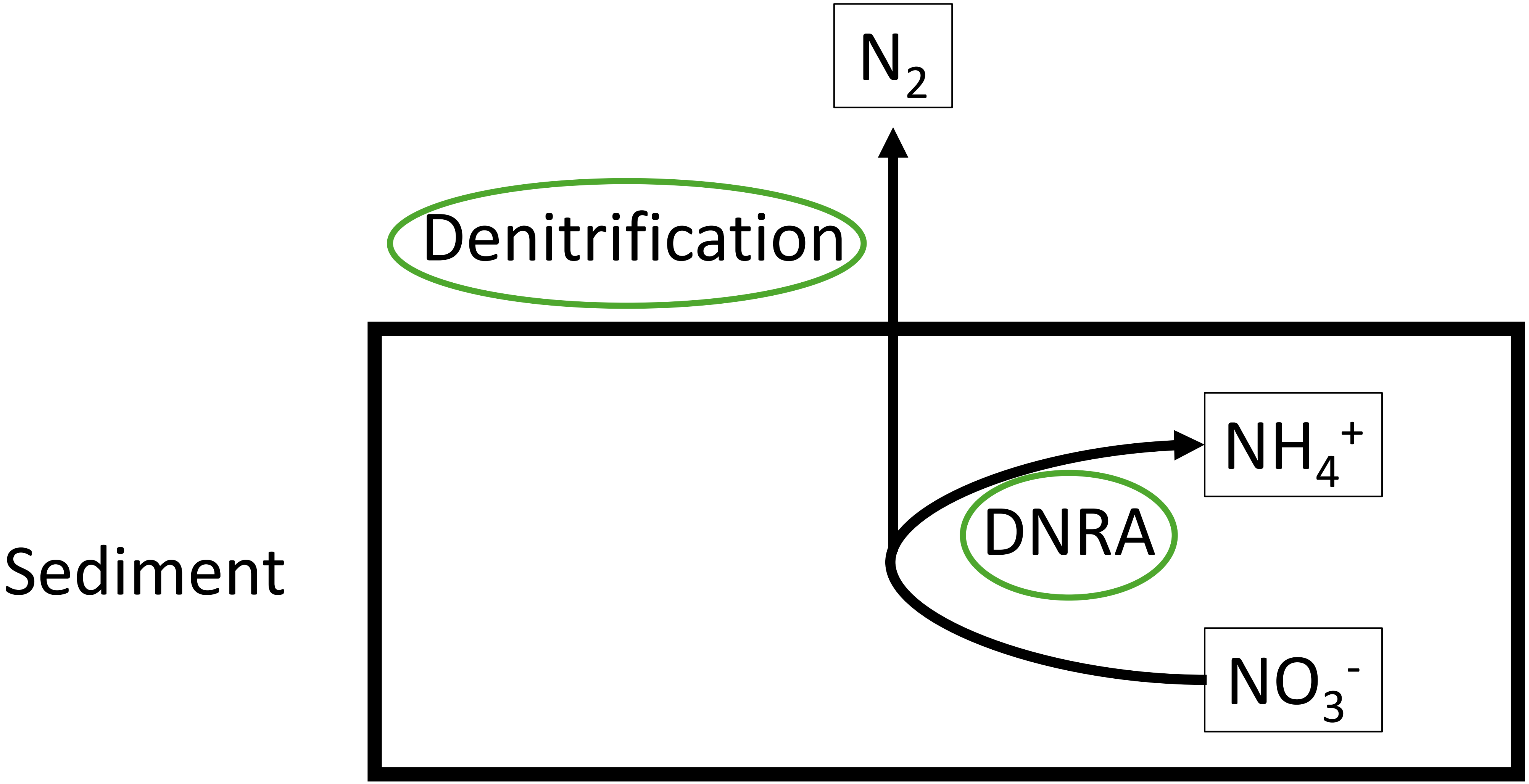


Collected sediment cores in control and breakwater marshes

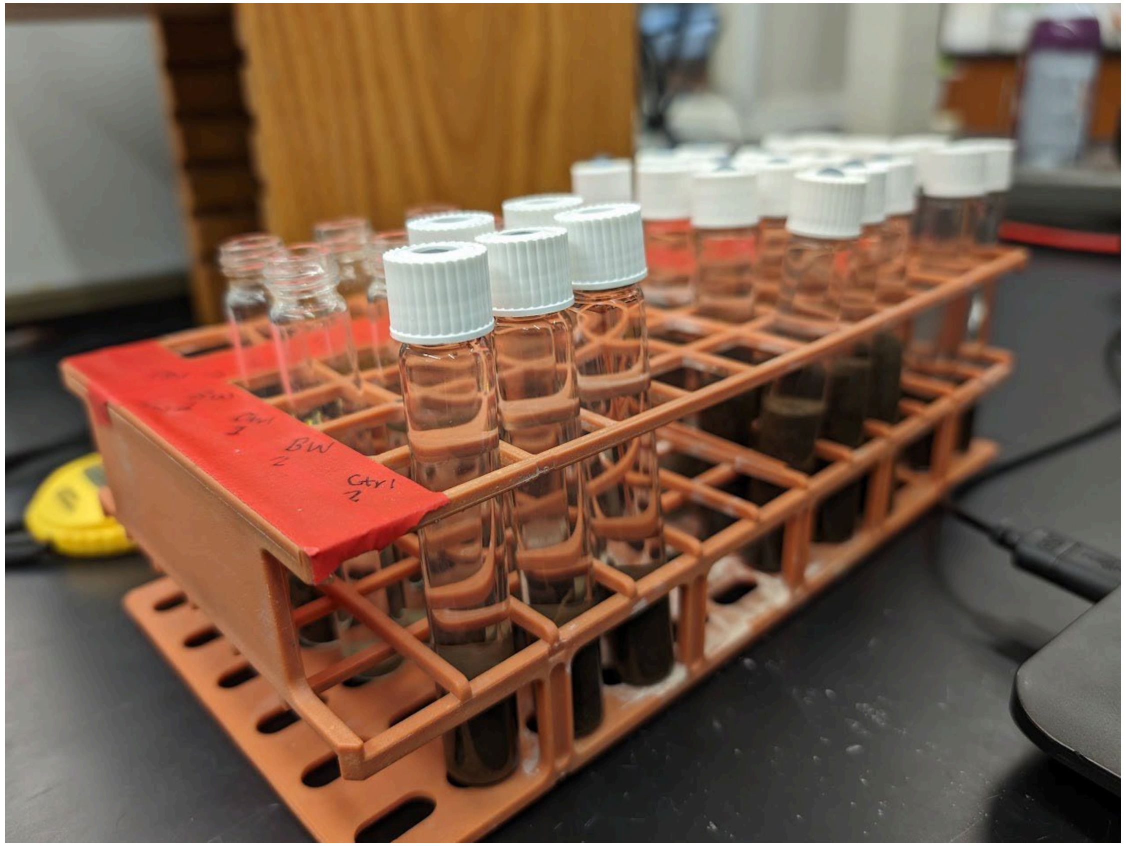


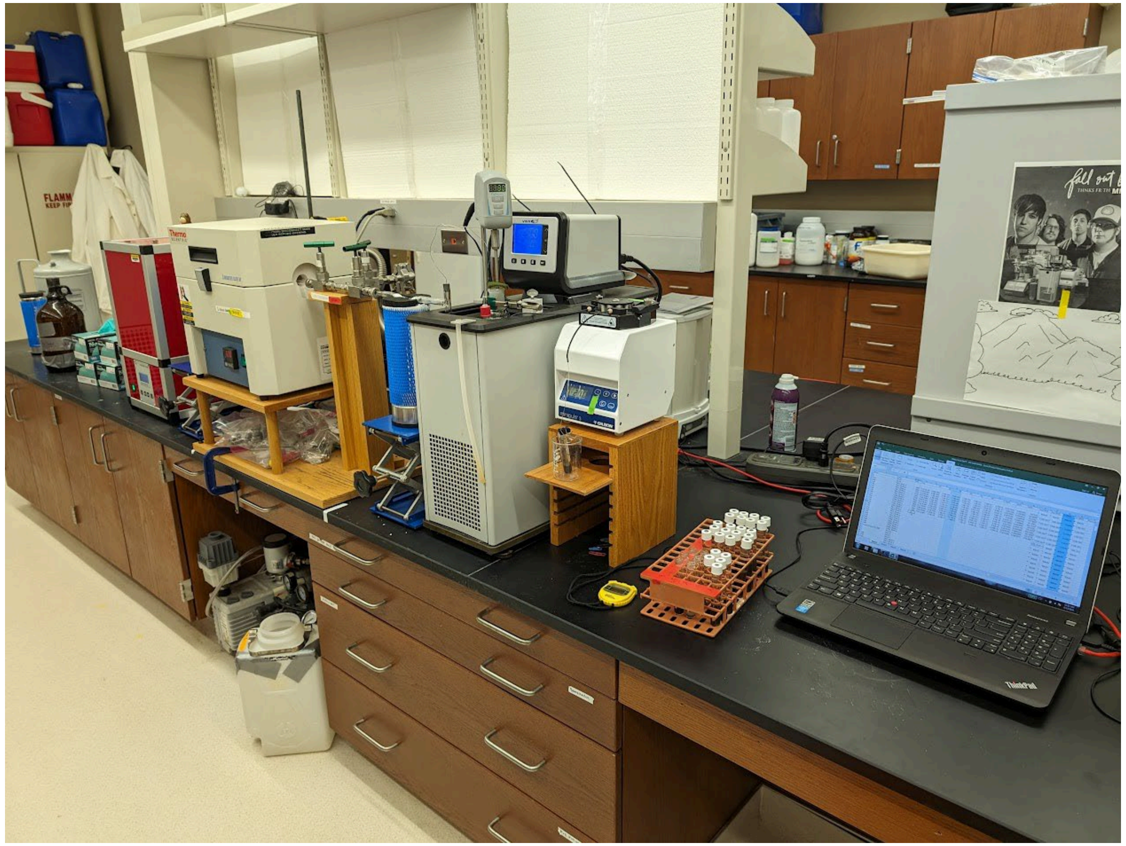
Collected sediment cores in both marsh and unvegetated mudflat

Measured rates of denitrification and DNRA



Measured potential denitrification and DNRA using isotope pairing technique





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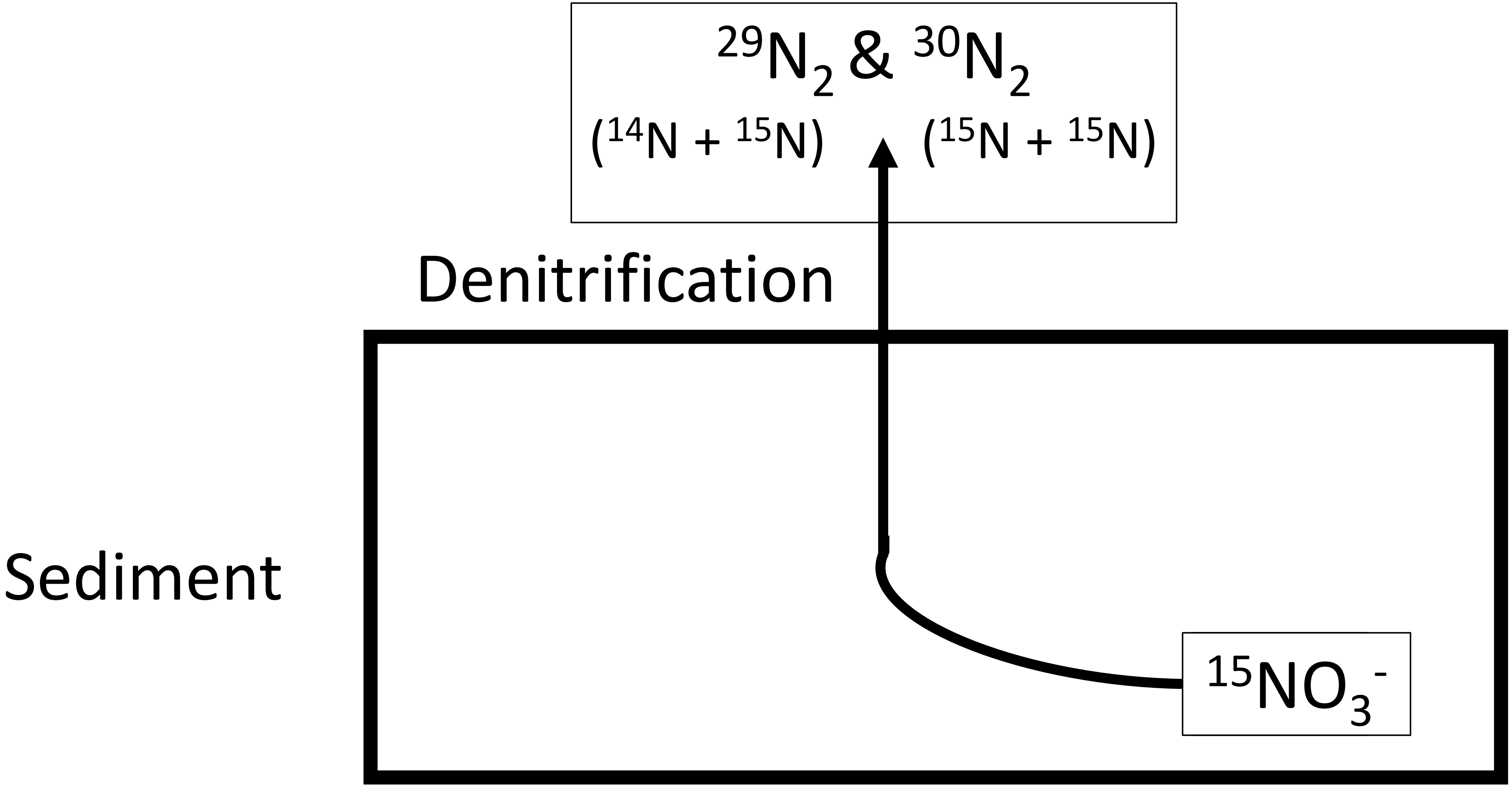

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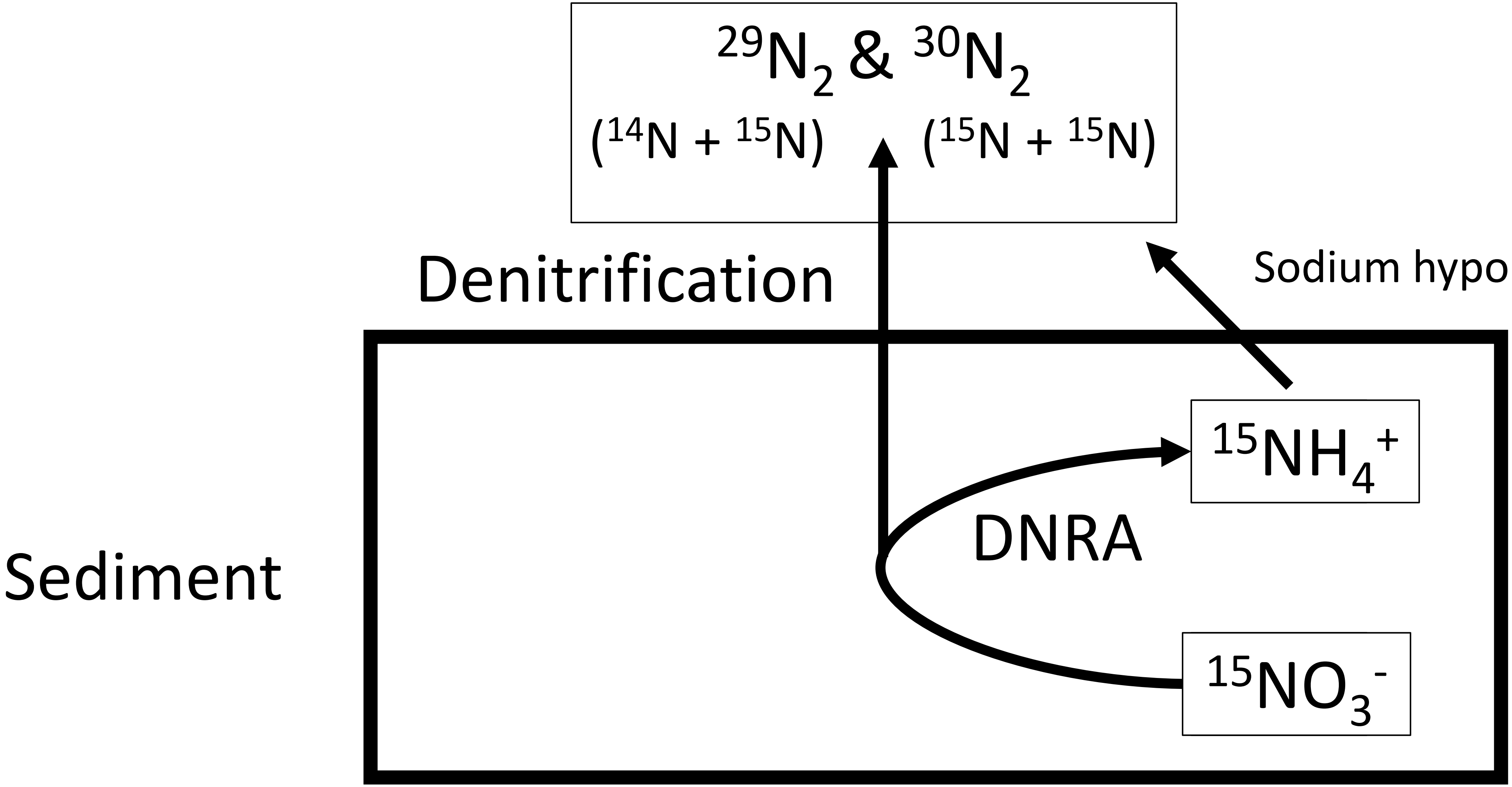


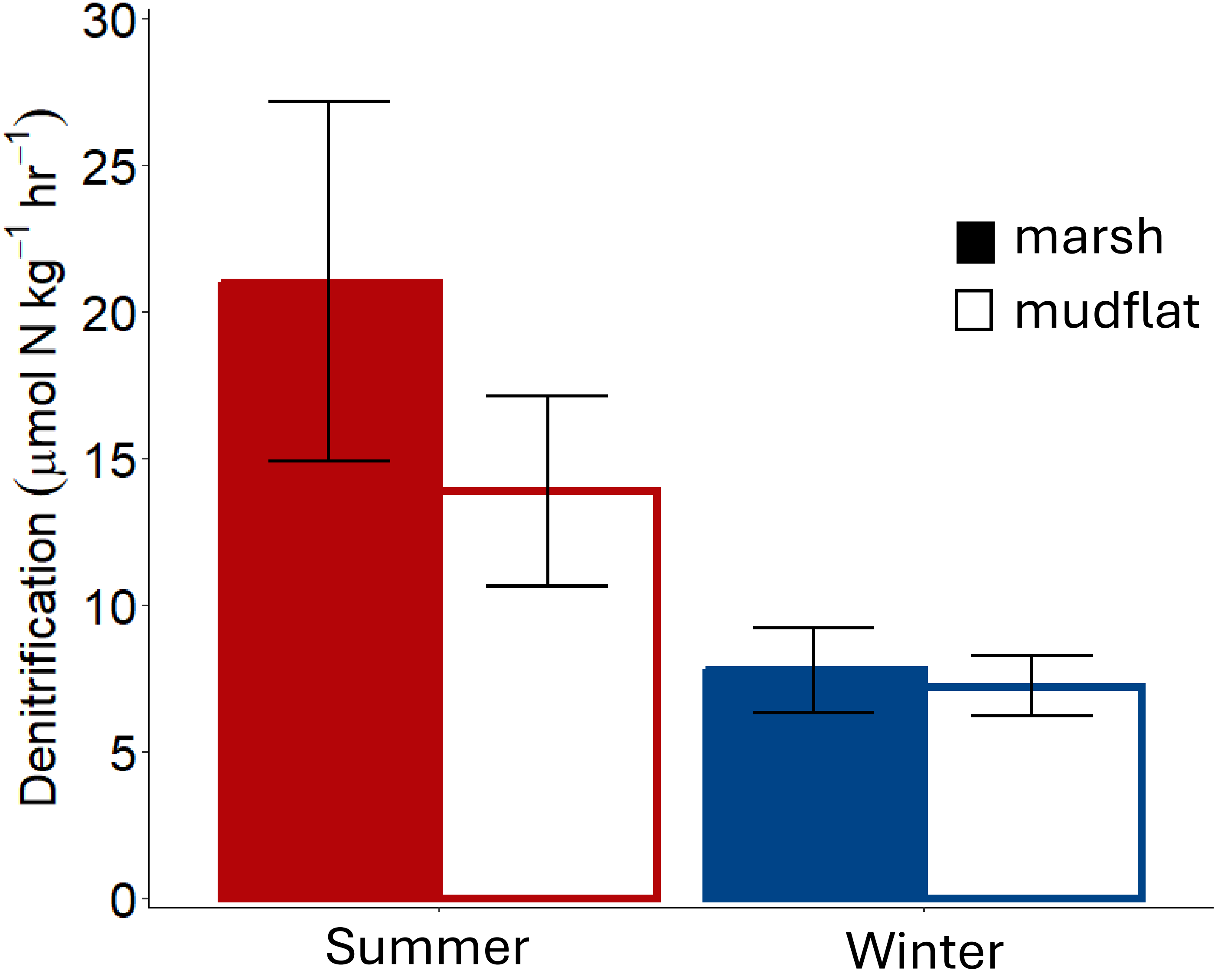
Calculate balance between nutrient removal vs retention

$$\text{\% of total } NO_3^- \text{ reduction attributed to denitrification} = \frac{\text{Denitrification}}{\text{Denitrification + DNRA}} \times 100$$

Compared differences in denitrification and DNRA rates using a 3-factor ANOVA

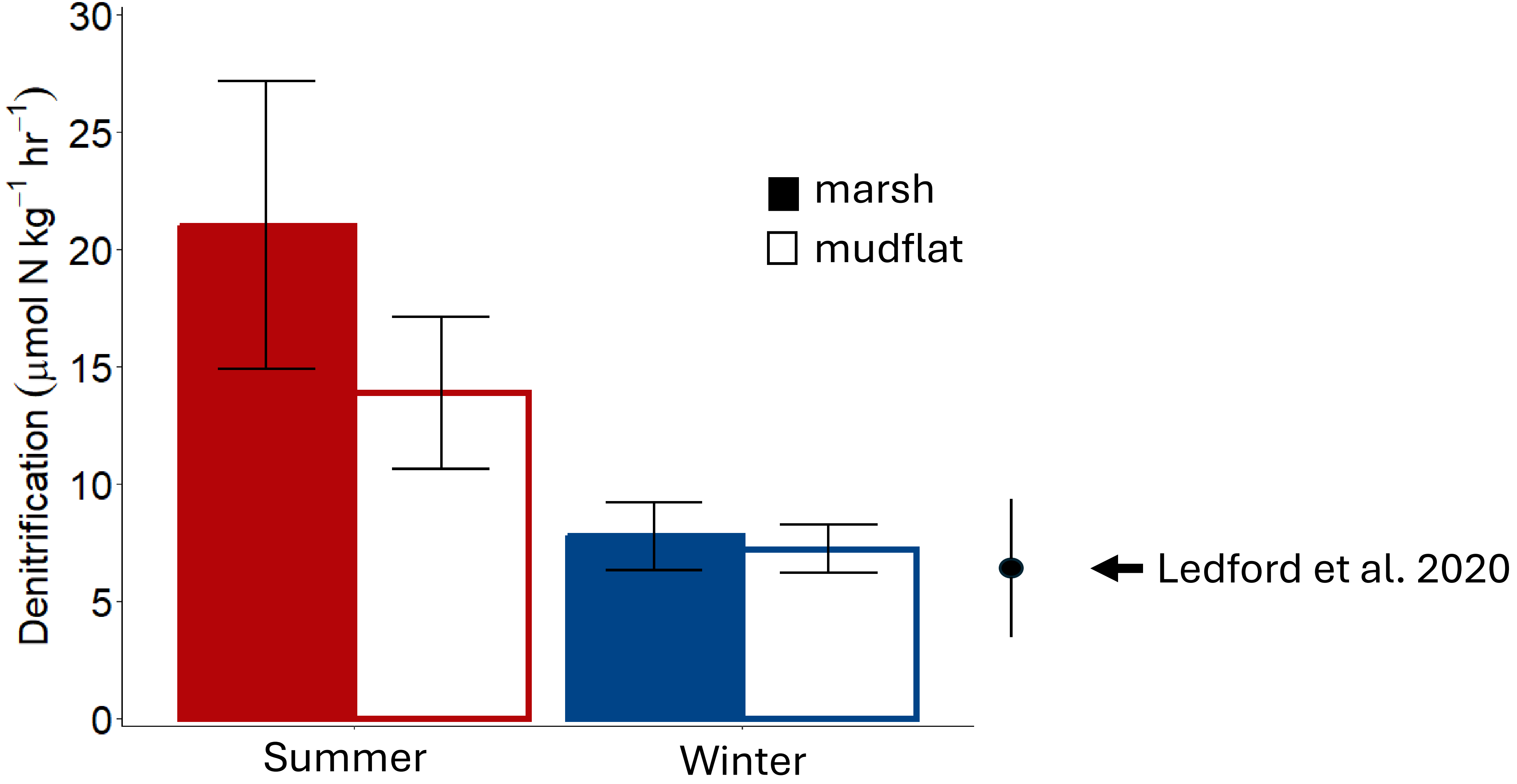
- Season
  - Summer
  - Winter
- Site
  - Control
  - Old Breakwaters (2012)
  - New Breakwaters (2017)
- Zone
  - Marsh
  - Mudflat

No differences in denitrification for any measured factor

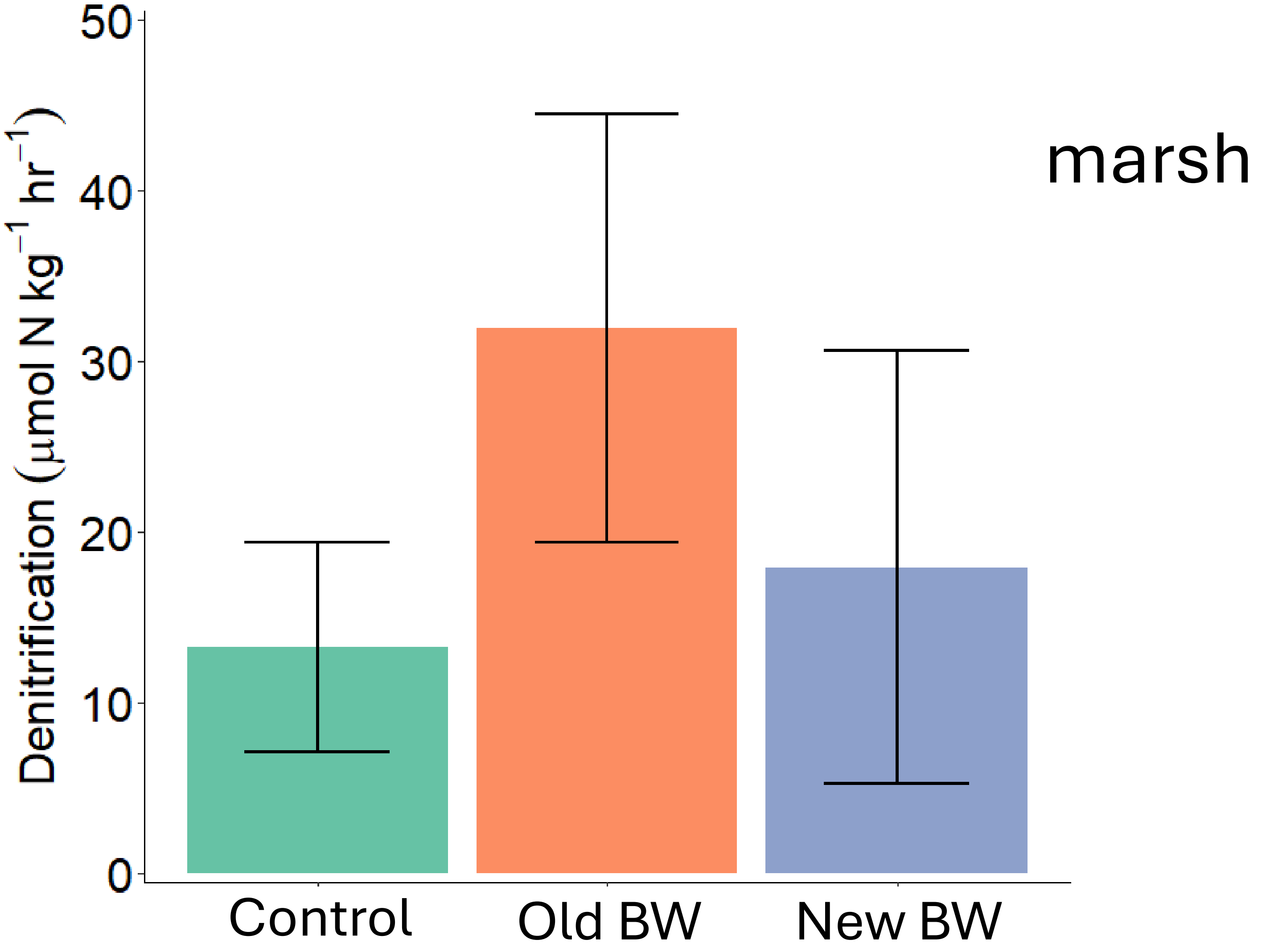


Site: $p = 0.15$
Zone: $p = 0.71$
Season: $p = 0.11$
Site * Zone: $p = 0.73$
Site * Season: $p = 0.89$
Zone * Season: $p = 0.71$
Site * Zone * Season: $p = 0.45$

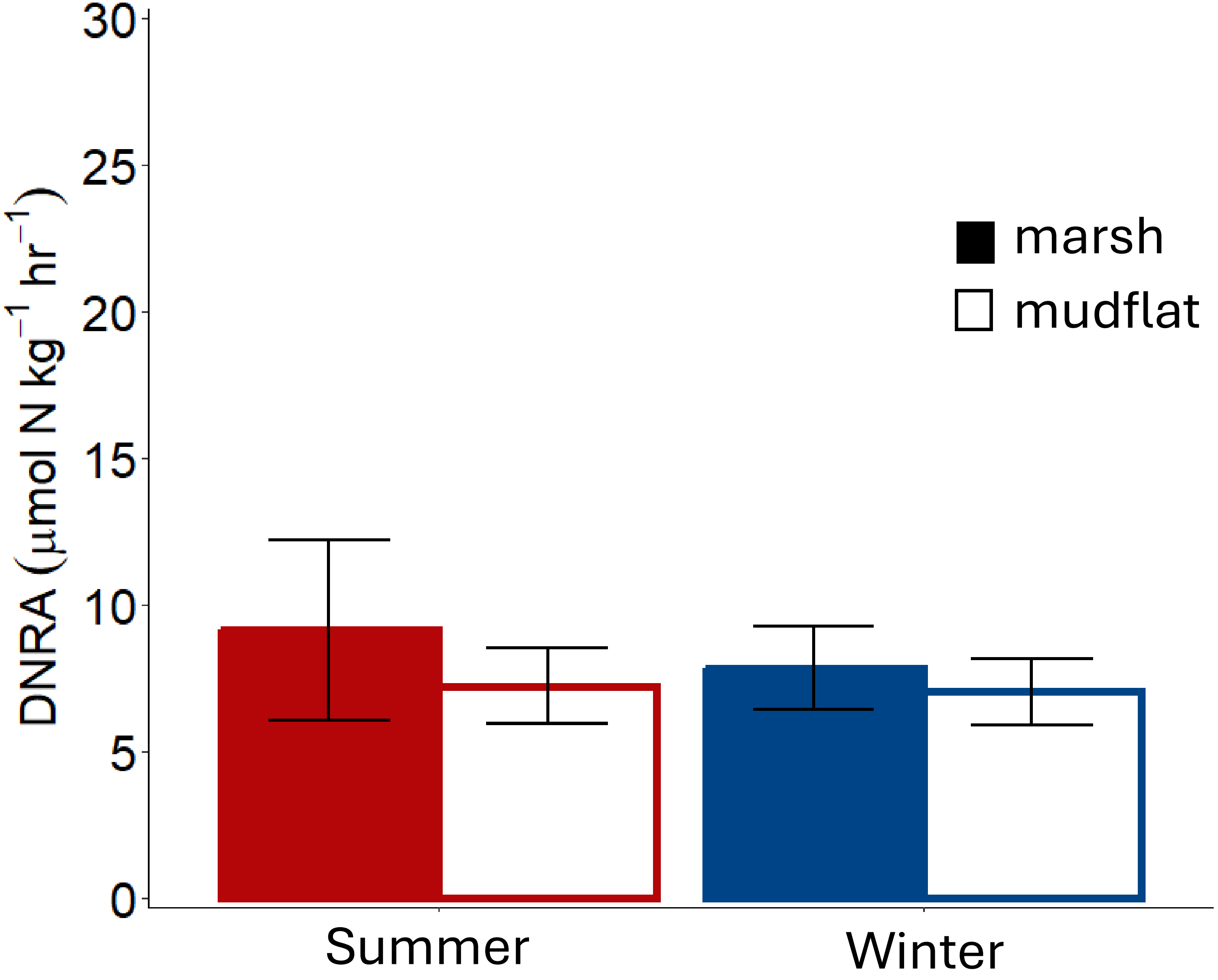
No differences in denitrification for any measured factor



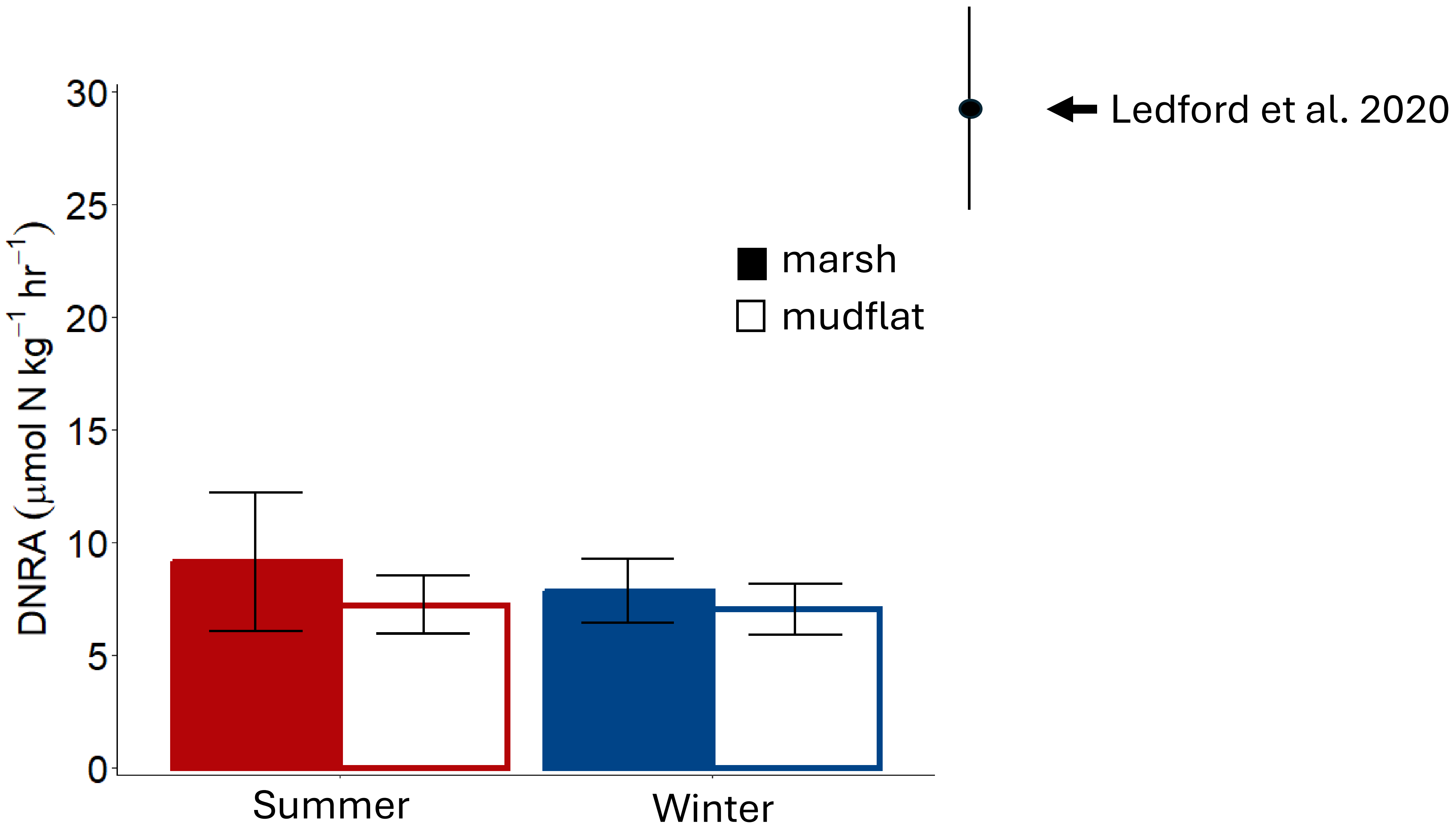
Very high variation in denitrification rates, especially in summer



No differences in DNRA for any measured factor

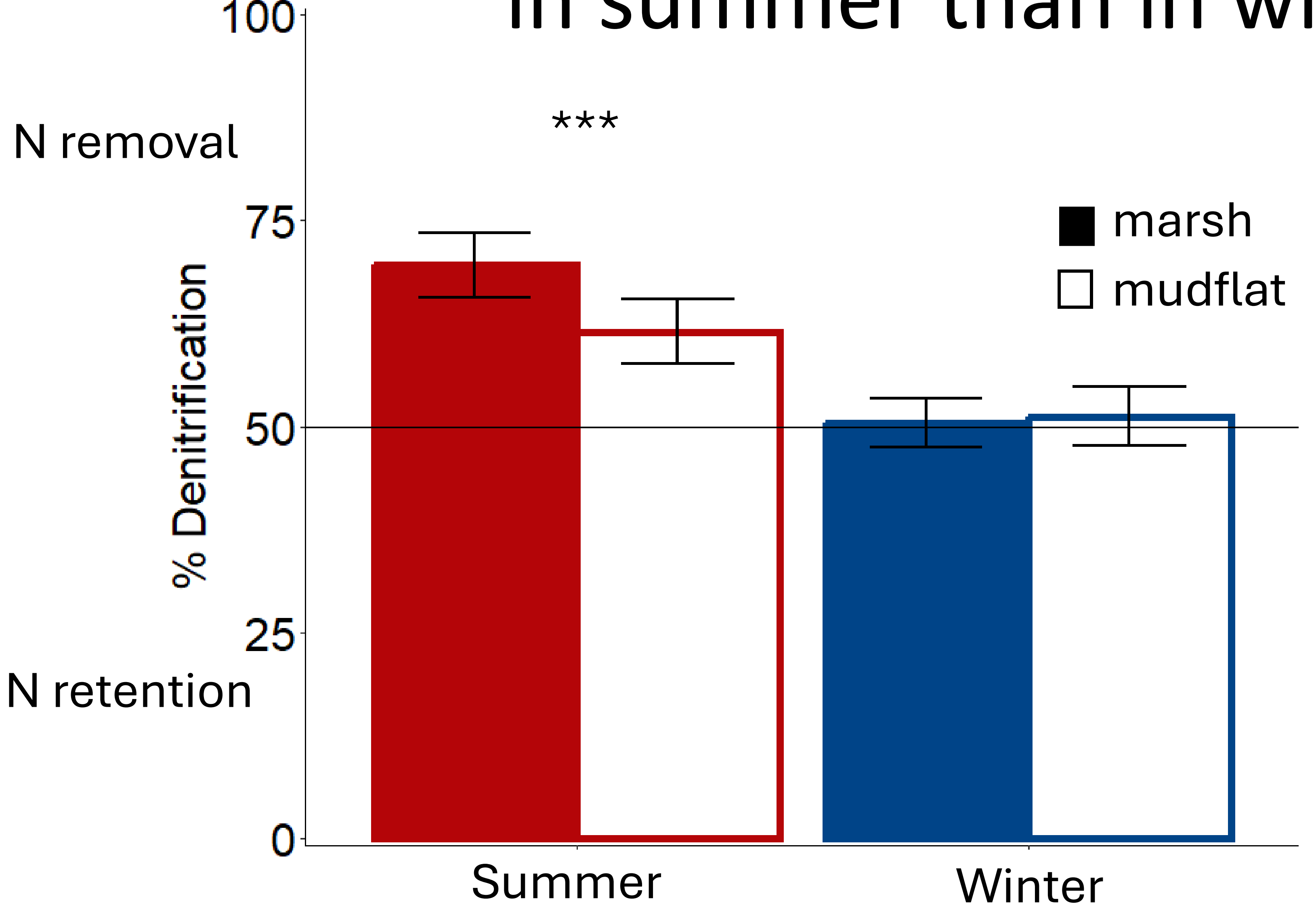


Site: p = 0.39
Zone: p = 0.81
Season: p = 0.65
Site * Zone: p = 0.36
Site * Season: p = 0.85
Zone * Season: p = 0.73
Site * Zone * Season: p = 0.43



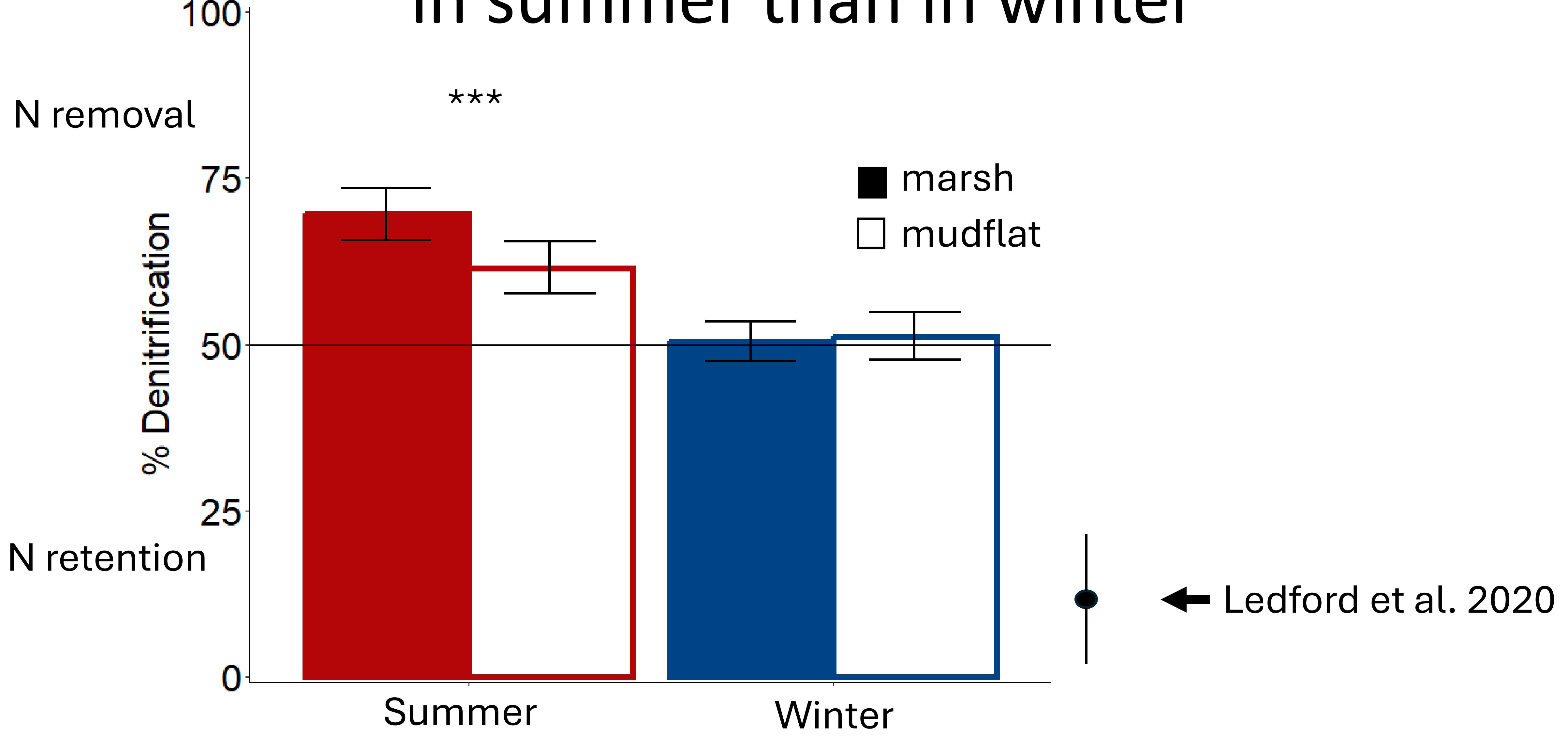
DNRA (μmol N kg^{-1} hr^{-1})
30
25
20
15
10
5
0
Summer
Winter
marsh
mudflat
Ledford et al. 2020

Higher % denitrification of total N reduction in summer than in winter



Site: p = 0.11
Zone: p = 0.30
Season: p = 0.0003 ***
Site * Zone: p = 0.18
Site * Season: p = 0.46
Zone * Season: p = 0.21
Site * Zone * Season: p = 0.81

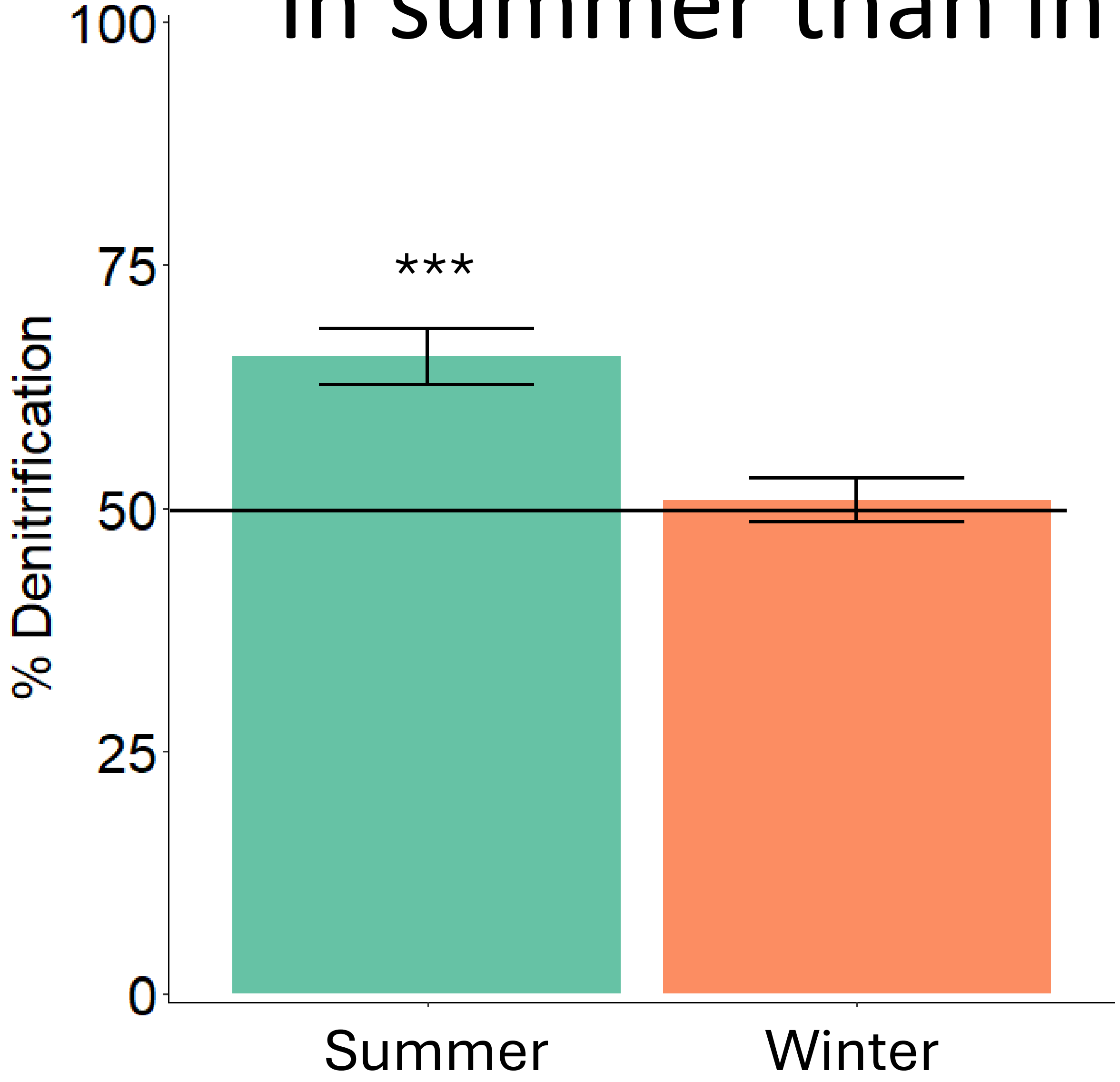
Higher % denitrification of total N reduction in summer than in winter



Higher % denitrification of total N reduction in summer than in winter

N removal

N retention



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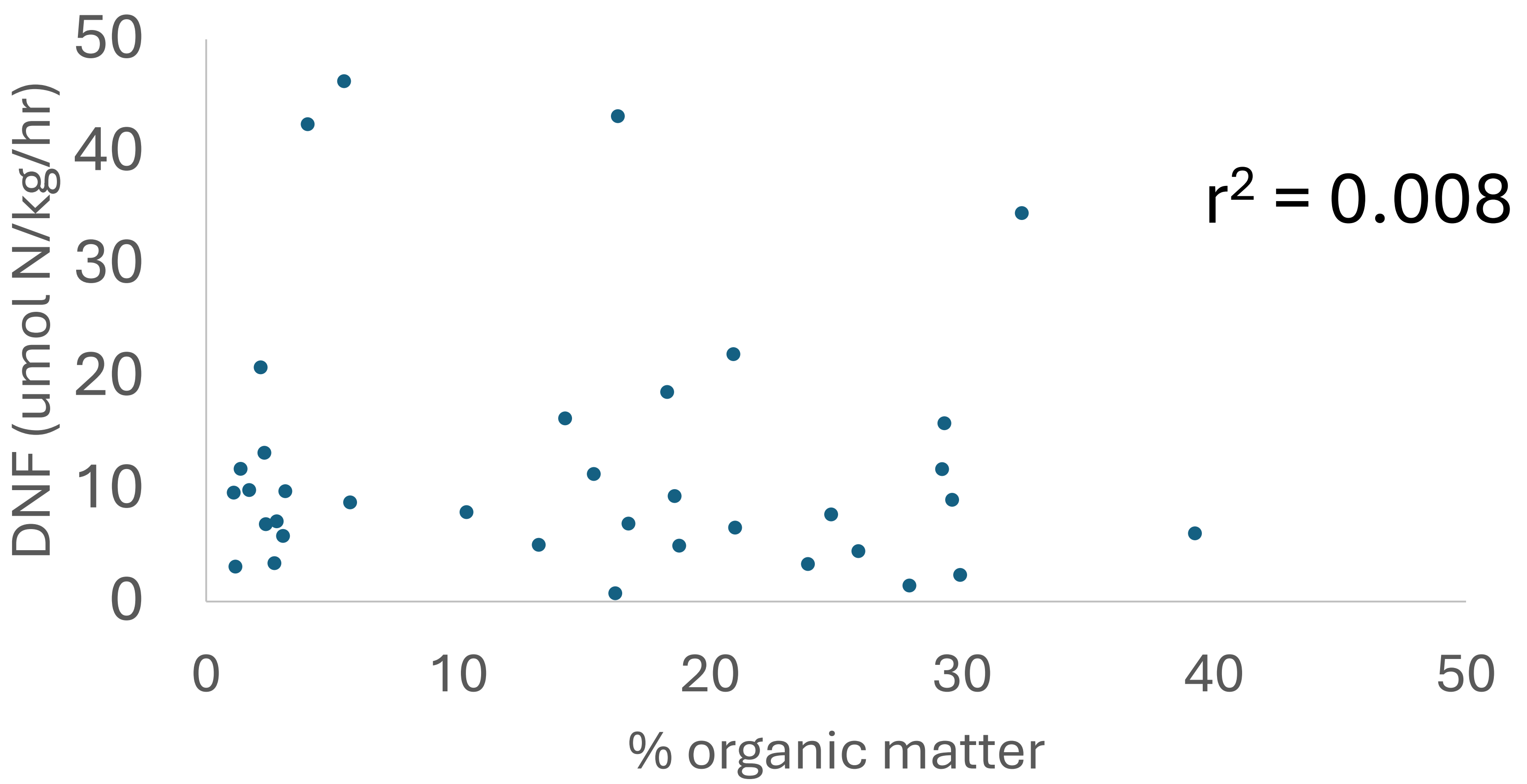
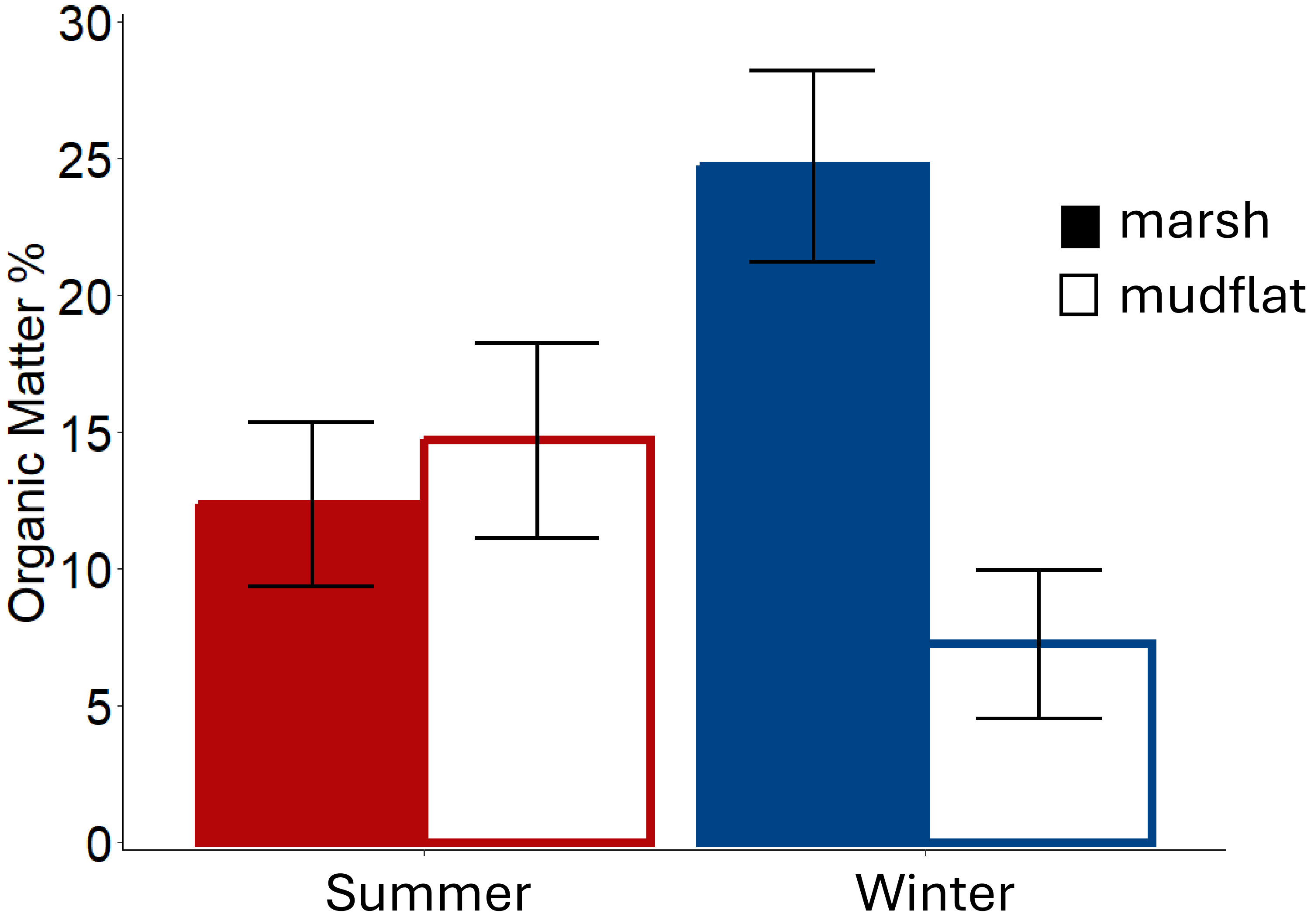
% organic matter did not explain differences in denitrification rates

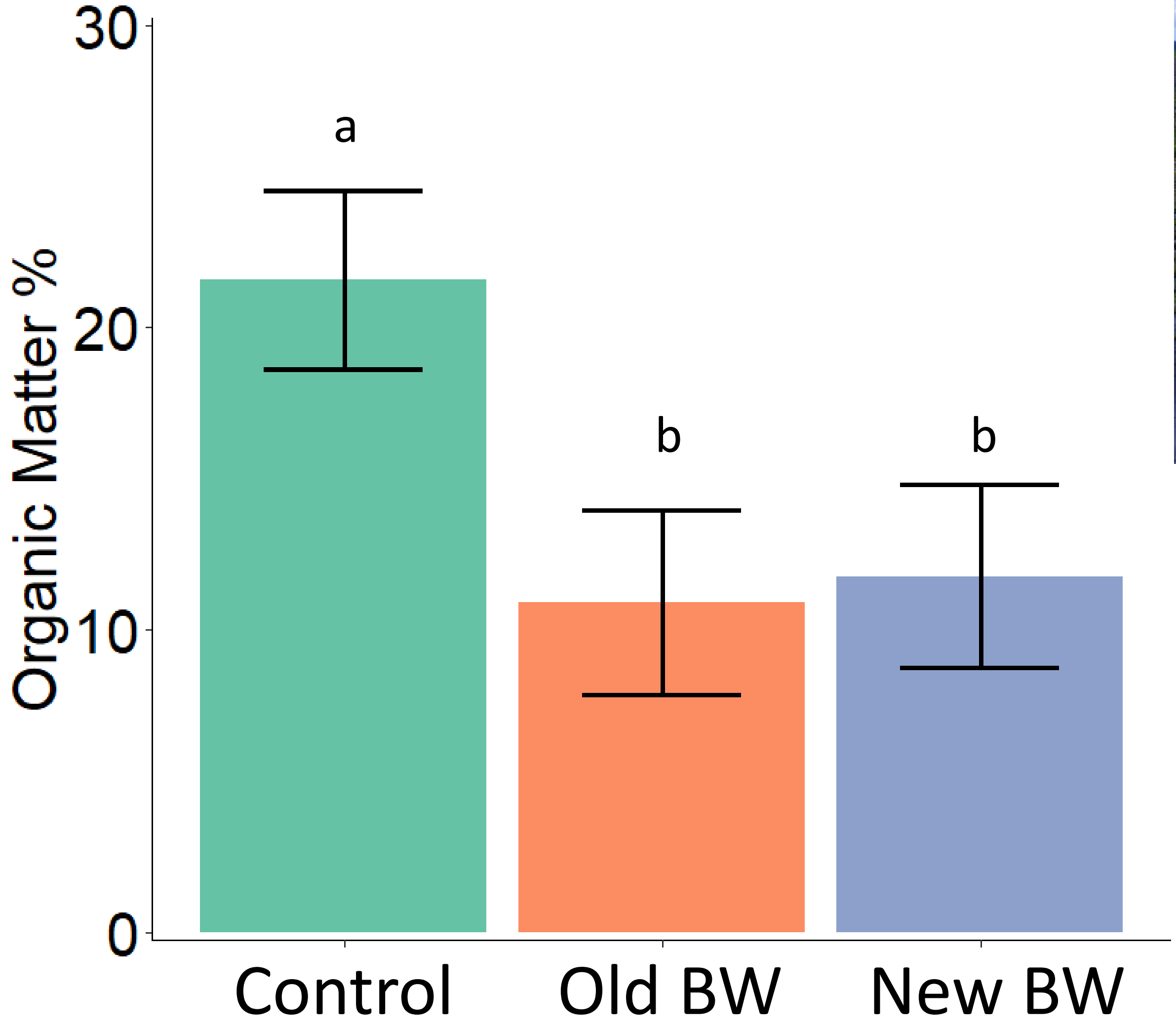


Organic Matter % varied by sites and zones



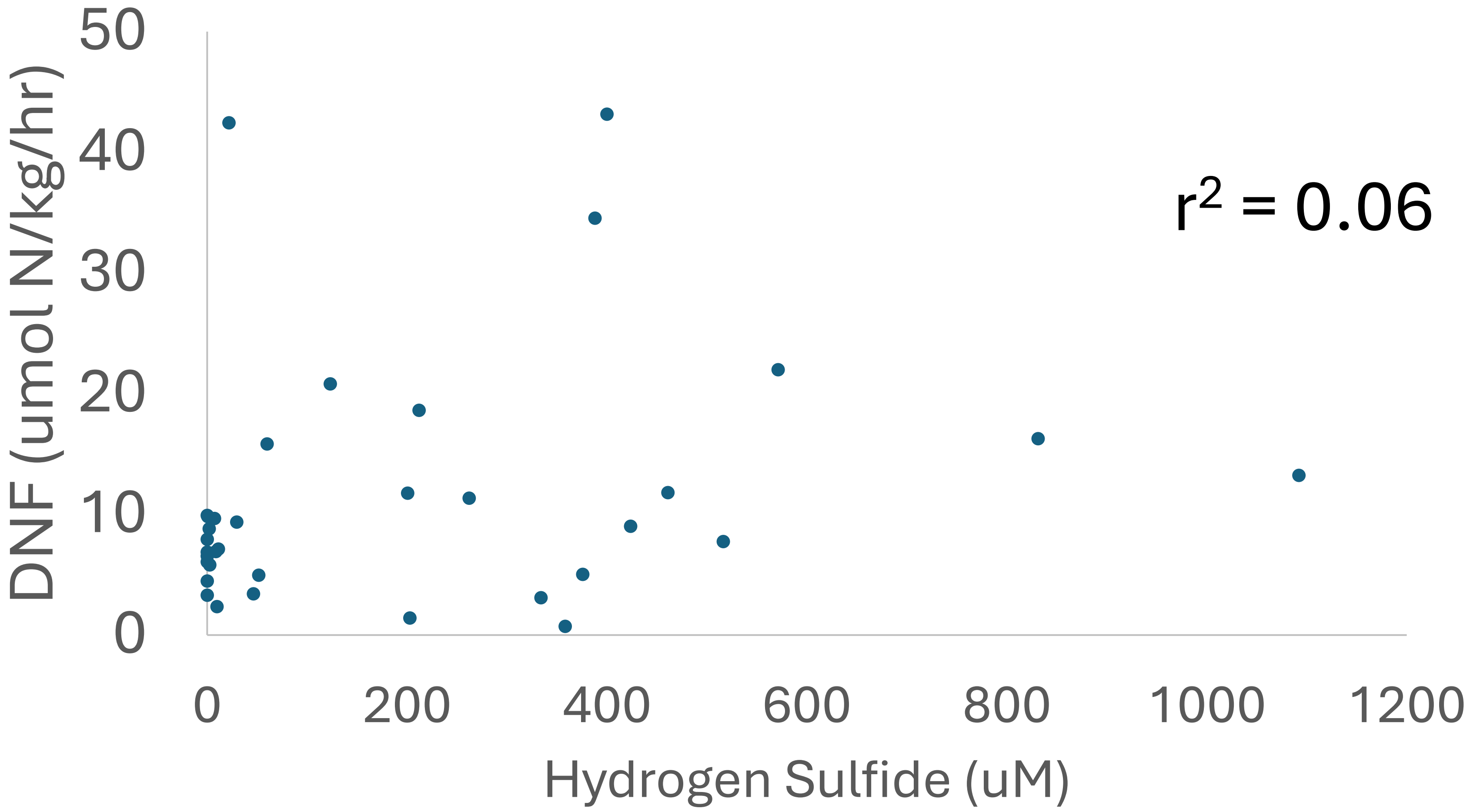
Site: p = 0.02
Zone: p = 0.02
Season: p = 0.43
Site * Zone: p = 0.97
Site * Season: p = 0.93
Zone * Season: p = 0.003
Site * Zone * Season: p = 0.54

Organic Matter % highest in control marsh



Site: $p = 0.02$
Zone: $p = 0.02$
Season: $p = 0.43$
Site * Zone: $p = 0.97$
Site * Season: $p = 0.93$
Zone * Season: $p = 0.003$
Site * Zone * Season: $p = 0.54$

Hydrogen Sulfide concentrations did not explain differences in denitrification rates



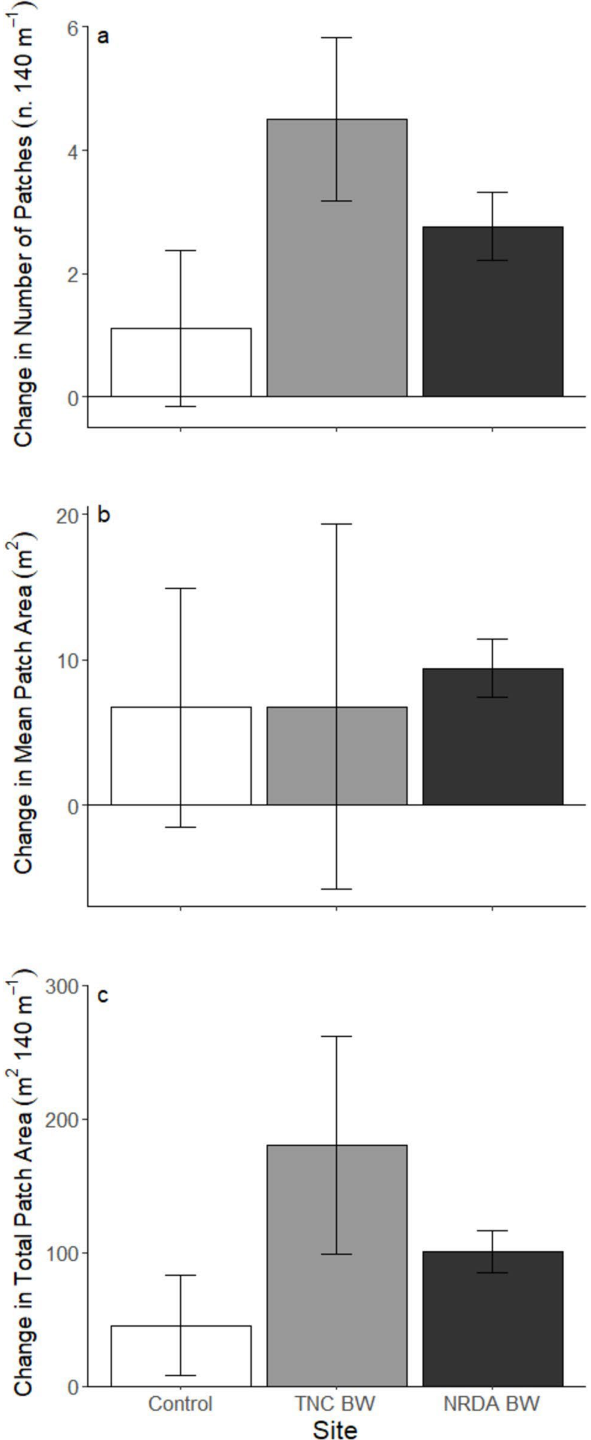
Take Home

- Breakwaters of two ages did not change denitrification or DNRA rates
- Breakwaters are protecting denitrification services by decreasing marsh erosion (Siders et al. 2025)
- Net N removal during the summer
- High heterogeneity over relatively large spatial extent

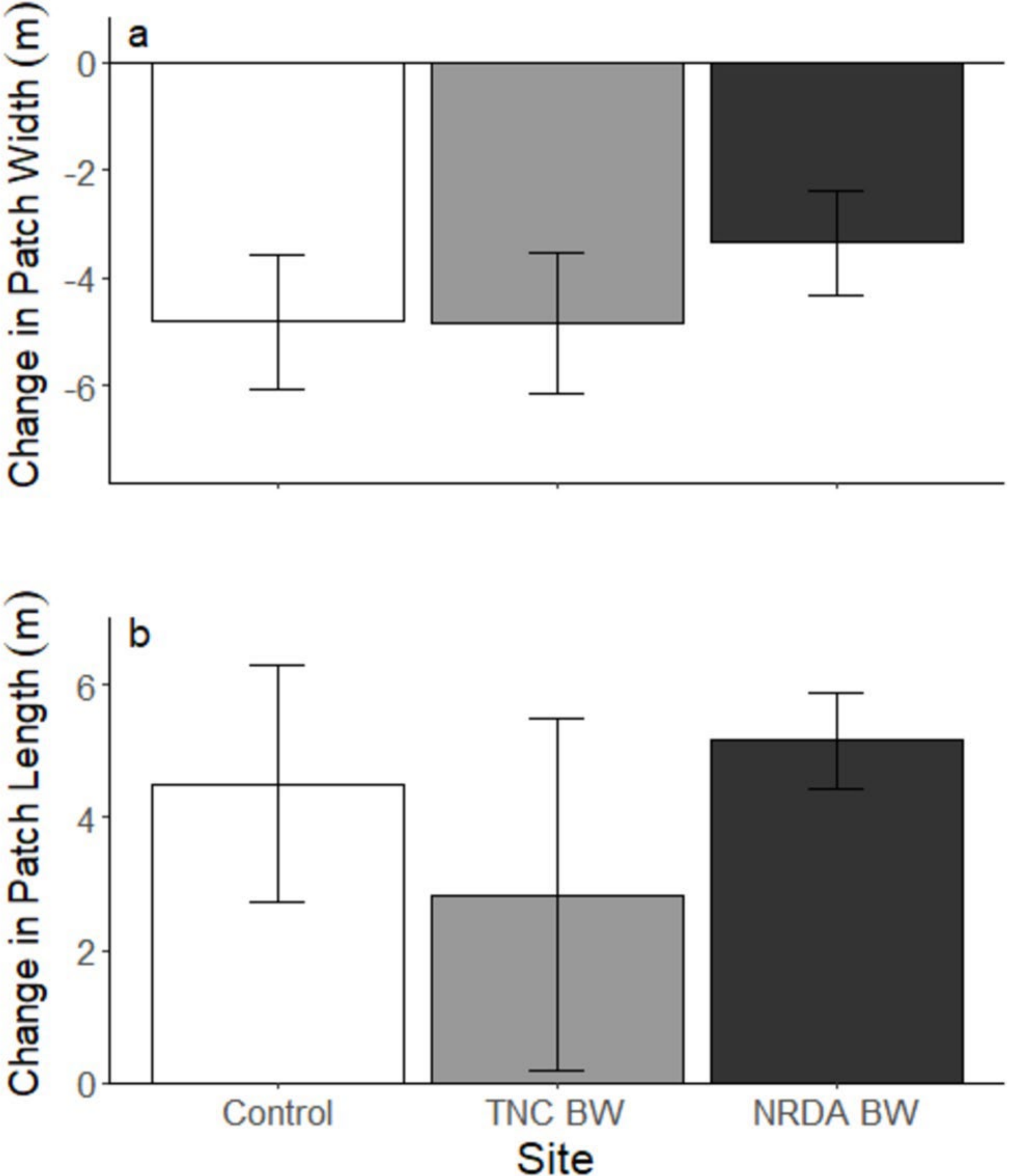
Acknowledgements

- Scott Phipps
- Lidia Molina
- Anne Wynn
- Blake Ellet
- Taylor Ledford
- Corianne Tatariw

- Funding provided by The University of Alabama College Academy of Research, Scholarship and Creative Activity (CARSCA).
- Additional funding for this project was provided by the NOAA, awarded to the Cooperative Institute for Research on Hydrology (CIROH) through the NOAA Cooperative Agreement with The University of Alabama



Siders et al. 2025



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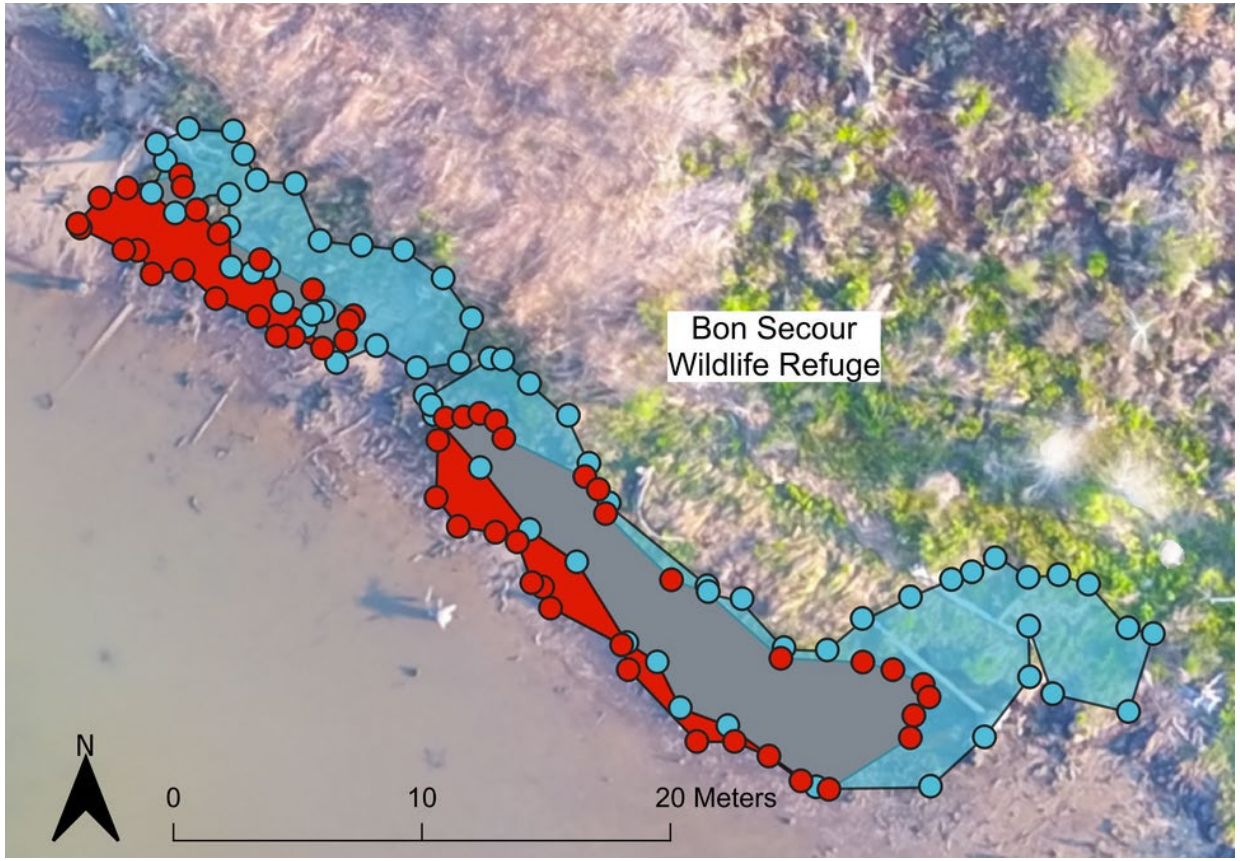
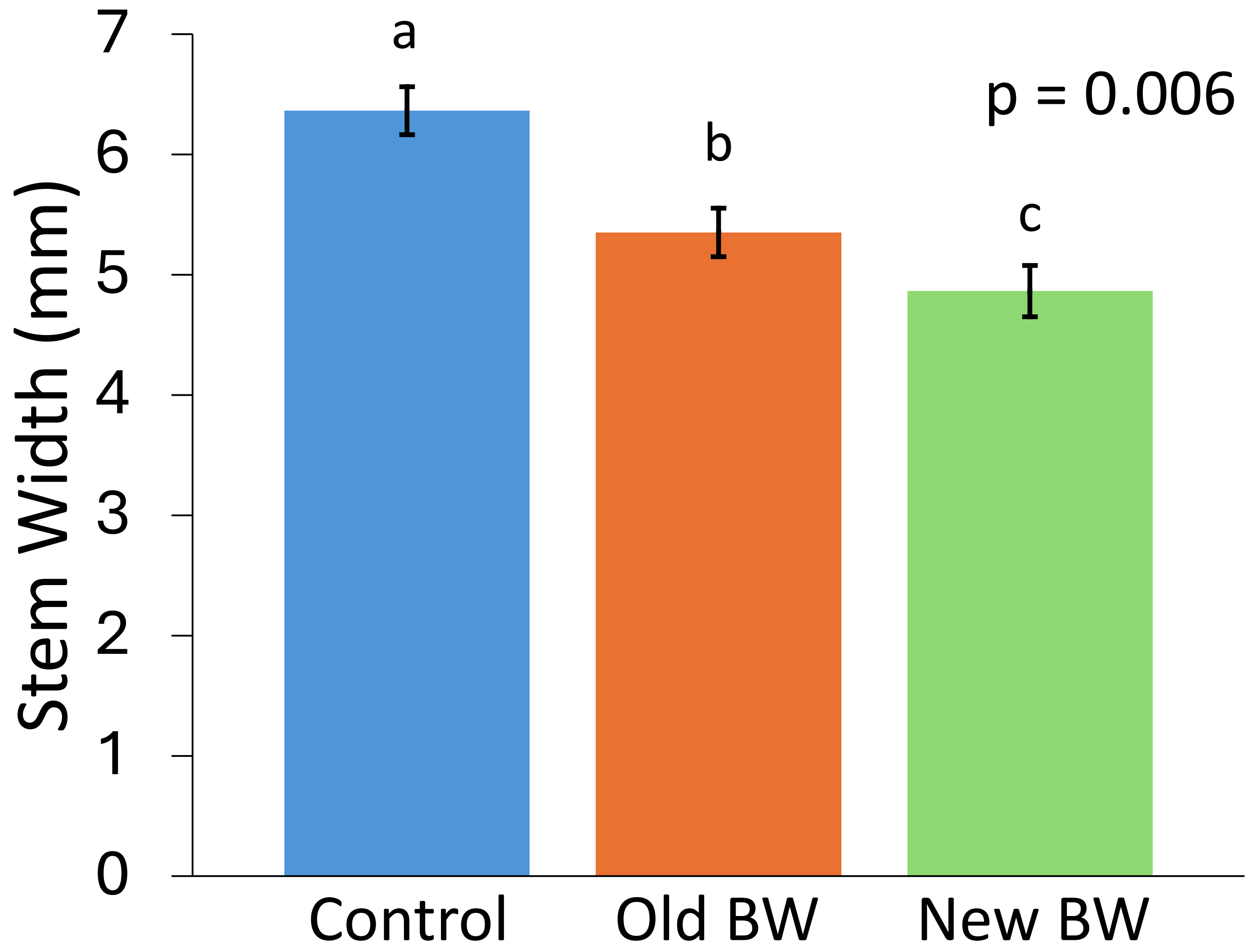
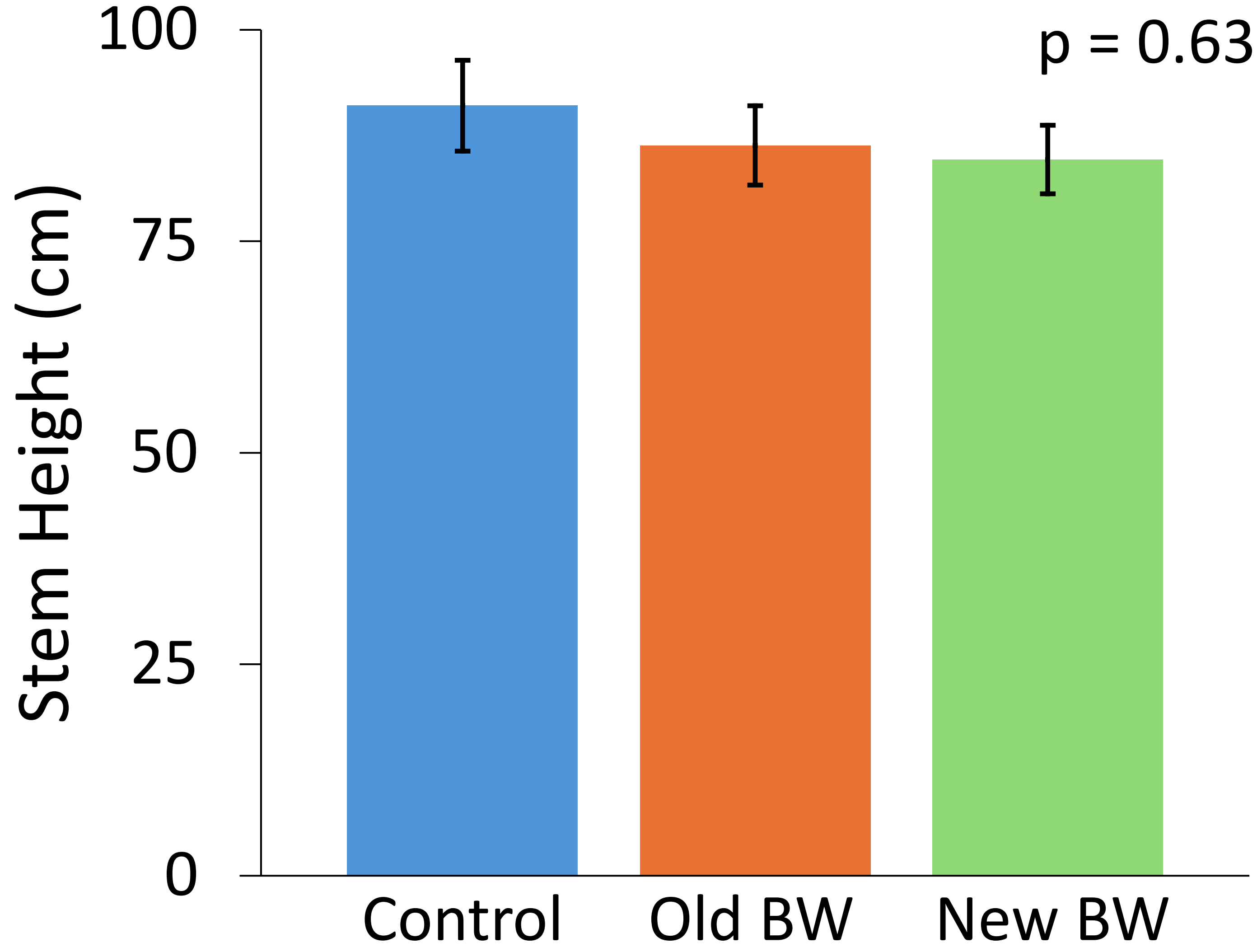
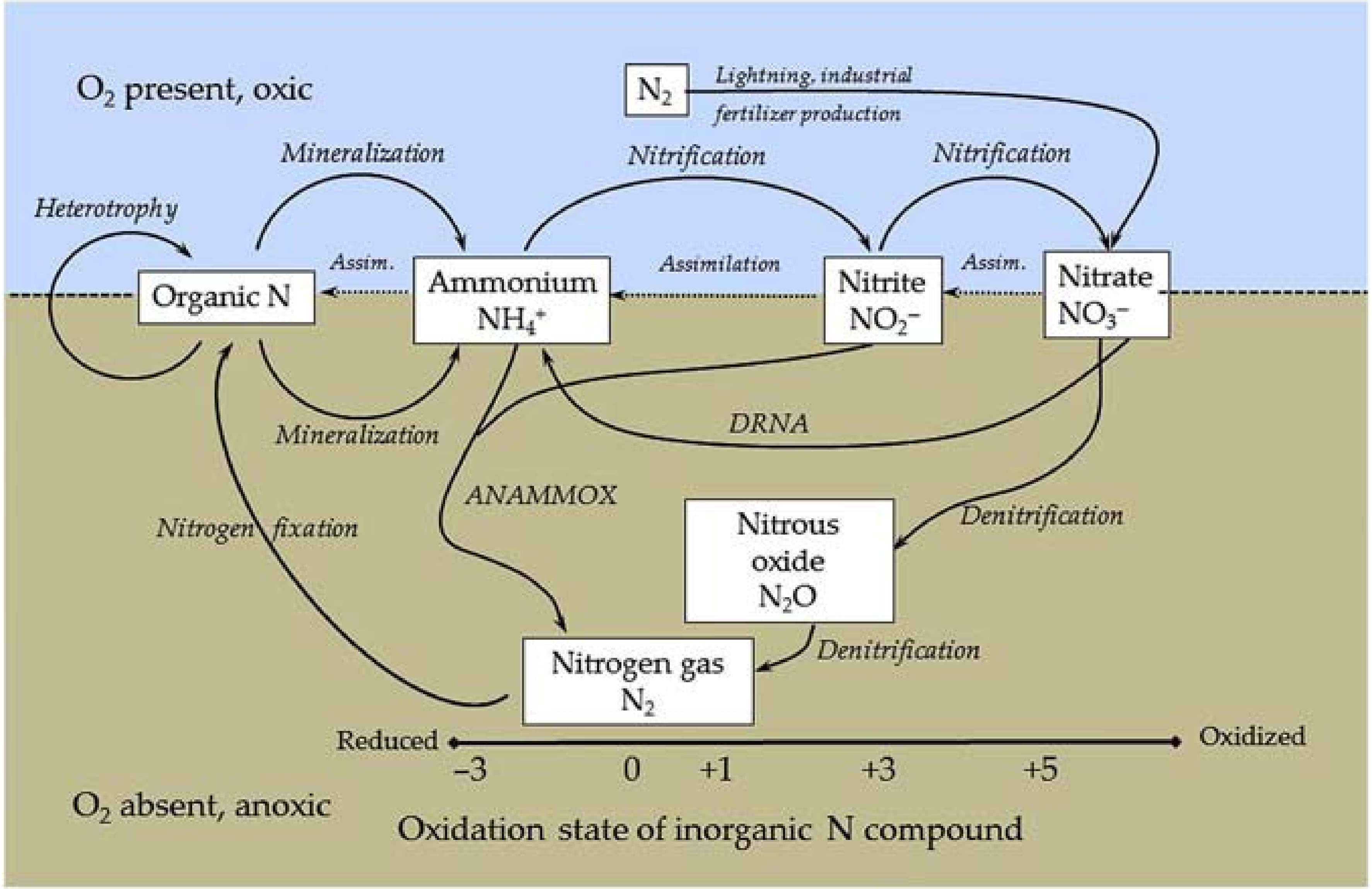

Bon Secour
Wildlife Refuge
N
0
10
20 Meters

Stem width was significantly wider in control sites relative to breakwater sites



No differences in stem heights between control and breakwater sites





Oxygenated water column

Anoxic sediment

Dodds and Whiles 2019