Nitrogen attenuation potential of restored retired cranberry bogs

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Excess nitrogen is harming estuaries

- Wetland restoration is a potential “nature-based” nitrogen removal strategy
- Evidence for the connection between restoration outcomes and restoration features is needed

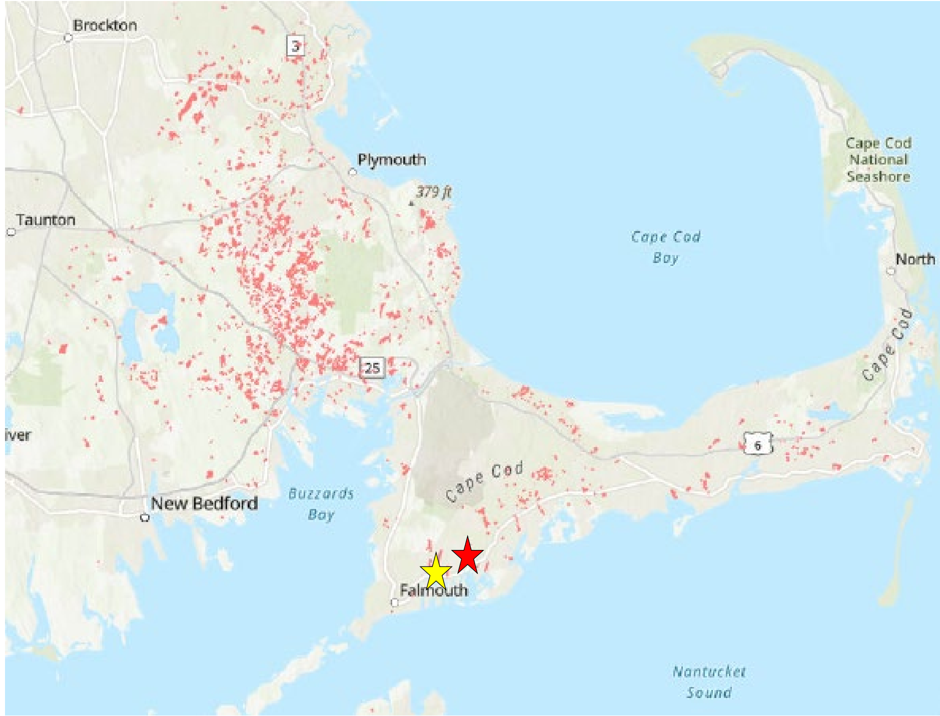
Pre-restoration

Immediately following restoration

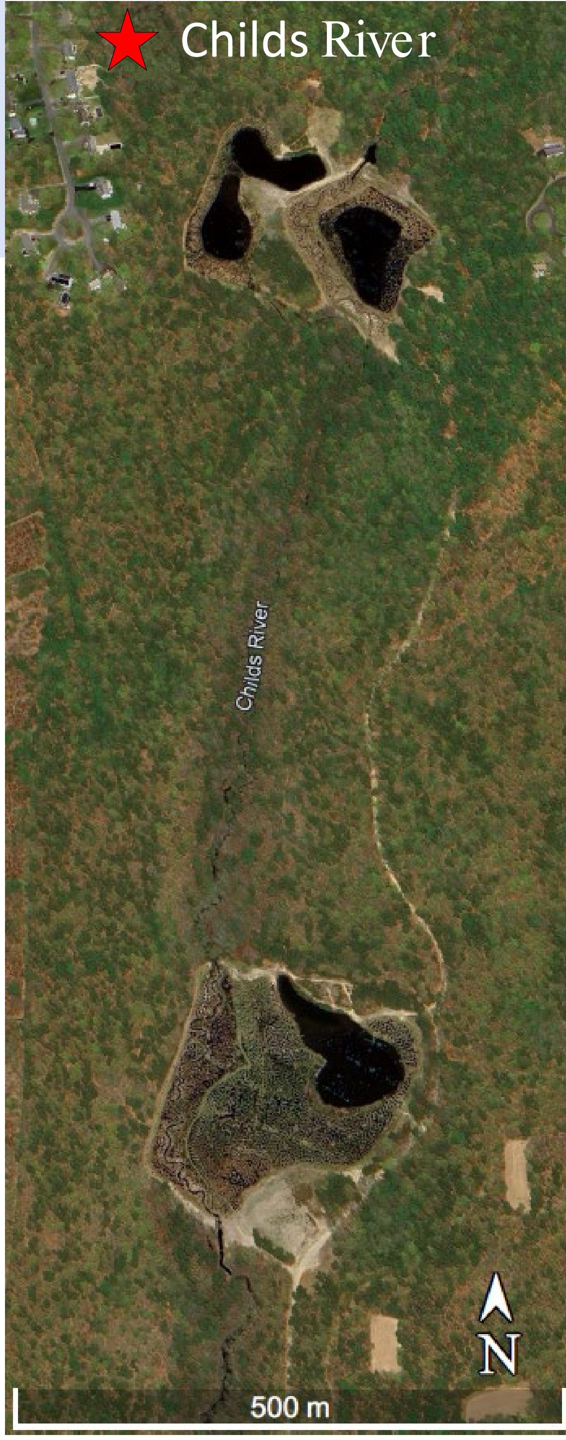
2 months post-restoration

Restored cranberry bog nitrogen removal

1. Drivers of denitrification in a restored bog ☆
2. Nitrogen budgets of restored bogs ☆ ★

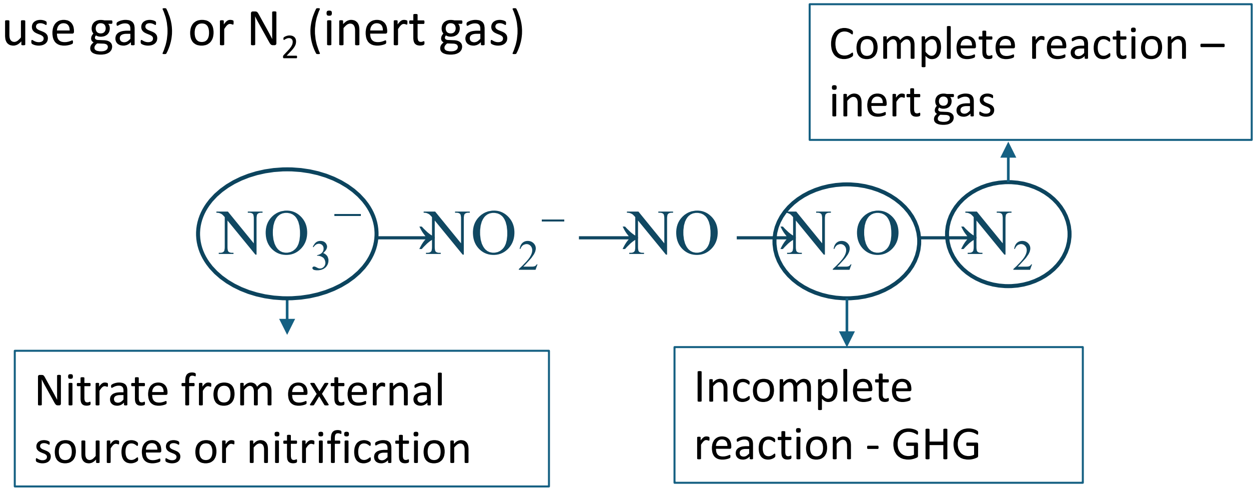


Both watersheds have high-nitrate groundwater



Denitrification

- Denitrification permanently removes nitrogen
  - Microbially-mediated, anaerobic reaction
  - Requires anoxic conditions (wetlands!) and an organic carbon source
  - Nitrate converted to N_2O (potent greenhouse gas) or N_2 (inert gas)

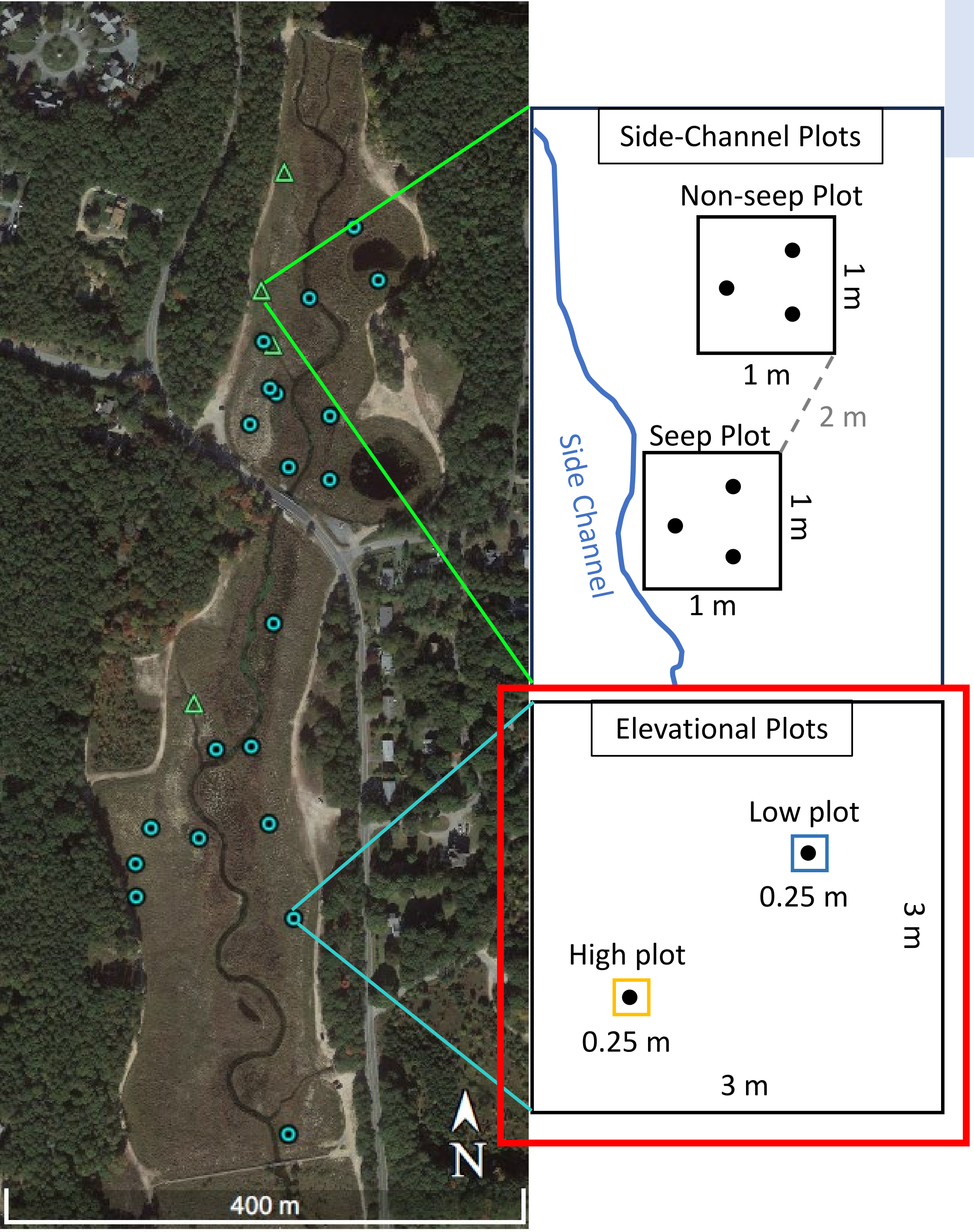


- Biotic uptake temporarily removes nitrogen
  - Short-term to very long-term

1. Do vegetation and microtopography of restored sites affect denitrification potential?

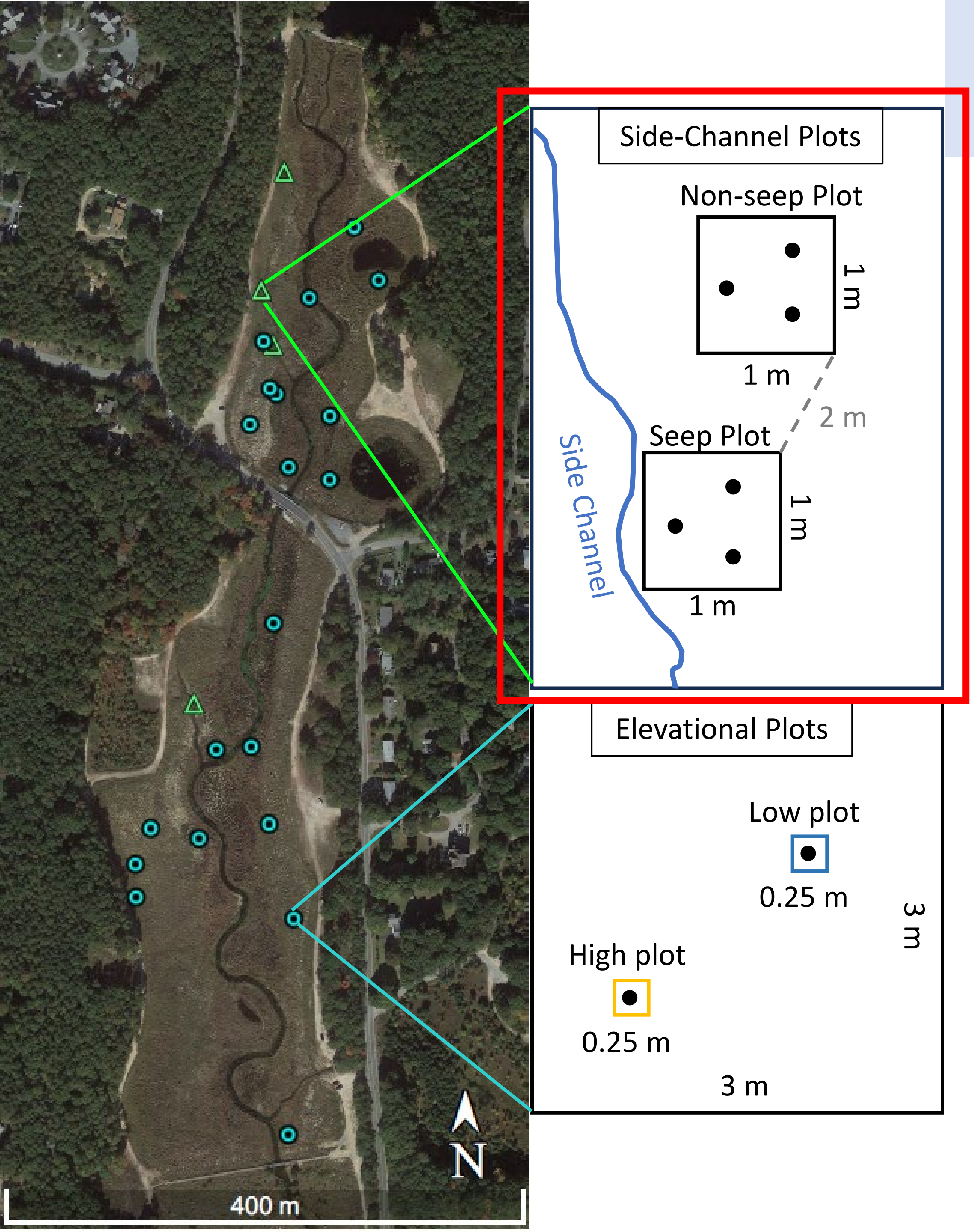
- Dominant plant species and plant functional diversity may influence denitrification potential[19,20]
- Microtopography in wetlands helps create coupled aerobic-anaerobic zones, which may promote nitrification-denitrification[18]

[18]Wolf et al. 2011, [19]Alldred and Baines 2016, [20]Sutton-Grier et al. 2011



Denitrification Approach

- Microtopography
  - Mapped high and low points in 20 plots (9 m^2)
  - Established high and low subplots (0.0625 m^2)
- Plant community in plots and subplots
  - Species and % cover
  - Above/below ground biomass, root porosity



Denitrification Approach

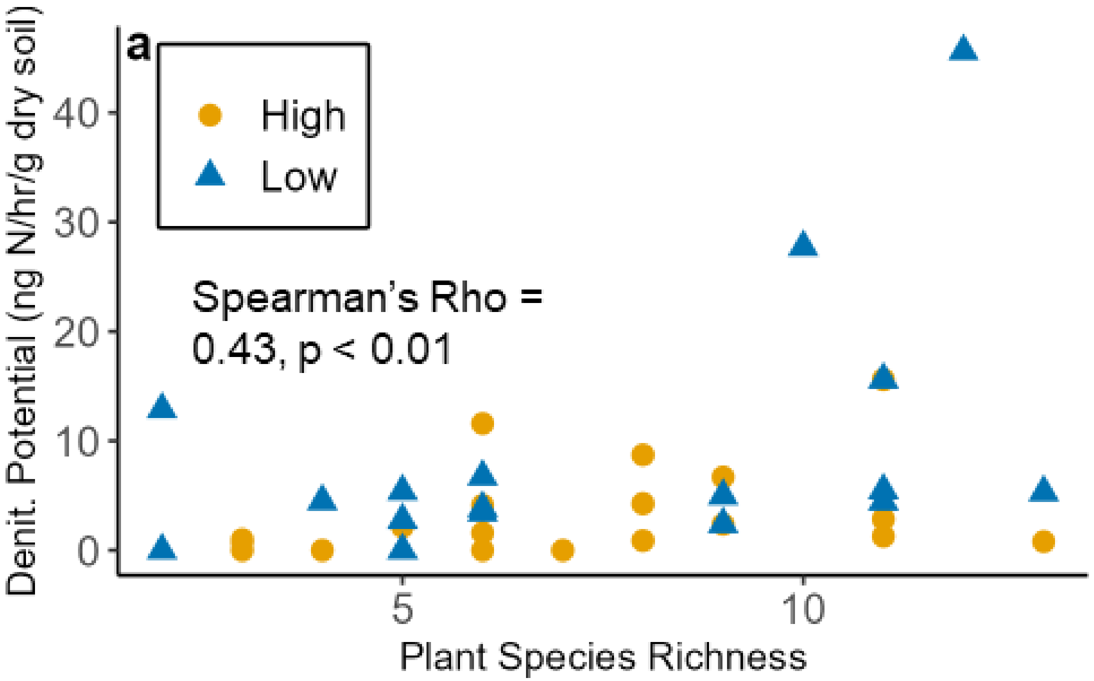
- Microtopography
  - Mapped high and low points in 40 plots (9 m^2)
  - Established high and low subplots (0.0625 m^2)
- Plant community in plots and subplots
  - Species and % cover
  - Above/below ground biomass, root porosity
- Groundwater seeps
  - Located with infrared camera
  - Paired seep/non-seep plots
- Soil chemistry
  - %C and %N, nitrate, ammonium, nitrification
  - Soil moisture, pH, EC, bulk density
- N removal: denitrification potential (denitrification enzyme activity assays), *in situ* N_2O flux

Species richness correlates with denitrification potential

High plot indicator species

Toxicodendron radicans

Dichanthelium clandestinum



Low plot indicator species

Juncus canadensis

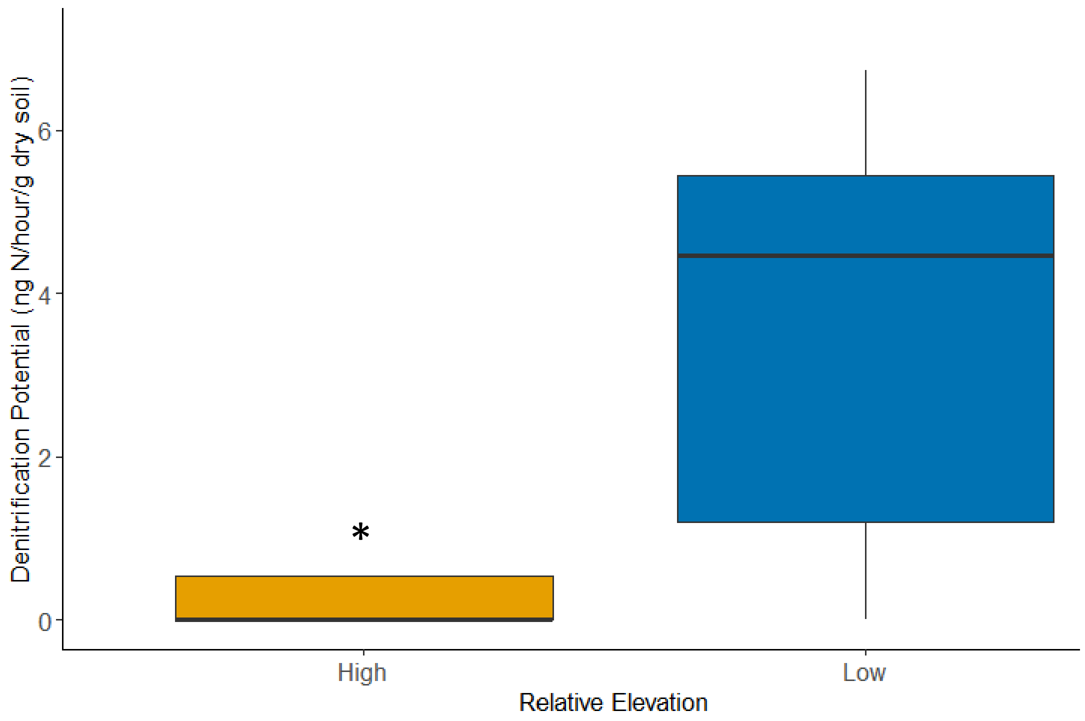
Ludwigia palustris

Leersia oryzoides

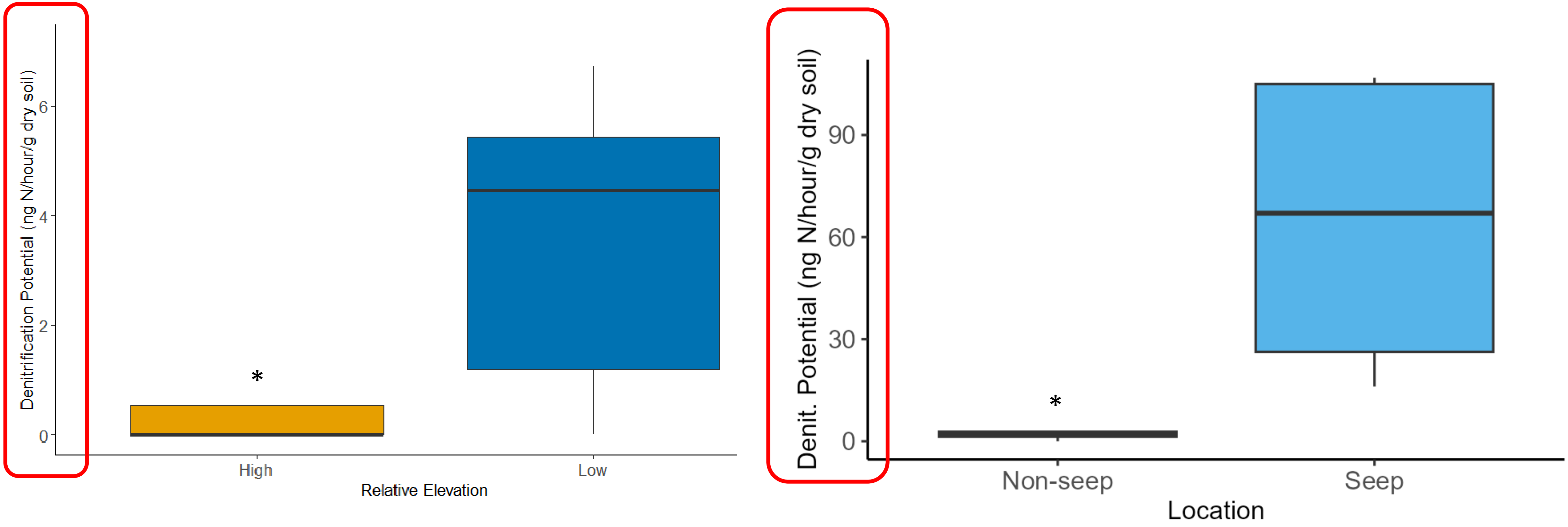
Sparganium americanum

Eleocharis obtusa

Higher denitrification potential at lower relative elevations



Much higher denitrification potential at groundwater seeps



Seep/non-seep soil nitrate 180-300x greater than high/low soil nitrate

Nitrate and carbon likely limiting denitrification in much of the wetland

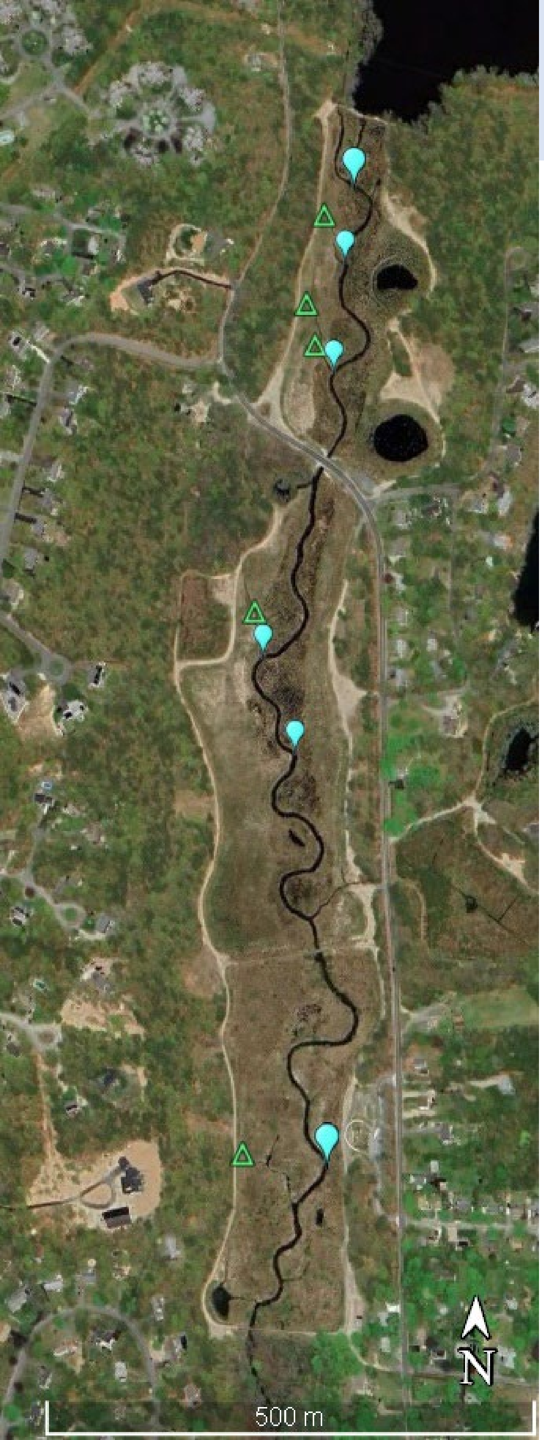
Low N_2O emissions

- N_2O emissions mostly very low or undetectable
- Higher emissions at groundwater seeps
- Emissions variable at small spatial scale
- No evidence that N_2O emissions are a big concern

2. How much nitrogen do restored stream reaches remove?

- Excess nitrogen is primarily from septic systems, little legacy agricultural nitrogen[24,25]
- Water residence time is important for nitrogen removal[21]
- Restoration features that slow water and increase organic material in stream substrate enhance removal[22,23]

[21]Saunders and Kalff 2001, [22]Groffman et al. 2005, [23]Bernal et al. 2012, [24]Kennedy et al. 2020, [25]Balogh et al. 2022

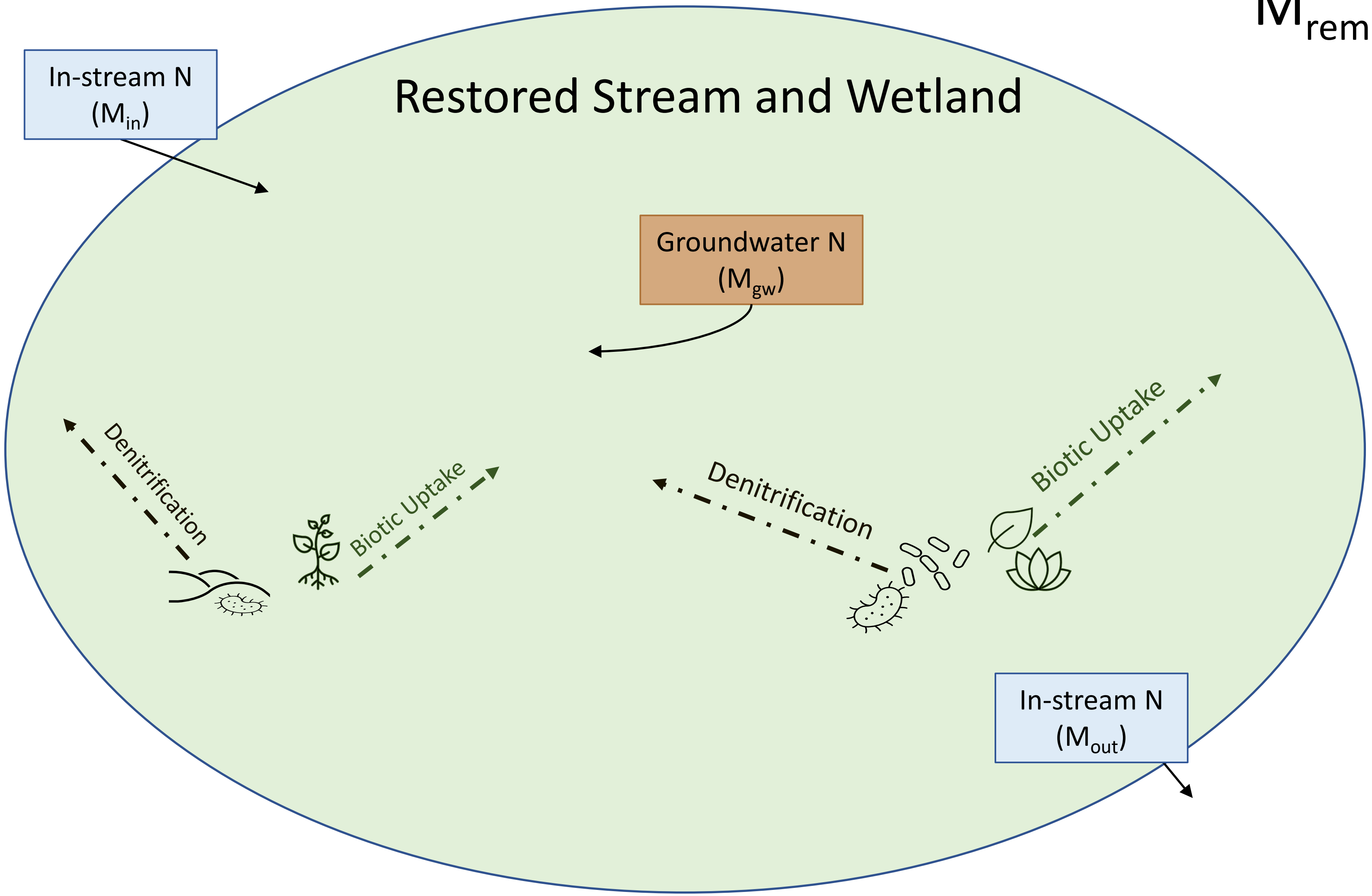


Nitrogen Budget Approach

- Upstream and downstream discharge
  - Flow measurements
  - Continuous water level measurements
  - Rating curve to extrapolate across the year
  - Baseflow separation algorithm

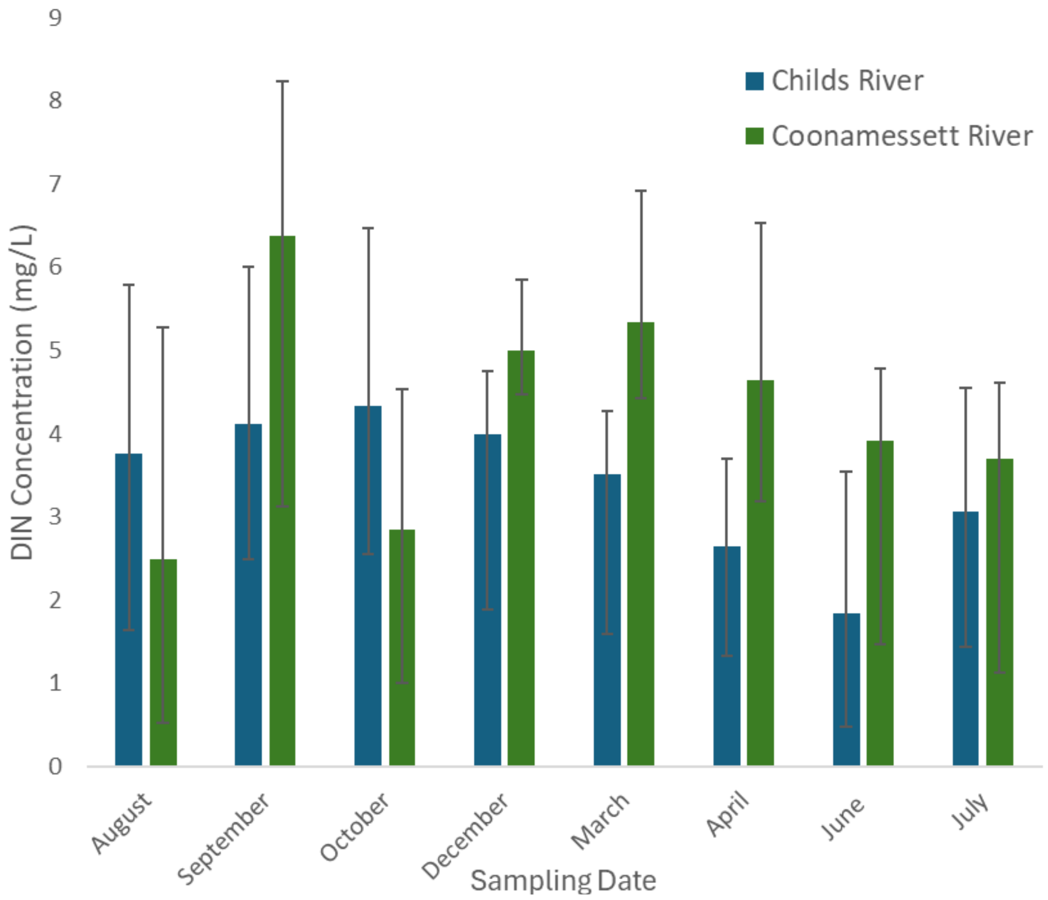
    Verified with isotopic ratios (^{18}O, ^{2}H)
- Groundwater and stream water sampling
  - 8 times throughout the year
  - Nitrogen concentrations
    - Nitrate
    - Ammonium
    - Dissolved organic nitrogen

$$M_{rem} = (M_{in} + M_{gw}) - M_{out}$$



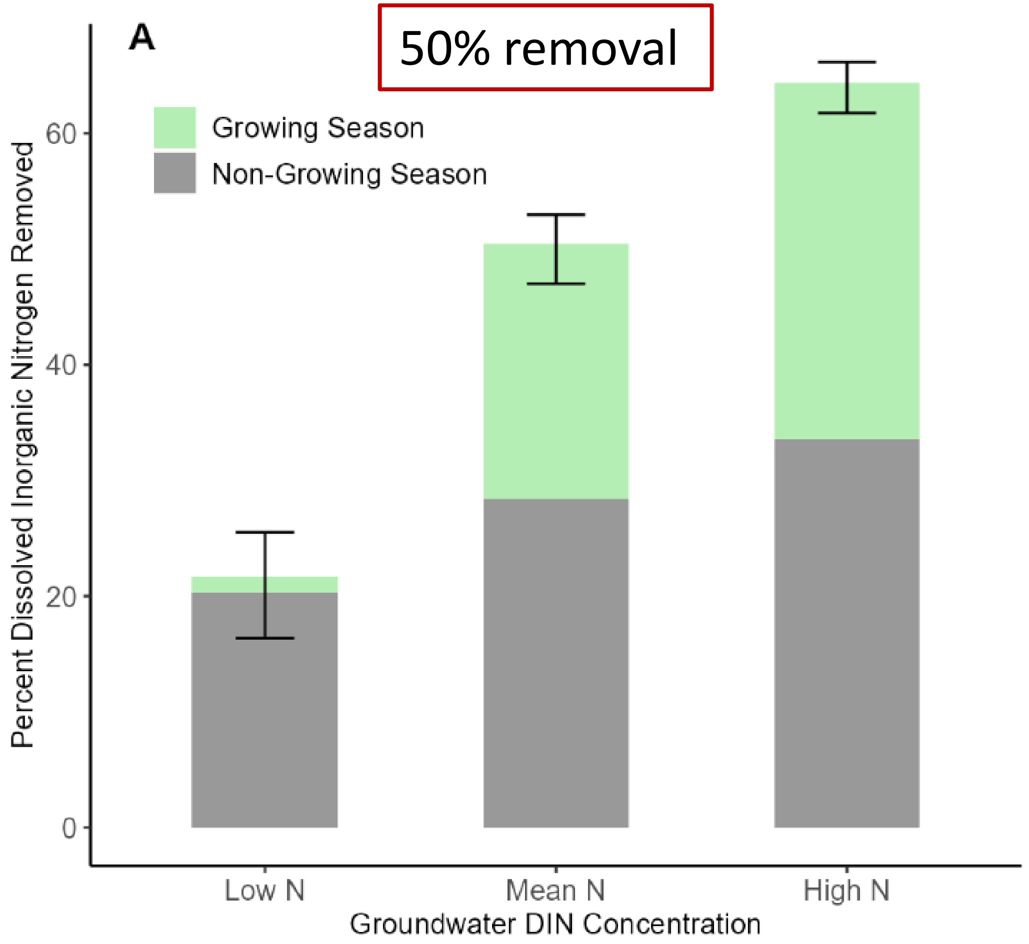
Nitrate-rich, groundwater fed streams

- Groundwater fed streams (68-91%)
- Aqueous nitrogen is primarily nitrate (>70%)
- Groundwater inorganic (nitrate + ammonium) nitrogen concentrations are high and variable

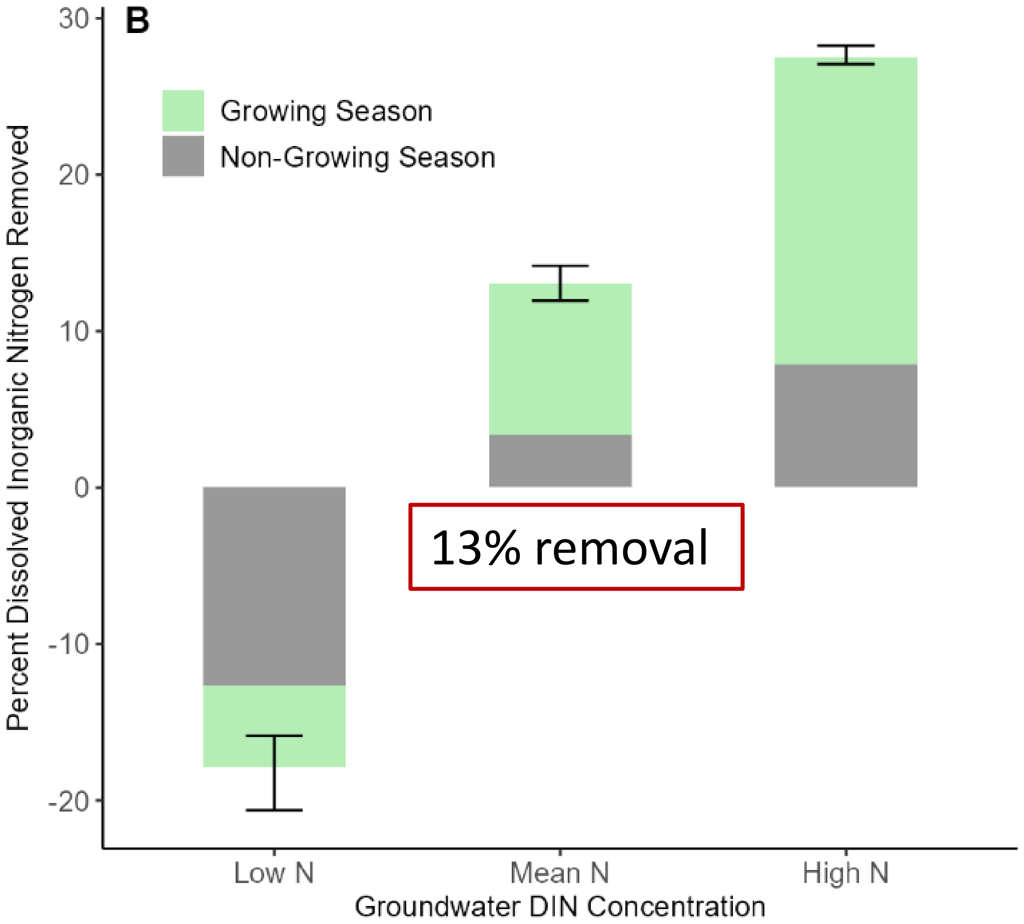


Nitrogen removed at different rates

Coonamessett River:
6.70 kg N/year/river meter of DIN removed



Childs River:
0.62 kg N/year/river meter of DIN removed



Nitrogen budgets and restoration design

- Restoration design
  - Purposeful interception of groundwater seeps at Childs
    - Restored stream at edge of wetland
    - High-nitrate groundwater directly into stream
  - Stream more central in riparian wetland at Coonamessett
    - Some groundwater discharged into very slow-moving feeder creeks
- Increasing residence time of discharged groundwater in will likely increase nitrogen removal
- Seasonality of removal not consistent

Take Aways

- Restored streams remove nitrogen but amounts vary
- Nitrogen budgets show more N removal than we measured
- Denitrification is likely limited by availability of nitrate and carbon
- Maintaining a diverse plant community may enhance nitrogen removal
- Wet microsites will be important if high-nitrate groundwater reaches them
- Limited N_2O emissions from restored cranberry bogs

Trade-offs Among Ecosystem Services

Consider restoration goals and priorities:

Nitrogen removal

Cool-water fish habitat

Fish passage

Plant diversity

N_2O emissions

Questions?

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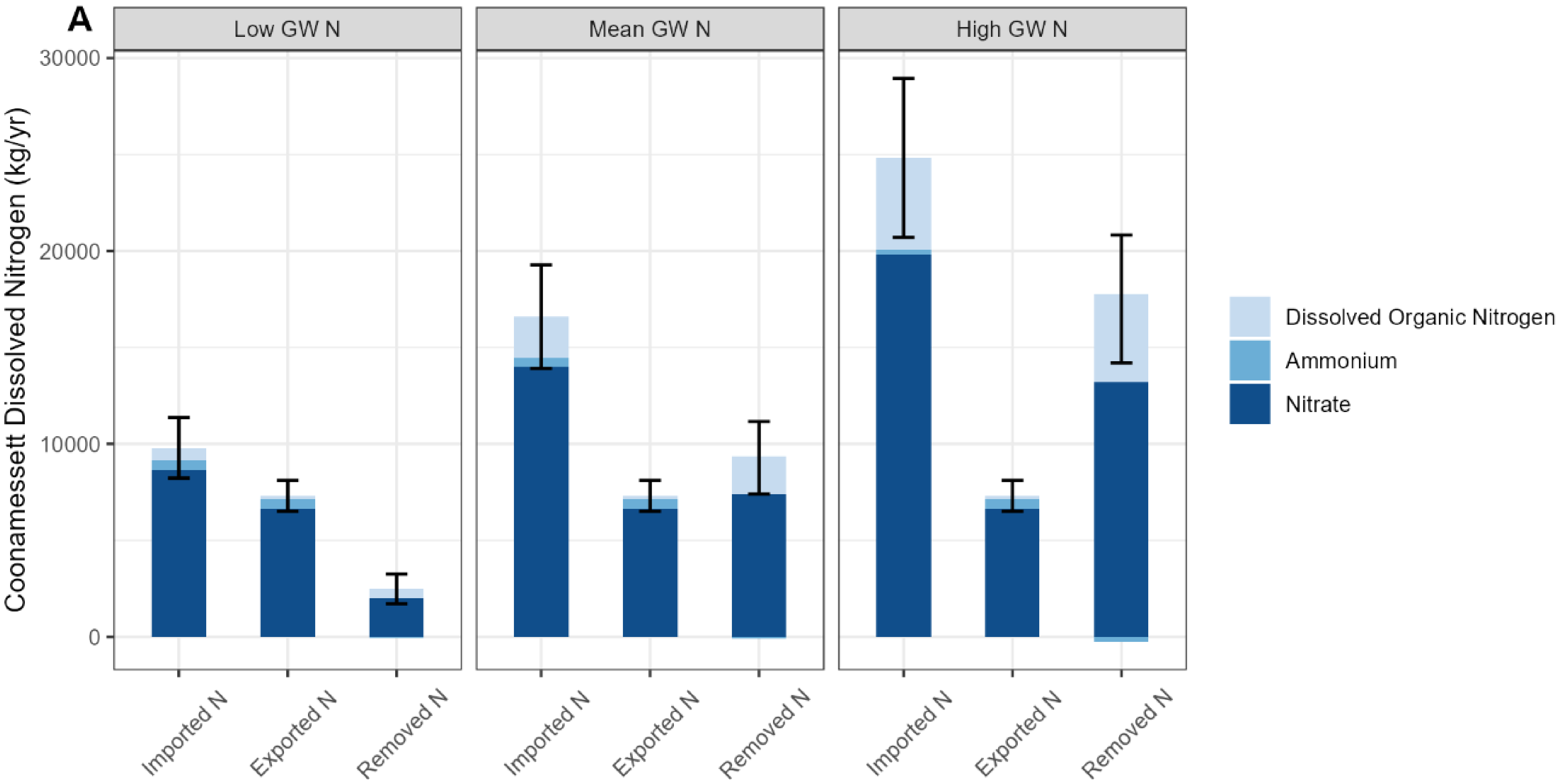
NATURAL RESOURCES AND THE ENVIRONMENT

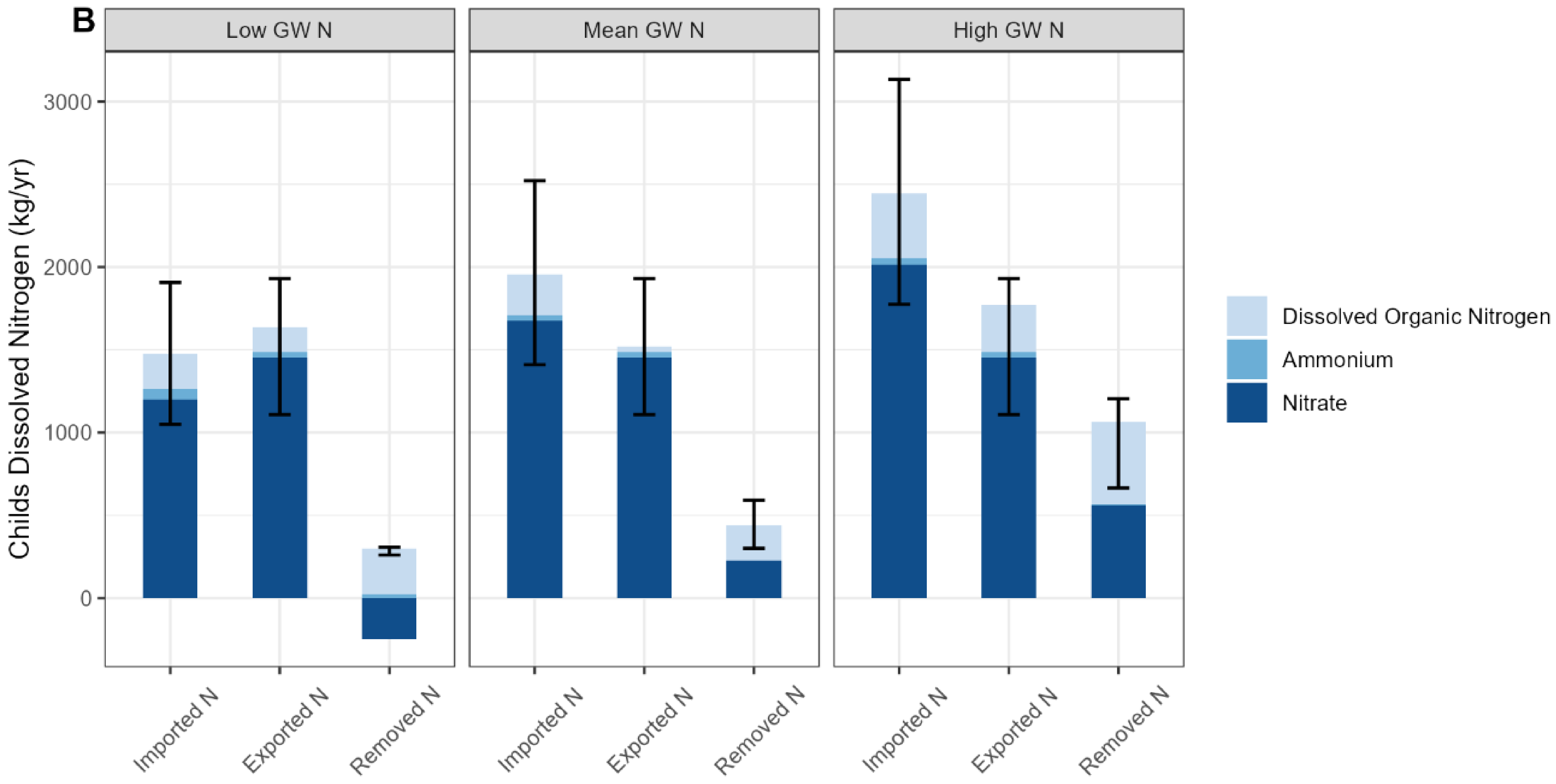
USDA United States Department of Agriculture
National Institute of Food and Agriculture

Woodwell Climate Research Center

GCA THE GARDEN CLUB of AMERICA

PHIPPS


A
Low GW N
Mean GW N
High GW N
Coonamessett Dissolved Nitrogen (kg/yr)
30000
20000
10000
0
Imported N
Exported N
Removed N
Dissolved Organic Nitrogen
Ammonium
Nitrate


B
Low GW N
Mean GW N
High GW N
Childs Dissolved Nitrogen (kg/yr)
3000
2000
1000
0
Imported N
Exported N
Removed N
Dissolved Organic Nitrogen
Ammonium
Nitrate