How does saltwater intrusion alter anaerobic microbial metabolism in a freshwater wetland?

Timberlake Wetland, Coastal N.C.

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Sea Level Rise Predictions for N.C.

By 2100, North Carolina will lose 2330 – 5180 sq. kilometers of coastline (900-2000 square miles)

Increasing air temperatures predicted to increase drought

What are the biogeochemical implications of SLR and salt water intrusion for coastal wetlands?

Figure 3: Map of Coastal North Carolina and Sea Level Rise (Source: Poulter and Halpin 2008).
Timberlake Restoration Project

- Ashley Helton (11:20)
  - Simulating the Influence of Salt Water Intrusion on Coupled Elemental Cycles

- Valerie Schoepfer (11:40)
  - The Effect of Salt Water Intrusion on Coupled Iron and Sulfur Cycling

- Marcelo Ardón (2:20)
  - Salt Water Intrusion Alters N and C Export from a Restored Coastal Wetland

- Kristy Hopfensperger (4:00)
  - Plant Chemistry in a Freshwater Wetland Experiencing Salt Water Intrusion
Timberlake Restoration Project

- Privately owned 1000ha mitigation bank
- Focus → 440ha agricultural field (formerly pumped)
- <5 m range in surface elevation
- Freshwater with wind-driven tides & bidirectional flow
Timberlake Timeline

- **1980**: Swamps, pocosins drained
- **1985**: First crops planted
- **1986-2001**: Corn, soy
- **1996**: GDSMB buys site
- **2004**: Last crops
- **2005**: Earth-moving; Seedlings planted
- **2007**: Canals plugged; pumping stops
Timberlake Overview

OUTFLOW = SALT WATER EXPOSED

MIDPOINT

2 INFLOWS = MINIMAL SALT EXPOSURE
OUTFLOW = SALT WATER EXPOSED

MIDPOINT

2 INFLOWS = MINIMAL SALT EXPOSURE
2007 & 2008 Drought = Saltwater intrusion

Ions in Salt Water

- Sodium (Na\(^+\)) 10.556 g
- Sulfate (SO\(_4^{2-}\)) 2.649 g
- Magnesium (Mg\(^2+\)) 1.272 g
- Bicarbonate (HCO\(_3^-\)) 0.140 g
- Calcium (Ca\(^{2+}\)) 0.400 g
- Potassium (K\(^+\)) 0.380 g
- Chloride (Cl\(^-\)) 18.980 g

Other
How does salt water intrusion affect the distribution of anaerobic microbial metabolism?

Increased $\text{SO}_4^{2-}$ from SLR

Increased $\text{NO}_3^-$ from Ag.

$R^2 = 0.89$
Slope 0.86

$R^2 = 0.81$
Slope 0.59

$R^2 = 0.24$
Slope 0.20
How does salt water intrusion affect the distribution of anaerobic microbial metabolism?

(b) Biochemical redox = coupling e\(^-\) movement to energy storage

(c) Biogeochemical redox = the energy economy

Burgin et al. (2011) Frontiers in Ecology and the Environment
How does salt water intrusion affect the distribution of anaerobic microbial metabolism?

Biogeochemical Reality is Messy:

- Oxic
  - Fe$^{3+}$
  - PO$_4^{3-}$

- Anoxic
  - Fe$^{2+}$
  - Fe-P$O_4^{3-}$
  - Fe-S

- N$_2$, N$_2$O
  - NH$_4^+$, N$_2$
  - NO$_3^-$

- CO$_2$
  - H$_2$S
  - SO$_4^{2-}$

- OC

Elements:
- Carbon
- Nitrogen
- Sulfur
- Iron
- Phosphorus
Goal: Create a simplified reality to examine how individual components of nitrate, salt and sulfate inputs affect anaerobic pathways and microbial communities at Timberlake.

- **Q₁**: Does previous exposure to salt water affect how soil microbial communities react to simulated salt water intrusion?
- **Q₂**: Are their differential effects of salt and sulfate on anaerobic microbial communities?
- **Q₃**: How salt water intrusion affect the denitrification capacity of coastal wetlands?

**How does salt water intrusion affect the distribution of anaerobic microbial metabolism?**
“Simplified Reality” = Slurries

Three-way Full Factorial:
$^{15}\text{NO}_3^-$ = 0.1, 1, 3 mg N L$^{-1}$
(7, 71, 214 μM)
Salt = 0 (fresh), 2, 4 ppt

$\text{SO}_4^{2-}$ = 5, 50, 500 mg L$^{-1}$
(52, 520, 5205 μM)

+ 5g soil + 60 ml
anoxic = site water

9 reps of the same trt combination
Destructively harvested over 3 days

Analyzed for: $\text{CH}_4$ (GC), $\text{NO}_3^-$ (colorimetric)
$^{30}\text{N}_2$ = denitrification (MIMS)
“Simplified Reality” = Slurries

Three-way Full Factorial:
$^{15}$NO$_3^-$ = 0.1, 1, 3 mg N L$^{-1}$
(7, 71, 214 μM)
Salt = 0 (fresh), 2, 4 ppt

SO$_4^{2-}$ = 5, 50, 500 mg L$^{-1}$
(52, 520, 5205 μM)
Nitrate Reduction – Salt & Nitrate Effects

[NO$_3^-$] controls nitrate reduction rates.
Salt does not consistently influence nitrate reduction capacity.
Neither $SO_4^{2-}$ nor Salt influence nitrate reduction capacity.
[NO$_3$] controls denitrification rates
Clear salt effect on denitrification with excess NO$_3$-
Unexposed > Exposed denitrification rates
Increased $\text{SO}_4^{2-}$ does not effect denitrification rates.
Salt stimulates methane in the **unexposed**, but not **exposed**.

At high salt, increasing [NO$_3^-$] decreases methane.
High sulfate stimulates methane in exposed, but not unexposed.

At high salt, increasing [NO$_3^-$] decreases methane.
Summary of Findings

• $Q_1$: Does previous exposure to salt water affect how soil microbial communities react to simulated salt water intrusion?
  – *Yes*, particularly for *methane* production.

• $Q_2$: Are there differential effects of salt and sulfate on anaerobic microbial communities?
  – *Yes*, particularly for *methane* production. *Exposed* sites responded to increased *sulfate*, *unexposed* responded to increased *salt*.

• $Q_3$: How salt water intrusion affect the denitrification capacity of coastal wetlands?
  – *Maybe*. Does not affect nitrate reduction, but may affect *denitrification*.
Implications for Coastal Wetland Biogeochemistry under Salt Water Intrusion

- Increased methane production in areas previously exposed and under continual exposure
- Wetlands may still reduce/remove nitrate, but increased salt may shift the reduction away from denitrification to other retention processes
Acknowledgements

• Medora Burke-Scoll and Anna Fedders
• Terry Loecke
• Kristy Hopfensperger
• Sarah Harvey, Erin Cull, Melanie Stall, James Detraz, and Geraldine Nogaro
• NSF Ecosystems
Drought-induced saltwater intrusion

Water elevation

Inflow
Midpoint
Outflow

Water elevation (m)

Conductivity (mS/cm$^3$)

Outflow

Midpoint

Inflows
Spatial and temporal variability in SWI

Outflow

$$R^2=0.89$$
$$\text{slope}=0.10$$

Midpoint

$$R^2=0.81$$
$$\text{slope}=0.04$$

Inflow

$$R^2=0.24$$
$$\text{slope}=0.02$$
5 Year Outflow Conductivity Record

- Water elevation
- Conductivity at Outflow

Water elevation (m):
-0.8
-0.4
0.0
0.4
0.8
1.2

Conductivity (mS/cm³):
0
6
12

2/07  8/07  2/08  8/08  2/09  8/09  2/10  8/10  2/11  8/11  2/12
Nitrate Reduction Rates

$\uparrow [\text{NO}_3^-]$ = Higher NO$_3^-$ reduction rates; no site difference

- 3 mg L$^{-1}$ NO$_3$-N (214 μM)
- 1 mg L$^{-1}$ NO$_3$-N (71 μM)
- 0.1 mg L$^{-1}$ NO$_3$-N (7 μM)

Salt Exposed (Outflow)

Salt Unexposed (Inflow)
Denitrification Rates

$[\text{NO}_3^-]$ controls dnt rates; at $\uparrow \text{NO}_3$, $\uparrow$ salt decreases dnt

Effects Unexposed more than Exposed

3 mg L$^{-1}$ NO$_3$-N (214 μM)

1 mg L$^{-1}$ NO$_3$-N (71 μM)

0.1 mg L$^{-1}$ NO$_3$-N (7 μM)

Salt Exposed (Outflow)

Salt Unexposed (Inflow)
Fe Reduction

No influence of $[\text{NO}_3^{-}]$; salt*site interaction

Unexposed > Exposed?

3 mg L$^{-1}$ NO$_3$-N (214 μM)
1 mg L$^{-1}$ NO$_3$-N (71 μM)
0.1 mg L$^{-1}$ NO$_3$-N (7 μM)

Fe Reduction rates (nmoles hr$^{-1}$)

Salt Exposed (Outflow)

Salt Unexposed (Inflow)
Methanogenesis

Everything effects Methane, mostly $[\text{NO}_3^-]$ Salt vs. $[\text{SO}_4^{2-}]$ mechanisms in different sites

Salt Exposed (Outflow)

Salt Unexposed (Inflow)
Timberlake Overview

- Outflow
- 2 Inflows
  - dry
  - int
  - wet

2 Inflows
Testing Mechanisms at Multiple Scales

• Field-scale
  – hydrologic (wet to dry) and saltwater (fresh to 4 ppt) gradients with 2 depths (0-5, 10-15 cm)
  – June during early intrusion
  – Sulfate reduction rates, Fe reduction potential, Methanogenesis potential

• Bench-scale manipulations
  – NO$_3^-$, SO$_4^{2-}$, NaCl at 3 levels (L, M, H)
  – Exposed and Unexposed sediments
  – Sulfate reduction rates, Fe reduction, Methanogenesis potential
Sulfate Reduction Rates ($^{35}$S)

SO$_4^{2-}$ Reduction (μmole C g$^{-1}$ d$^{-1}$)

- 0-5 cm
- 10-15 cm

Dry
Interm.
Wet

Arrow map showing the distribution of dry, intermediate, and wet areas.
Methanogenesis Potential

Methanogenesis (µmole C g⁻¹ d⁻¹)

-2
0
2
4
6
8
10
12
14
16
18

0-5 cm
10-15 cm

Dry
Interm.
Wet

101 105b 106 107 108 1a01 1a02 601 602

Dry
Interm.
Wet