Foraminiferal denitrification and deep bioirrigation influence benthic biogeochemical cycling in a seasonally hypoxic fjord

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Introduction

- Coastal and shelf regions are important site for nutrient cycling specially for bioavailable N.
- Bedford Basin is a eutrophic 70 m deep seasonally hypoxic fjord connected to the at Atlantic ocean through a 20 m deep sill which restricts water circulation below the sill depth. The basin gets oxygenated in winter, and hypoxia develops in summer/fall (Rakshit et al., 2023).
- Due to the seasonal cycle the basin acts as "natural laboratory" and can help us in understanding the biogeochemical processes across redox gradient.
- This is also a weekly water column timeseries station for the last 30 years.
- Several works have been done to understand the hydrography and water column nutrient cycling, but the benthic nutrient cycling has remained largely overlooked (Haas et al., 2021).
- Here we present the first detailed work on the benthic nutrient cycling from Bedford Basin.

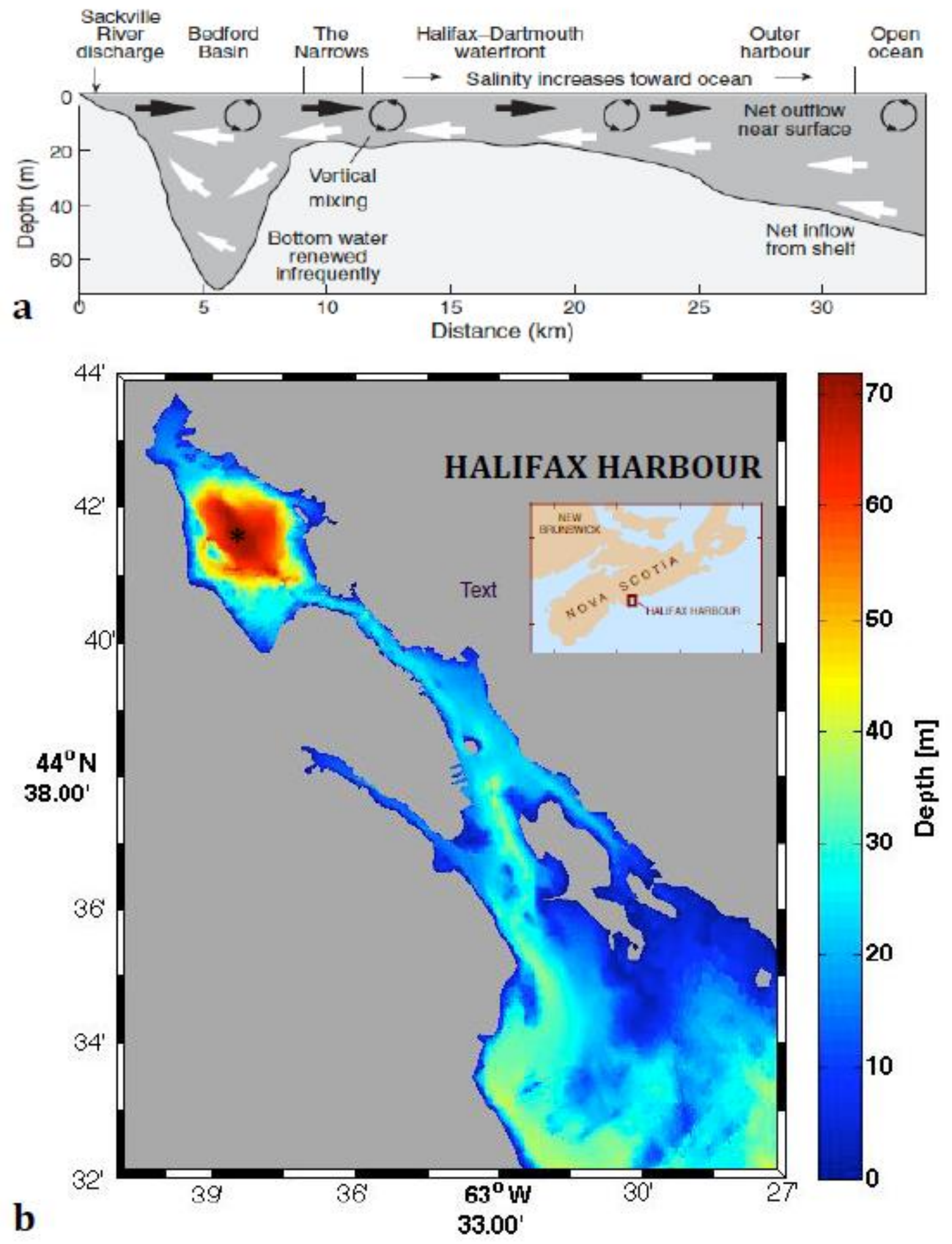


Figure: *(A) Schematic cross section and (B) bathymetry of Bedford Basin located in Nova Scotia, Canada.*

Methods

- Sediment cores were collected seasonally over three years.
- Oxygen profiles were recorded with Unisense microsensors.
- Sediment porewater nutrients and solids were measured.
- Benthic fluxes are measured by ex-situ whole core incubation.
- Anoxic incubation was performed to measure organic carbon remineralization rate at different depth of the sediment cores.
- Foraminiferal abundance was measured in the sediment, and intracellular nitrate content was measured in living foraminifera.
- A reactive transport model was developed and constrained with the above measurements.

Reactive transport modeling

$$\varphi \frac{\partial C_p}{\partial t} = \frac{\partial}{\partial z}\left(\varphi D_s \frac{\partial Cp}{\partial z} - \varphi u C_p\right) + \varphi\alpha\left(C_{p.bw} - C_p\right) + \varphi \sum R$$

← Porewater

$$(1-\varphi)\frac{\partial C_s}{\partial t} = \frac{\partial}{\partial z}\left((1-\varphi) D_b \frac{\partial C_s}{\partial z} - (1-\varphi) v C_s\right) + (1-\varphi)\sum R$$

← Solids

$$\varphi \frac{\partial C_{cNO3}}{\partial t} = \varphi\gamma\left(C_{cNO3.0} - C_{cNO3}\right) + \varphi \sum R$$

← Intracellular NO_3 in foraminifera

State variables:
OM (3 fractions), Fe-oxides (3 fractions), FeS, pyrite, Mn-oxides (2 fractions), O_2, DIC, NH_4^+, NO_3^-, Fe^{2+}, Mn^{2+}, SO_4^{2-}, H_2S, CH_4, $NO^-_{3\ foraminifera}$

Transport Processes:
- Diffusion, advection
- Bioturbation
- Bioirrigation
- Foraminiferal nitrate uptake

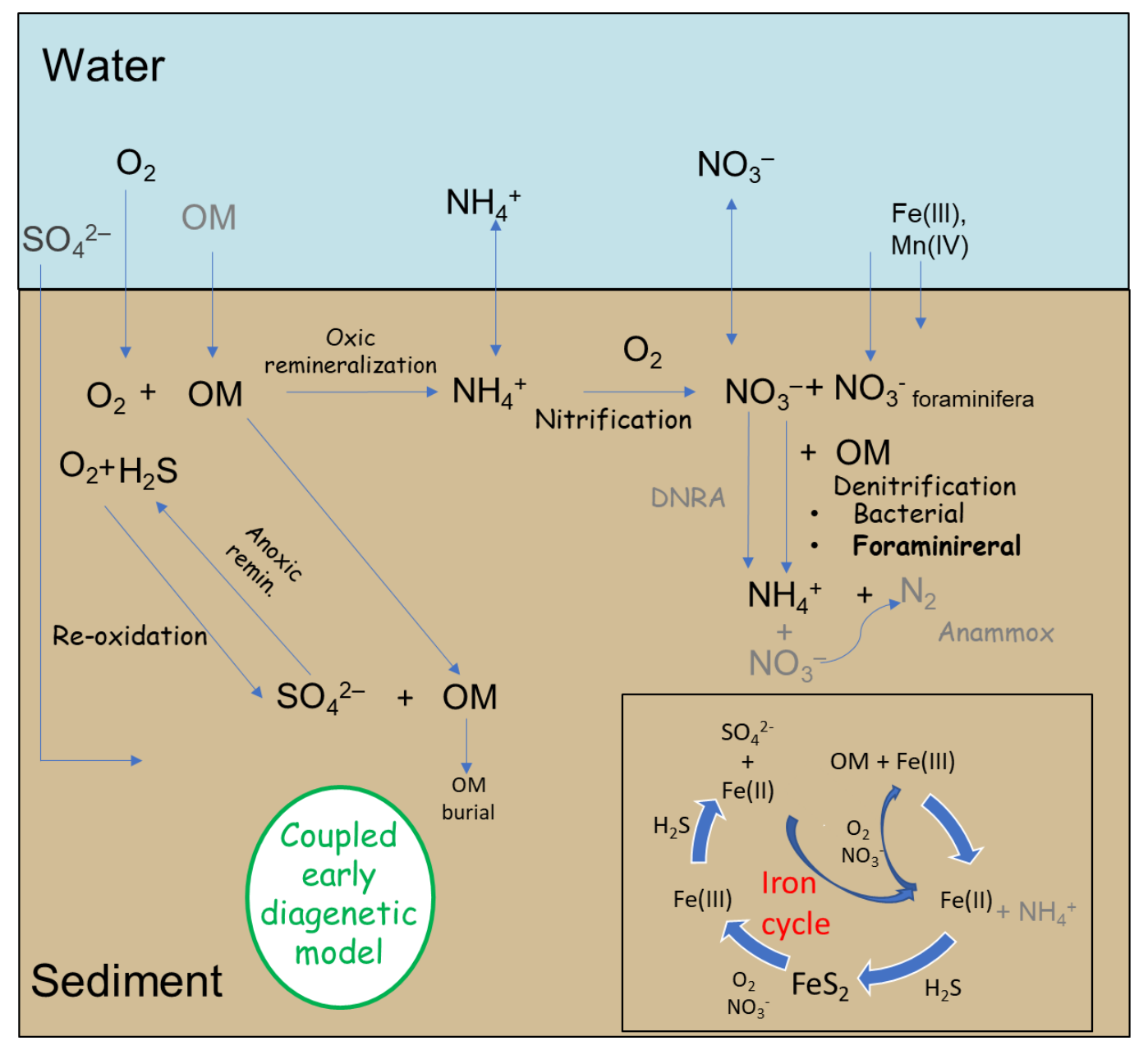
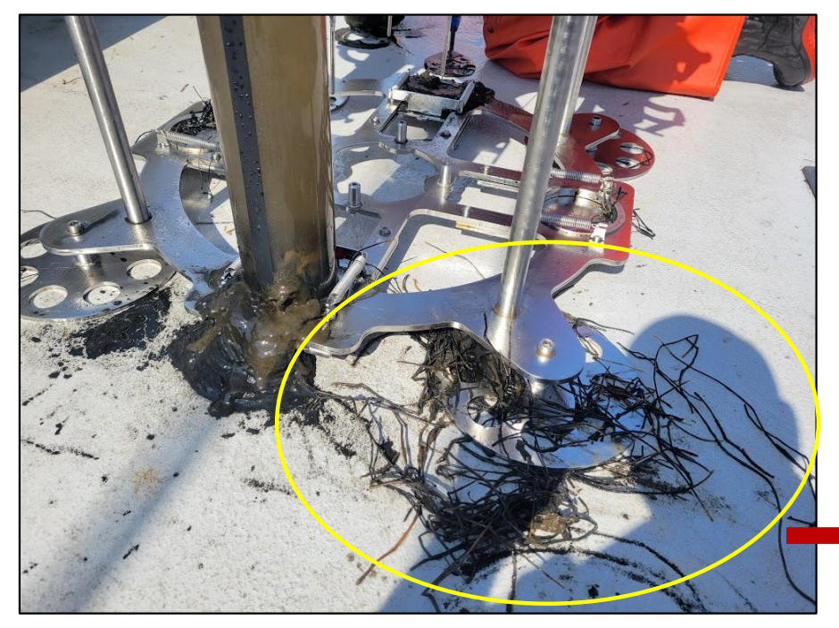


Figure: *Modelled reaction network.*

Results



Long (up to 1-1.5 ft) tubeworms *Spiochaetopterus sp.* Bioirrigation a dominant feature?

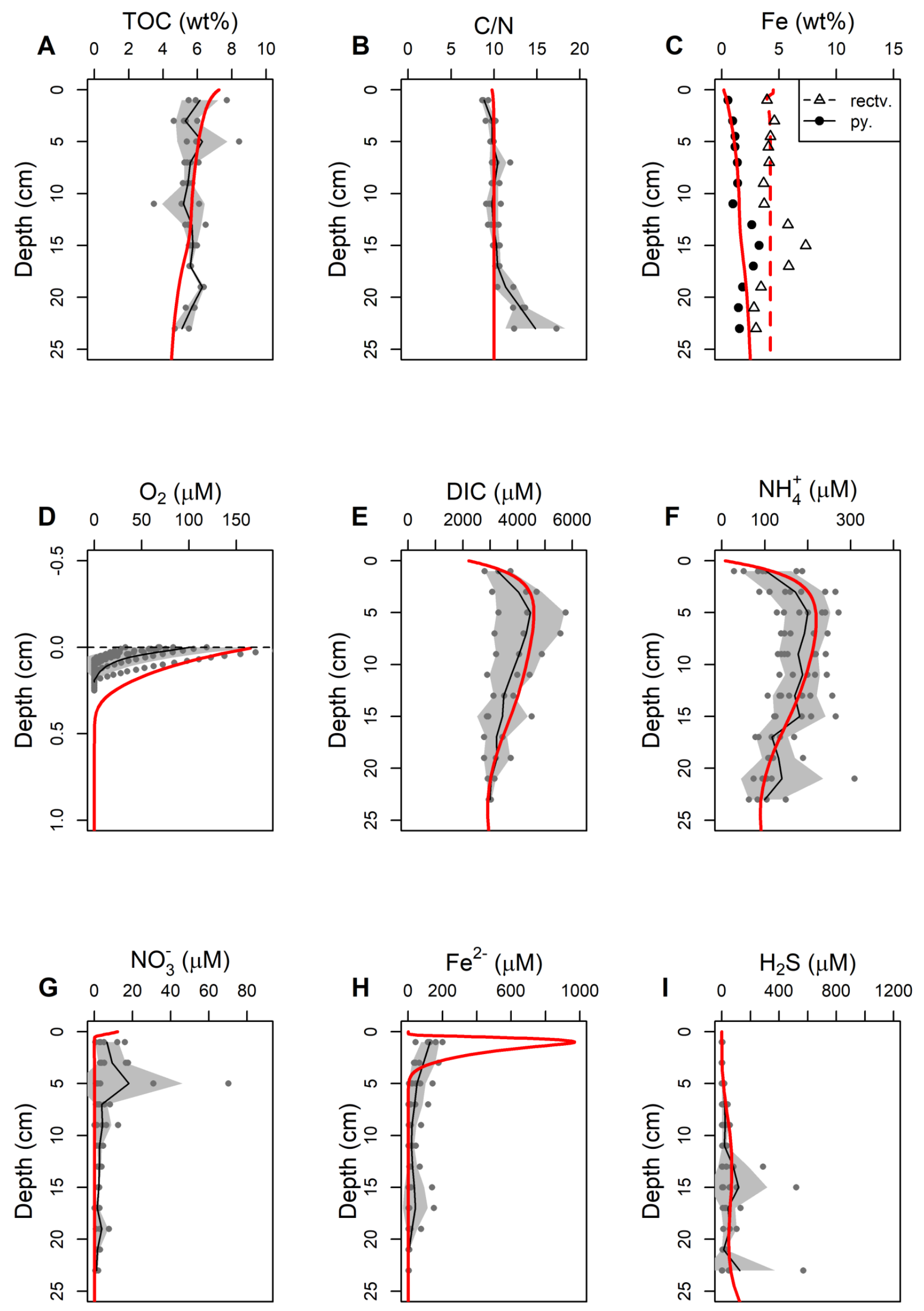


Figure: *Sediment porewater nutrients and solids distribution in Bedford Basin sediment. Symbols, black line and shaded area represent all seasonally measured data, mean, and std. dev. respectively. The red lines are the steady state model simulation.*

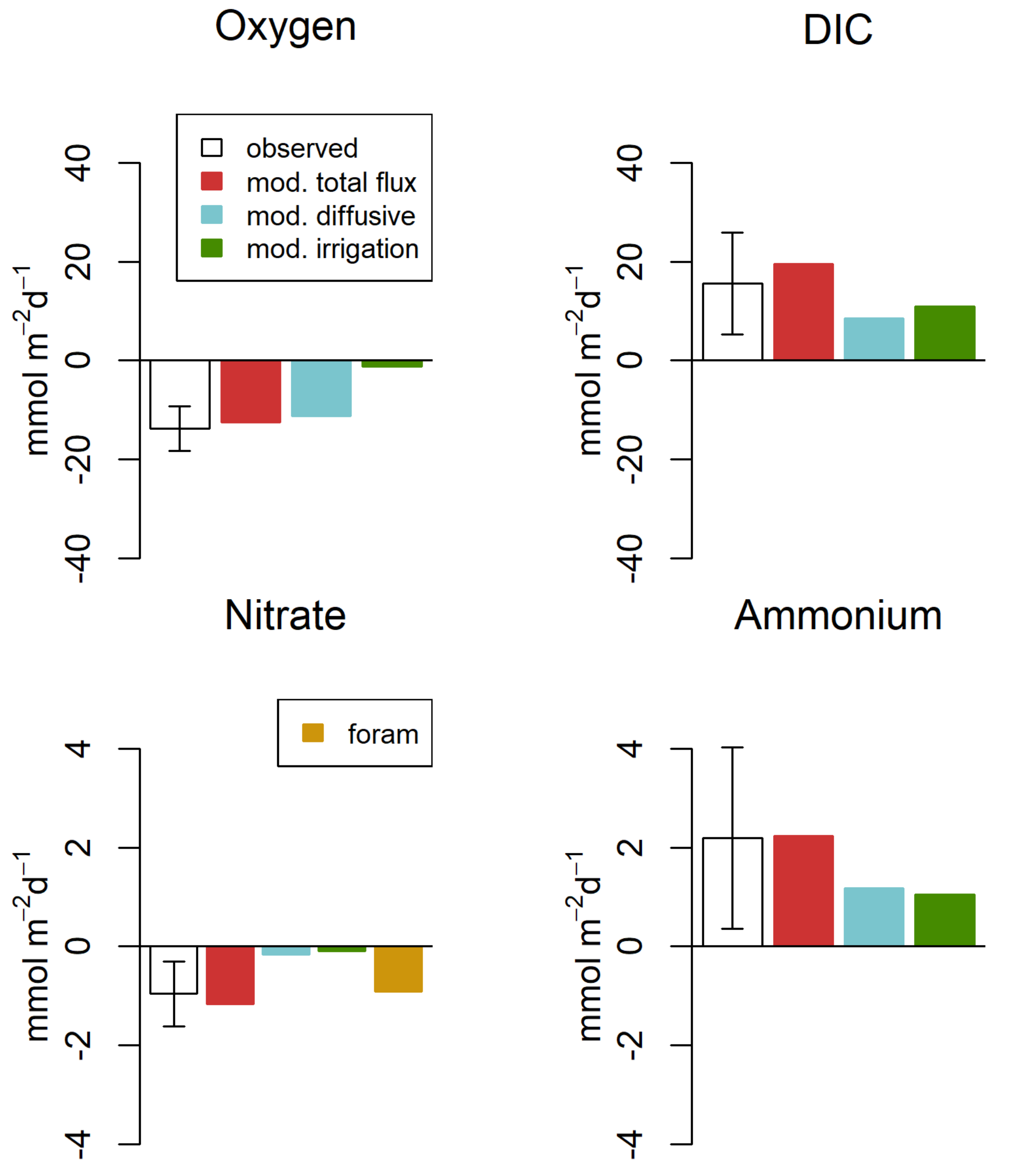
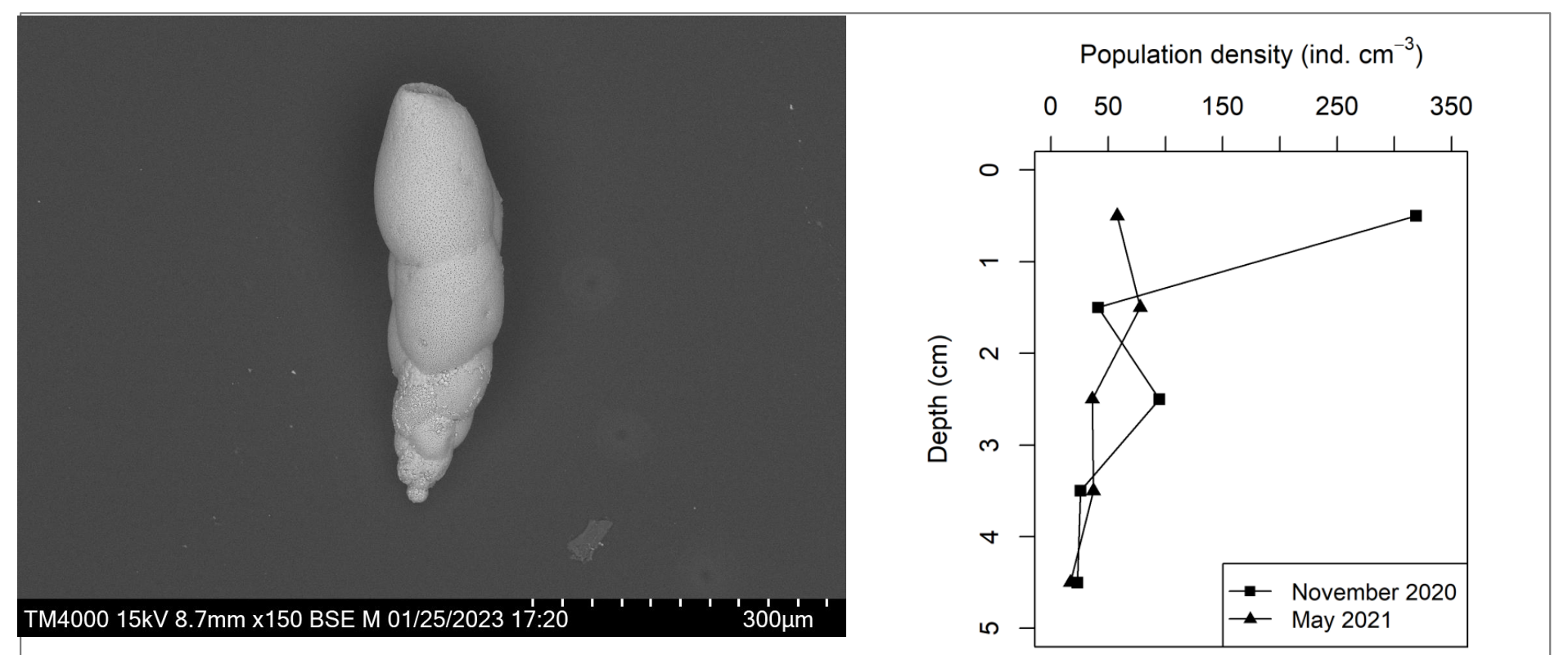
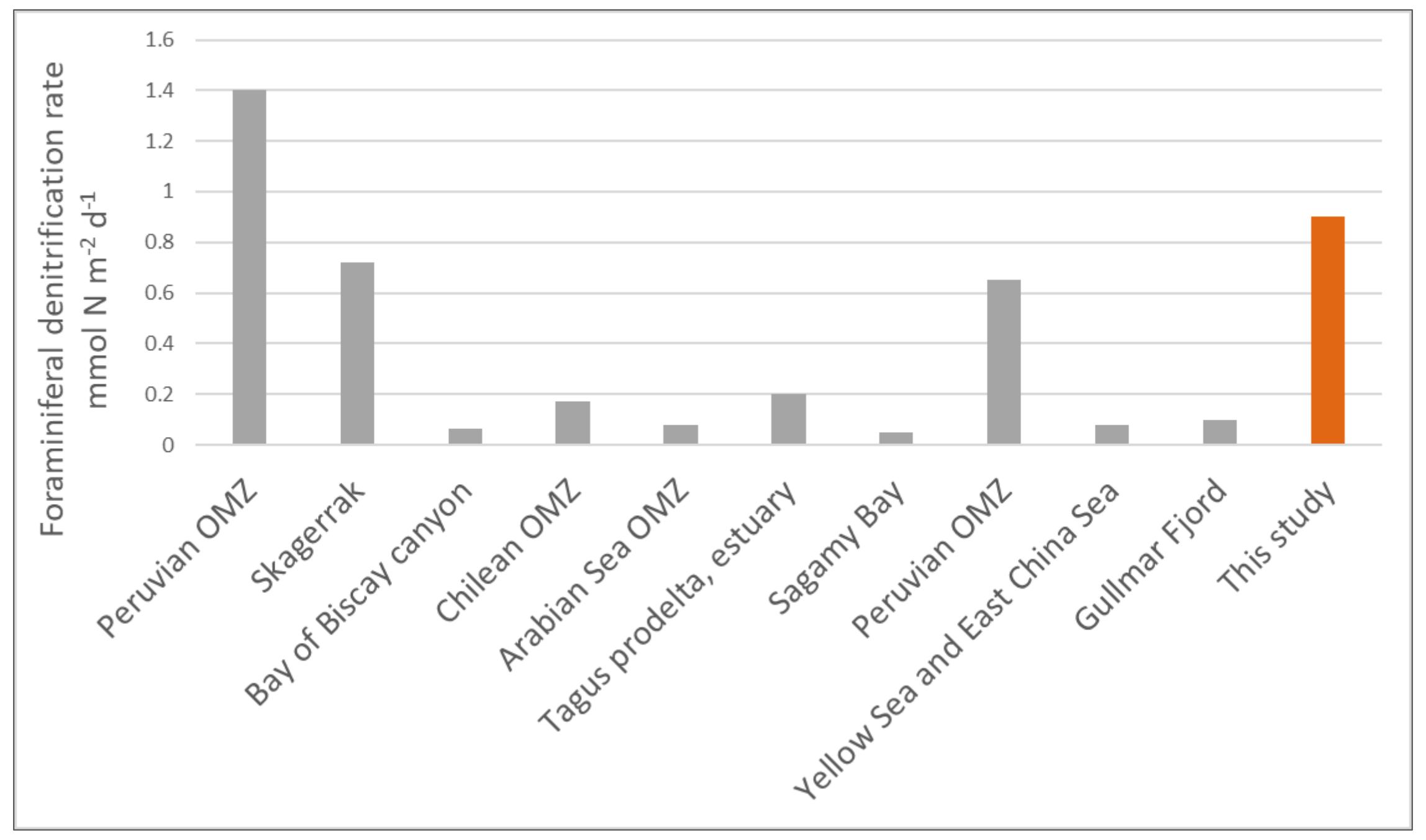


Figure: *Sediment-water fluxes.*



Benthic denitrifying foraminifera
Stainforthia fusiformis dominated(>85%) the foraminiferal assemblage in Bedford Basin, and they were found distributed in the top 5 cm of the sediment.

Summary and conclusions



- Foraminiferal denitrification (Risgaard-Petersen et al., 2006) contributed up to 70% of the total denitrification in Bedford Basin sediment.
  - First evidence of this process from Western Atlantic sediment.
- Bioirrigation shapes the benthic geochemical distribution, and ~50% of benthic efflux of DIC and NH_4^+ could be attributed to bioirrigation.
- Bioturbation, along with intense iron cycling helped maintaining a foot long suboxic zone i.e. sediment devoid of O_2 or H_2S, while oxygen penetration depth was only 1 mm.
- Demonstrates how observation and modeling together can unravel biogeochemical processes which otherwise could have been overlooked.

Acknowledgement

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References:

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