Nutrient enrichment alters the carbon storage function of a New England salt marsh

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Background

Figure 1. Marshes from the ecosystem N-enrichment experiment. The control creek (a, b, c) possesses healthy creek banks, while the N-fertilized creek (d, e, f) shows significant bank collapse (Deegan et al. 2012).

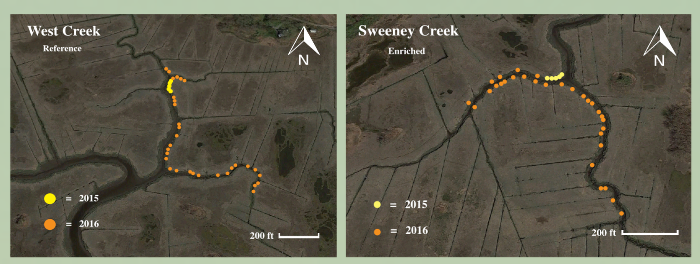

Figure 2. Study sites at the Plum Island Ecosystem LTER site in Rowley, Massachusetts. Locations of carbon flux sampling at reference (top) and enriched (bottom) creeks are overlain.

- Coastal wetlands are among the most productive ecosystems on Earth, and are responsible for numerous ecosystem services such as flood protection, water filtration, and carbon (C) sequestration
- Few manipulative studies have evaluated empirically how global change factors like nutrient enrichment could influence blue carbon processes at the ecosystem scale
- A prior study (Deegan et al. 2012, Nature 490:388-392) suggested that chronic nutrient pollution at our study site can reduce belowground productivity, and induce eco-geomorphic feedbacks that induce creek bank instability and conversion to mudflats
- Nitrogen (N) can stimulate primary production and theoretically increase net ecosystem exchange (NEE) and gross primary productivity (GPP)
- However, N may also stimulate activity of anaerobic bacteria (increasing ecosystem respiration (R_{eco}))
- Given the important role of coastal wetlands as blue carbon stores, there is a pressing need to understand how landscape-level N pollution alters C fluxes (GPP, R_{eco}, and NEE) and influences ecosystem C dynamics

Research Question

How could chronic N-enrichment impact the C storage ability of salt marsh ecosystems?

Methods

- **TIDE Project** = long-term nutrient enrichment experiment in MA that studies two creeks; Sweeney Creek (N-enriched with NO_3^- from May-October from 2004-2016) and West Creek (reference control) Sweeney Creek was enriched to ~70-100 µM NO_3^-, which is ~15× that of the reference creek (West Creek).
- Fluxes of greenhouse gases (GHG) CO_2 and CH_4 were measured using static, gas-tight chambers placed in low marsh *S. alterniflora* stands from June-August in 2015 and 2016
- On sampling periods, we measured GHG concentrations in chamber headspace w/ a portable Greenhouse Gas Analyzer (Los Gatos Research, San Jose, USA) under light & dark conditions (Figure 3a,b) while recording ambient air temp., soil temp., and photosynthetically active radiation (PAR)
- Generated NEE light response curves for both treatments by supplementing the dataset with fluxes measured under medium and low light (i.e, using one or two mesh shade cloths, respectively)
- Aboveground biomass (AGB) and belowground biomass (BGB) within each flux collar was destructively sampled after flux measurements, dried, and weighed
- Mixed-effects linear models determined how strongly N enrichment influenced C fluxes and *S. alterniflora* biomass. Fixed effects used in the models: day of year (DOY), temperature (air temp. for GPP and NEE but soil temp. for R_{eco} and CH_4), year (2015 or 2016), creek (Reference or Enriched) and interaction effects
- We used multi-model inference to quantify the influence of fixed effects on response variables in R 3.3.2

Total Ecosystem C Budget

To determine the net growing-season effect of N enrichment, we estimated C fluxes at 15 minute intervals April-October 2016. GPP was estimated using a PAR time series in combination with treatment-specific light response curve; R_{eco} was added to NEE to determine GPP. Resulting GPP and R_{eco} estimates were then adjusted to ambient temperature conditions using Q_{10} coefficients. Separtate coefficients were used for GPP and R_{eco}, with typical values from the literature applied. NEE was calculated as the sum of temperature-adjusted GPP and R_{eco} values. Finally, rates were summed over the course of each day.

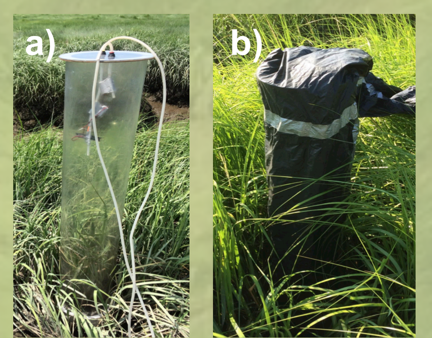

Figure 3. Flux chambers in the field in 2016. (a) Net ecosystem exchange (NEE) of carbon was calculated from the uptake rate of CO_2 over two-three minute intervals while chambers were exposed to ambient PAR. (b) To estimate ecosystem respiration (R_{eco}), flux chambers were darkened by covering the chamber with a reflective, opaque material. GPP was calculated as the difference between NEE and R_{eco}. The chambers used in 2015 were larger with metal frames.

Results

We found that N enrichment increased ecosystem respiration (R_{eco}) by 8-65%, gross primary productivity (GPP) by 67-113%, and aboveground biomass by 77-179%. However, nitrogen had no effect on net ecosystem exchange (NEE), methane emissions, or belowground biomass. Our estimate of net C flux throughout the growing season (May 1 – September 1, 2016) indicated that the reference marsh released 355 g C m^{-2} yr^{-1} into the atmosphere, while the N enriched marsh released 1062 g C m^{-2} yr^{-1}, given its greater R_{eco} rates but similar NEE rates. The total ecosystem C budgets are fairly high compared to previous findings, but will likely decrease when we have adjusted our model to include soil temperatures. However, the relative difference will remain the same once we adjust our model, given the differences in R_{eco} between the two creeks.

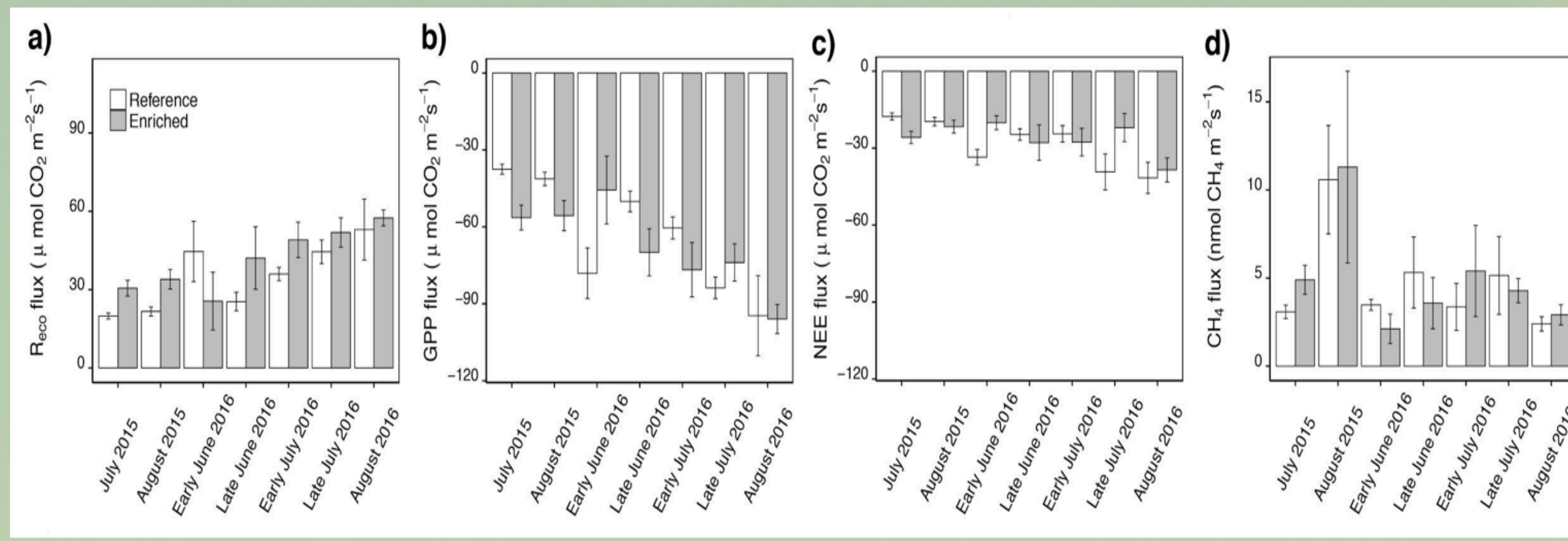

Figure 4. Mean (± SE) carbon flux rates at reference and nitrogen enriched creeks in 2015 and 2016. (a) R_{eco}, ecosystem respiration; (b) GPP, gross primary productivity; (c) NEE, net ecosystem exchange; and (d) CH_4, methane emissions.

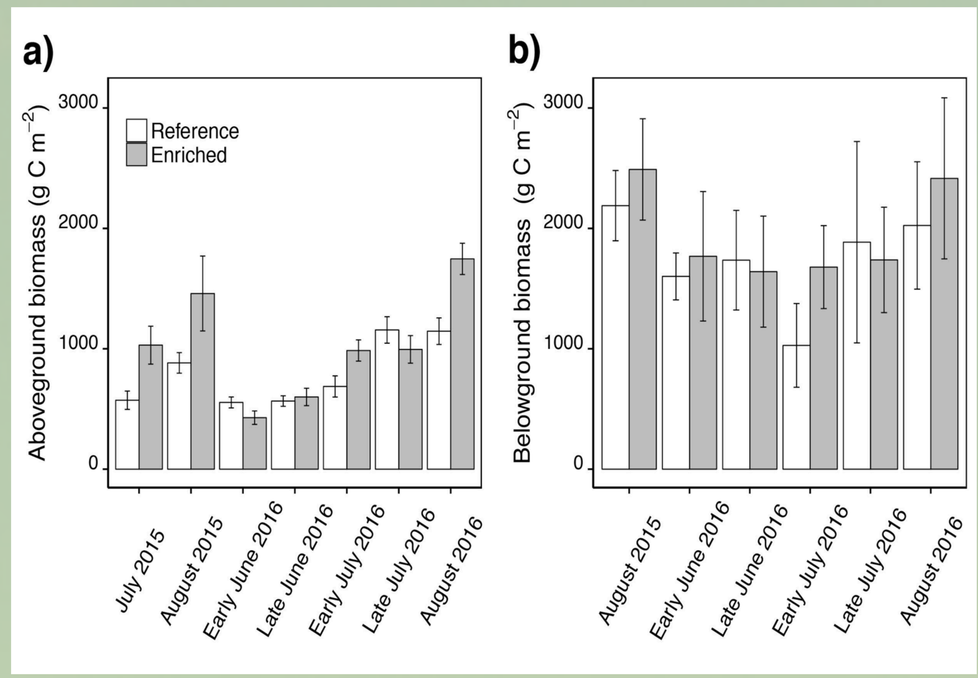

Figure 5. Mean (± SE) standing crop aboveground (a) and belowground (b) biomass at the reference and nitrogen enriched creeks. July 2015 AGB values were estimated via an allometric model. No data are available for belowground biomass in 2015.

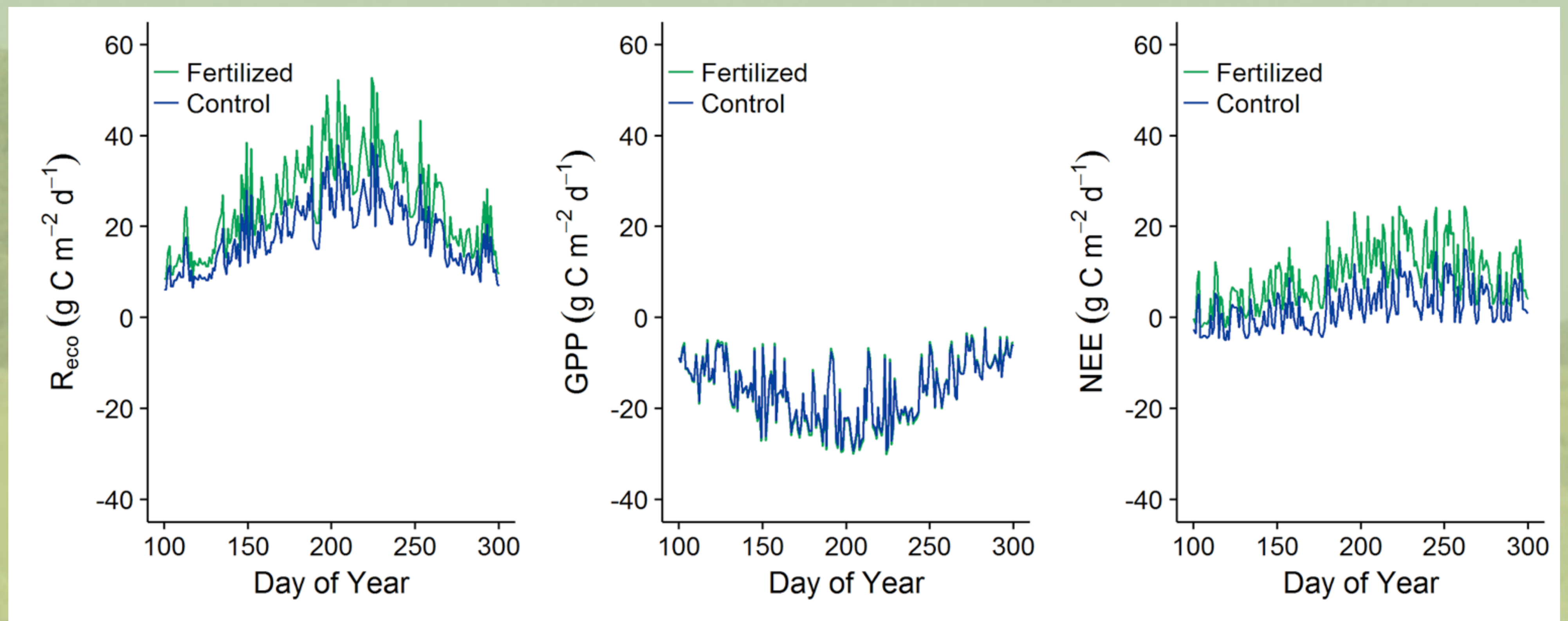

Figure 6. Simulated GHG fluxes of both creeks throughout the 2016 growing season (approx. April-October). Light response curves were generated from measuring NEE under three light conditions (full light, medium light, and low light). Model normalized for biomass and light levels were projected daily.

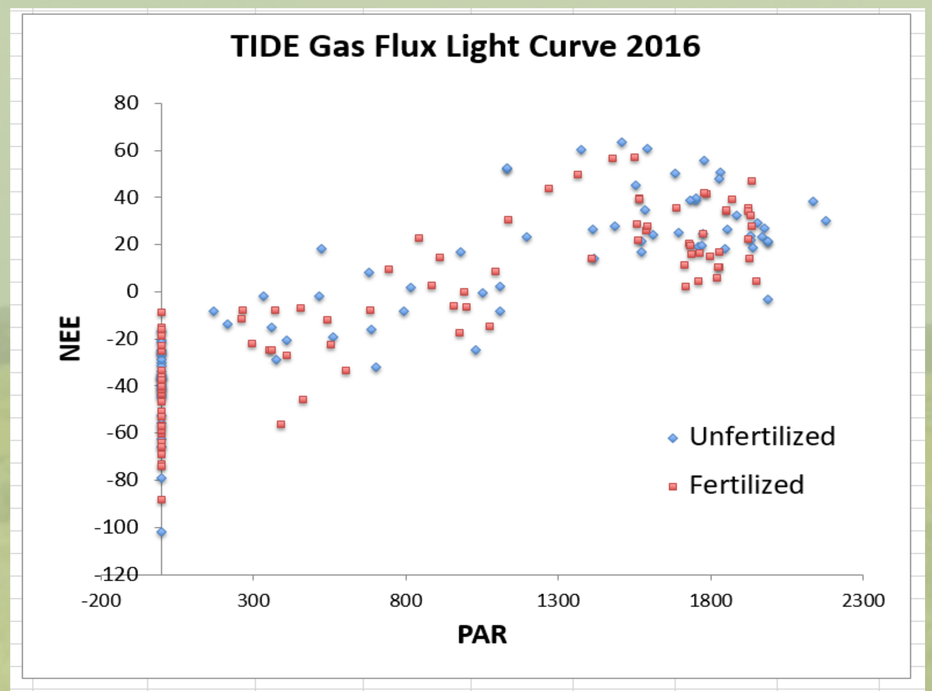

Figure 7. Gas flux curve generated from GHG NEE and PAR data collected in 2016 using different light levels. This curve was applied to the total ecosystem C budget model that summed daily NEE within each creek (Unfertilized and Fertilized) over the course of the growing season.

Discussion

- By stimulating R_{eco} but not GPP, N-fertilization could transform this and similar salt marshes from well-established C sinks into weak sinks or even sources of atmospheric C
- While our study did not differentiate between soil and plant respiration, the similar levels of belowground biomass in our study (Figure 4) suggest that changes in R_{eco} are likely due to N altered soil microbial activity
- Given the established role of soil organic matter in maintaining surface elevation, losses of soil C through accelerated R_{eco} may decrease soil surface elevation
- Affected marshes and would be more susceptible to sea level rise and marsh bank collapse could accelerate, creating a positive feedback
- Unless coastal N management improves, wetlands such as this may export centuries' worth of sequestered soil C into the oceans and atmosphere

Conclusions

Our results suggest that increased N input to tidal salt marshes could weaken their C storage function through enhanced respiration of sequestered C. In some cases, marshed that were net C sinks may reverse to become C sources.

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