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Carbon dioxide uptake fluxes in coastal salt marshes reveal ecological similitudes and environmental regimes

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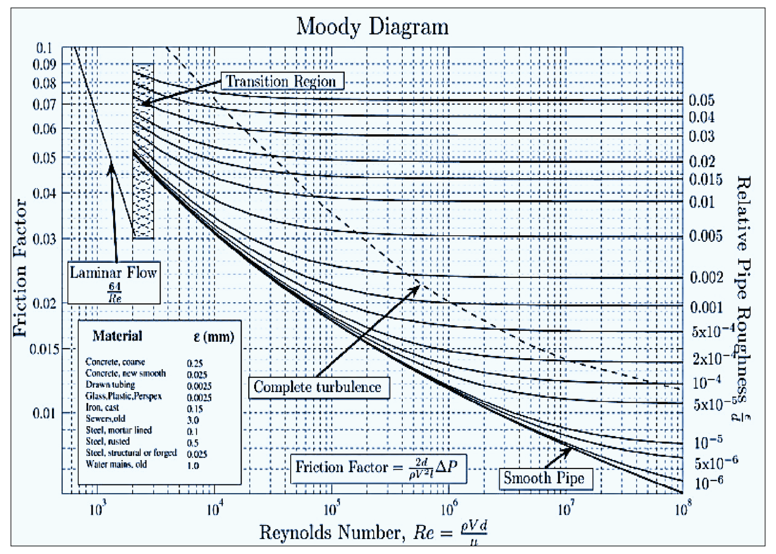
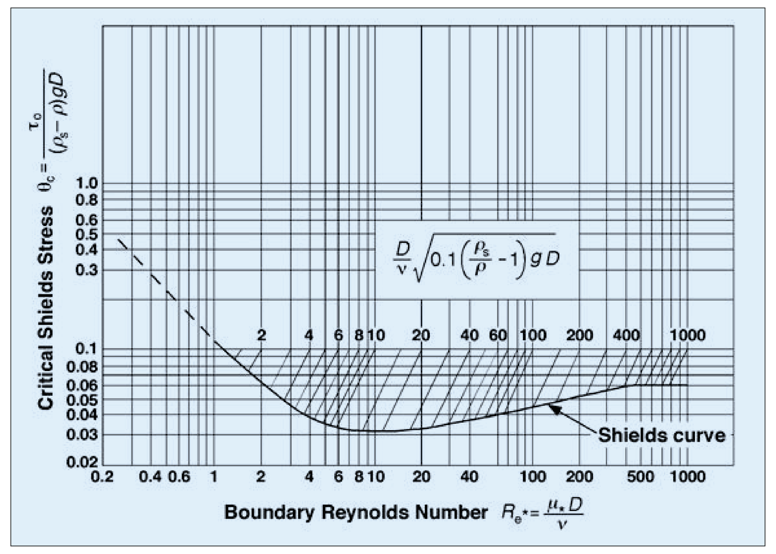
Background

Coastal wetlands are among the most potent carbon sinks on earth. Understanding of the wetland carbon dioxide (CO_2) exchange processes is pivotal to the ecological stability because of the vulnerability of wetland ecosystems to global environmental change. The magnitude and variability of CO_2 in coastal wetlands depend on their complex nonlinear interplay with the major environmental drivers.

It remains unexplored whether the primary drivers of wetland CO_2 fluxes can be grouped into a reduced set of emergent generalizable entities that represent the coastal wetland productivity potentials in response to a changing environment. A fundamental scientific question therefore is, can we identify ecological parametric reductions, known as "similitudes" in fluid mechanics and hydraulic engineering, describing environmental regimes of CO_2 uptake in wetlands?

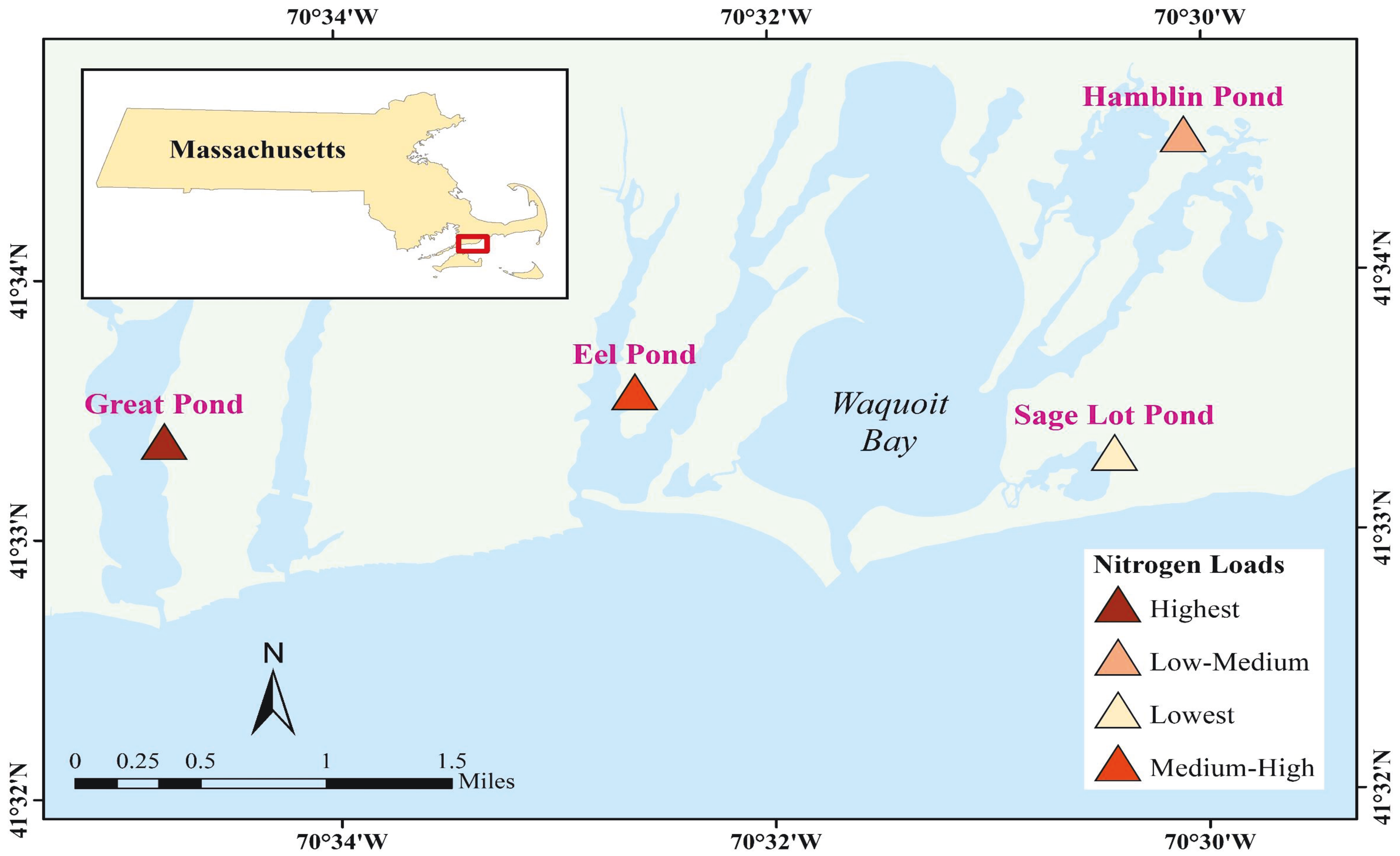




Classical examples of "similitudes" that led to the development of generalized process diagrams and scaling relationships include "Moody diagram" in fluid mechanics and "Shields diagram" in sediment transport

To answer this question we applied similitude and dimensional analysis to provide insights into ecological parameter reductions and emergent patterns of CO_2 fluxes, and identify the environmental regimes that wetland CO_2 fluxes follow (Ishtiaq and Abdul-Aziz 2020).

Study site



Locations of the case study salt marshes along the southern shore of Cape Cod in the Waquoit Bay and adjacent estuaries, MA. Nitrogen (N) loading rates of the Sage Lot Pond, Hamblin Pond, Eel Pond, and Great Pond were 5, 29, 63, and 126 kg/ha/year, respectively, although no significant differences in the measured CO_2 fluxes were observed with these variations in N loading (Abdul-Aziz et al. 2018)

Results

Variables, units and dimensions used for the dimensional analysis

Variables	Units	Dimensions
Daytime net uptake fluxes of CO_2 ($NEE_{CO2,uptake}$)	µmol/m²/s	$[ML^{-2}T^{-1}]$
Photosynthetically active radiation (PAR)	µmol/m²/s	$[ML^{-2}T^{-1}]$
Soil temperature (ST)	K	[K]
Porewater salinity (SS)	g/m³	$[ML^{-3}]$
Atmospheric pressure (P_a)	g/m/s²	$[ML^{-1}T^{-2}]$
Specific heat of wet soil (c_p = 1480)	J/g/K	$[L^2T^{-2}K^{-1}]$
Time (t = 1)	s	[T]

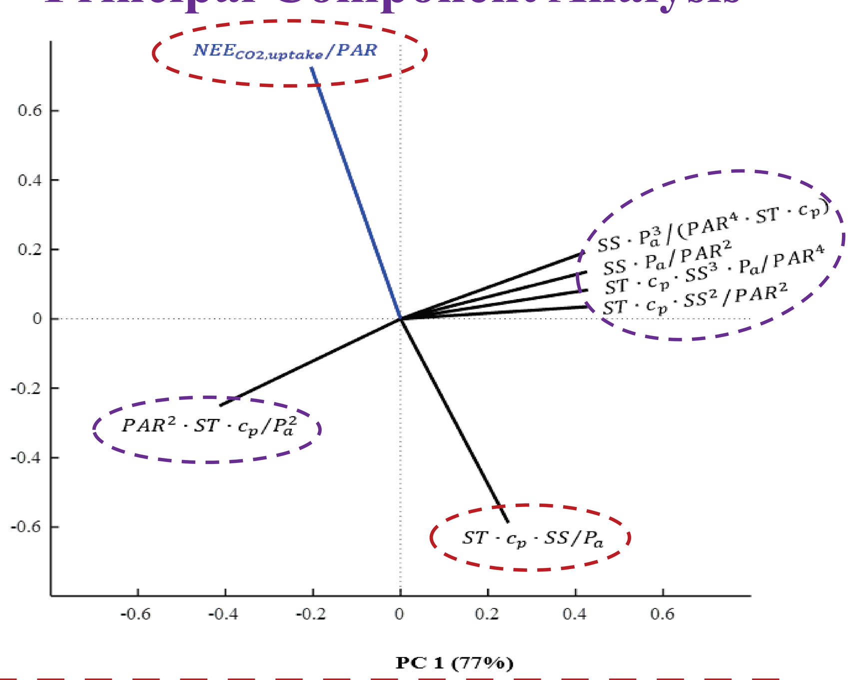
M = mass; L = length; K = temperature; T = time

Ecological parameter reduction

Buckingham Pi Theorem

$\frac{NEE_{CO2,uptake}}{PAR}$	
$\frac{SS \cdot P_a}{PAR^2}$	$\frac{ST \cdot c_p \cdot SS}{P_a}$
$\frac{ST \cdot c_p \cdot SS^2}{PAR^2}$	$\frac{PAR^2 \cdot ST \cdot c_p}{P_a^2}$
$\frac{ST \cdot c_p \cdot SS^3 \cdot P_a}{PAR^4}$	$\frac{SS \cdot P_a^3}{PAR^4 \cdot ST \cdot c_p}$

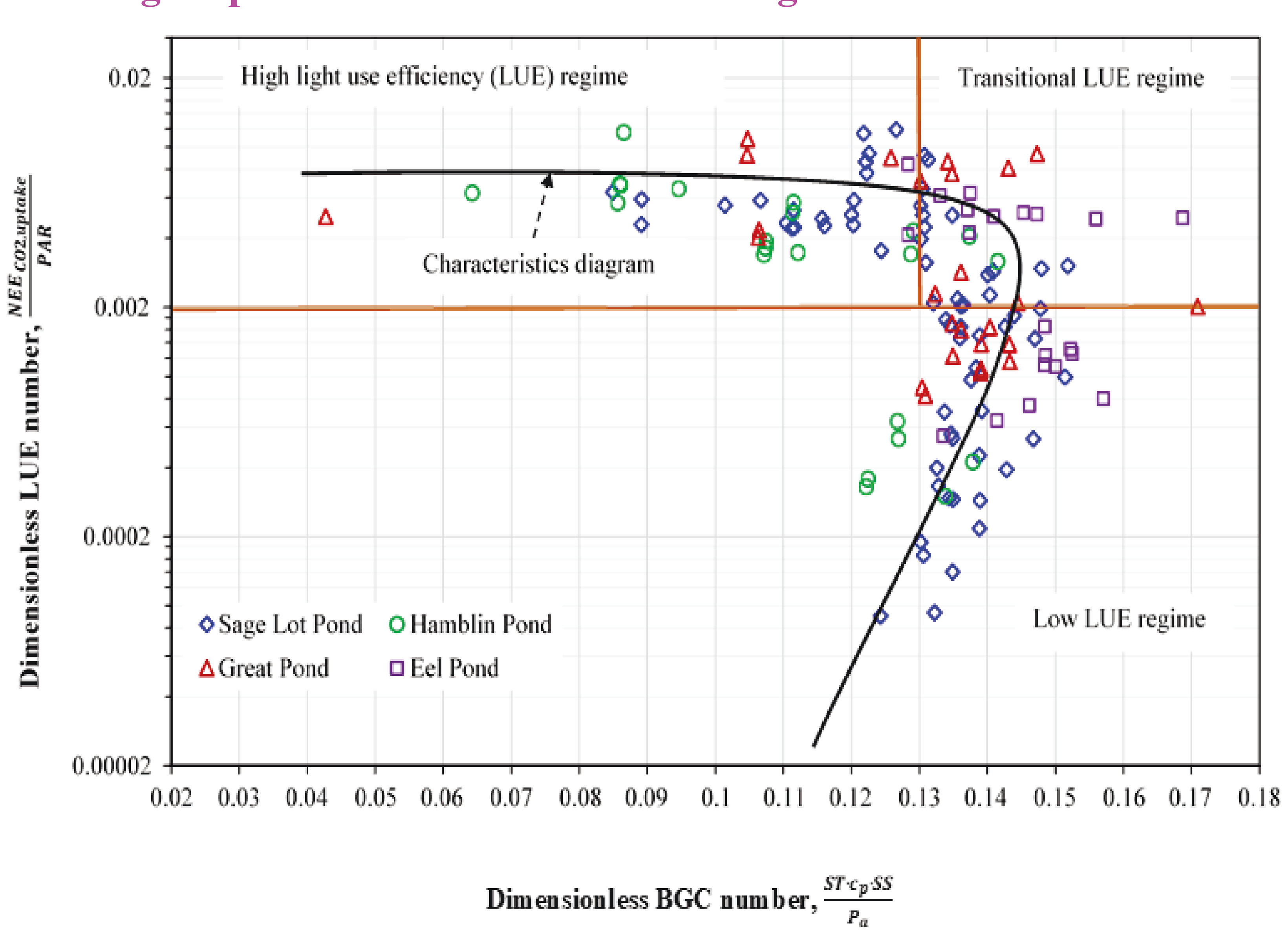
Principal Component Analysis



$\frac{NEE_{CO2,uptake}}{PAR}$ → Dimensionless Light Use Efficiency (LUE) number = $NEE_{CO2,uptake}$ normalized by daylight

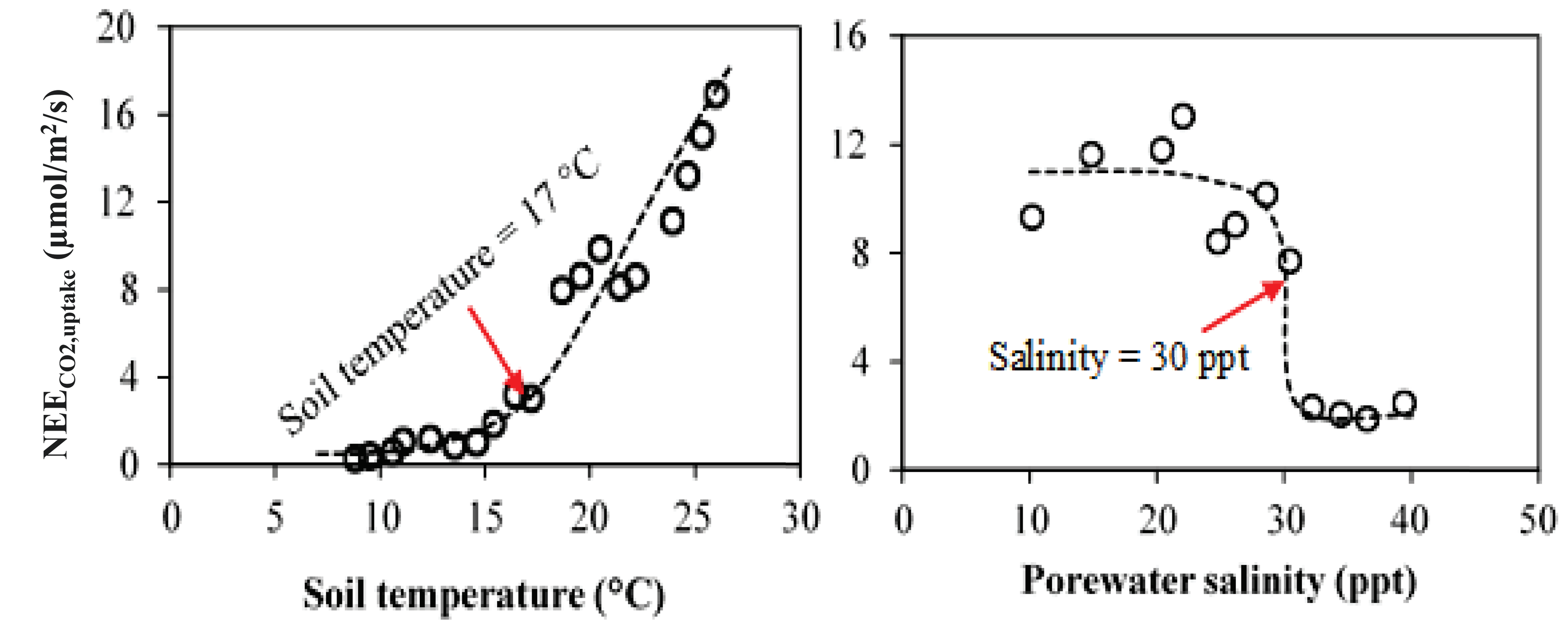
$\frac{ST \cdot c_p \cdot SS}{P_a}$ → Biogeochemical (BGC) number = interactions among soil temperature, salinity, and atmospheric pressure

Emergent patterns and environmental regimes



Results

Environmental thresholds of the identified regimes



Environmental Regimes	Thresholds of environmental variables	Environmental conditions
High	ST > 17°C and SS ≤ 30ppt	Favorable
Transitional	ST > 17°C and SS > 30ppt ST ≤ 17°C and SS ≤ 30ppt	Transition between high and low efficiency regimes
Low	ST ≤ 17°C and SS > 30ppt	Unfavorable

Conclusions

- Net CO_2 uptake fluxes in coastal salt marshes revealed ecological similitudes and distinct environmental regimes.
- Ecological similitude and dimensional analysis reduced 5 flux and ecological variables into 2 mechanistically meaningful dimensionless groups.
- Observed data revealed an emergent pattern of the dimensionless numbers that was distinctly characterized by high, transitional, and low LUE regimes and dictated by thresholds of ST (17°C) and SS (18ppt).
- The findings provided key insights into the underlying organizing principles of CO_2 uptake and the major environmental drivers in coastal salt marshes.

Acknowledgements

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