Soil carbon stocks, lability and decomposition rates of surficial and buried organic matter in a large tropical seagrass landscape

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There is a substantial amount of organic carbon stored in seagrass beds worldwide (and >90% of that is in soil), and it is at risk of loss to the atmosphere:

1. Total estimate of C_{org} stored in top meter of the world's seagrass meadows

4.2-19.8 PgC

2. 29% loss of seagrasses in 20th century, rates of loss accelerating.

3. Estimated emissions at current rates of loss of seagrass meadows:

63-297 TgC y^{-1}

Fourquean et al 2012 Nat Geosci

Is C stored in seagrass meadows relevant for climate change mitigation strategies?

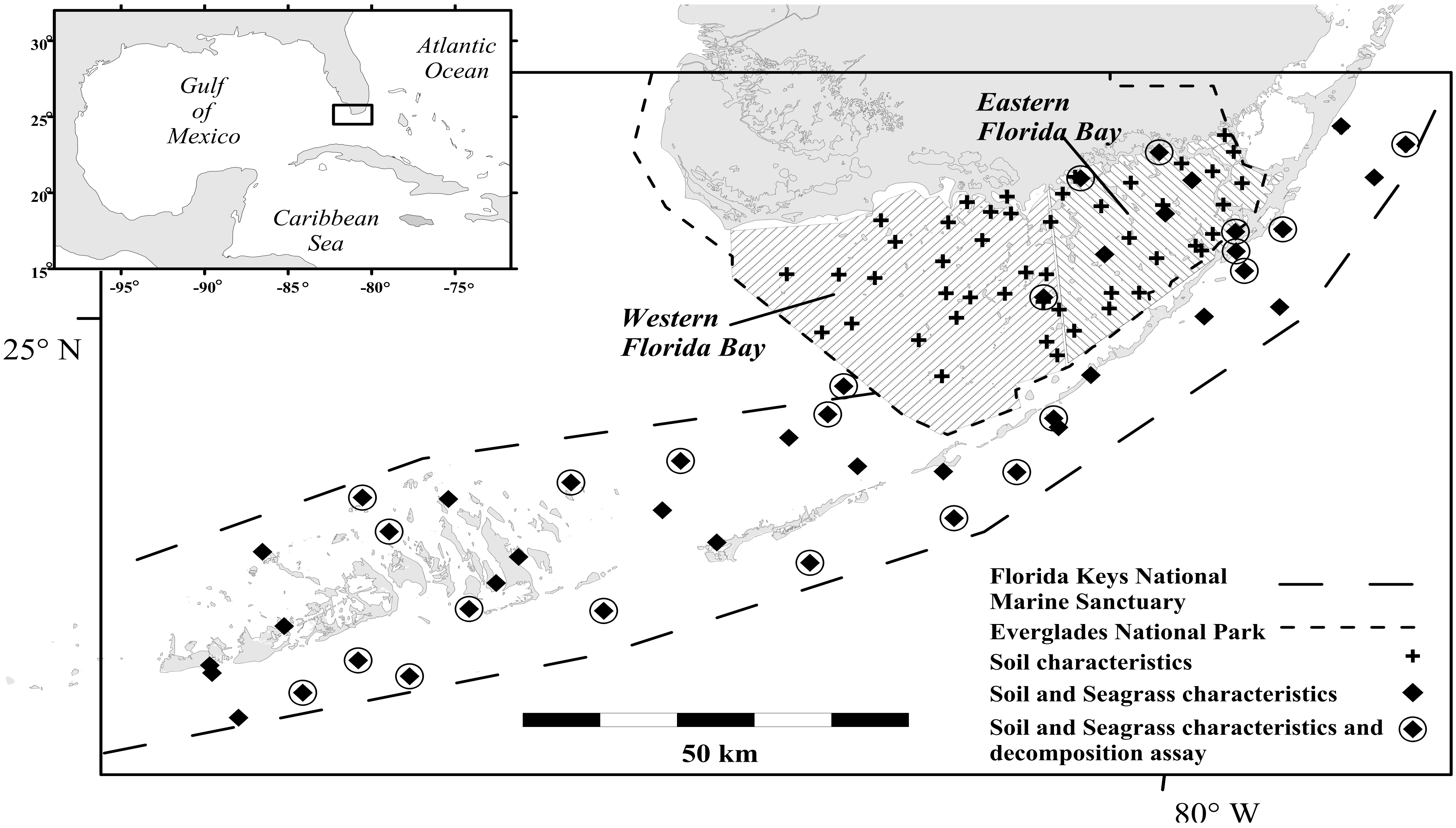
- **Business as usual is leading to huge losses of seagrass beds**
- **Would discrete actions to slow loss or create new seagrass meadows have a net atmospheric C benefit?**
  - **How labile is the C in seagrass soils?**
  - **Does the presence of seagrass encourage C deposition and stability?**
  - **Does burial increase stability of deposited C?**
  - **Is C eroded from disturbed seagrass beds returned to the atmosphere?**
- **Can net carbonate deposition in seagrasses counteract net autotrophy?**

We make the assumption that seagrasses influence the depositional environment so that seagrasses promote :

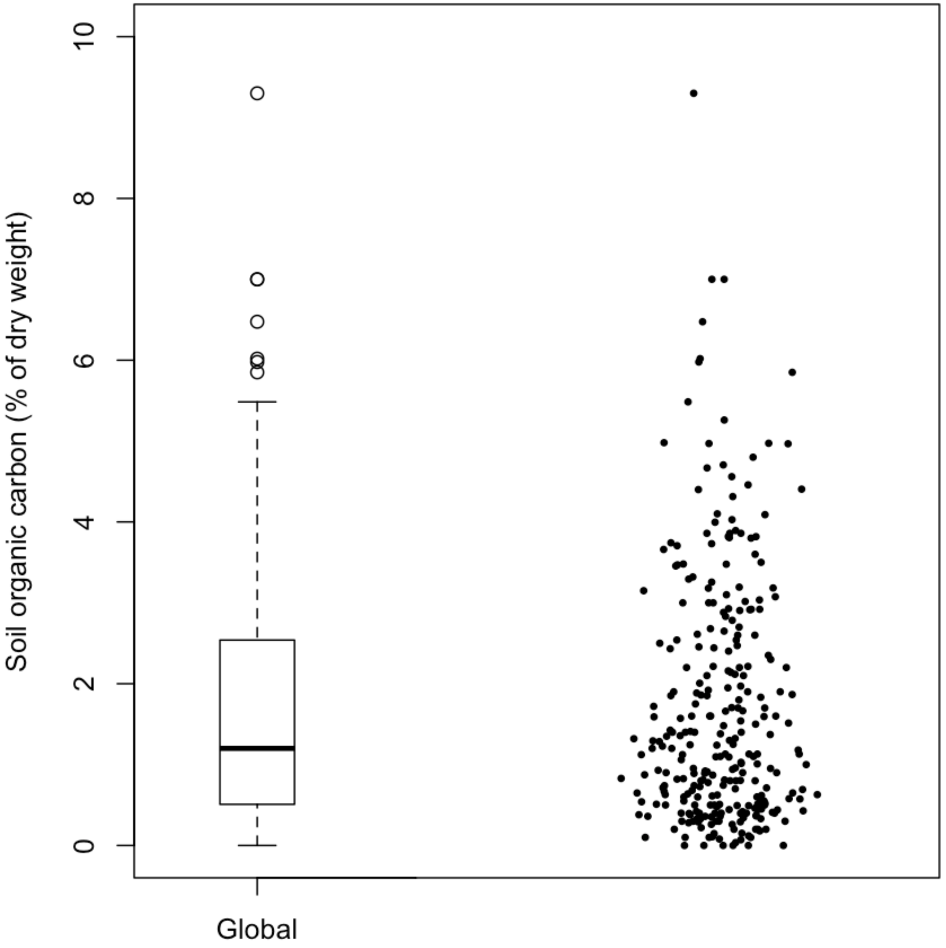
1) Sediment deposition and reduced sediment grain size
2) Anoxia, and therefore sediment OM preservation, in their soils

Given these assumptions, we tested:

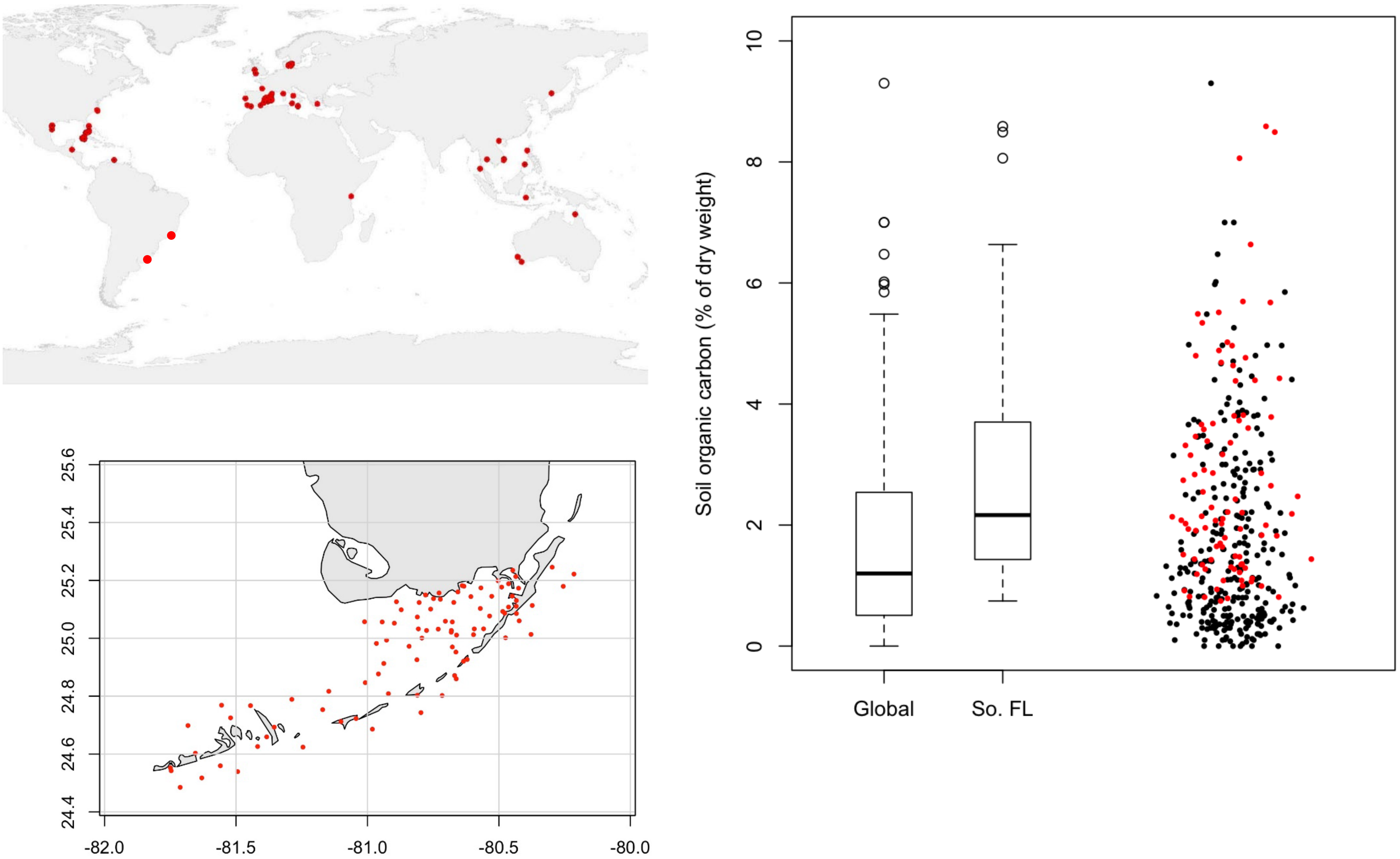
1) Whether seagrass density is negatively correlated with sediment grain size and OM content of deposits at the landscape scale
2) Whether sediment grain size is a predictor of the lability of OM stored in seagrass soils
3) If burial in seagrass soils decreases the decomposition rate, and therefore enhances preservation, of OM in seagrass soils



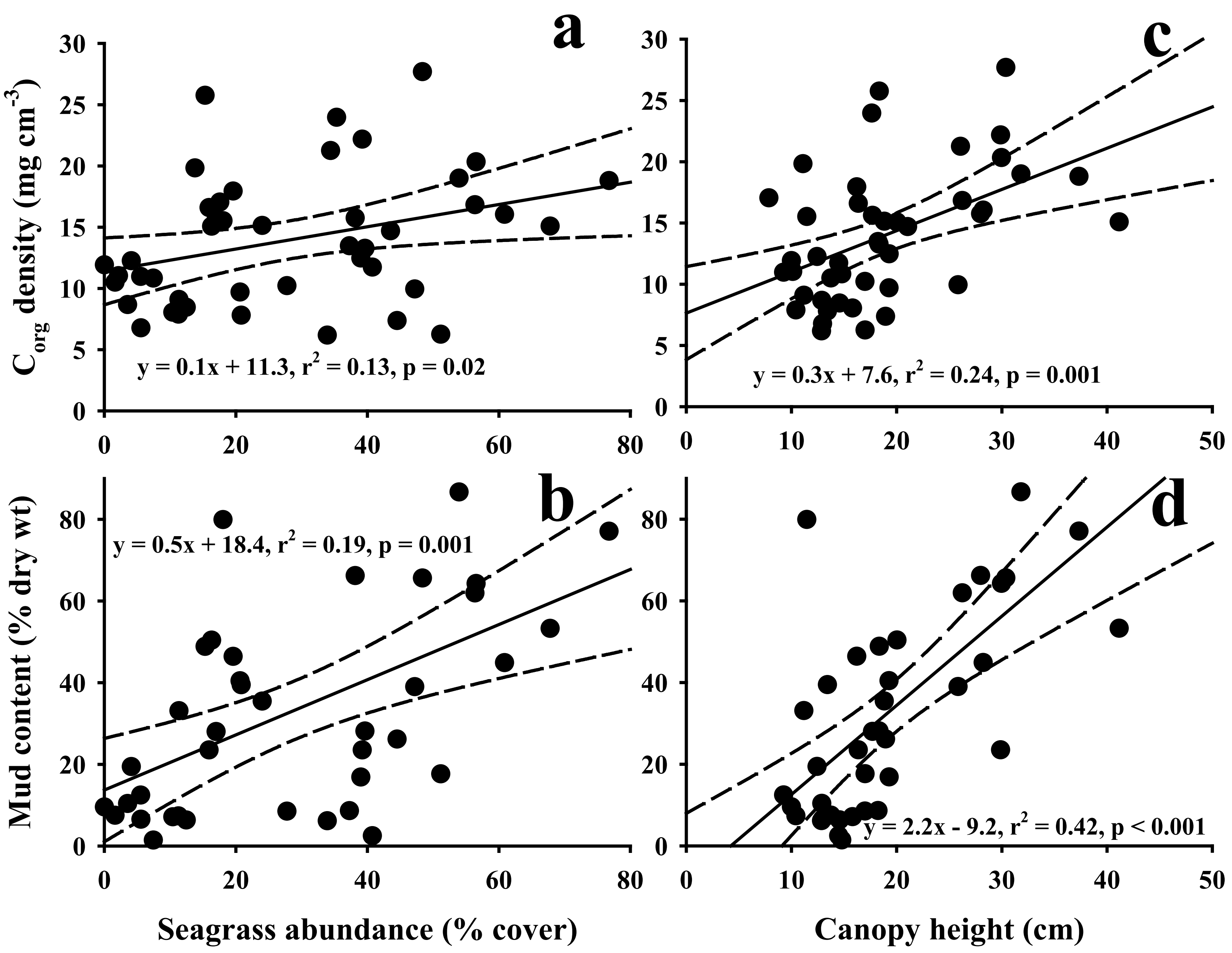
Atlantic Ocean
Gulf of Mexico
Caribbean Sea
30°
25°
20°
15°
-95°
-90°
-85°
-80°
-75°
Eastern Florida Bay
Western Florida Bay
25° N
80° W
50 km
Florida Keys National Marine Sanctuary
Everglades National Park
Soil characteristics
Soil and Seagrass characteristics
Soil and Seagrass characteristics and decomposition assay



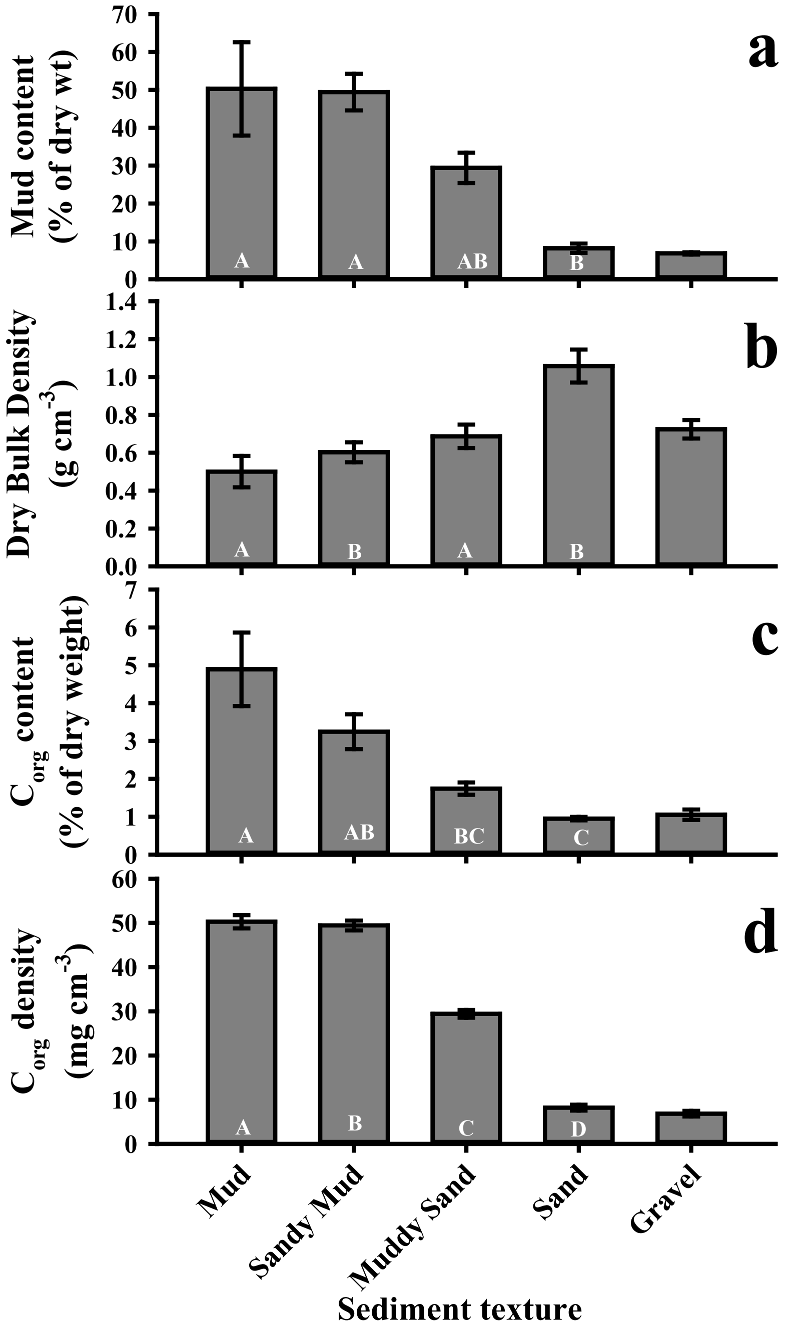
Fourqurean et al 2012 Nat Geosci



25.6
25.4
25.2
25.0
24.8
24.6
24.4
-82.0
-81.5
-81.0
-80.5
-80.0
Soil organic carbon (% of dry weight)
10
8
6
4
2
0
Global
So. FL

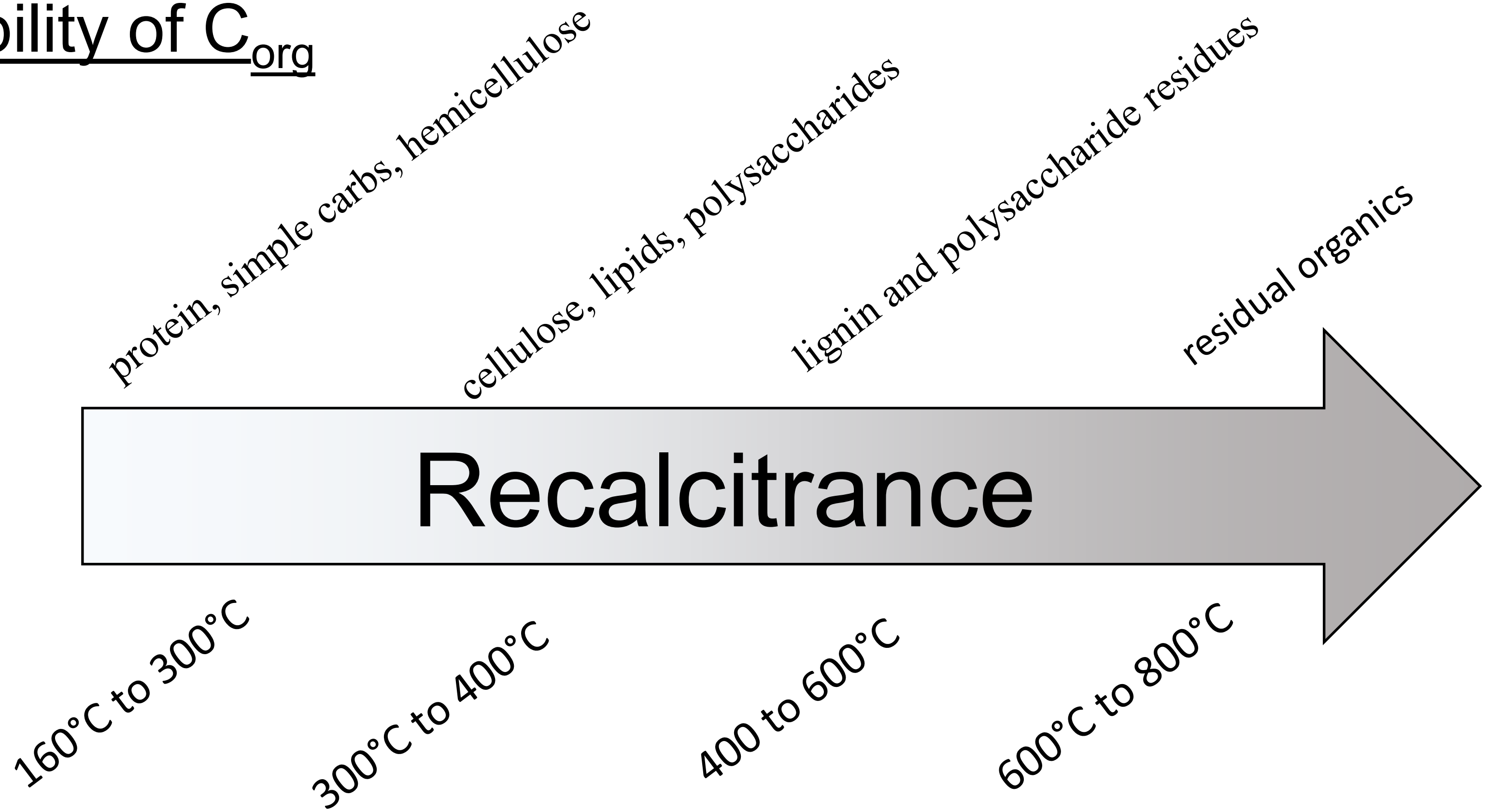


Seagrass abundance and canopy structure is correlated with sediment grain size and C_{org}, but these relationships yield poor predictive power



In comparison, seagrass soil grain size is a very good predictor of other soil properties, including C_{org} stock

Lability of C_{org}



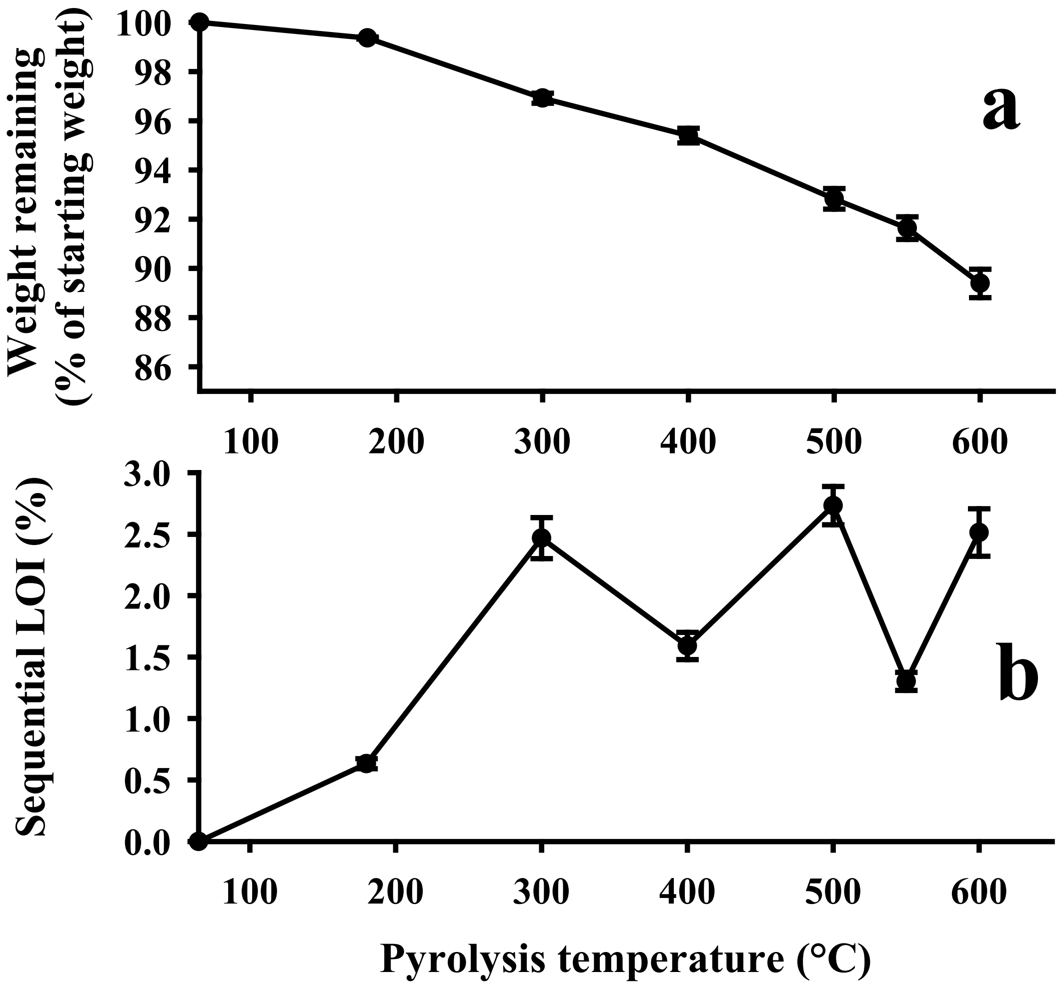
$C_{total} - C_{inorg\ (550C)} = C_{org}$

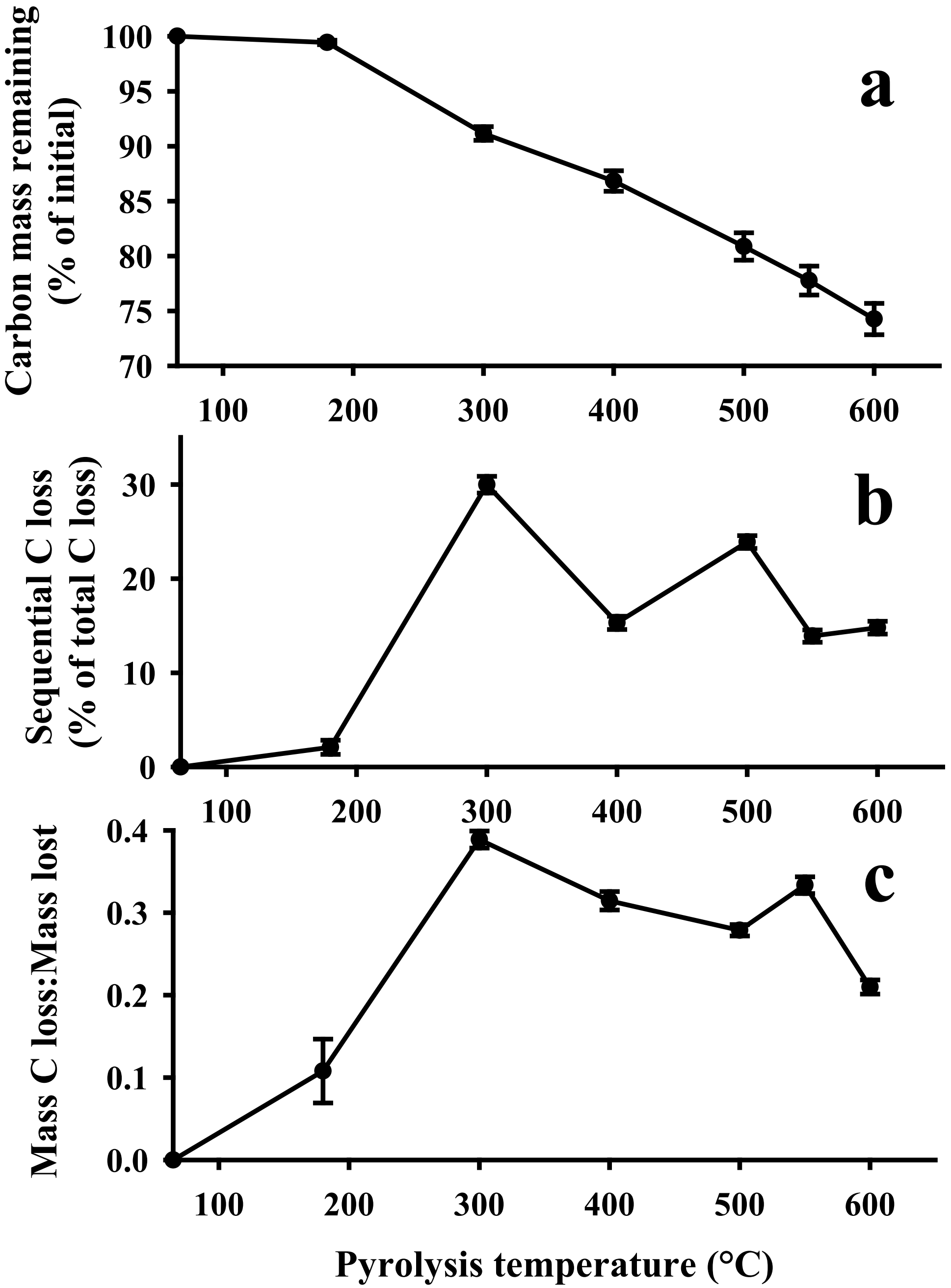
Recalcitrance Index (RI):

$$RI = \frac{C_{org}\ lost\ \ between\ 500°\ C\ and\ 550°\ C}{C_{org}\ lost\ between\ 180°\ C\ and\ 550°\ C}$$

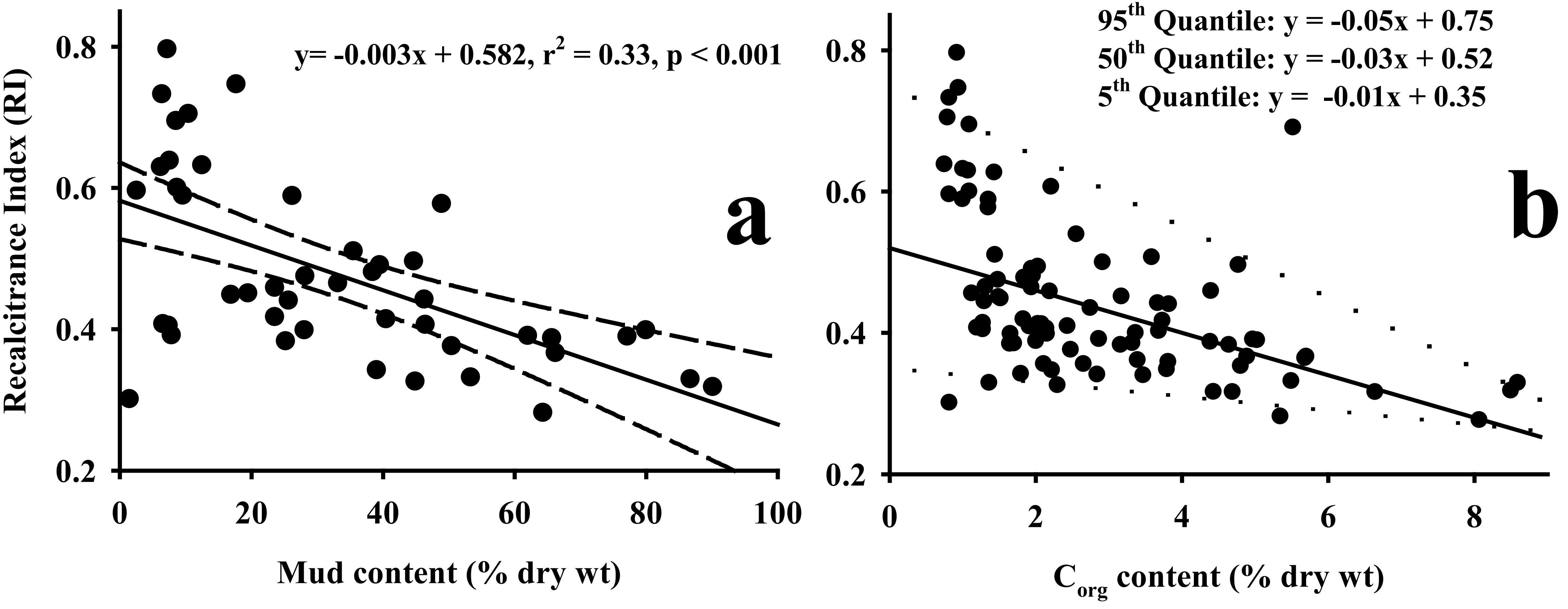
Trevathan-Tackett et al 2017 *Front Plant Sci*, Howard et al. 2021)

Mass and C continue to be lost from soil samples at all combustion temperatures from 160° to 600° C





Seagrass soil Organic matter is more labile in muddy sites with high C content



How to compare organic matter deposition rates among sites and between buried and surficial material?

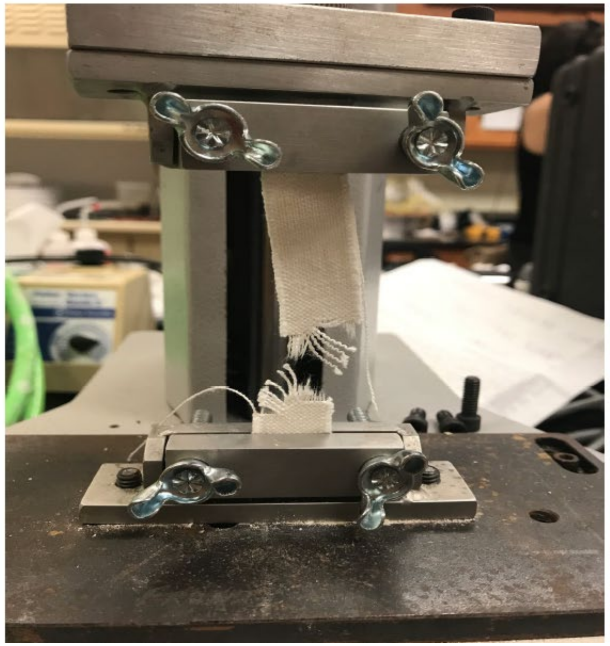
Classic decomposition experiments done with litter bags, but this technique has well-known serious problems, including:

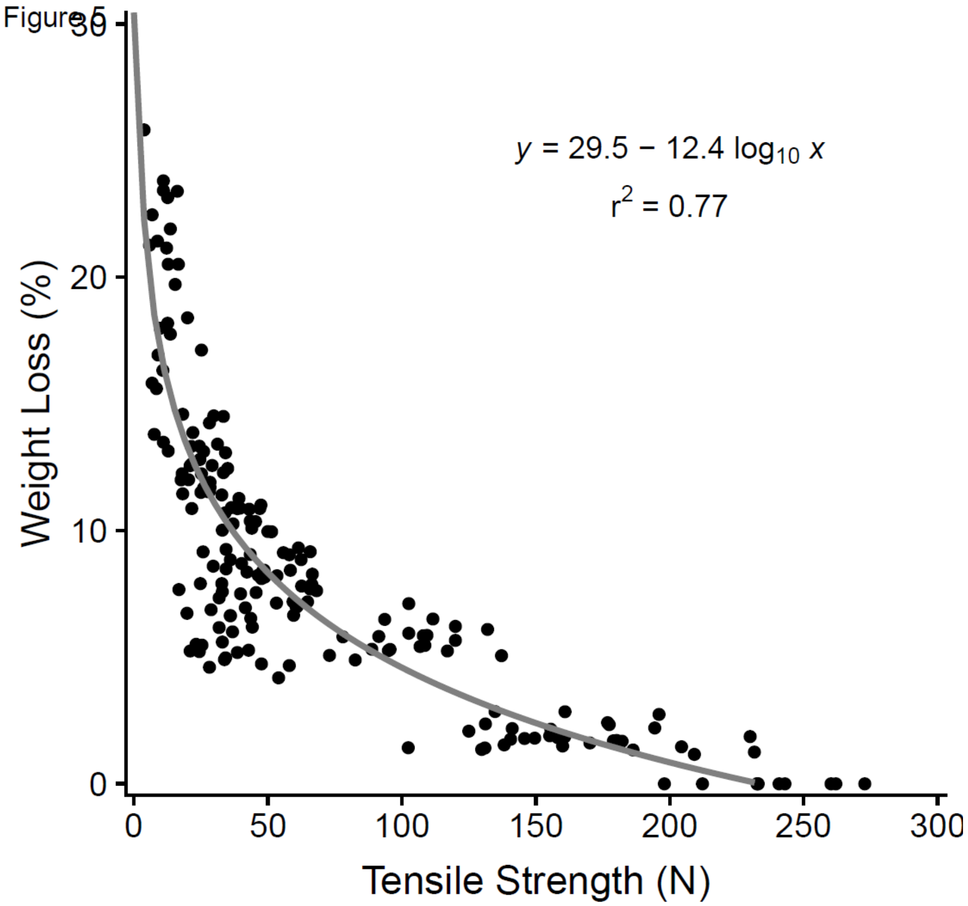
- Bag micro habitats
- Exclusion of shredders
- Loss of small particles
- Infiltration of mud into litterbags
- Heterogeneous starting material
- Colonization of bags by plants and animals

To get around these problems, we chose to assess decomposition of a model substrate: artist's canvas, red and green tea bags

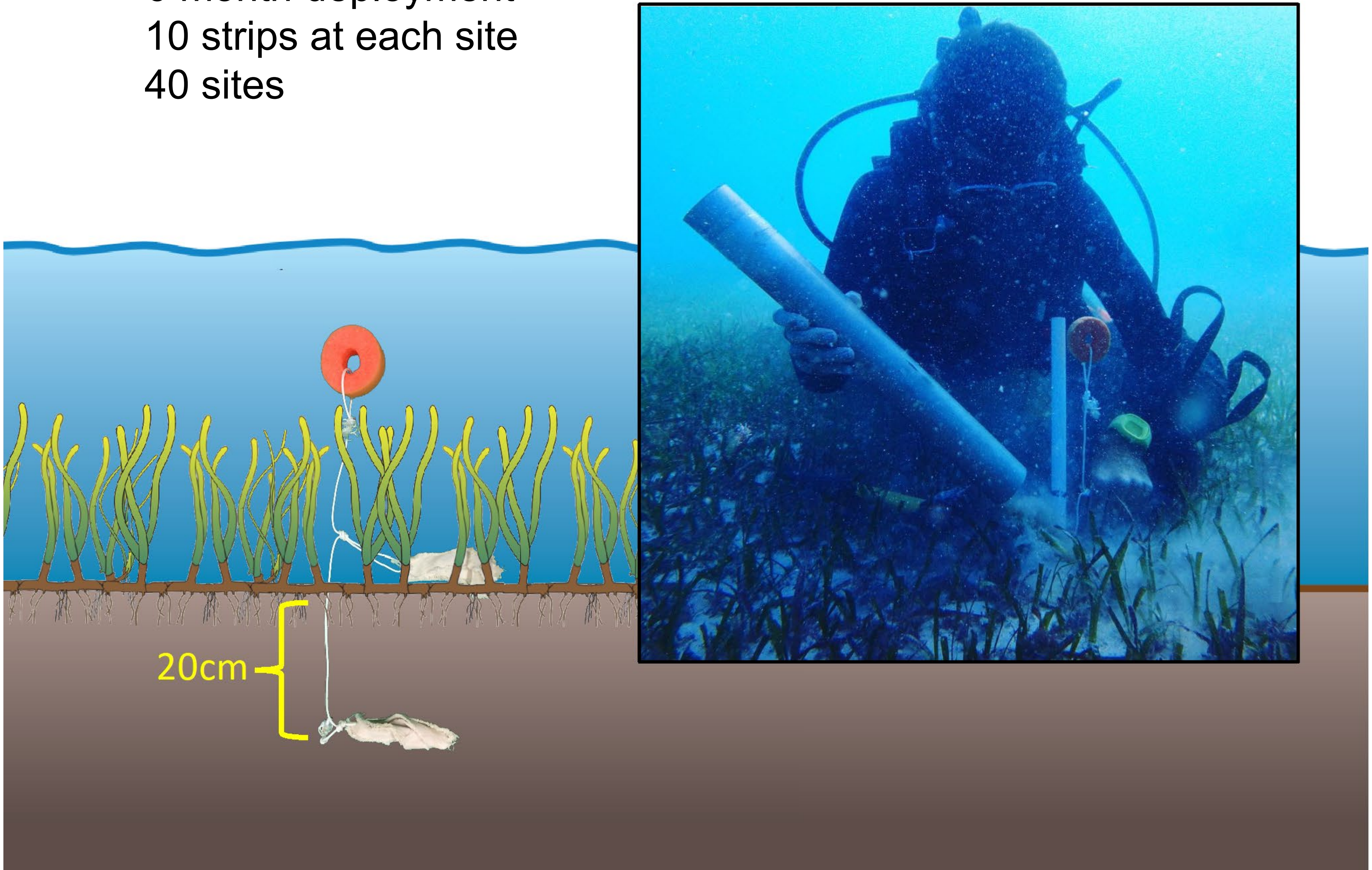
Growth on decomposing seagrass leaf

We deployed uniform canvas strips in different environments and assessed their decomposition by measuring loss of tensile strength. Loss of tensile strength is directly related to mass loss and doesn't require cleaning of fouled samples

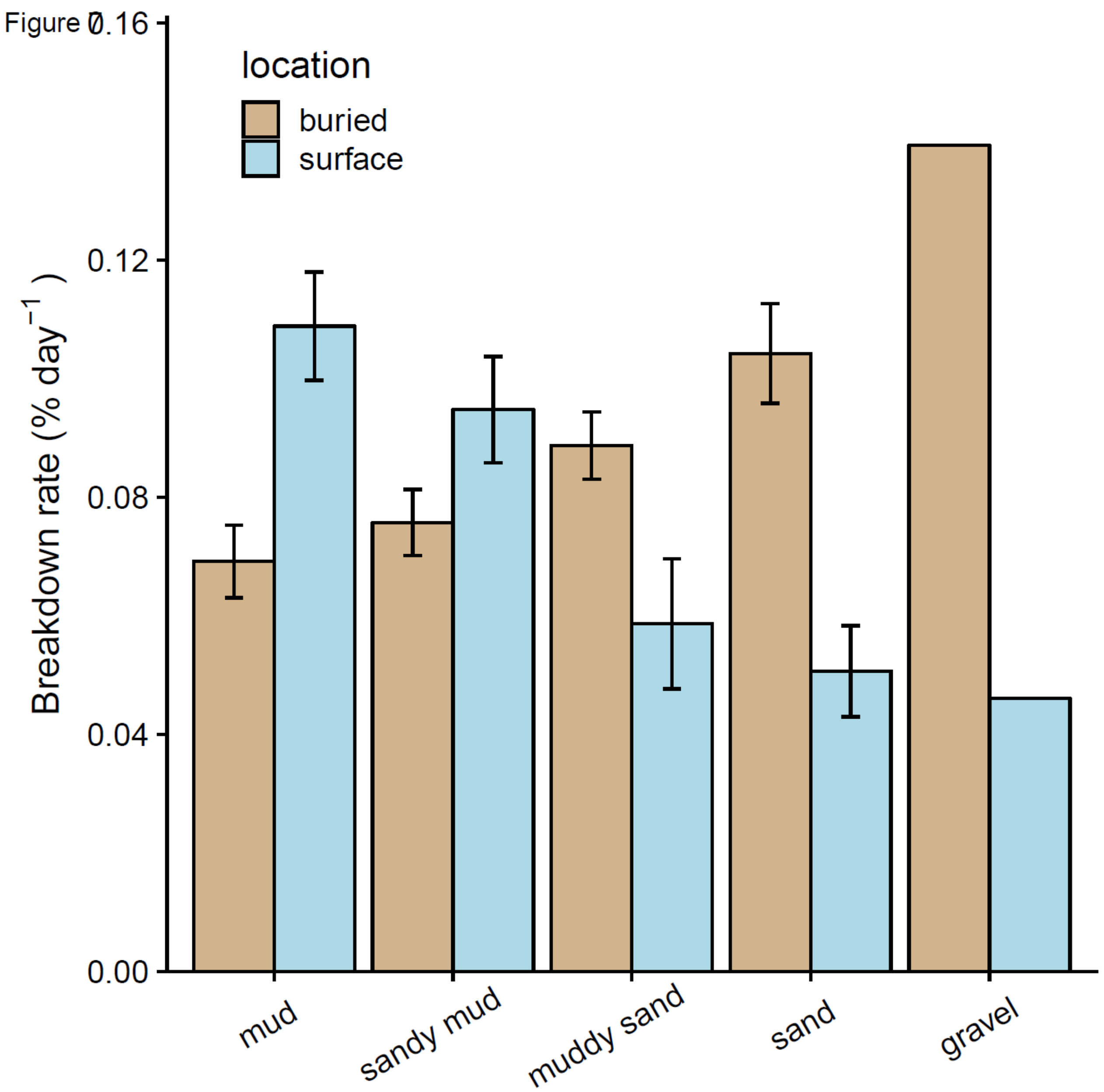




~ 6 month deployment
10 strips at each site
40 sites



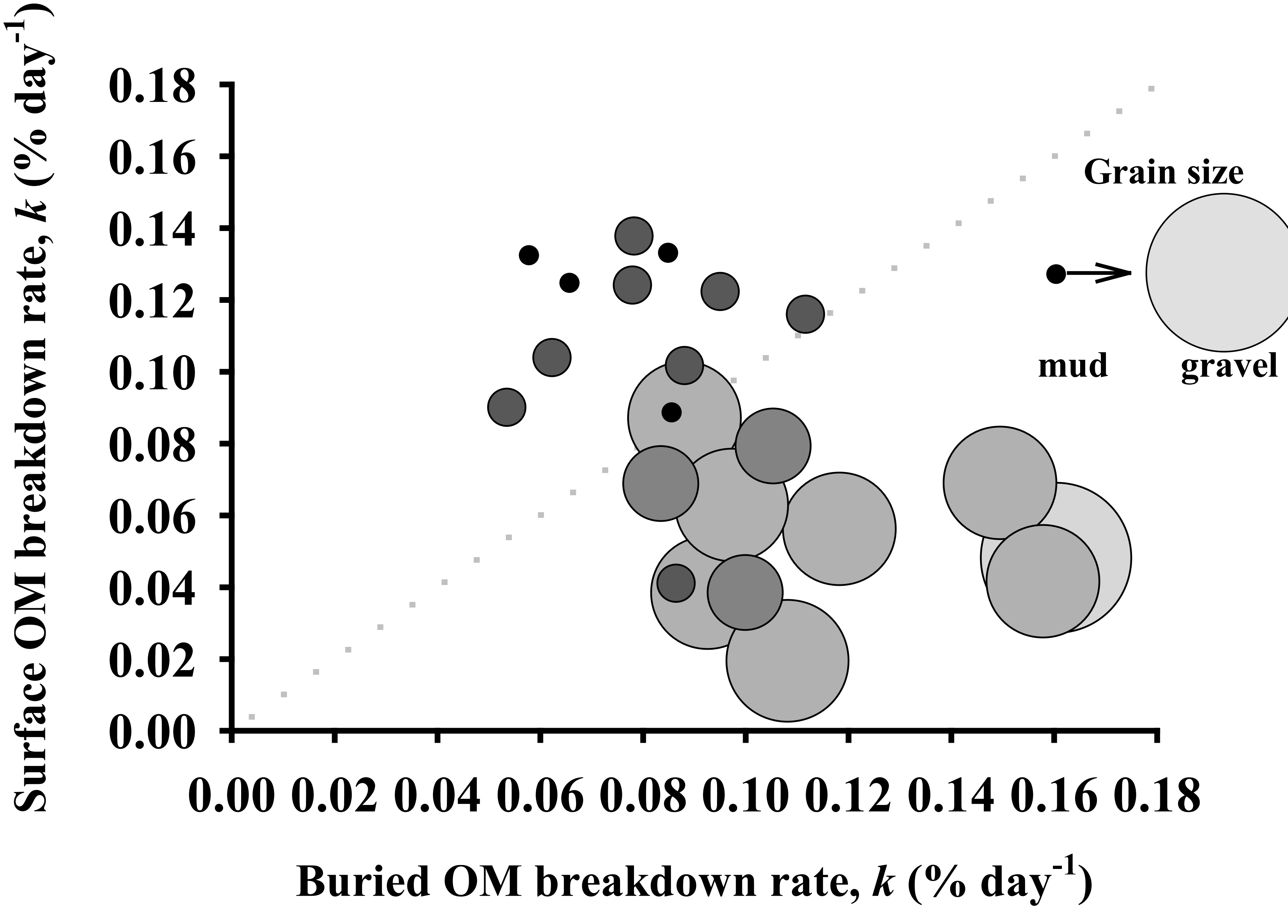

Nasco WHIRL-PAK
WHIRL-PAK



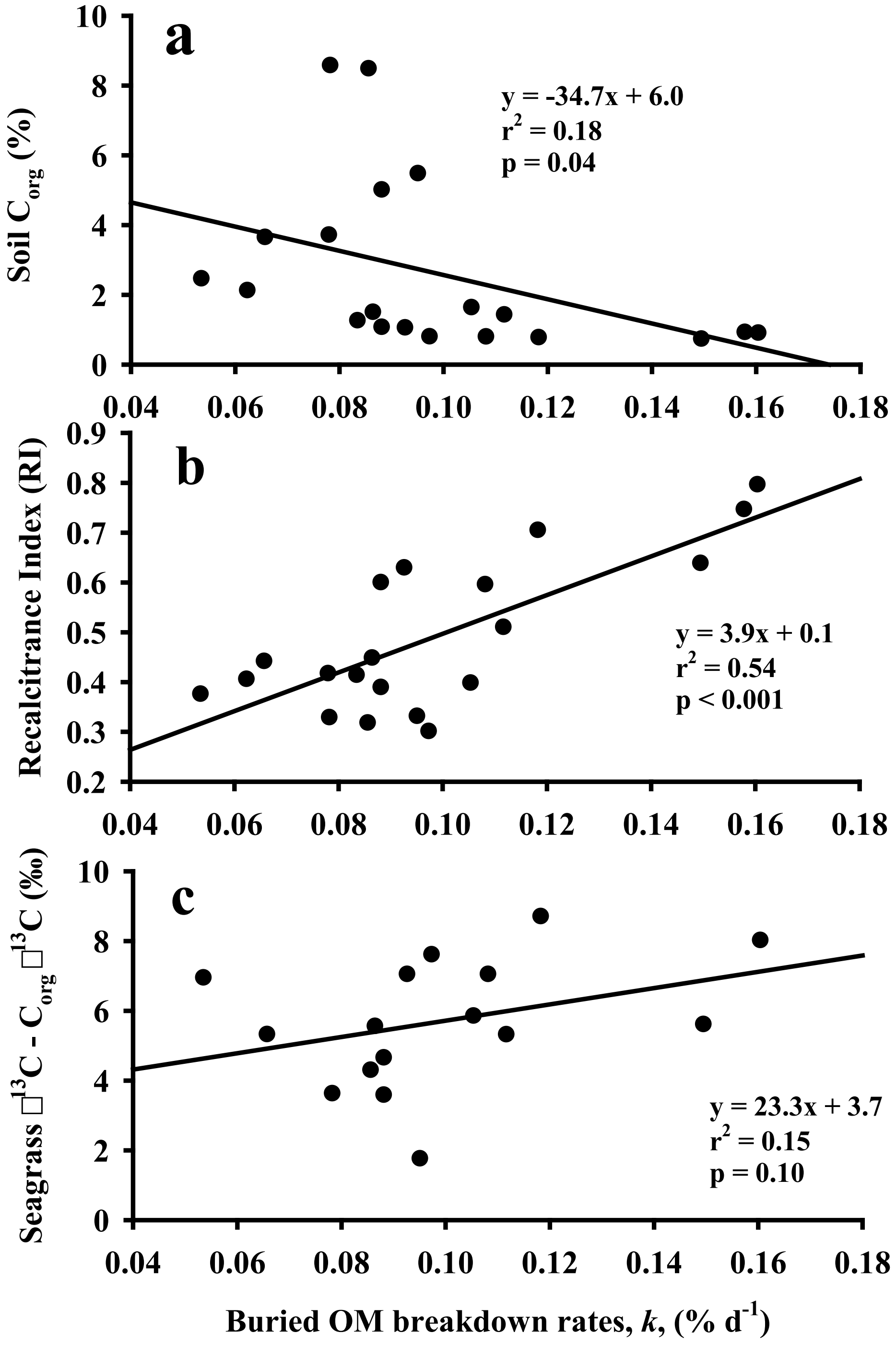
Cellulose deposited on the sediment surface decomposes faster in muddy environments than coarse sediment environments

Cellulose buried in seagrass soils decomposes faster in coarse-grained environments

Burial SLOWS decomposition in muddy environments but ACCELERATES decomposition in coarse sediment environments.



Surface OM breakdown rate, k (% day-1)
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
0.00 0.02 0.04 0.06 0.08 0.10 0.12 0.14 0.16 0.18
Buried OM breakdown rate, k (% day-1)
Grain size
mud
gravel

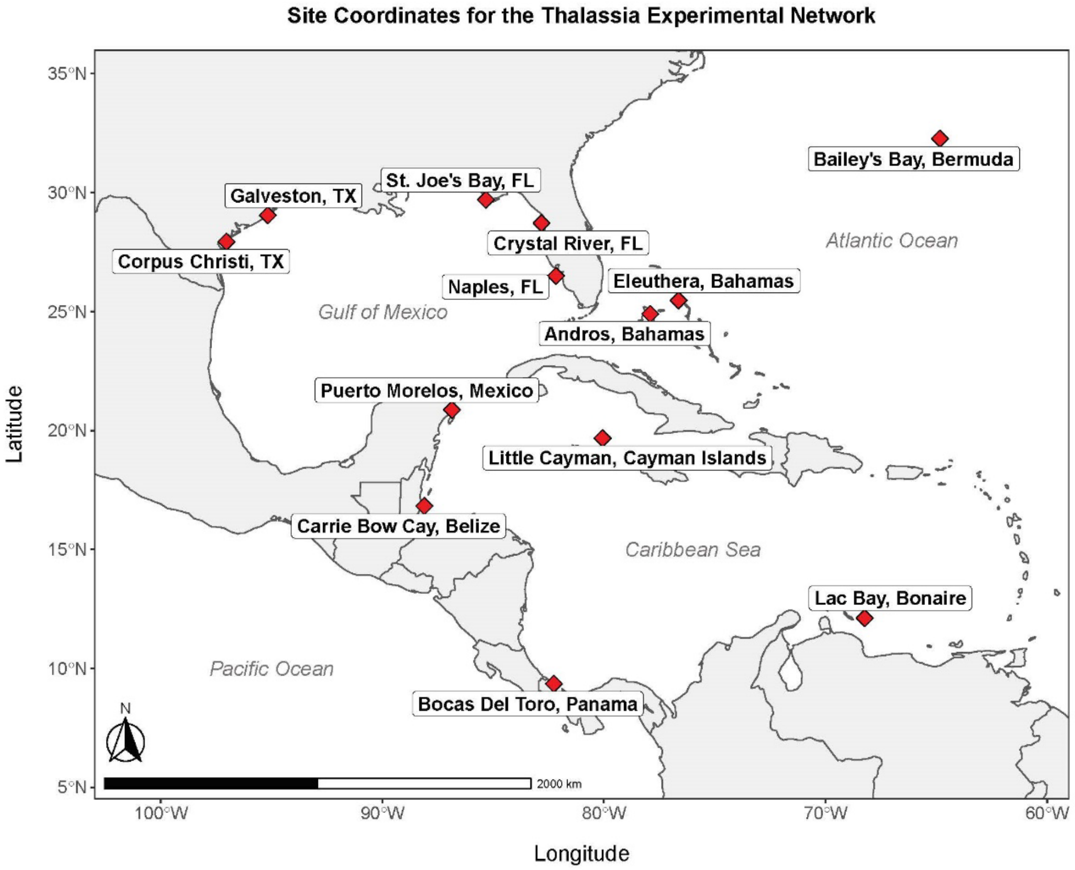


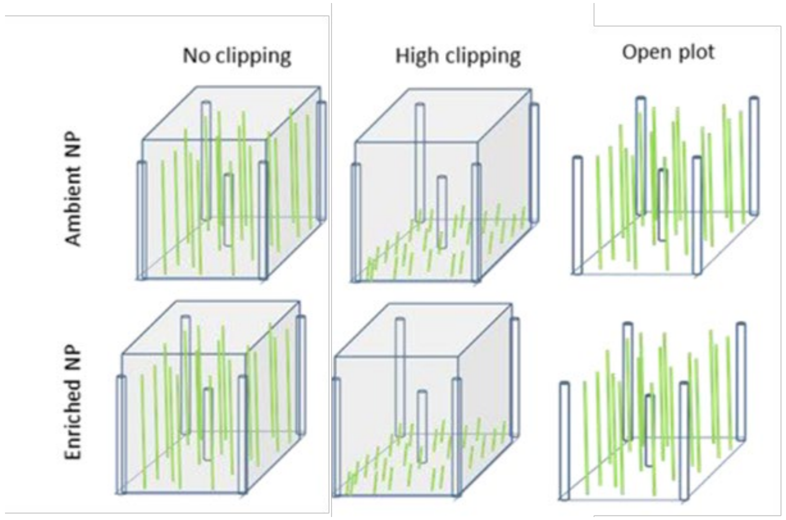
Decomposition rates of our model substrate predicted soil organic matter properties

We tested these important questions for seagrass Blue Carbon:

1) **Whether seagrass density is negatively correlated with sediment grain size and OM content of deposits at the landscape scale:**
   Over the landscape scale, mud content and organic carbon stocks are only loosely correlated with seagrass abundance - *Only in locations where the seagrass canopy causes an increase in fine sediment will seagrasses enhance soil C_{org} stocks*
2) **Whether sediment grain size is a predictor of the lability of OM stored in seagrass soils:**
   Muddy soils contain more organic carbon that is more labile than carbon found in coarse grained soils
3) **If burial in seagrass soils decreases the decomposition rate, and therefore enhances preservation, of OM in seagrass soils:**
   In muddy soils, burial decreases cellulose decomposition rate, but in coarse grained soils, burial enhances cellulose decomposition rate – *Burial does not decrease decomposition nor enhance C_{org} storage in all environments.*

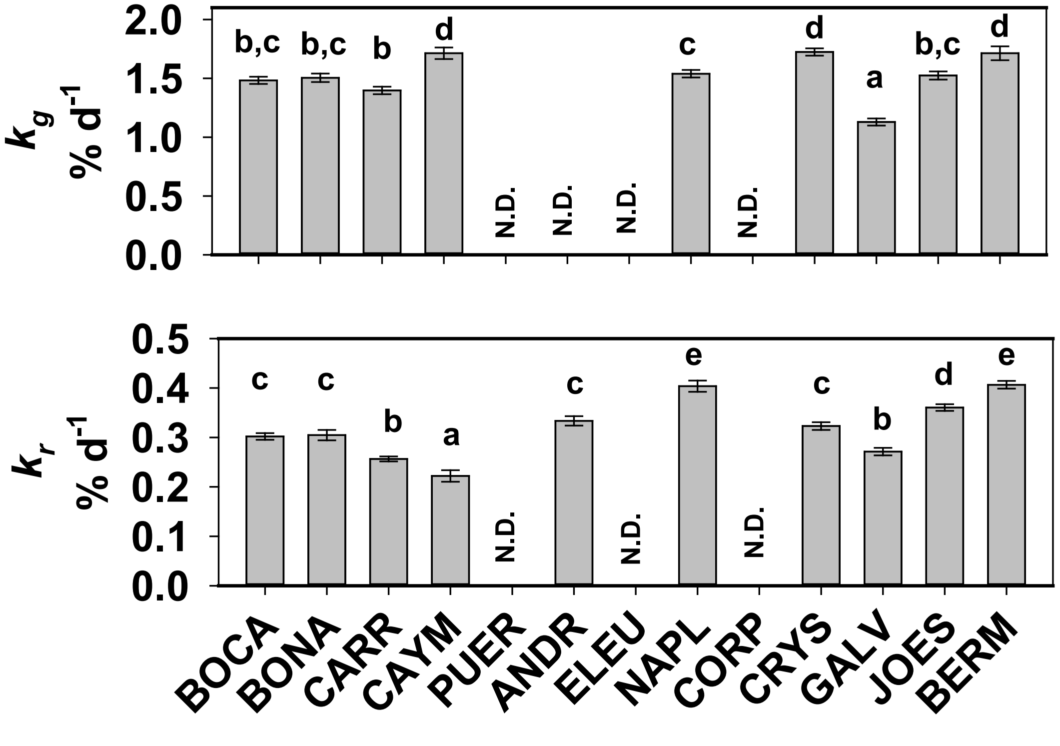
Does nutrient availability and herbivory influence the decomposition rate of organic matter?
Thalassia Experimental Network (TEN)

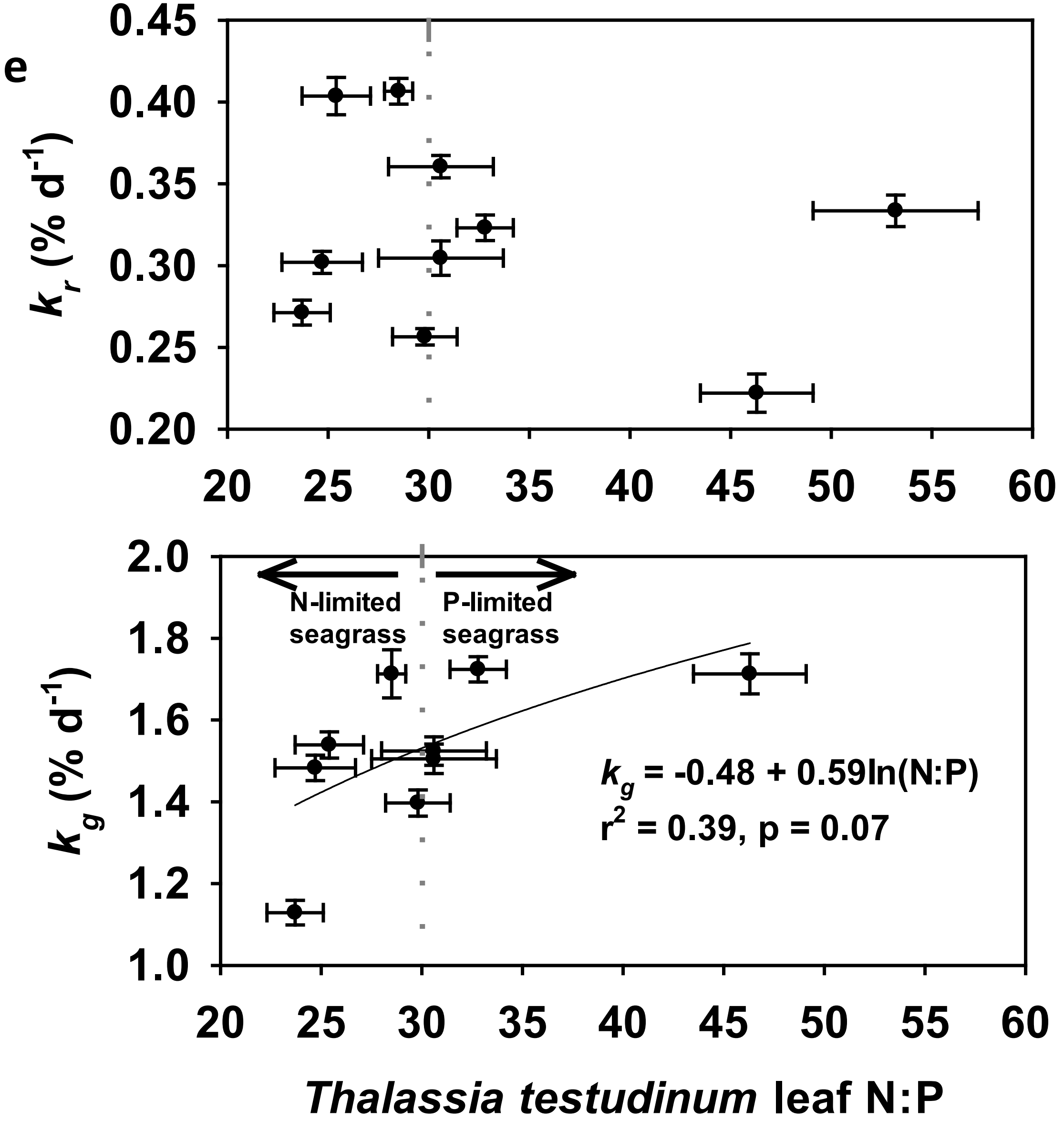




Decomposition of both refractory (red tea) and labile (green tea) substrates vary by site, but nutrient availability only influenced decomposition of the labile substrate

Fourqurean et al in preparation, *J. Ecol.*

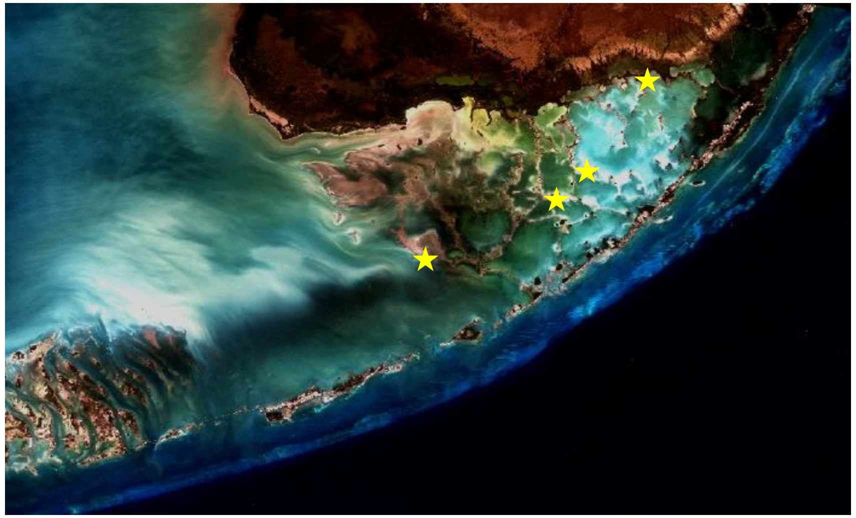




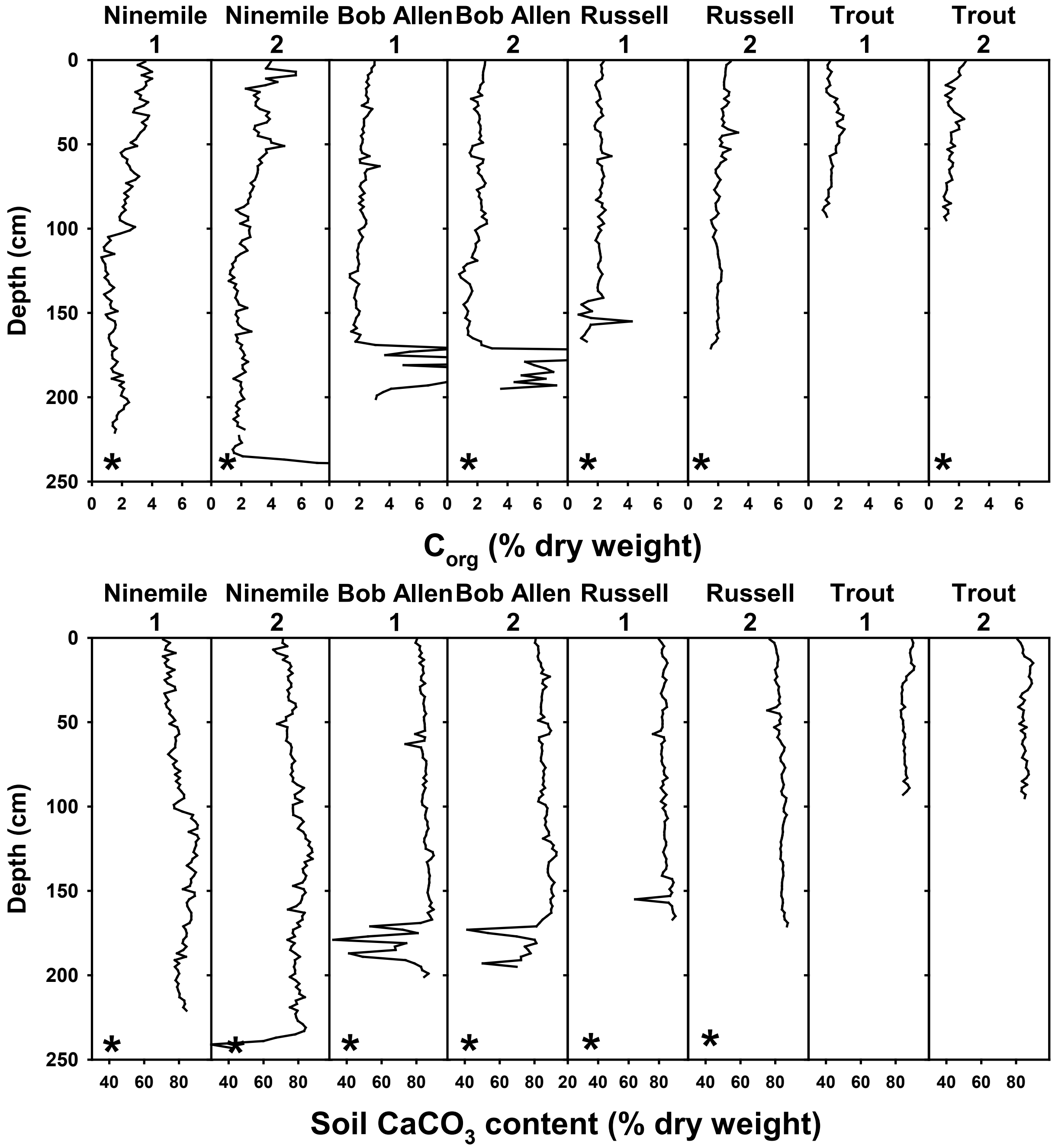
Florida Bay is net autotrophic – resulting in burial of C_{org} over the last 5000 y

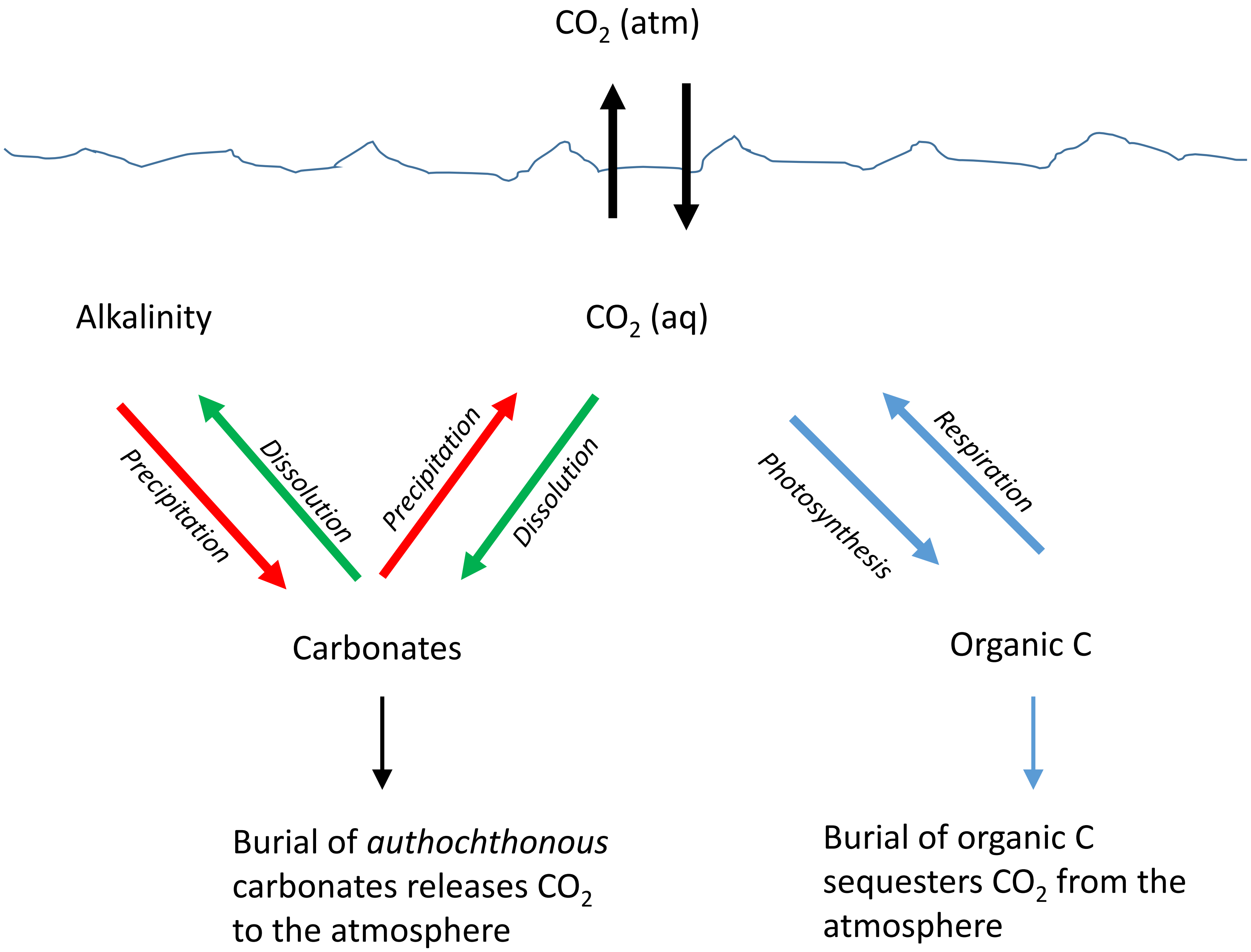
BUT:

Florida Bay also produces carbonates, and buries about 3x more C_{inorg} than C_{org}



Fourqurean et al 2012 *Mar Freshwater Res*





CO_2 (atm)
Alkalinity
CO_2 (aq)
Precipitation
Dissolution
Precipitation
Dissolution
Photosynthesis
Respiration
Carbonates
Organic C
Burial of *authochthonous* carbonates releases CO_2 to the atmosphere
Burial of organic C sequesters CO_2 from the atmosphere

Direct measurements of net ecosystem exchange between the atmosphere and the coastal ocean

e.g. Carbon accounting suggests inorganic C can dominate vertical fluxes

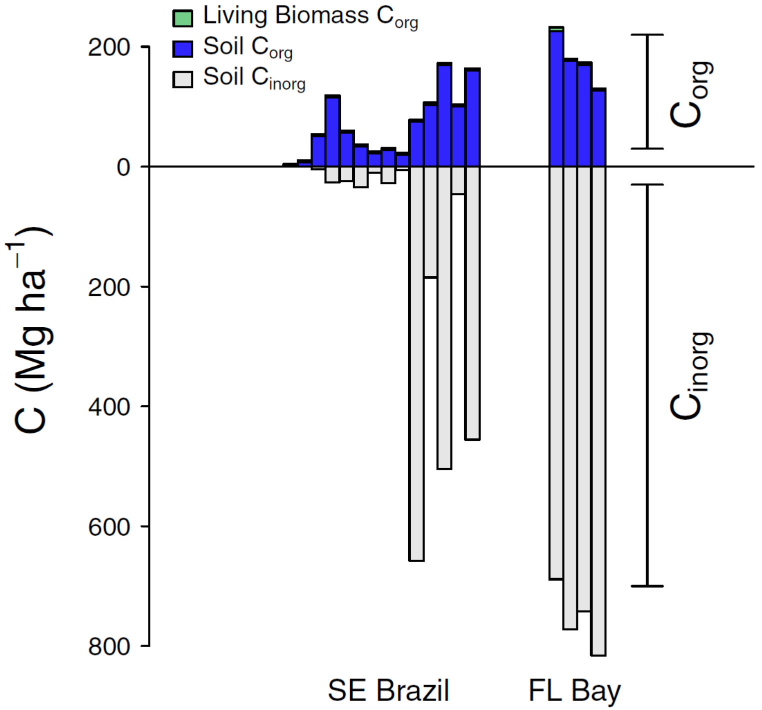


Fig. 3. Site specific carbon areal stocks including C_{org} and C_{inorg} associated with living biomass and soils. Sites are arranged from southernmost survey site on the left to northernmost site on the right. [Color figure can be viewed at wileyonlinelibrary.com]

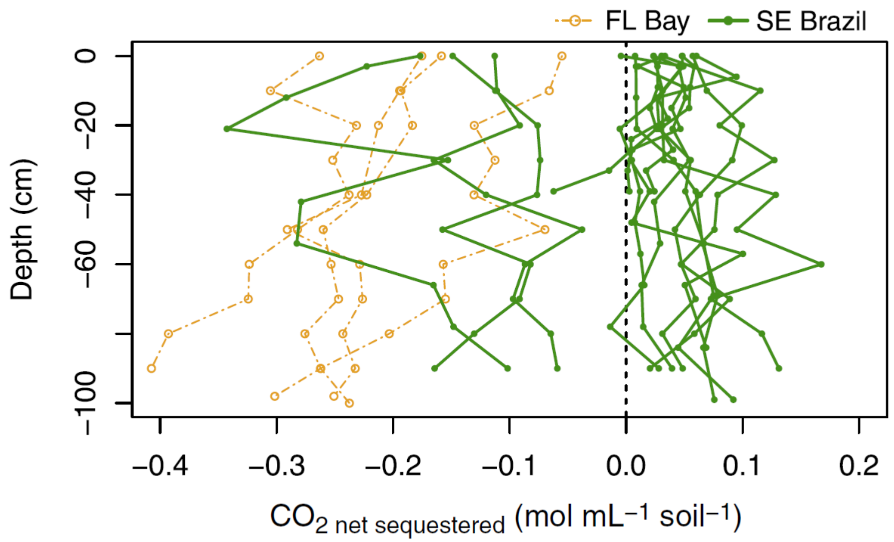
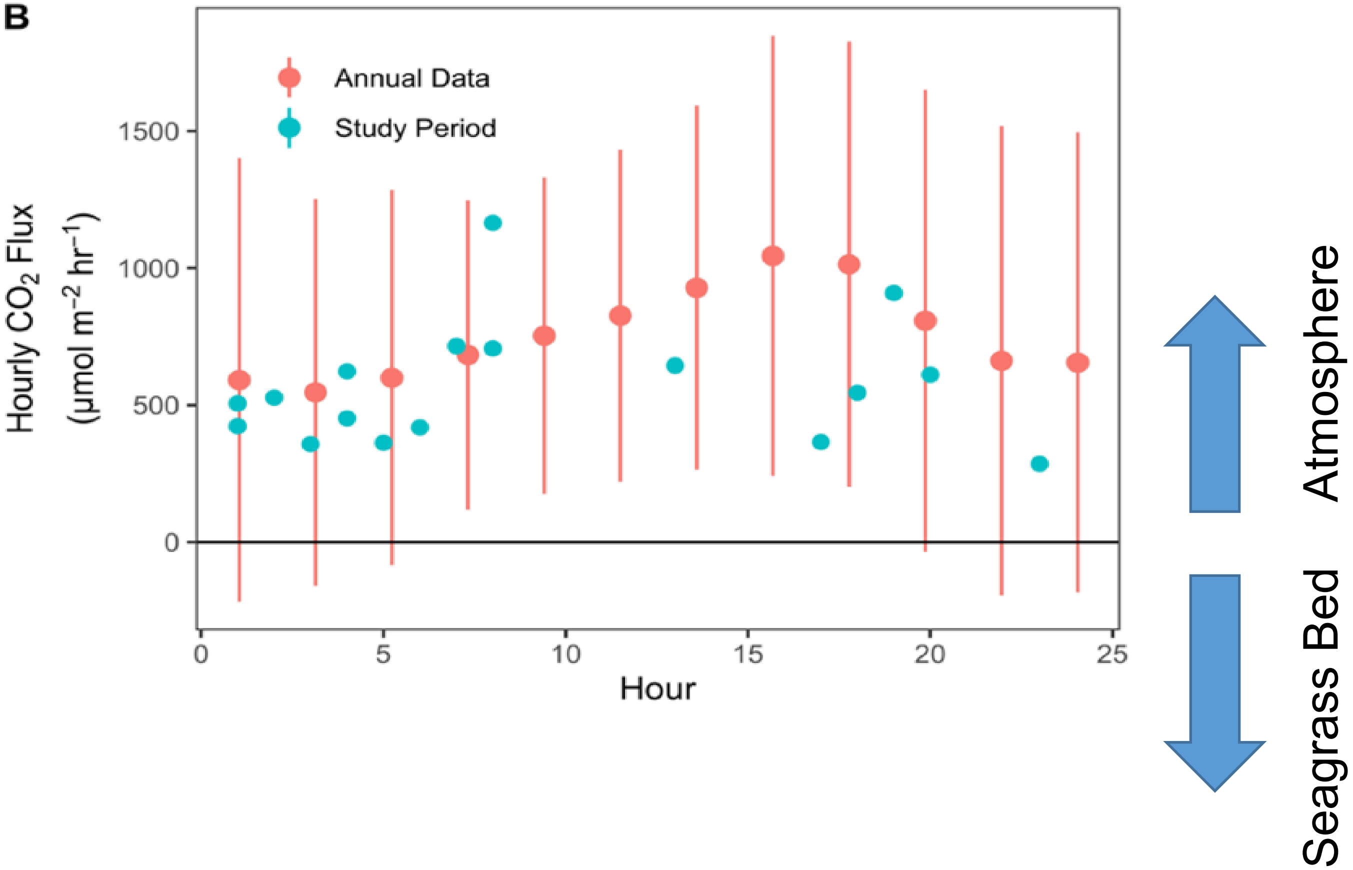


Fig. 4. Down core profiles of mean CO_2 net sequestration across survey sites. Positive values indicate that CO_2 is consumed during soil production while negative values indicate that the production of soil carbon resulted in net CO_2 production. Data derived from both C_{org} and C_{inorg}, assuming standard gas exchange : reaction ratios. [Color figure can be viewed at wileyonlinelibrary.com]

Howard et al. 2018 *L&O*

The (limestone) fly in the seagrass Blue Carbon ointment:



Van Dam et al 2021 L&O, GBC, Science Advances