Water Mass Histories Modulate Reef Carbonate Chemistry: A High-Resolution Model for the Florida Keys

Heidi Hirsh

Cooperative Institute for Marine and Atmospheric Studies, University of Miami

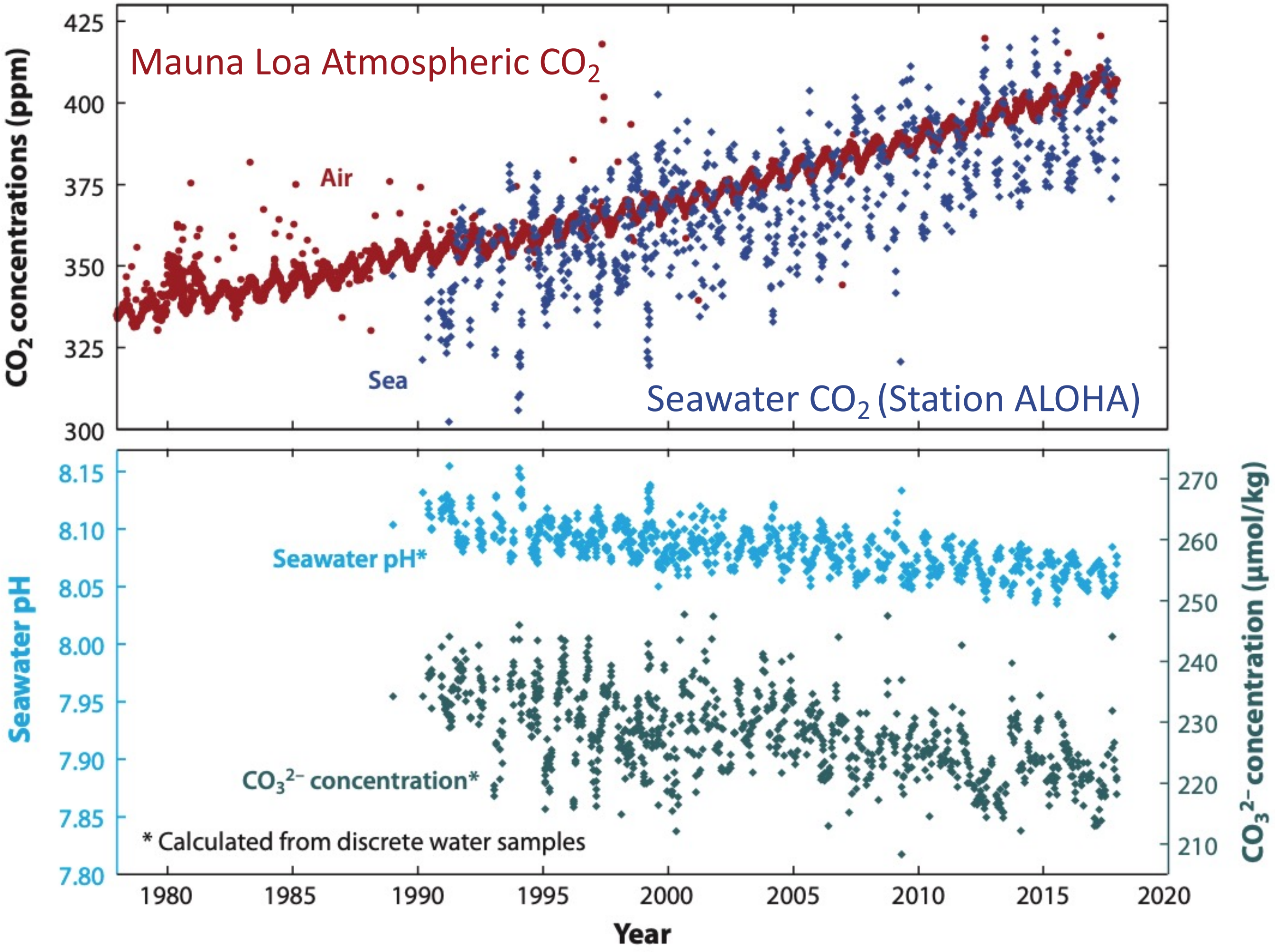
Session 12: Watershed to Reef: Assessing Hydrology and Water Quality Challenges in the Florida Keys

FLORIDA KEYS

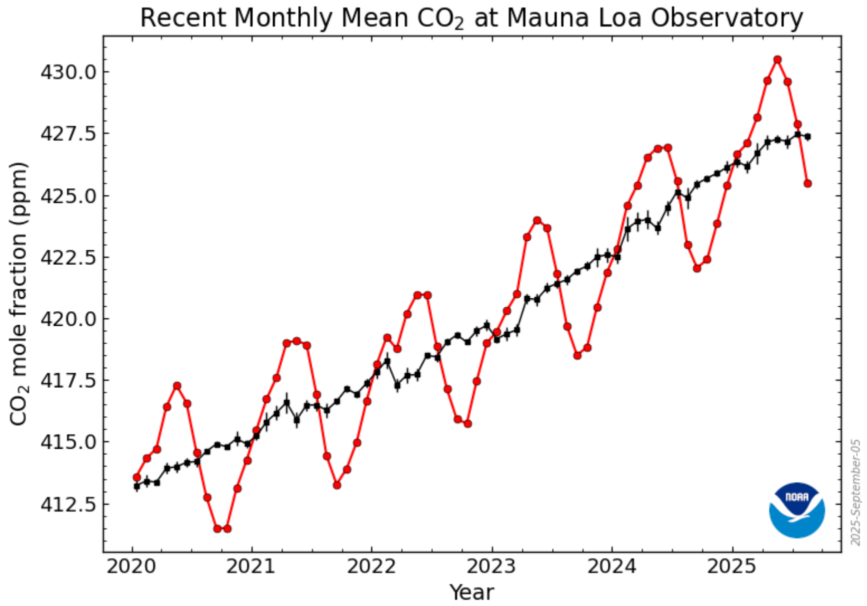
MARINE SCIENCE CONFERENCE & WORKSHOP

October 29, 2025

Ocean Acidification



Latest CO_2 = 425.20 ppm (Oct. 19, 2025)



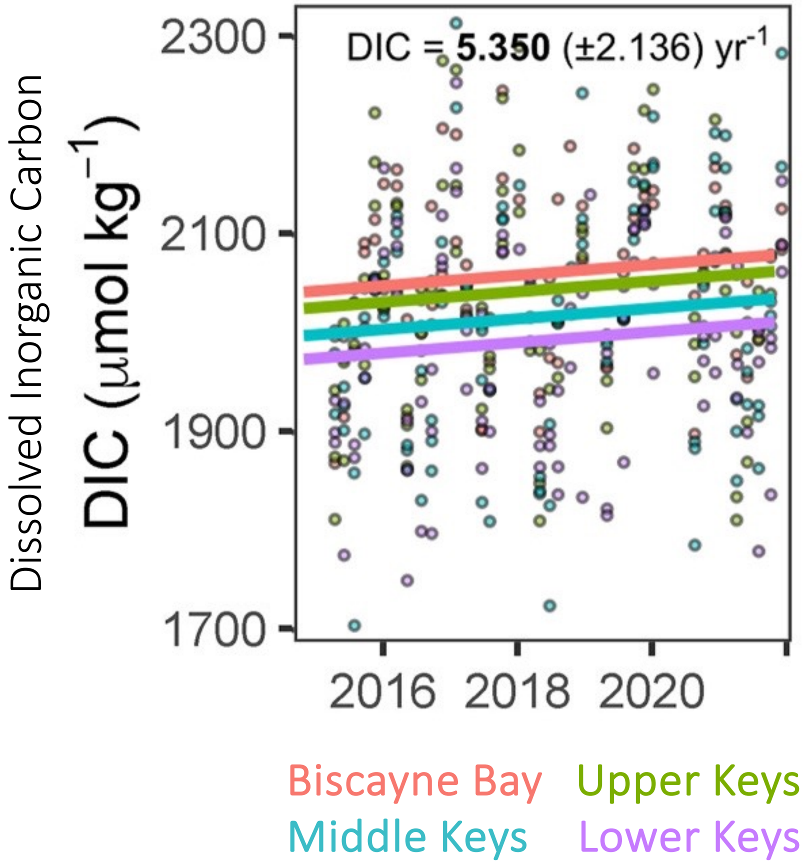
Week beginning on October 19, 2025: 425.20 ppm
Weekly value from 1 year ago: 422.17 ppm
Weekly value from 10 years ago: 398.65 ppm
Last updated: October 26, 2025

https://gml.noaa.gov/ccgg/trends/weekly.html

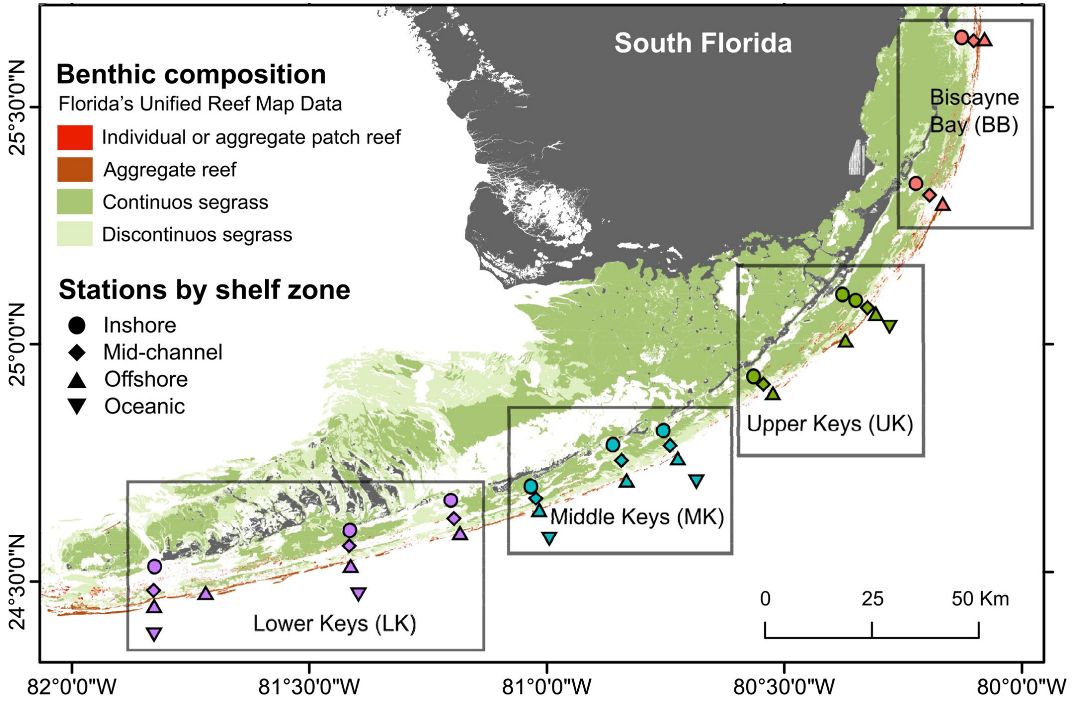
Doney et al., 2020; Data source: Hawai'i Ocean Time-series Data Organization & Graphical System (HOT-DOGS)

Ocean Acidification in the Florida Keys

INSHORE STATIONS



DIC is increasing on Florida's reefs at a rate of 5.35 μmol kg^{-1} year^{-1}



South Florida Ecosystem Restoration (SFER) cruises

(Palacio-Castro, Hirsh, et al., *Global Biogeochemical Cycles*, 2023)

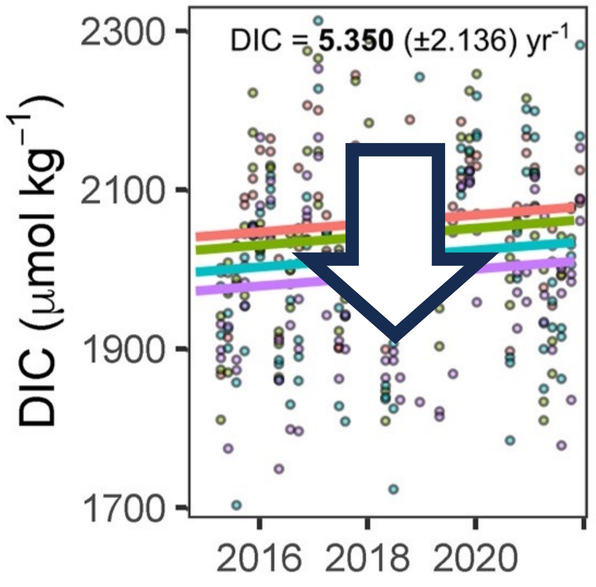
Can we combat OA with noncalcifying photosynthesis?

Metabolic Modification

Photosynthesis

$$CO_2 + H_2O \rightleftarrows CH_2O + O_2$$

Respiration



Can we combat OA with noncalcifying photosynthesis?

Metabolic Modification

Photosynthesis

$CO_2 + H_2O \rightleftharpoons CH_2O + O_2$

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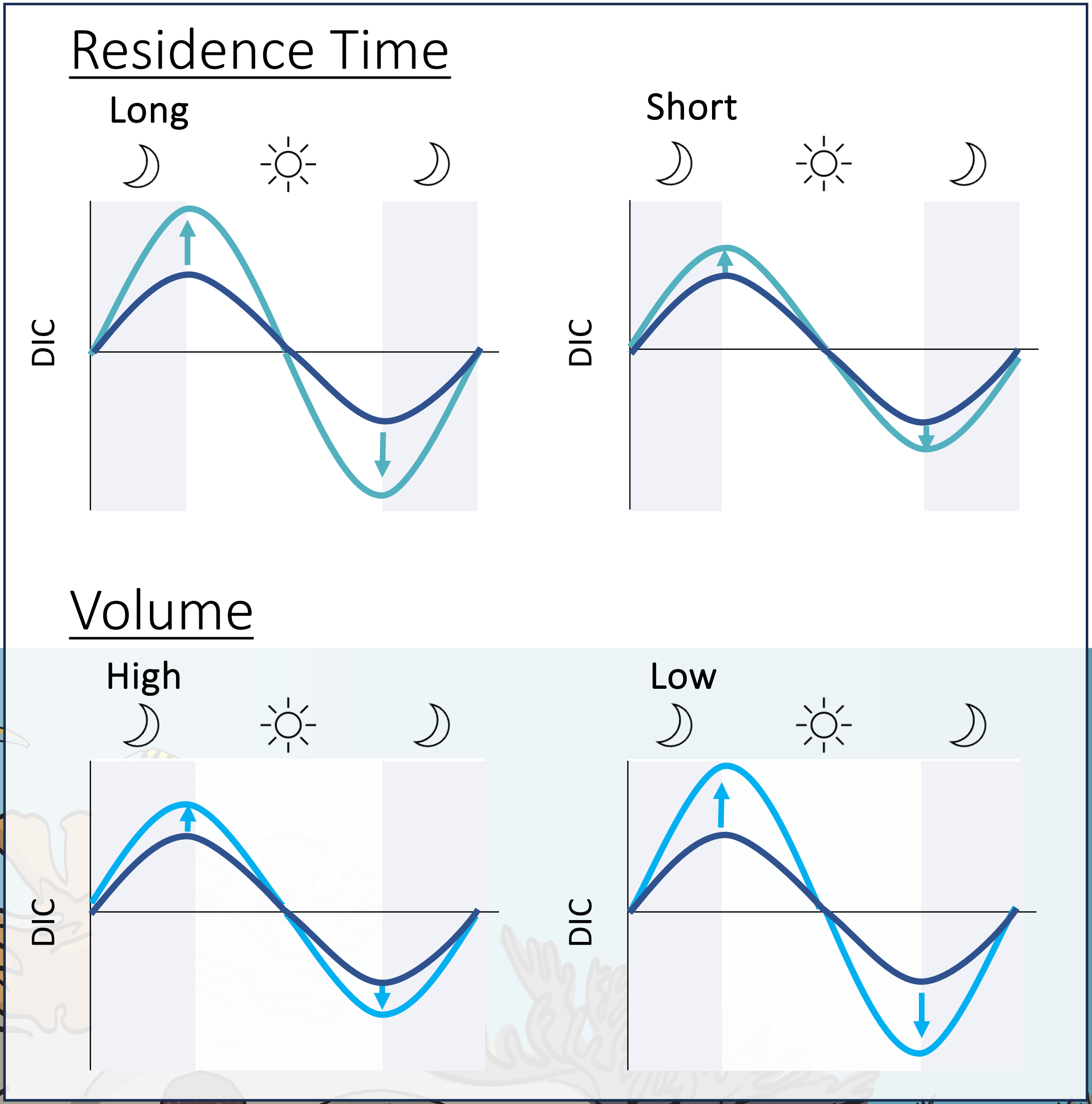
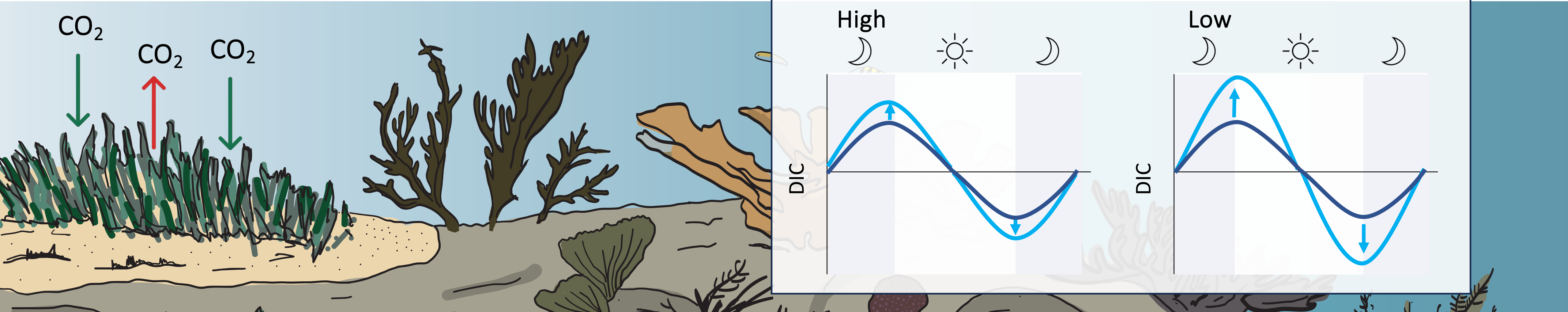




Modeling reef carbonate chemistry as a function of…

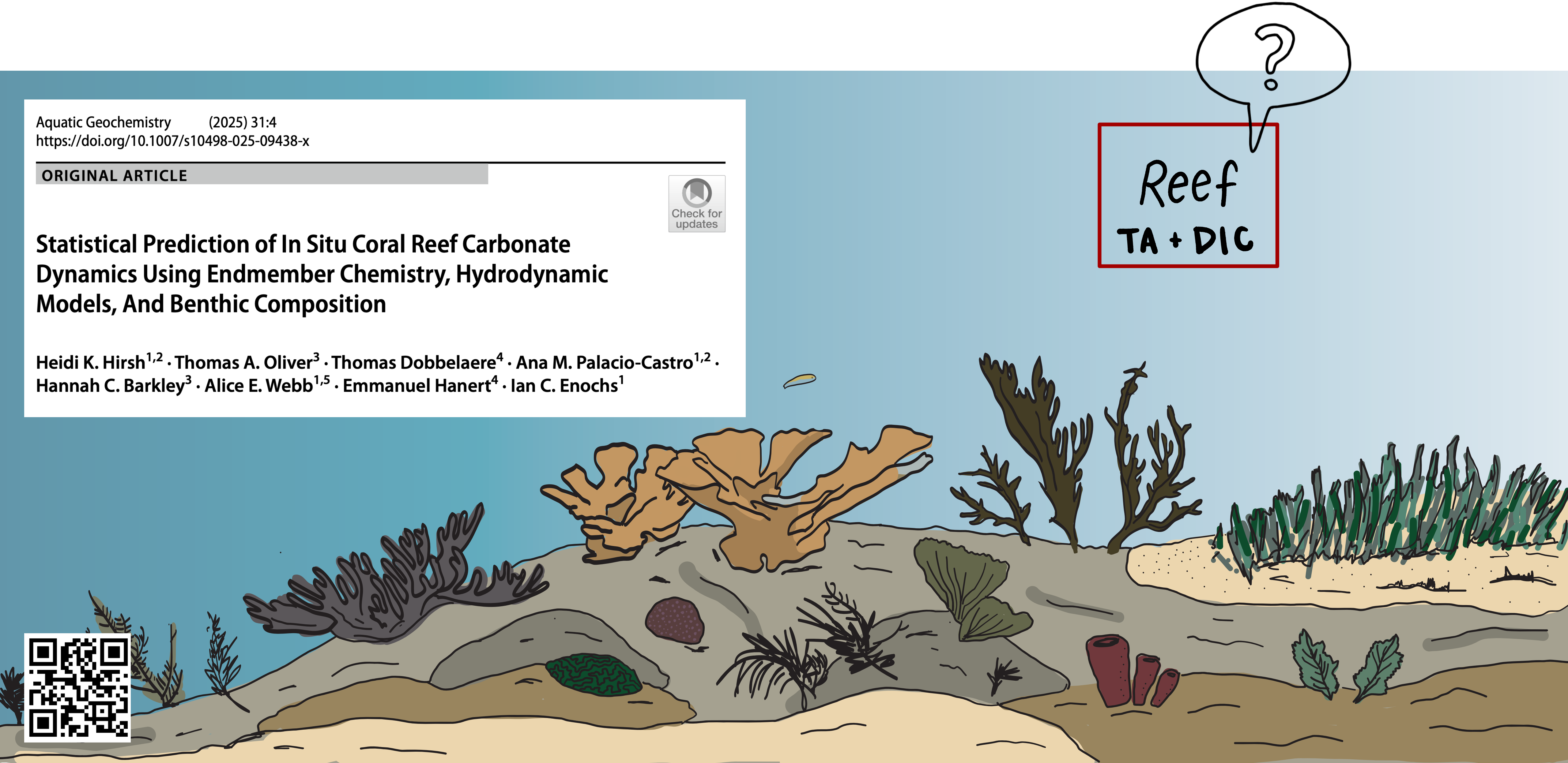
Aquatic Geochemistry (2025) 31:4
https://doi.org/10.1007/s10498-025-09438-x

ORIGINAL ARTICLE

Check for updates

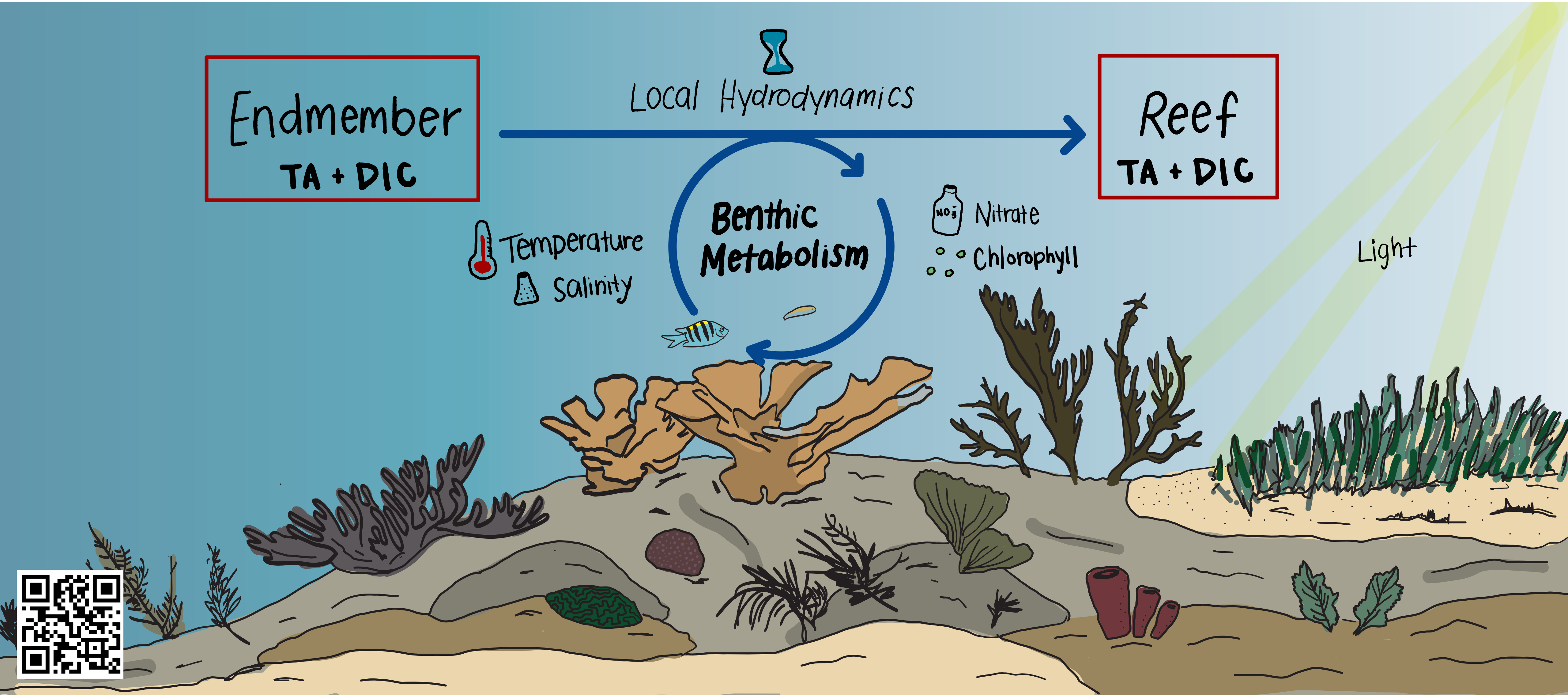
Statistical Prediction of In Situ Coral Reef Carbonate Dynamics Using Endmember Chemistry, Hydrodynamic Models, And Benthic Composition

Heidi K. Hirsh[1,2] · Thomas A. Oliver[3] · Thomas Dobbelaere[4] · Ana M. Palacio-Castro[1,2] · Hannah C. Barkley[3] · Alice E. Webb[1,5] · Emmanuel Hanert[4] · Ian C. Enochs[1]

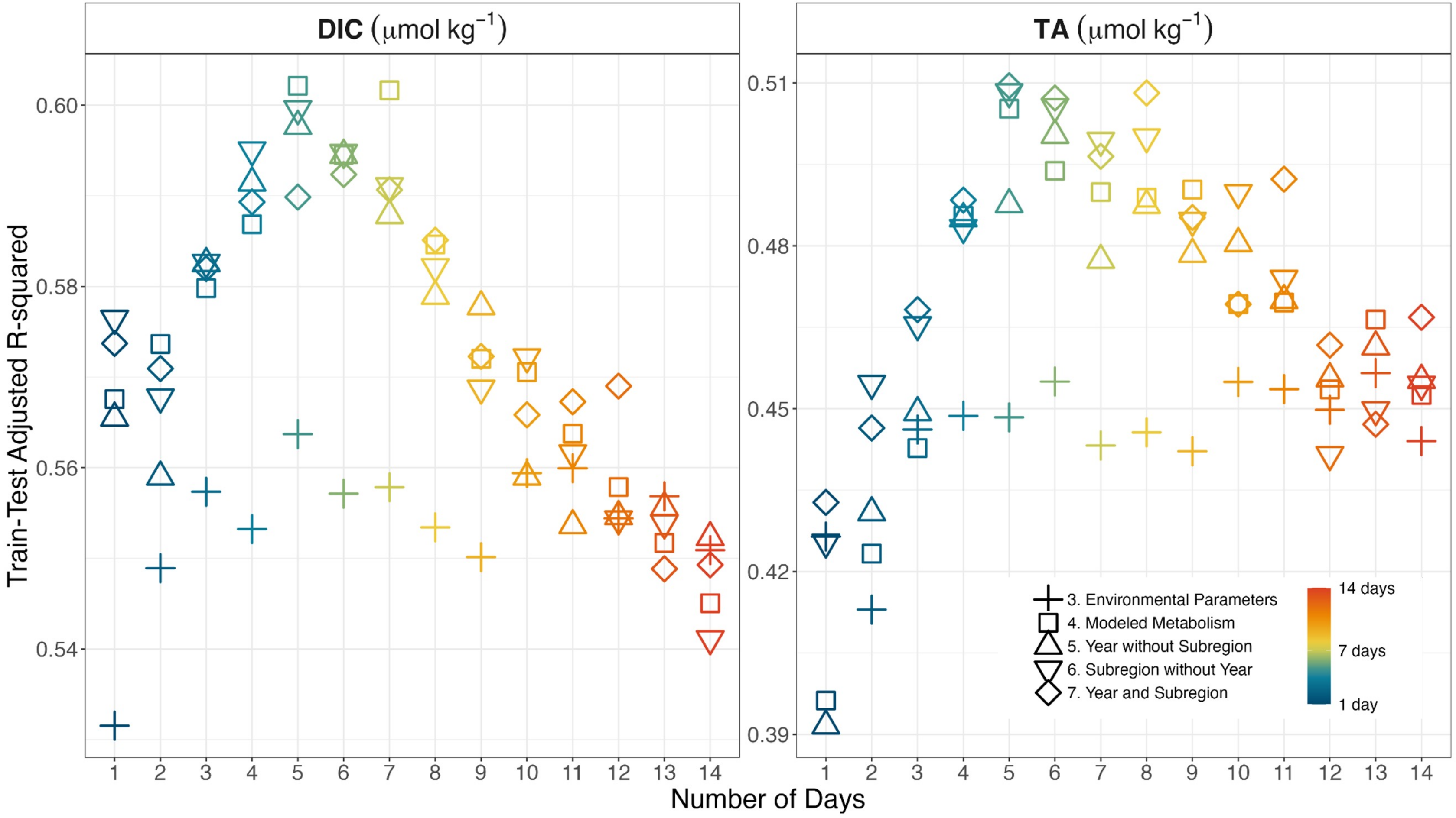


Modeling reef carbonate chemistry as a function of...

Endmember Chemistry > Benthic Metabolism > Local Hydrodynamics > Environmental Parameters

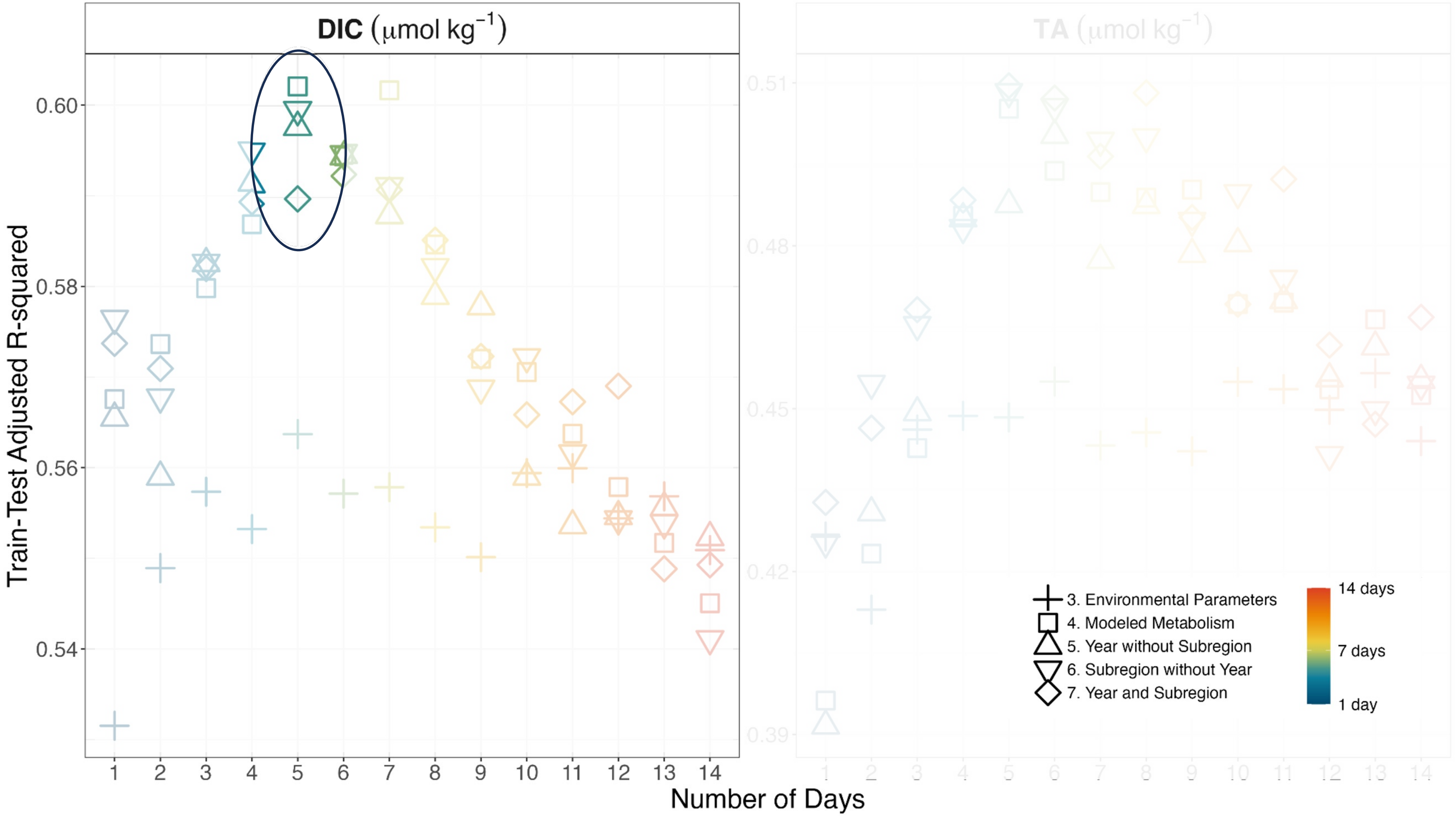


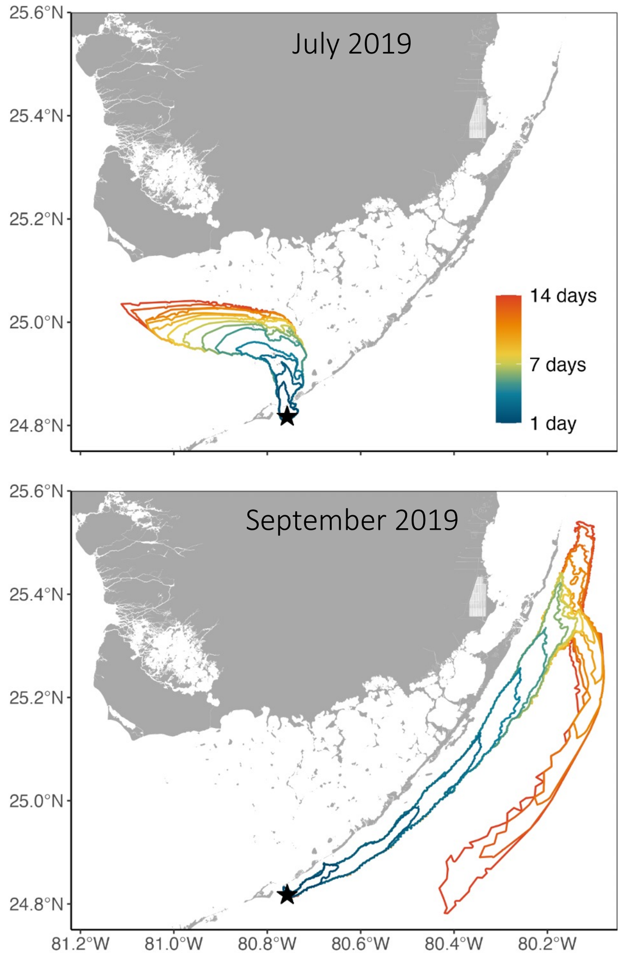
Statistical Prediction of Reef Carbonate Chemistry in the FKNMS



(Hirsh et al., *Aquatic Geochemistry*, 2025)

Statistical Prediction of Reef DIC in the FKNMS

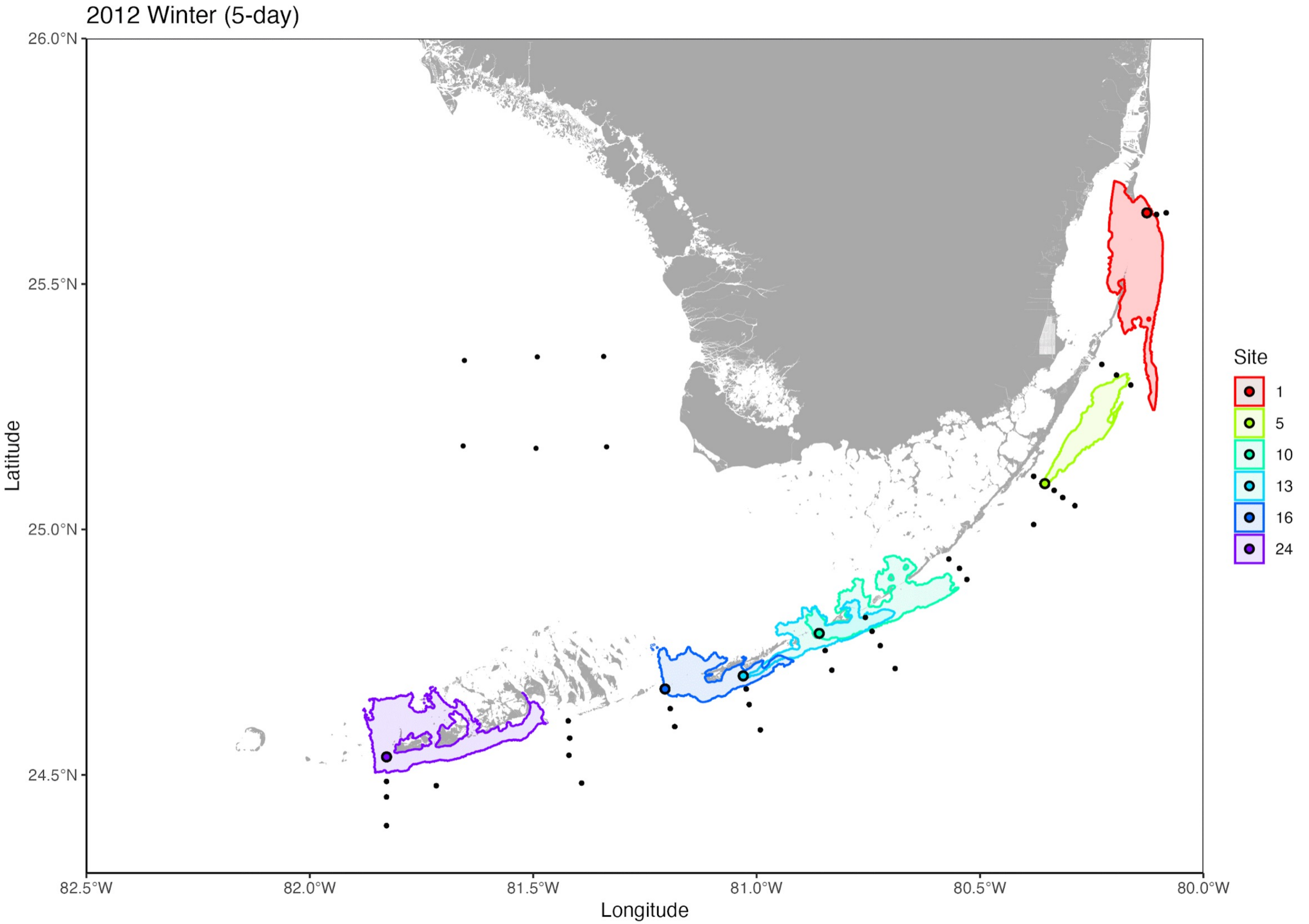




Best models account for 5-day water mass history

(Hirsh et al., *Aquatic Geochemistry*, 2025)

Flowsheds capture variability in the metabolic footprint for each site



5-day water mass history for inshore (reef) stations

(Hirsh et al., *Aquatic Geochemistry*, 2025)

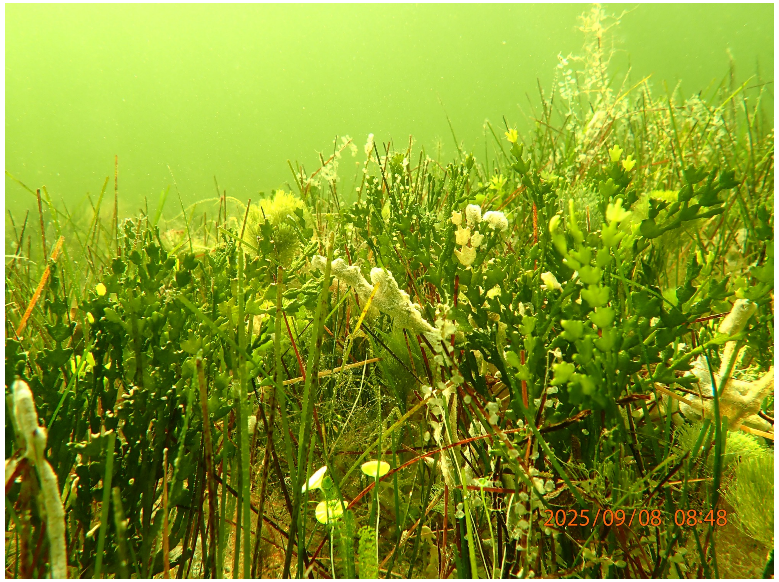
Emmanuel Hanert, Thomas Dobbelaere, Louis Rycx
Université Catholique de Louvain

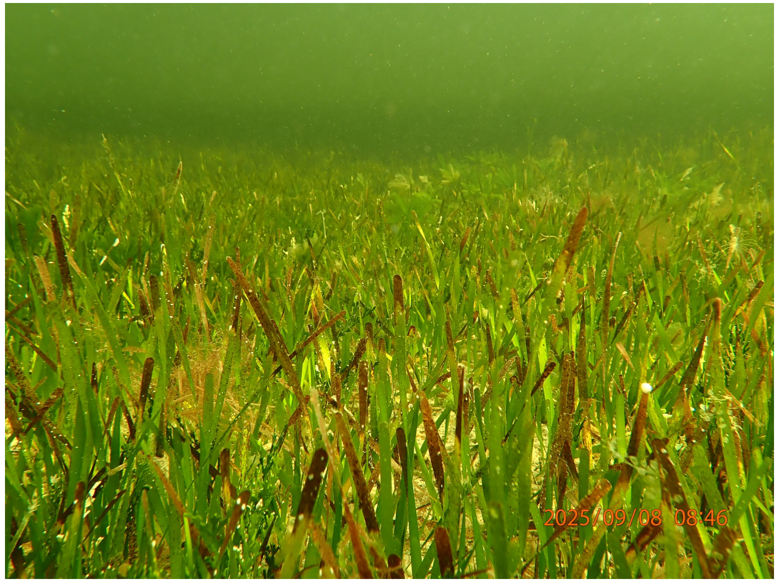
https://www.slim-ocean.be/

What happens if we increase photosynthetic habitat?

How much does it change the chemistry and **where** is it most effective?

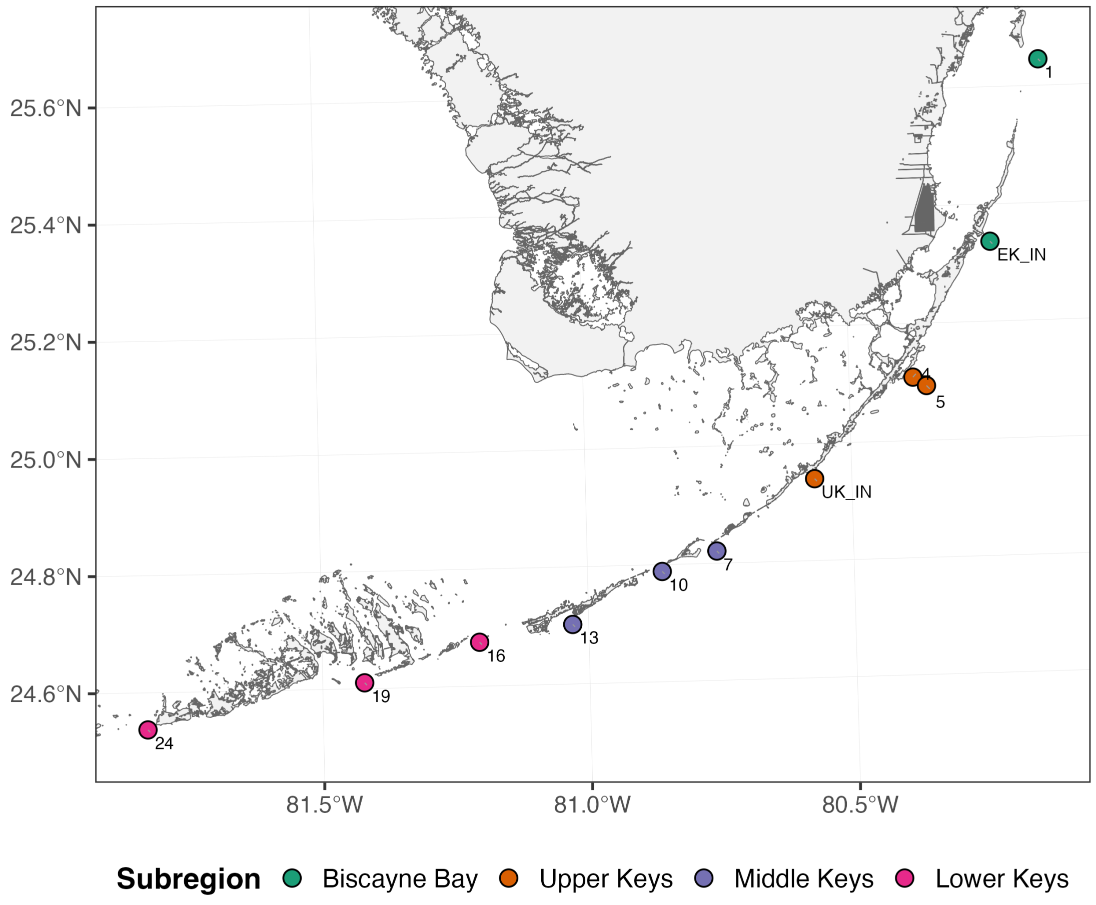
1. Rate
2. Space

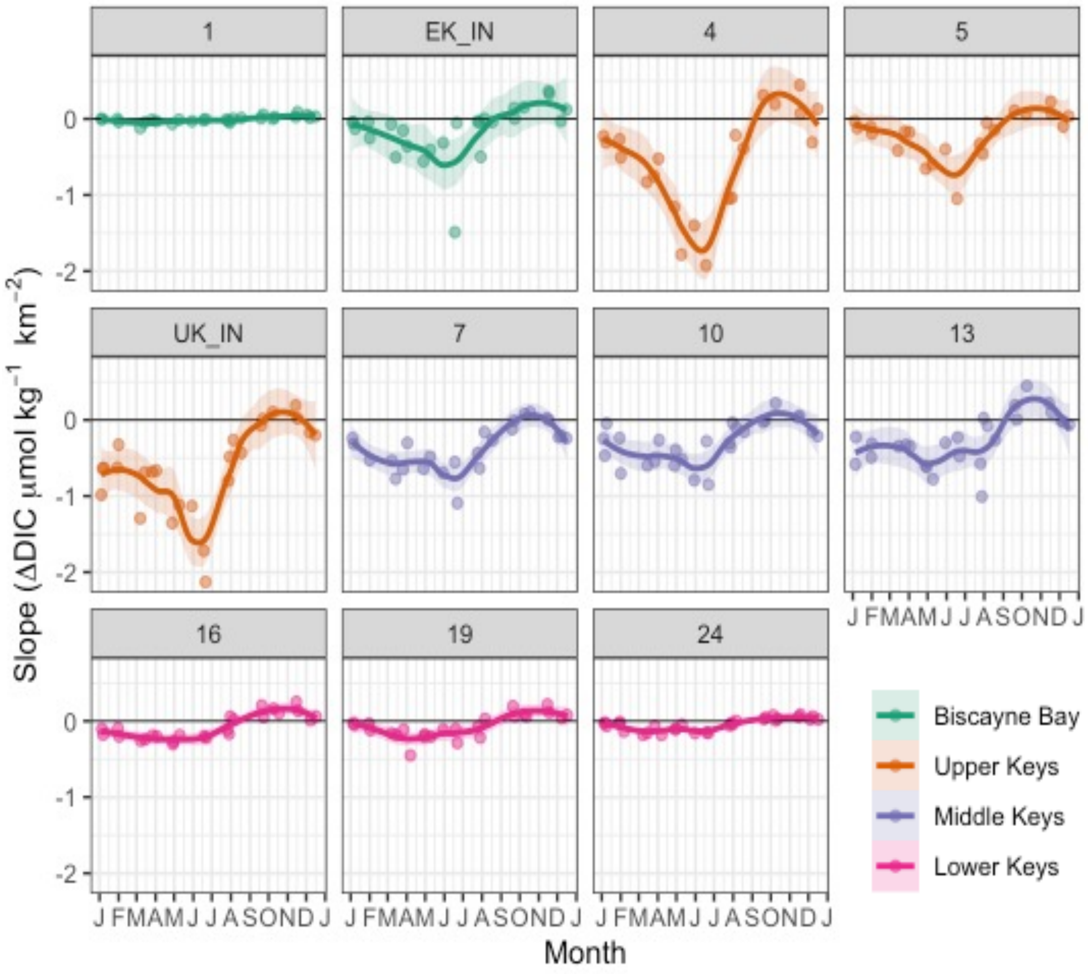




Photos from Florida Bay, September 2025

Annual sensitivity of ΔDIC to addition of seagrass habitat





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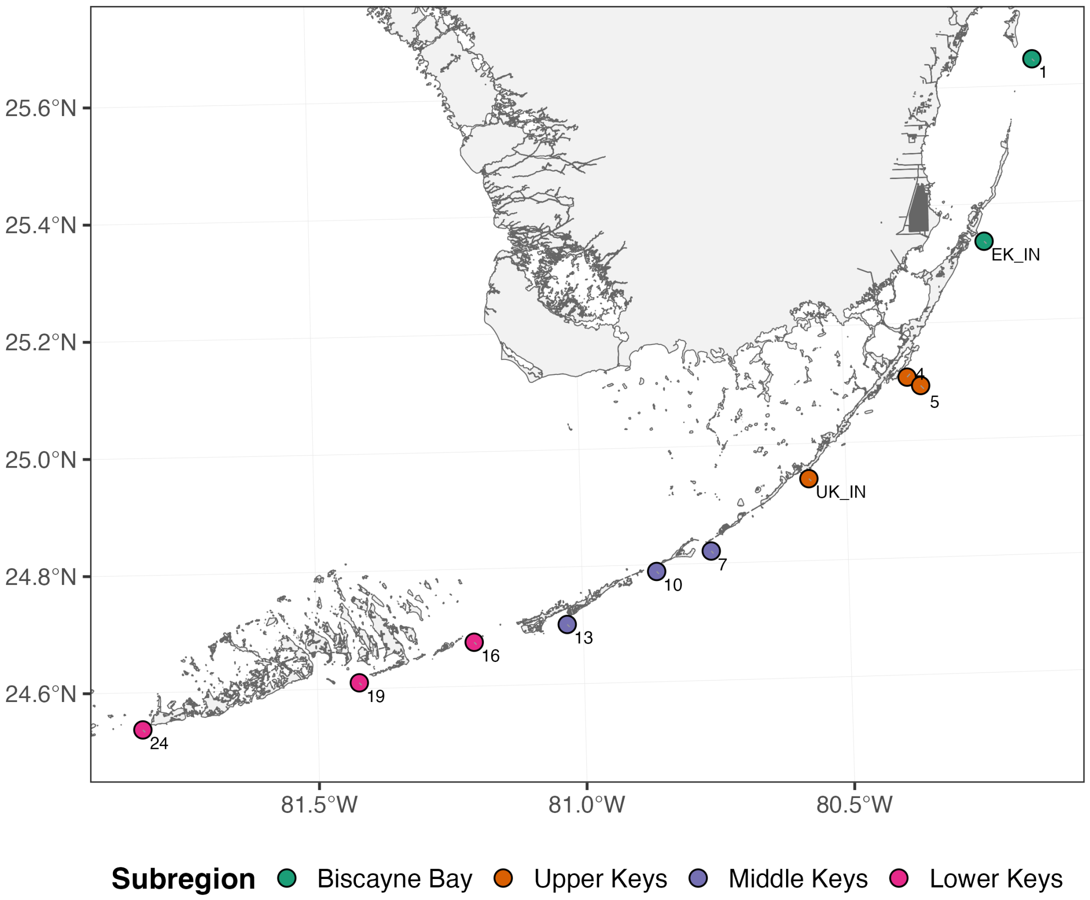
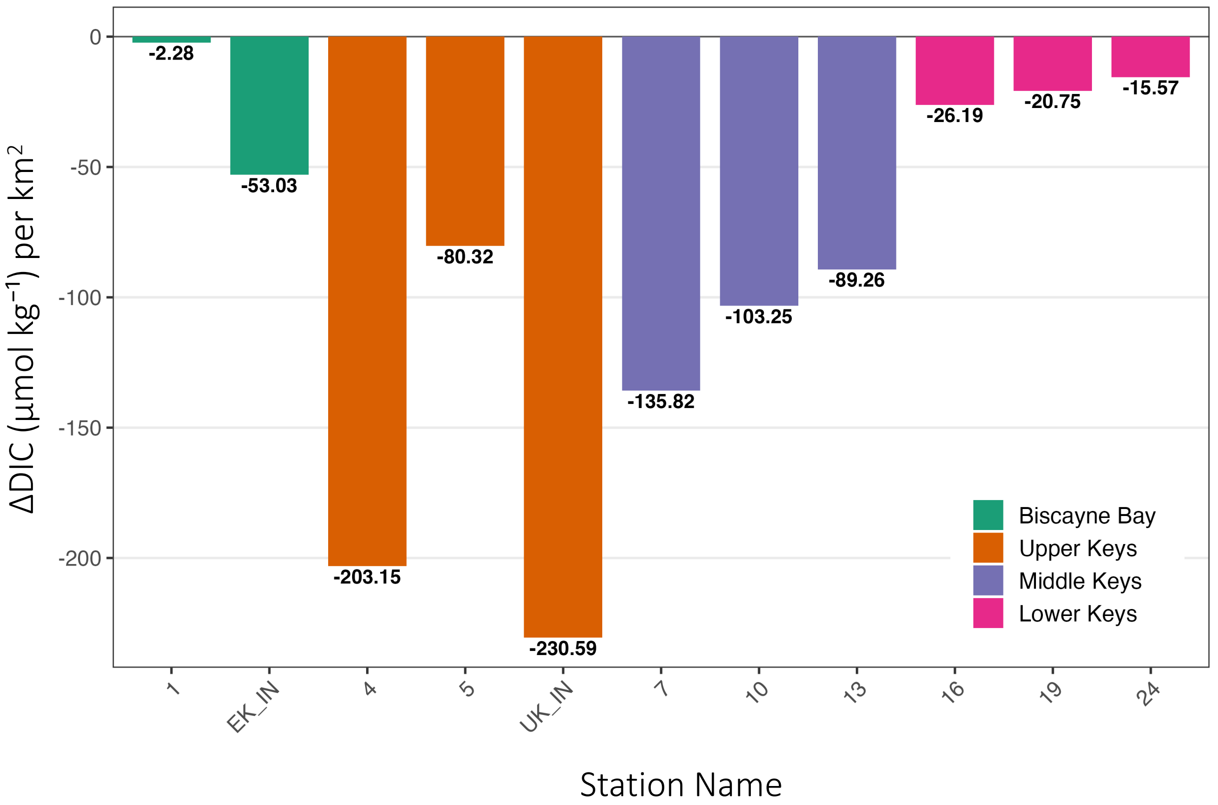
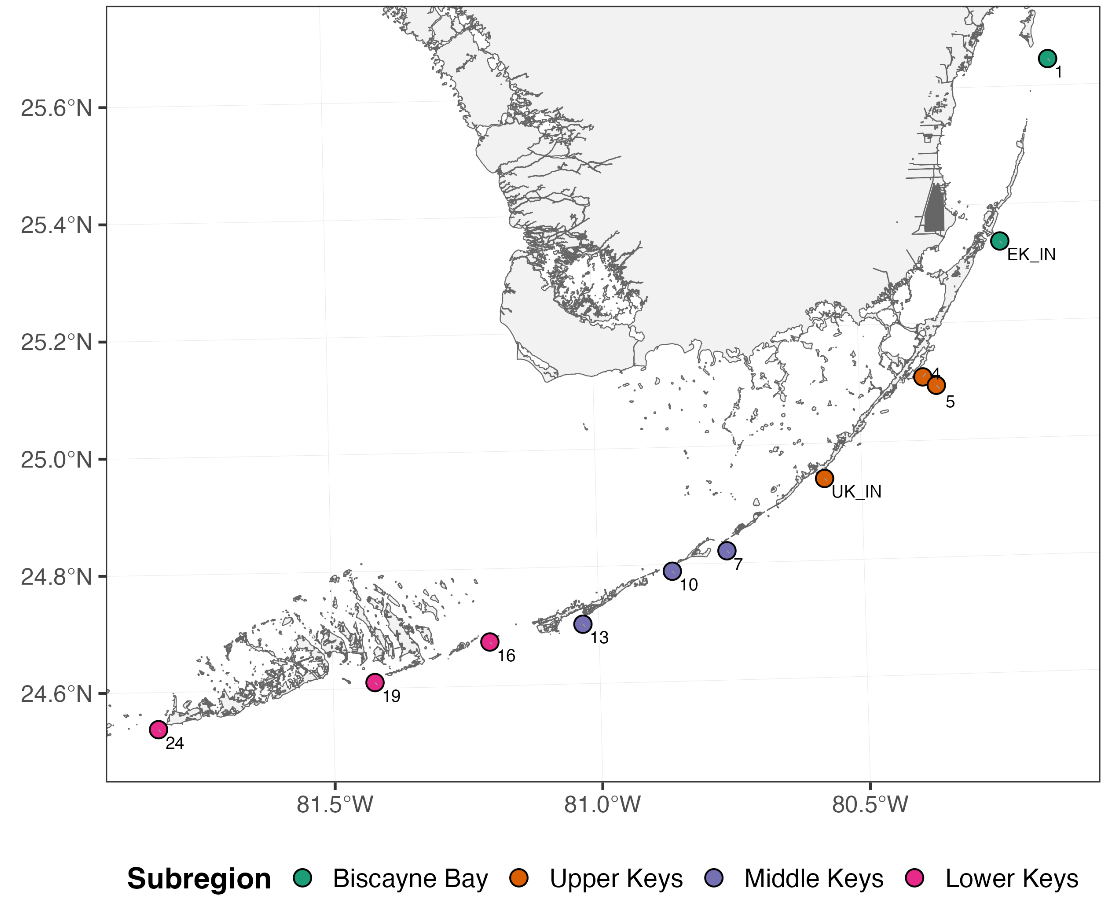
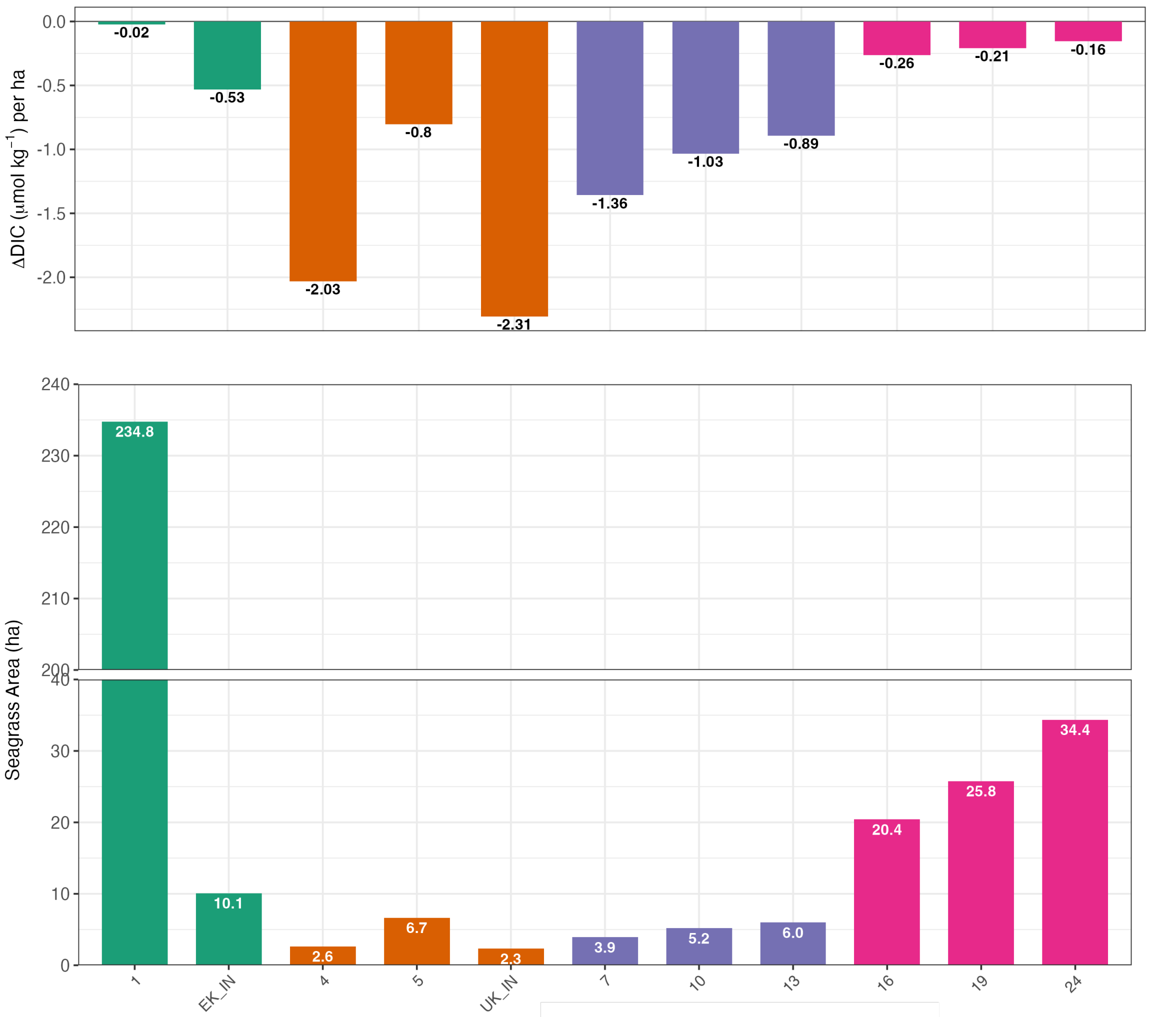




How much additional seagrass is needed to offset the annual increase in DIC in the Florida Keys?

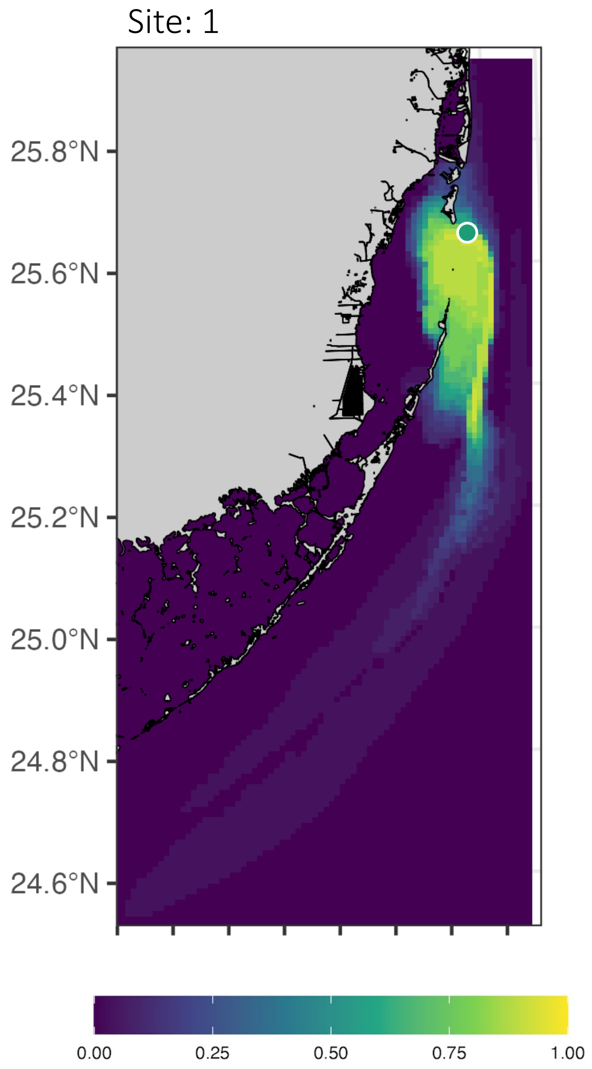




$$\text{Required Area (ha)} = \frac{5.35\ \mu\text{mol kg}^{-1}\ \text{yr}^{-1}}{\text{DIC Sensitivity } (\mu\text{mol kg}^{-1}\ \text{yr}^{-1})}$$

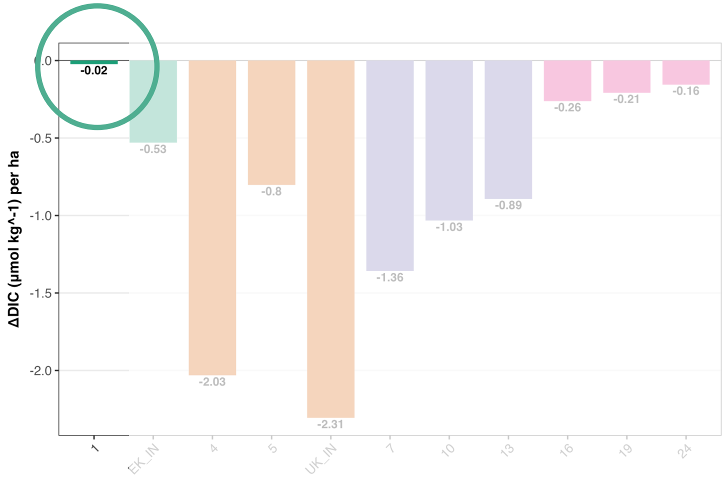
Annual Spatial ΔDIC Sensitivity: Biscayne Bay

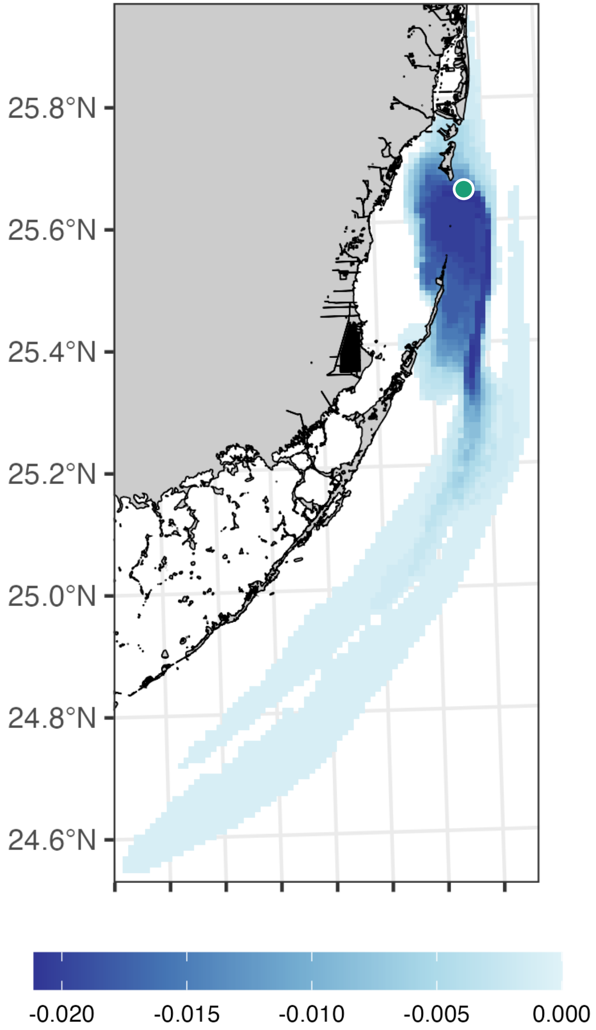
Sensitivity = (probability of inclusion) x (ΔDIC per hectare)



Probability of Inclusion (visit-normalized)

Annual ΔDIC = -0.02
(μmol kg^{-1} ha^{-1})



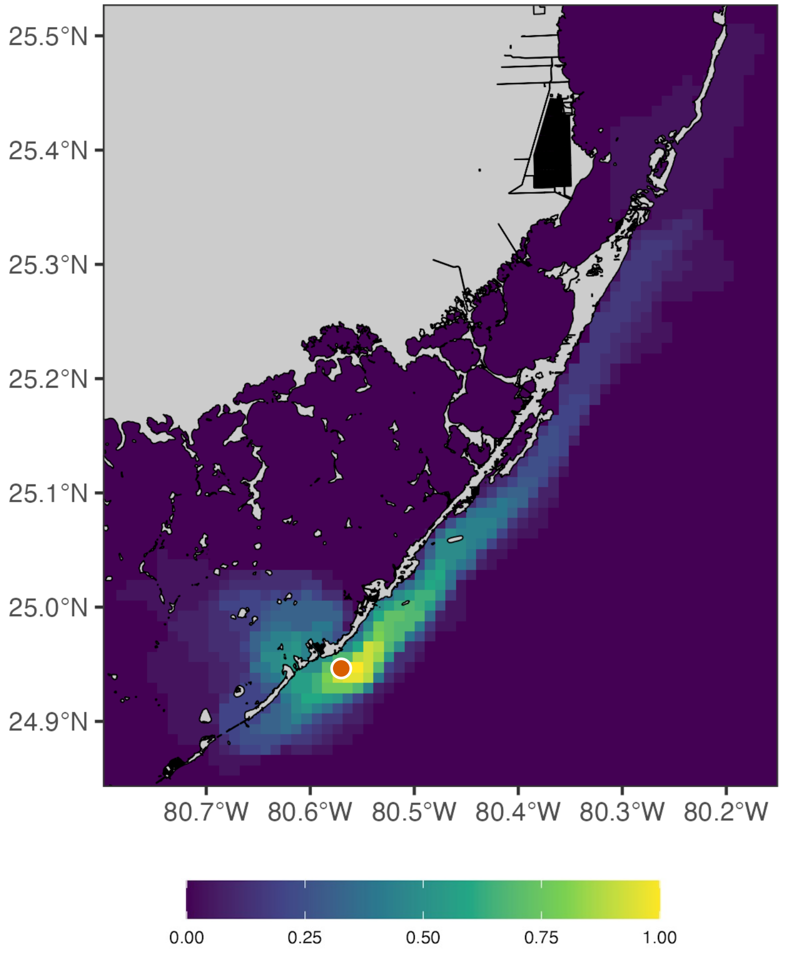


ΔDIC (μmol kg^{-1}) per hectare

Annual Spatial ΔDIC Sensitivity: Upper Keys

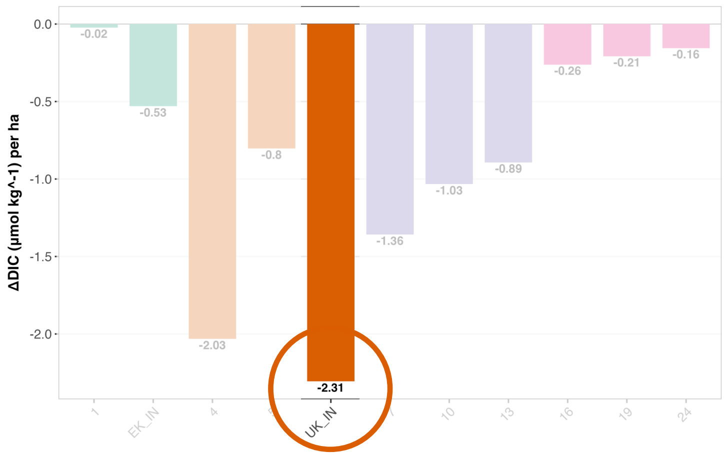
Sensitivity = (probability of inclusion) x (ΔDIC per hectare)

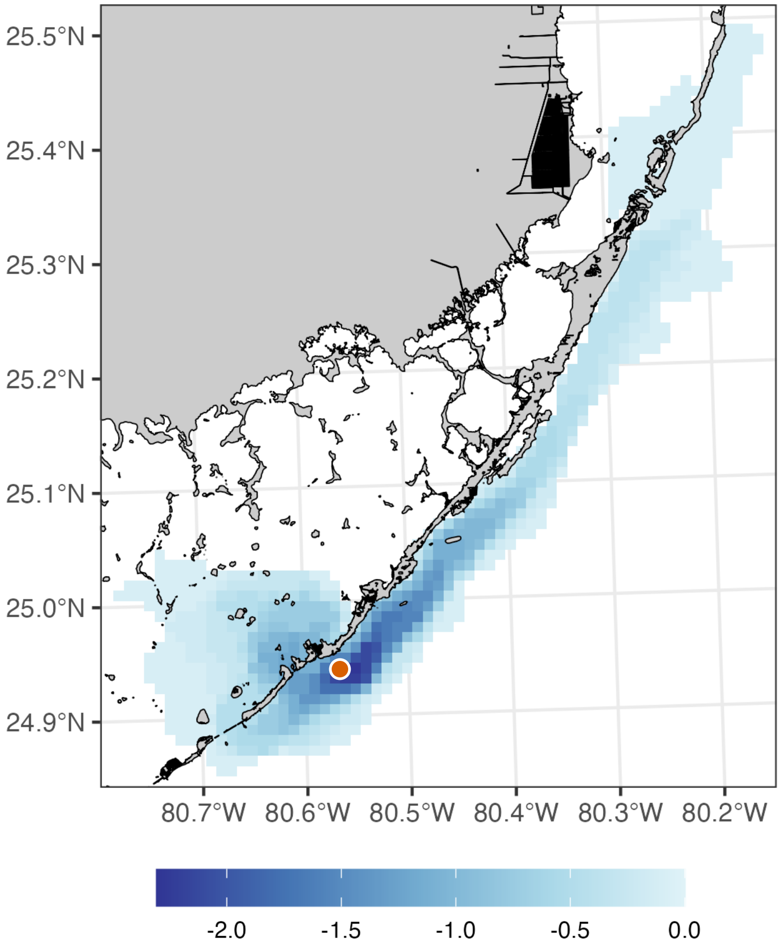
Site: UK_IN



Probability of Inclusion (visit-normalized)

Annual ΔDIC = -2.31
(μmol kg^{-1} ha^{-1})

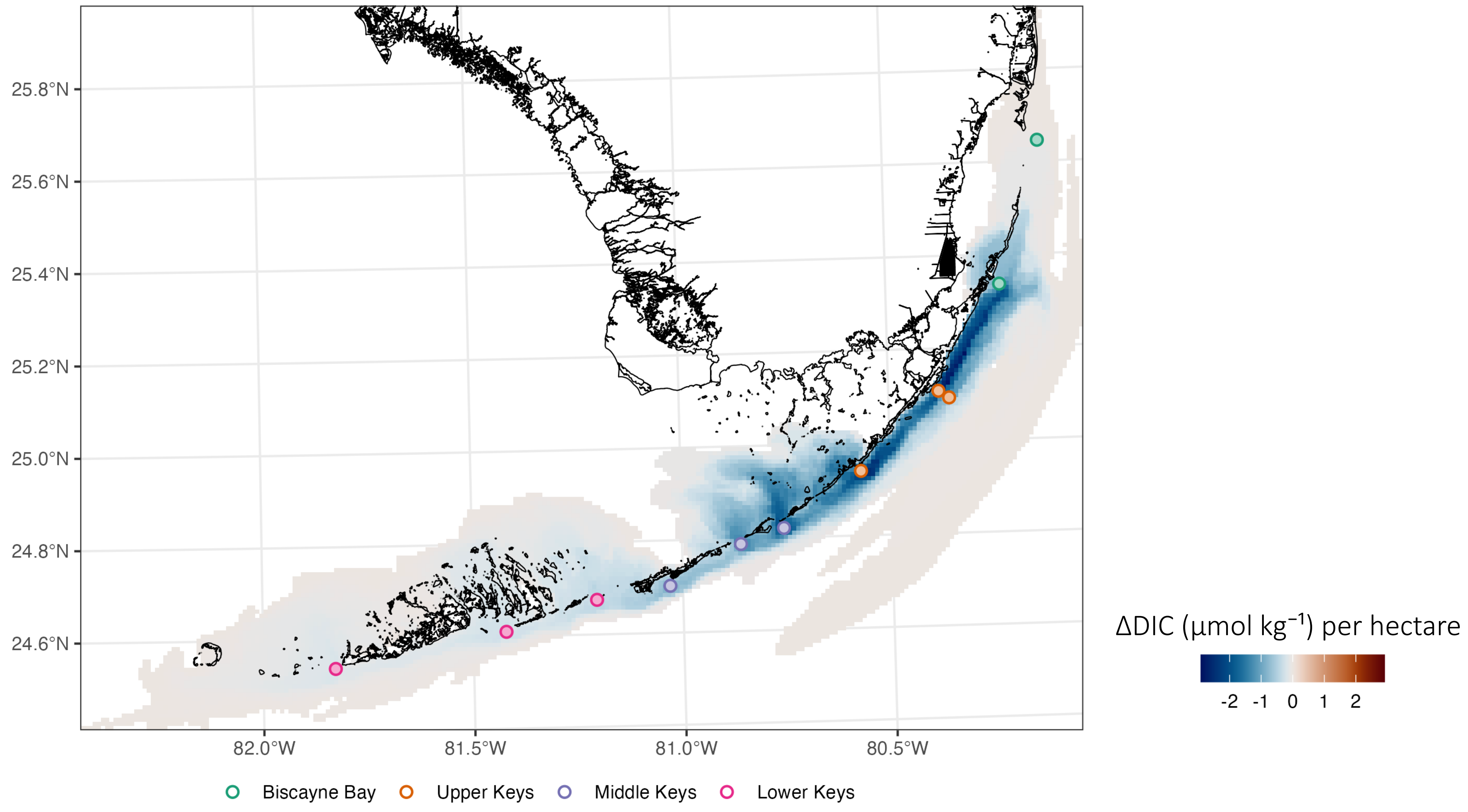




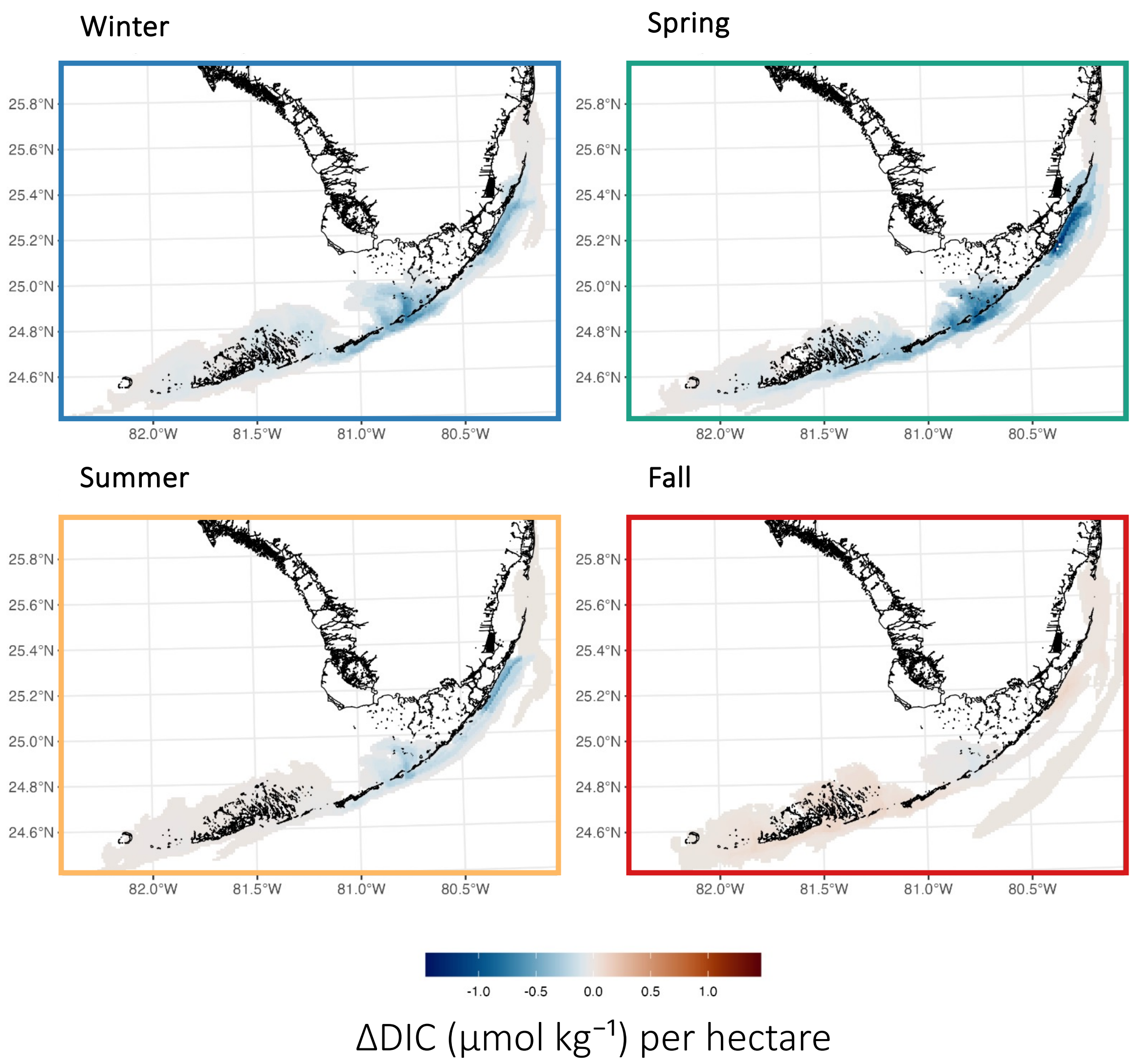
ΔDIC (μmol kg^{-1}) per hectare

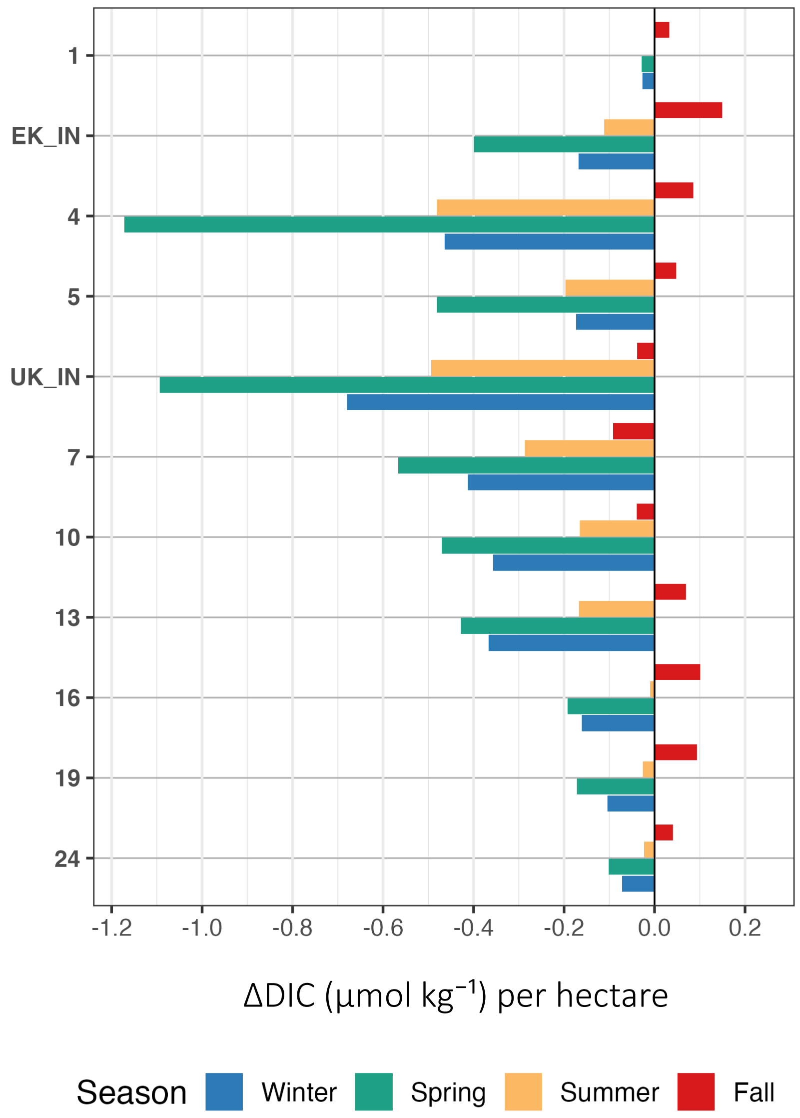
Net Annual ΔDIC Sensitivity to Seagrass Habitat Change

Regional Sensitivity = ∑(probability of inclusion × ΔDIC per hectare)



Seasonal ΔDIC Sensitivity to Seagrass Habitat Change





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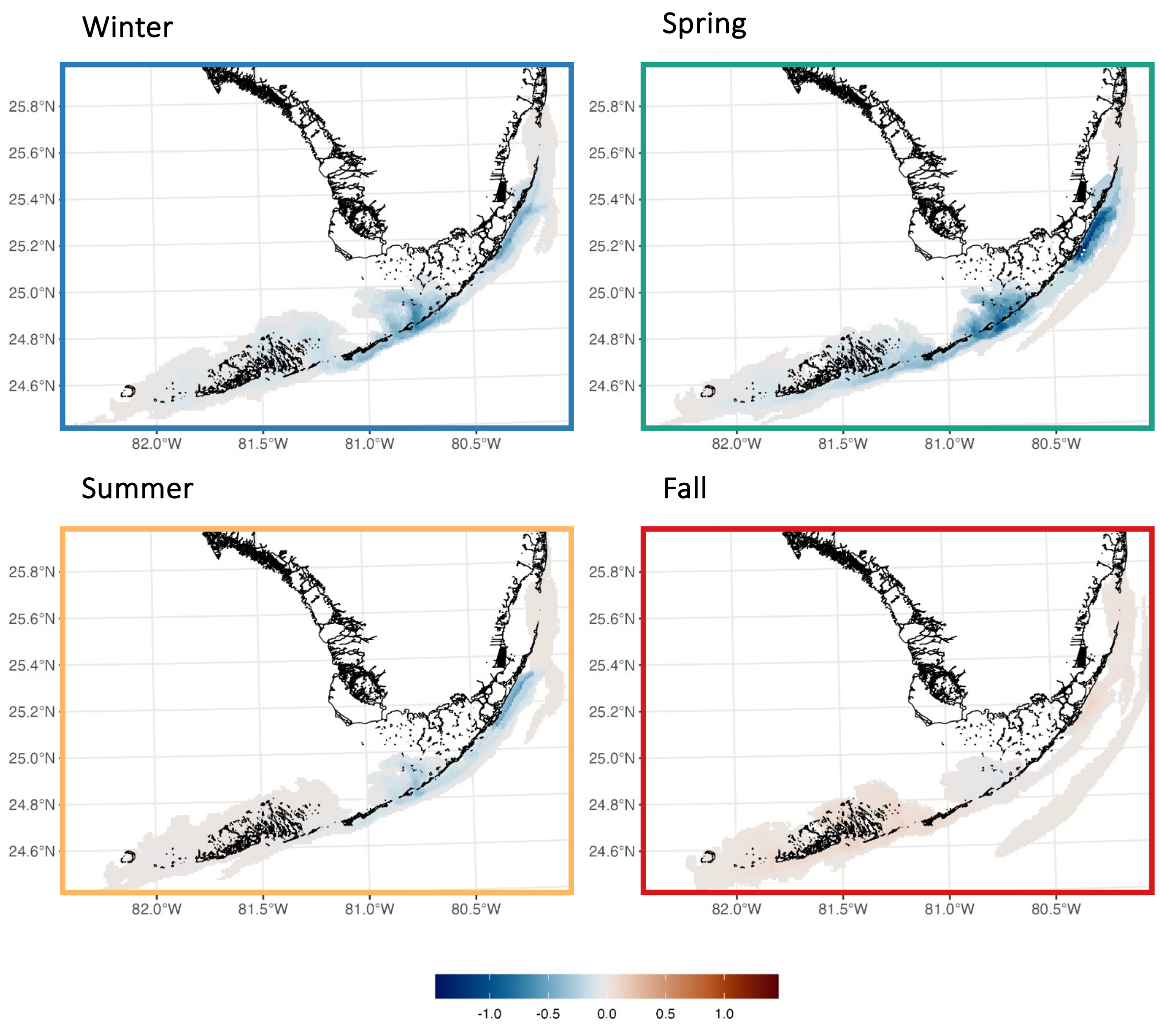
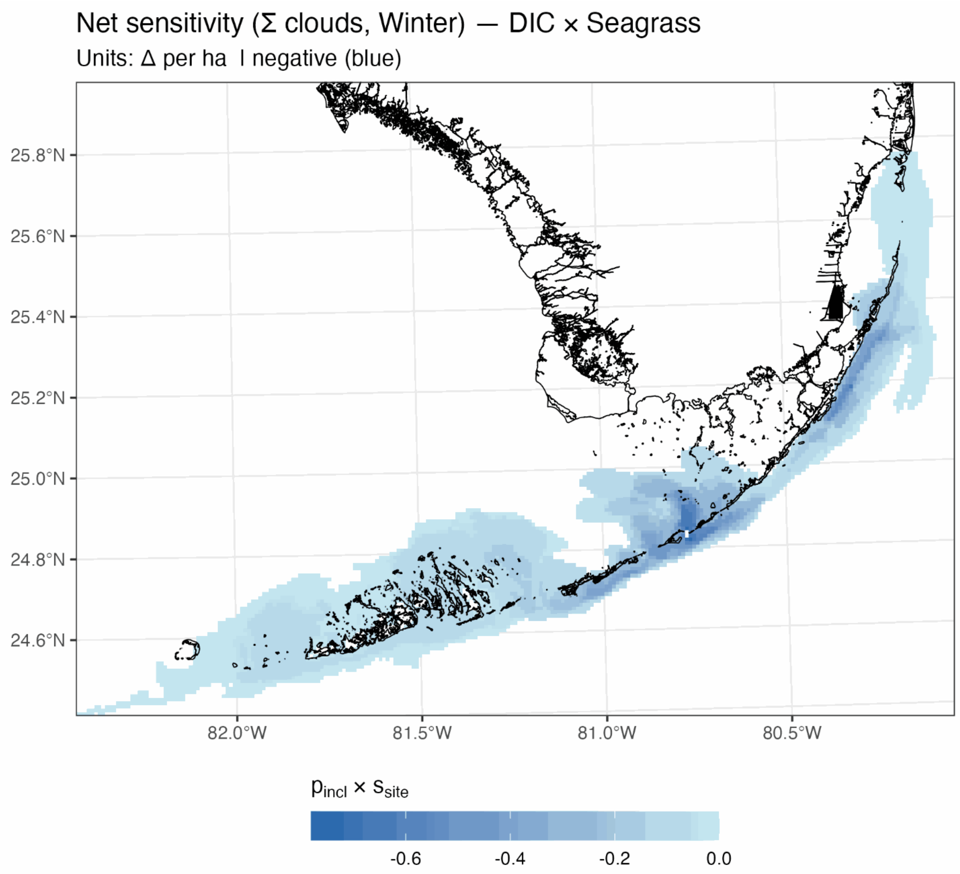


ΔDIC (μmol kg^{-1}) per hectare



ΔDIC (μmol kg^{-1}) per hectare

Preliminary Conclusions & Thinking Forward

1. Upstream seagrass communities may be able to offset increasing DIC at achievable restoration scales.
2. Strategic siting could amplify metabolic impact.
3. Restoration design should consider biogeochemical and hydrodynamic context.

What are the opportunities and barriers for scaling seagrass restoration for biogeochemical benefit in the Florida Keys?*

Preliminary Conclusions & Thinking Forward

"While local efforts have had success at small spatial scales, the rate of restoration has not been able to keep up with the overall rate of reef health decline in the Florida Keys. In order to restore Florida Keys reefs to benefit generations to come, ***restoration efforts must be scaled up with focus at the ecosystem level and with long term resiliency in mind."***

(Restoring Seven Iconic Reefs: A Mission to Recover the Coral Reefs of the Florida Keys, 2019)

Acknowledgements

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NOAA Climate Program Office

National Marine Sanctuaries

NOAA NCCOS

OAP NOAA Ocean Acidification Program

IOOS Integrated Ocean Observing System

Mission: Iconic Reefs

Restoring America's Everglades

NOAA Coral Reef Conservation Program

U Miami

NGI Northern Gulf Institute

NOAA Fisheries

Florida Fish and Wildlife Conservation Commission

NOAA Atlantic Oceanographic & Meteorological Laboratory

USF University of South Florida

VIMS

Florida Department of Environmental Protection

National Park Service

SECOORA

Florida Regional Ecosystem Stressors Collaborative Assessment

FRESCA

FRESCA Goal: Assess current and future impacts of five key stressors under climate change: **ocean acidification**, **ocean warming**, **hypoxia**, **harmful algal blooms**, and **eutrophication**.

Florida
Regional
Ecosystem
Stressors
Collaborative
Assessment

https://www.aoml.noaa.gov/fresca/

FLORIDA REGIONAL ECOSYSTEM STRESSORS COLLABORATIVE ASSESSMENT

FRESCA

Aquatic Geochemistry (2025) 31:4
https://doi.org/10.1007/s10498-025-09438-x

ORIGINAL ARTICLE

Statistical Prediction of In Situ Coral Reef Carbonate Dynamics Using Endmember Chemistry, Hydrodynamic Models, And Benthic Composition

Heidi K. Hirsh[1,2] · Thomas A. Oliver[3] · Thomas Dobbelaere[4] · Ana M. Palacio-Castro[1,2] · Hannah C. Barkley[3] · Alice E. Webb[1,5] · Emmanuel Hanert[4] · Ian C. Enochs[1]

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Abstract
In the face of rapidly compounding climate change impacts, including ocean acidification (OA), it is critical to understand present-day stress exposure and to anticipate the biogeochemical conditions experienced by vulnerable ecosystems like coral reefs. To meaningfully predict nearshore carbonate chemistry, we must account for the complexity of the local benthic community, as well as connectivity between habitats and relevant endmember carbonate chemistry. Here, we adopt a system-scale approach to predict site-scale effects of benthic metabolism on the carbonate system of the Florida Reef Tract (FRT). We utilize bimonthly carbonate chemistry data from ten cross-shelf transects spanning 250 km of the FRT to model changes in dissolved inorganic carbon (DIC) and total alkalinity (TA). Benthic habitat maps were used to broadly classify communities known to impact carbonate chemistry. A SLIM 2D hydrodynamic model with mesh resolution reaching 100 m over reefs and along the coastline was used to determine the relevant water mass histories and identify the upstream benthic communities shaping local carbonate chemistry. These historical metabolic footprints, or "flowsheds", were used to build predictive models of the change in DIC and TA at each station. The best predictive models included the chemical impacts of benthic ecosystem metabolism, as defined by water mass trajectories, weighted endmember chemistry, volume, time, and other environmental parameters (light, temperature, salinity, chlorophyll-a, and nitrate). Considering water mass for 5 days prior to sample collection yielded the highest model skill.

Keywords Coral reef carbonate chemistry · Statistical modeling · Water mass history · Benthic metabolism · Endmember biogeochemistry · Florida reef tract

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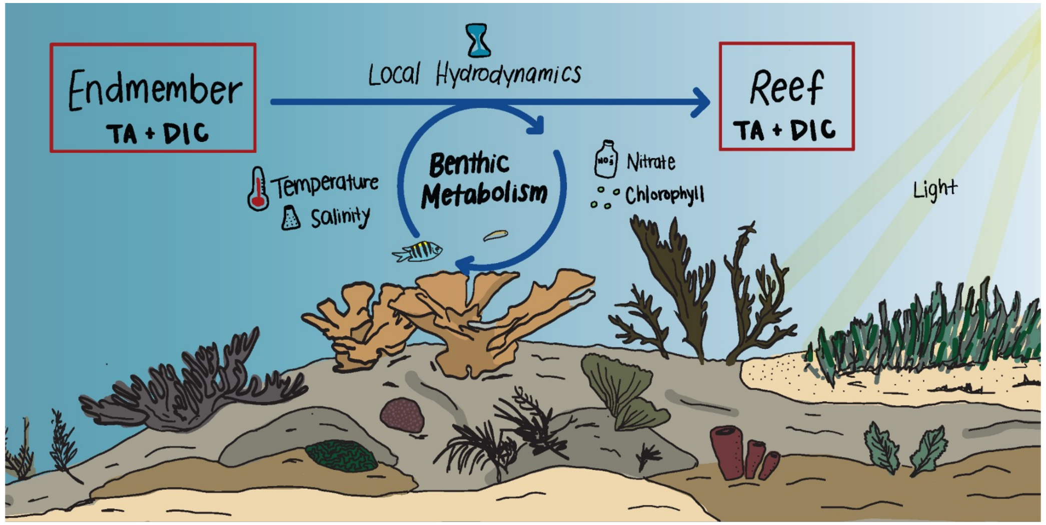
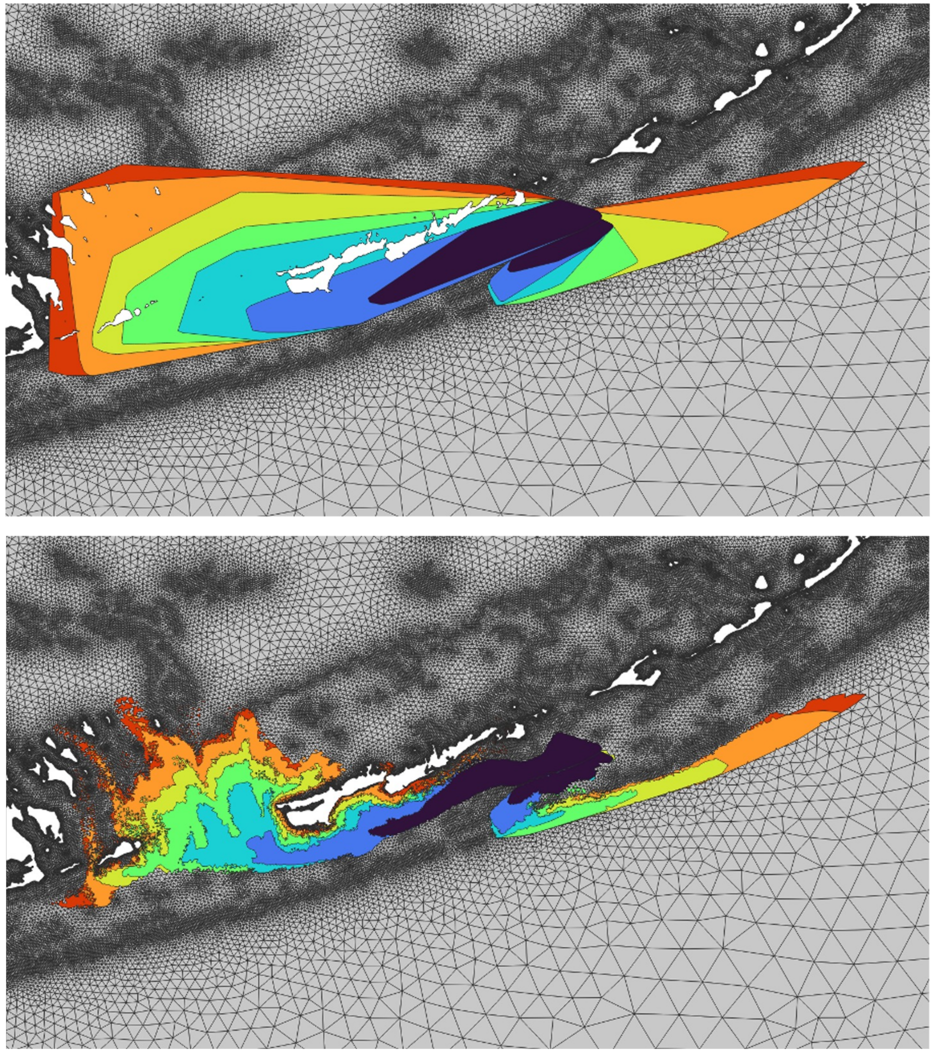


https://link.springer.com/article/10.1007/s10498-025-09438-x

SLIM (unstructured mesh hydrodynamic model)



SLIM2D Hydrodynamic Model
South Florida, 2012-2021

https://www.slim-ocean.be/index.php/florida/