A Model for Understanding the Effects of Flow Conditions on Oyster Reef Development and Impacts to Wave Attenuation

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Background

As a form of **nature-based infrastructure** (NBI), oyster reefs can act as **natural breakwaters** and provide **ecosystem services**[6]

Coastal salt marshes offer **protection from storm surge and waves** and **habitat for keystone coastal species**[3]

The **conditions that promote the growth of these systems** must be understood to develop guidelines for implementation as NBI, wherein **depth and velocity** are the primary drivers of growth and mortality in oysters[2]

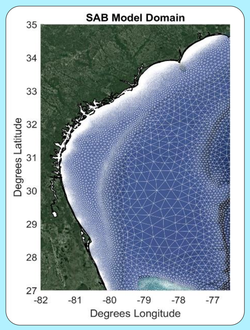
https://blogs.ifas.ufl.edu/santarosaco/2016/01/19/panhandle-florida-master-naturalist-graduates-opt-to-use-living-shorelines-to-enhance-habitat-and-protect-their-coastal-properties/

Understanding how these forms of NBI respond to their hydrodynamic environment will contribute to the development of **robust design guidelines** in integrating natural processes with shoreline defense

Methods

Hydrodynamic Conditions (ADCIRC)

ADCIRC: ADvanced CIRCulation[5]



Harmonic Analysis
Obtains amplitude, angular frequency, and phase angle for each constituent at each node of the mesh to calculate depth and flow velocity

***'MARSH'* Mesh**[1]
- 540,114 nodes and 1,005,008 elements
- Includes intertidal zones in estuaries

Velocity
Water Level

Oyster Reef Model[4]

Three governing differential equations[4] are calculated at each node within the SAB

Oyster Layer Volume

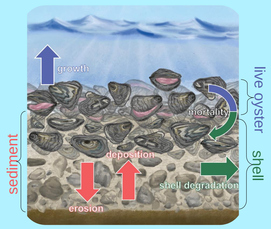
$$\frac{\partial O}{\partial t} = \underbrace{\frac{b_1 f O}{b_2 O + 1}}_{growth} - \underbrace{[\mu f + \varepsilon(1-f)]O}_{mortality}$$

Sediment Layer Volume

$$\frac{\partial S}{\partial t} = \underbrace{(C \cdot W_s)}_{deposition} - \underbrace{E}_{erosion}$$

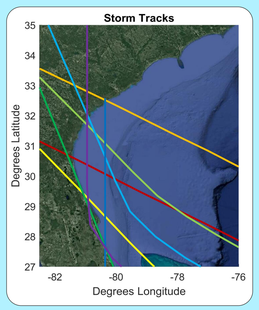
Shell Layer Volume

$$\frac{\partial B}{\partial t} = \underbrace{[\mu f + \varepsilon(1-f)]O}_{mortality} - \underbrace{\gamma B}_{degradation}$$



Storm Simulations (ADCIRC + SWAN)

SWAN: Simulating WAves Nearshore



8 synthetic storm[6] simulations were conducted to assess the **ability of the reefs to provide shoreline protection**.

Storms were chosen to capture protection capability across **range of intensities** and **angles to shoreline**

New Bathymetry

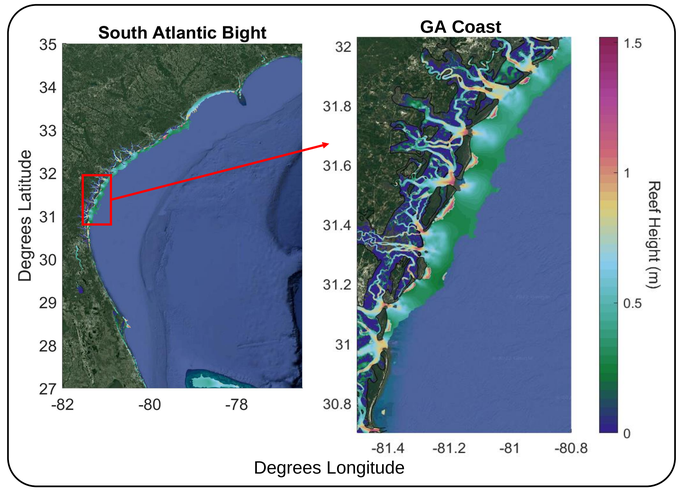
Predicted Oyster Reef Height

Max. water level
Max. significant wave height

Wave Attenuation

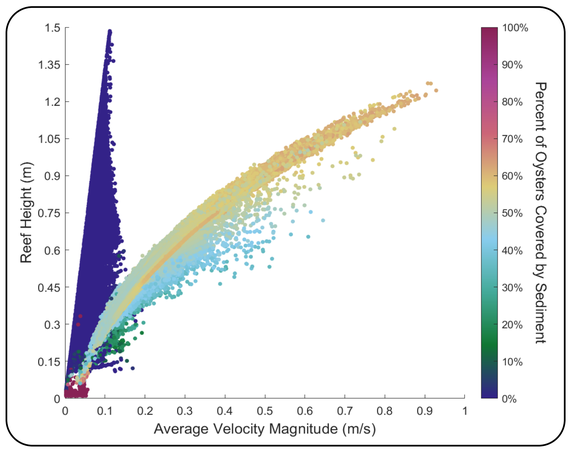
Reef height = shell layer height + oyster layer height

Results



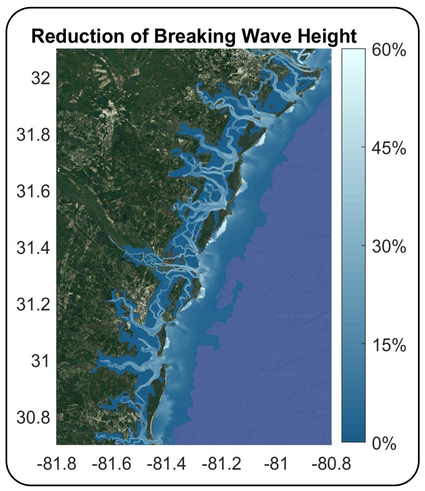
Highest predicted final reef heights: Areas between tidal inlets

Reef height is **velocity limited** due to sediment deposition dynamics



Sediment Dynamics - 2 'regimes'

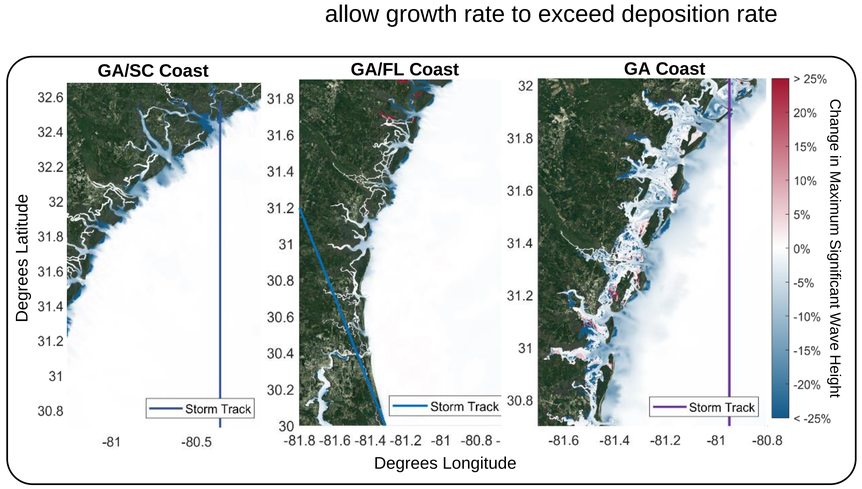
1. No sediment within oyster layer: maximum growth rate allowed by flow speed
2. Sediment within oyster layer: higher velocities allow growth rate to exceed deposition rate



Greatest wave energy dissipation:

Reefs between tidal inlets and along channel edges

Reduction in breaking wave height is **depth-limited**



Reduction in maximum significant wave height for all storms regardless of intensity or approach angle

Conclusions/Future Work

- Total reef height is velocity limited, where reef heights increase with flow speed
- Reduction in breaking wave height is highest at both tidal inlets and along tidal creeks where the water depth is smaller
- Reefs reduce maximum significant wave heights for all storm conditions
- Results reveal a promising outlook for the use of oyster reefs as NBI and may serve as a valuable tool in guiding design frameworks

Future Work

A similar approach will be followed in integrating MEM (Marsh Equilibrium Model) with ADCIRC to determine the impact of sea level rise on salt-marsh productivity (Hydro-MEM). Future Hydro-MEM adaptations include assessing tidal energy dissipation and the effects of tide creek order on marsh wetting and examining the use of sub-grid marsh porosity to improve simulations of hydroperiod.

References/Acknowledgements

[1] Bacopoulos, P., & Hagen, S. C. (2017). The intertidal zones of the South Atlantic Bight and their local and regional influence on astronomical tides. *Ocean Modelling*, *119*, 13–34.

[2] Byers, J. E., Holmes, Z. C., & Malek, J. C. (2017). Contrasting complexity of adjacent habitats influences the strength of cascading predatory effects. *Ocecologia*, *185*(1), 107–117.

[3] Halpin, P. M. (2000). Habitat use by an intertidal salt-marsh fish: trade-offs between predation and growth. Mar. Ecol. Prog. Ser. 198, 203-214

[4] Housego, R. M., & Rosman, J. H. (2016). A Model for Understanding the Effects of Sediment Dynamics on Oyster Reef Development. *Estuaries and Coasts*, *39*(2), 495–509.

[5] Luettich,R., & Westerink, J. J. (2004). *Formulation and Numerical Implementation of the 2D / 3D ADCIRC Finite Element Model Version 44* . 1–74.

[6] Nadal-Caraballo, N. C. et al. (2020). Coastal Hazards System: A Probabilistic Coastal Hazard Analysis Framework. *Journal of Coastal Research*, *95*(sp1), 1211–1216.

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