Morphodynamics of Oyster Reefs in Tidal Flats Under Various Sea-Level Rise and Wave Scenarios

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A. Introduction and Objective

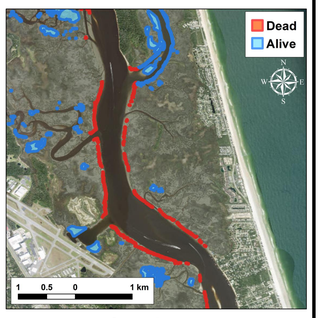
Oyster Reefs

Oyster reefs are self-organized structures, that establish and grow through feedbacks between internal population dynamics and external factors. Reef self-organization depends on the balance of production and occupancy of the local substrate

Objective

Analyze the feedback between hydrodynamics and reef evolution and survival in an estuarine environment

Oyster populating a reef in the Guana-Tolomato Matanzas Estuary, Florida, USA (Courtesy of the GTMNERR)



Oyster reefs in the GTM estuary, divided in **Dead** and **Alive**. (Map of the Fish and Wildlife Research Institute)

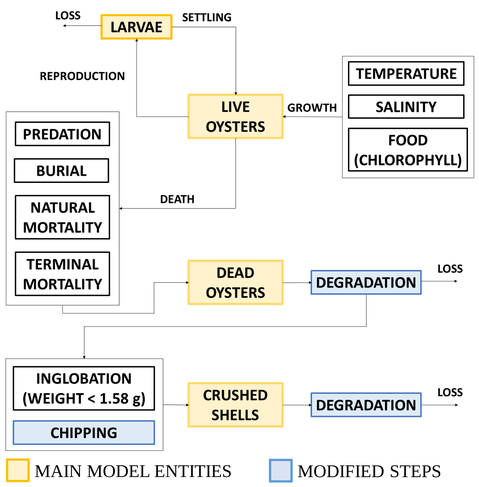
Method

We couple:

- The **oyster reefs individual-based model (IBM)** developed by Yurek et al. (2021) [1], which simulates the evolution of an oyster reef in time
- A **wave model** (Fagherazzi et al., 2006) [2], which computes the local wave height by using different combinations of: (1) water depth; (2) wave period; (3) wind speed; (4) sea level rise (SLR)

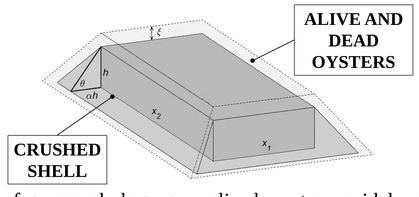
B. Coupled Model

Oyster reefs Individual-Based Model (IBM)



MAIN MODEL ENTITIES MODIFIED STEPS

Conceptual representation of the oyster reef individual-based model (IBM). The yellow boxes contains the **main entities** considered in the model



Reef geomorphology generalized as a trapezoidal volume

Video: example of the oyster evolution model results

Hydrodynamic Model

STEP1. Calculate the wave height (H) in the tidal flat

Wind wave energy; Wave group celerity; Source term

Used to calculate wave height

$$\partial E/\partial t + \nabla \mathbf{c}_g E = S_{in} \quad (1)$$

Wind Term f(wind speed U); Bottom friction term; Whitecapping term; Depth-induced breaking term

Calculated as function of wave energy

$$S_w = S_{bf} + S_{wc} + S_b \quad (2)$$

STEP2. Calculate the spats deposition ratio (R_D) on the oyster reef

Bottom shear stress; Friction factor; Max horizontal orbital velocity at the bottom; Wave height; Wave period; Water depth

$$\tau_b = 1/2 f_w \rho_w u_m^2 \quad \text{with} \quad u_m = \pi H / [T \sinh(kY)], \quad (3)$$

Spats deposition reduction factor; Critical shear stress = 0.10 Pa

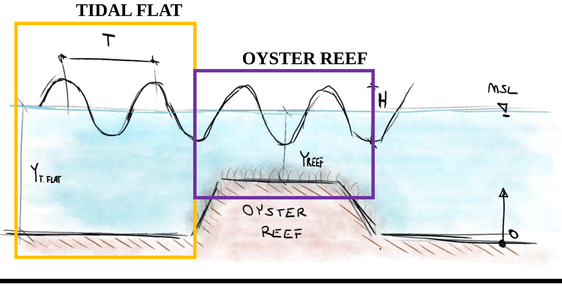
$$R_D = \min\left(\frac{\tau_{cr} - \tau_b}{\tau_{cr}}, 1\right) \quad (4)$$

NOT CALIBRATED YET

STEP3. Calculate wave contribution to the degradation of boxes [3]

Total percentage of degraded boxes; Chemical degradation boxes; Mechanical degradation boxes; Max additional pore pressure

$$deg_{box}^{tot} = deg_{box}^{ch} + deg_{box}^{mec} \Delta p_{max} \quad (5)$$



C. Model Scenarios

The model scenarios simulate **post-restoration conditions** (200 years), where:

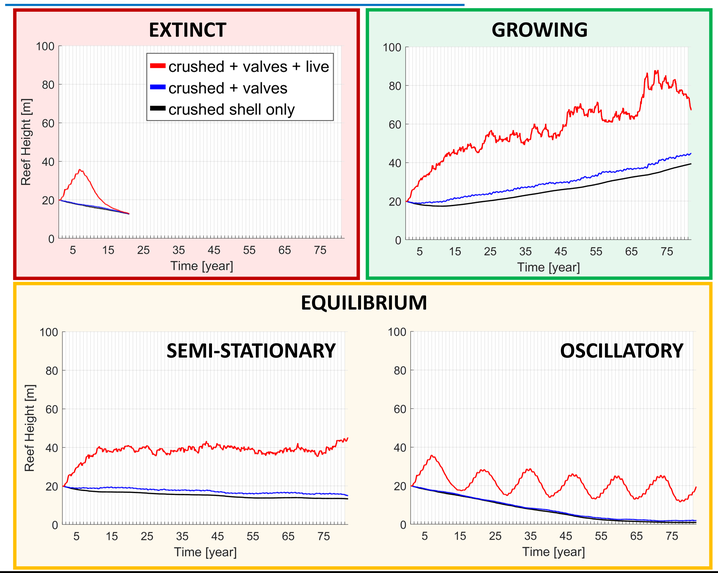
- the initial elevation of the reef is 20 cm above the reference level (see previous slide)
- the density of oysters is 400 individuals/m²

We considered all the possible combinations of the water depth, wave period, wind speed, SLR values reported in the following table

Parameter	Values	U.M.
Sea Level Rise (SLR)	0-3-10	mm/year
Wind Speed (U)	1-5-10	m/s
Wave Period (T)	0.5-1-2-4-6	s
Water Depth (Y)	0.50-0.75-1.00-1.50	m

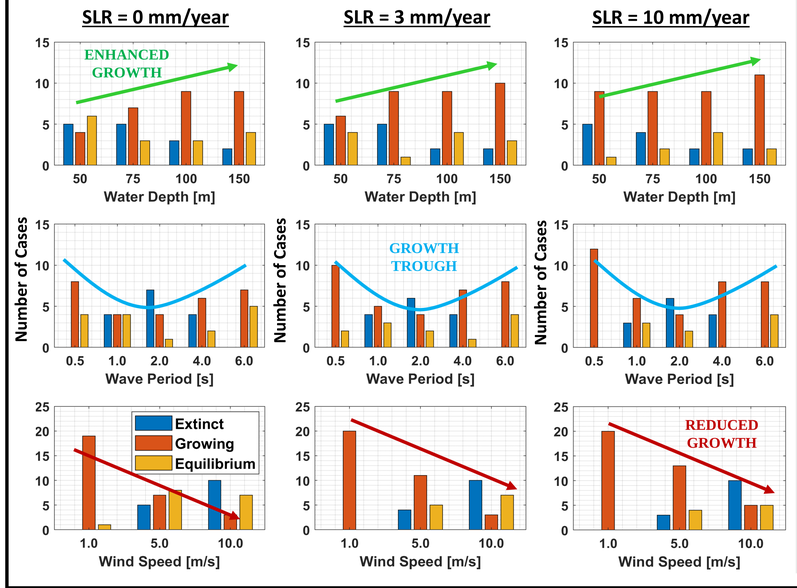
The Values of U, T, and Y are obtained from Lyddon et al., 2019 [4]; Jackson, 2010 [5]; and Carniello et al., 2010 [6].
The rates of SLR of 3 and 10 mm/year are the global average and maximum, respectively

D. Reef Evolution Scenarios

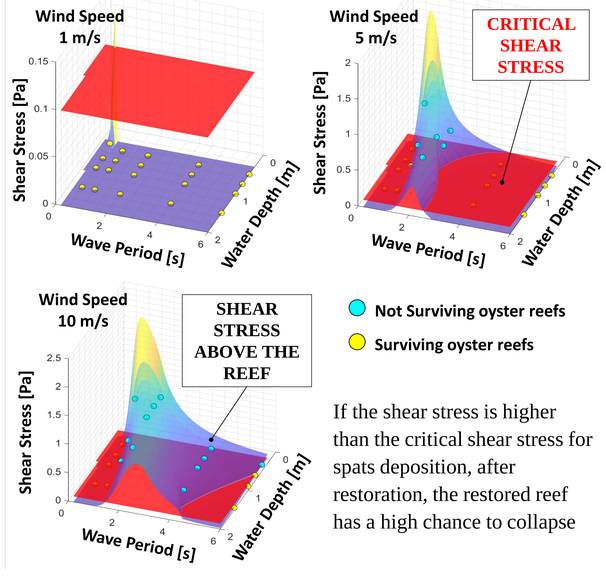


E. Results

Reef Evolution Scenarios Classification



Reef Survival Criteria



If the shear stress is higher than the critical shear stress for spats deposition, after restoration, the restored reef has a high chance to collapse

F. Limitations

- The value of the **critical shear stress for spats deposition** is not knows. In this study, we used the value observed for cohesive sediments
- The model does not (yet) consider the effect of **water currents** in reef growth
- The model does not (yet) consider the effect of **tide** in reef growth

G. Next Steps

- Determine the value of the critical shear stress at deposition for the oyster spats, using **laboratory tests**
- Couple the model with a hydrodynamic (and particle tracking) model (**Delft3D**), to simulate the effect of currents, tide, and the effect of spatial reef distribution on larvae availability
- Add the **wave contribution to the degradation of boxes** (dead oysters)
- Add the computation of Filtration Services (FS), as in Gray et al. 2021 [7]

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THANK YOU!

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