White Paper -- Combining artificial reef and kelp farming to protect local communities

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Background

The Rhode Island shoreline is directly exposed to tropical storms and Nor'easters, whose frequency and intensity is steadily growing, which combined with Sea Level Rise (SLR) poses an imminent threat to coastal infrastructures and communities (Grilli et al., 2017, 2020; Spaulding et al, 2019; Becker et al., 2022). Current efforts have evolved from hazard and risk assessment towards a search for optimal solutions for protecting communities, while balancing and enhancing local ecosystem services, such as ecological integrity, the "blue" economy, and tourism. From these studies, promising hazard mitigation "*interventions*" have emerged, such as the concept of "*artificial reef*", inspired from the efficient functionality of a natural reef (Schuh et al., 2022).

Natural reefs provide a powerful natural protection to shorelines as demonstrated and quantified by hazard assessment and cost-benefits analyses, which have estimated their values in the US to $1.8B in coastal risk reduction, reaching $10M/km in the high density areas of Hawaii and Florida (Reguero et al., 2021; Beck, et al., 2018). Natural reefs naturally dissipate wave energy, mostly through increased friction and wave breaking, providing a calm area landward of the reef and protecting the shoreline from the most damaging waves. Such efficient natural barriers have inspired the concept of an *artificial reef* (e.g., Fig. 1 DESIGN 4), which has recently been demonstrated to be an appealing solution for protecting shorelines from damaging storms (e.g., Schuh et al, 2022; Grilli et al., 2022). As described and documented in many studies (e.g., Agardi et al., 2022), artificial reefs built using ecosystem friendly material, both provide the shoreline with an additional line of defense to storms and increase biodiversity, creating new habitats, and reinforcing local ecosystems. Recent hybrid reef concepts further combine a structural design with natural native species, such as coral in Florida waters (e.g., Reguero et al., 2021,2024, Norris et al, 2024).

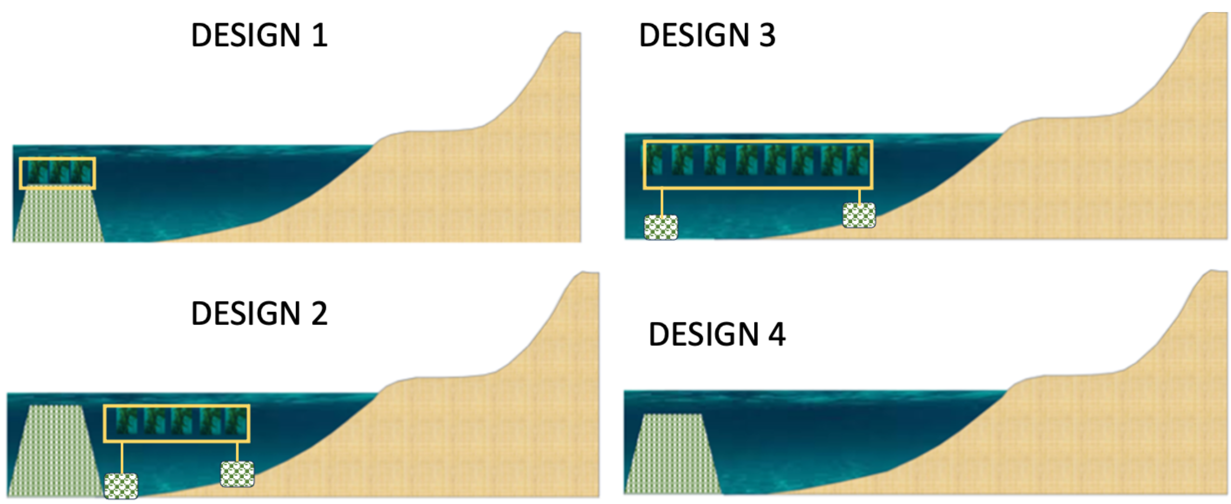

Fig. 1: Examples of four designs of artificial hybrid reefs combining reef and kelp.

In the similar spirit of a *hybrid reef*, we are proposing for colder New England coastal waters to develop a combination of an eco-friendly structural reef design with macro-algae, such as native kelp, which has been demonstrated to thrive in this environment (e.g., Fig. 1, DESIGNS 1,2). Such a combination has proved promising in damping wave energy in recent studies (e.g., test site in Chile (Correa and Winckler, 2024), in situ experiments in Portugal (Miranda et al., 2024)). However, to our knowledge, no rigorous research has addressed the optimal design of the combination of a reef and kelp (or a kelp farm), to optimally protect the shoreline. In particular, the wave attenuation potential of kelp, particularly in combination with an underlying reef, has not been assessed. Additional benefits to this hybrid design are to enhance the ecosystem's biodiversity and provide a positive economic impact on local communities. Finally, any reef design, whether hybrid or not, is site specific, in terms of the response of the adjacent shoreline to it; indeed, improperly designed artificial reefs can cause shoreline erosion rather than accretion (e.g., Schuh et al, 2022).

In this project, we propose to assess the protective ability of specific designs of hybrid and non-hybrid reef concepts (Fig. 1), at candidate test site(s) along the Rhode Island shoreline.

Objectives

We envision four successive phases for this project, that are briefly defined below. However, the aim of this white paper is to identify and secure preliminary funding to carry out Phase 1 only, which is a proof of concept.

<u>Phase 1:</u> Develop reliable numerical simulations of the design/siting/efficiency, in a selected community, of promising hybrid concepts, combining an artificial reef with a kelp farm (e.g., Fig. 1).

<u>Phase 2:</u> Conduct in-situ experiments in a controlled environment, to further refine the parametrization of modeled scenarios (based on Phase 1).

<u>Phase 3 :</u> Set-up an instrumented field test site to gather data and validate simulations.

<u>Phase 4 :</u> Refine numerical simulations to improve predictability, based on Phase 2 and Phase 3.

Funding permitting, Phases 2, 3 and 4 would be performed in sequence, after Phase 1 has been successfully completed and the community has given positive feedback to Phase 1 results.

Methods [Phase 1 only]

We propose to assess the protective ability for the shoreline, in terms of reduced erosion and flooding, of selected reef designs, hybrid and non-hybrid (Fig. 1), on the basis of numerical simulations. The hybrid design would combine a structural design and kelp farming. Anticipated results could help guiding further studies and coastal management to assess the short- and long-term impacts of such reef deployment on local ecosystem services. Two types of state-of-the-art numerical models would be used: (i) a phase-resolving wave model (FUNWAVE), to simulate wave propagation and induced currents; and (ii) a morpho-dynamic model (XBeach) to simulate the induced shoreline erosion. These simulations would characterize the impact of each design concept on flow, current, sediment transport, and the resulting water levels (flooding) and erosion of the shoreline during storm events.

Sites of interest

The selection of relevant sites will be part of Phase I work. However, examples of sites of interest in Rhode Island, in terms of variety of the morphology and wave exposure, include:

- Offshore of Breakwater Village (Point Judith Harbor of Refuge); low wave energy site
- Offshore of Westerly; medium energy site
- Offshore of Block Island (a preliminary Sea Grant study is in Progress); high energy site

Appendix

Submerged breakwaters have been deployed for many years around the world. Italy for example has a long history of creative coastal management and engineering resulting in many coastal cities being protected by submerged or emerged breakwaters, located slightly offshore of the shoreline. Ostia's (Rome old and current recreational harbor) submerged breakwaters were established in 1990, offshore of the city of Ostia, adjacent to Rome's International Airport, and proved very successful (Ferrante et al., 1993). Australia hosts the most famous surfing reef, specifically designed for combining protection and recreation, at Surfing Paradise, off of the Gold Coast (Black and Mead, 2001). A collaborative effort between the University of California, Santa Cruz, and the University of Miami is researching hybrid reefs combining specific structural designs and natural coral. In a similar spirit, Living Breakwaters were recently deployed In Raritan Bay in New Jersey, offshore of New York City (OnLine-Article, November 2024).

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