Limits to oyster development on breakwater structures

Aaron Bland - University of South Alabama, Dauphin Island Sea Lab

Background

Once a key feature of nearshore marsh environments, fringing oyster reefs have largely been lost from estuaries throughout the coastal United States[1]. Oyster reefs protect marsh habitat by altering water flow and stabilizing sediment[2], and improve the nearshore environment by improving water quality and providing habitat for mobile fish and crustaceans[3]. To maintain the ecosystem services of fringing oyster reefs at degrading marsh sites, coastal restoration projects often aim to recruit oysters to newly constructed breakwater structures[4]. Such endeavors fall under the category of 'living shorelines': projects that protect shorelines from erosion and storm surge using biogenic materials[5]. In fact, oyster reefs may be more effective at protecting marsh habitat than artificial structures given that oyster reefs can grow in pace with subsidence and sea level rise without requiring ongoing maintenance[6]. For these reasons, oyster reefs are a desired feature of living shorelines, and living shoreline designs that effectively recruit oysters are more likely to be implemented.

However, oyster restoration has outpaced the research needed to evaluate and improve restoration outcomes for successful oyster reef development[7]. For instance, the degree to which oysters settle and develop on living shoreline structures varies considerably across locations and structure types[8,9]. It is often unclear what is responsible for the variable success of living shoreline structures as substrate for oysters (Figure 1); this knowledge gap hampers our ability to plan coastal protection projects that maximize oyster recruitment. The success of future oyster restoration will depend on obtaining best-available information, including information about local oyster ecology that informs project siting and reef design[9].

Figure 1. Left: Oysters growing on a narrow, high-intertidal band on a Wave Attenuation Device (WAD) breakwater. Right: Southern oyster drills (Stramonita haemastoma) preying on an oyster; predation is one of many factors that may prevent adult oysters from surviving on breakwaters.

There are many ecological factors that might limit oyster development on breakwater structures. The supply of oyster larvae can vary spatially and temporally[10]; without oyster larvae, no spat can settle. Poor water quality can have lethal or sublethal effects on juvenile and adult oysters, including extreme temperatures and salinities[11] or low oxygen levels[12]. Oysters are also removed by predators including oyster drills[13] (Figure 1) and mud crabs[14]. The vertical distribution of oysters within the tidal prism has upper and lower limits set by various ecological forcings. The upper boundary is a consequence of low inundation periods that limits larval settlement for recruits, limits feeding time for settled oysters, and exposes oysters to greater desiccation stress. However, oysters that experience greater inundation are more susceptible to predation[15]. Furthermore, oysters that settle on low-relief substrate may be susceptible to bottom-water hypoxia or sedimentation[16].

Objective and Hypotheses

The objective of this project is *to identify the ecological factors that limit oyster development on breakwater structures.* A field experiment will be performed at two Alabama living shoreline sites that feature various breakwaters intended for oyster recruitment. Bare and pre-seeded settlement tiles will be deployed at various tidal elevations (and therefore inundation periods) and monitored to evaluate the importance of (1) larval availability, (2) water quality, (3) predation, and (4) tidal elevation on oyster settlement and survival.

I hypothesize that:

- Wild spat settlement will be higher on bare tiles at lower tidal elevations (greater inundation period)
- Hypoxic conditions will be observed intermittently, especially during the summer
- Predation will be higher on tiles at lower tidal elevations (greater inundation)

How the study benefits coastal wetlands

By identifying the factors that limit individual oyster development on breakwater structures, this project will help identify tangible restoration decisions that may improve oyster reef development. For example, if high vertical relief is found to increase oyster survival rates, future living shoreline breakwaters could prioritize designs with greater vertical relief. If predation is found to be a significantly limiting factor, restoration projects should consider seeding sites with predator-induced spat that better resist predation[17]. In turn, living shorelines that better develop oyster reefs will make coastal wetland restoration more effective and more likely to be implemented. Living shoreline structures with growing oyster reefs can function as self-sustaining breakwaters that protect marsh habitat[18] and provide additional ecosystem services that enhance the marsh system[3]. Conversely, if living shorelines fail to recruit oysters and protect shorelines, they are less likely to be implemented over traditional shoreline hardening (e.g., bulkheads and revetments) that replaces coastal marsh habitat.

Work already completed

The Alabama Chapter of The Nature Conservancy (TNC) conducts annual surveys of oyster densities on breakwaters at several Alabama living shoreline sites. This monitoring highlights high temporal variability in the densities of spat and adult oysters across multiple sites. The various sites feature breakwaters of various construction and may differ with respect to local water quality and predator regime; consequently, it is not clear what is responsible for the differing performances of living shorelines with respect to oyster recruitment.

Statement of work

This study will be performed at two publicly funded, highly visible Alabama LS marsh restoration sites with significant historic monitoring of oyster reef development to breakwater structures. Coffee Island (CI, 30.334907° N, -88.253240° E) is a 4.5 km long marsh island located in Portersville Bay, near Bayou La Batre. In 2010, nine subtidal breakwater segments were built to protect the southern extent of the island in an experimental configuration with differing materials: three segments made of bagged oyster shell, three made of Reef Ball™, and three made of ReefBLK℠. Point aux Pins (PaP, 30.385393° N, -88.300019° E) is a 1.2 km long fringing marsh located along the northeast coast of the Point aux Pins peninsula in Portersville Bay. In November 2020, 585 concrete Wave Attenuation Devices (WADs) were installed in a series of 15 segments each about 60 m in length.

I propose to conduct a field experiment to evaluate the factors limiting oyster development on the breakwaters at CI and PaP. I will use bare settlement tiles to monitor wild oyster spat settlement (<u>larval availability</u>), and I will use tiles pre-seeded with oyster spat to monitor post-settlement mortality. To prepare pre-seeded tiles, I will contract the Auburn Shellfish Laboratory to seed ceramic settlement tiles. I will allow the seeded spat to grow in a flow-through mesocosm tank to a sufficient size (2 weeks) to be identified, and spat will be culled to standardize spat density on tiles (10 per tile).

Prior to tile field deployments, I will deploy depth loggers to CI and PaP to determine the tidal range at planned deployment locations. When possible, I will identify the elevation and tidal range of wild oysters on existing structures. Tiles will be deployed in the field fixed on vertical PVC poles along a range of heights, including below and above (1) the measured mean tide and (2) the elevation range of wild oysters in the area (Figure 2). This will ensure that the tiles are subjected to differing inundation periods (<u>tidal elevation</u>), so rates of oyster larval settlement and mortality can be compared across differing tidal elevations. I will also deploy some tiles directly onto living shoreline breakwater structures to see if the existing structures affect oyster settlement or mortality (Figure 2). I will use depth loggers to confirm the inundation duration of the deployed tiles for the duration of the experiment.

After deployment, I will frequently visit the tiles to track new oyster settlement and oyster mortality. Tiles will be removed from the water and imaged, then evaluated for the number of spat and adult oysters (live and dead), mussels, oyster drills and other predators (<u>predation</u>), and percent cover of barnacles and algae. Dead oysters will be examined for signs of predation (e.g. crushed or bored shells) and used to estimate mortality rates. Initially, I will visit tiles every 2 weeks, and when the density of oysters stabilizes (e.g., when most of the pre-seeded oysters are eaten), I will increase the sampling interval to monthly or bimonthly. Tiles will be monitored for a maximum of 9 months in the field.

I will monitor <u>water quality</u> using a combination of in-situ sensors (sondes), reference stations (ARCOS, arcos.disl.org), and opportunistic site visits (YSI probe). Water quality (temperature, salinity, dissolved oxygen) measured throughout the experiment period will be compared against known oyster tolerance thresholds to determine whether water quality is a likely limiting factor for oyster recruitment.

How the funds would be used

Funds will be used for materials for the project ($800), water level loggers ($1400), contracting the shellfish lab to seed oysters ($250), attendance at a conference ($1250), and boat transportation to the sites ($1200). Additional boat time, vehicle transportation to the boat ramps, and intern or technician time for field and lab work will be covered as part of ongoing monitoring work.

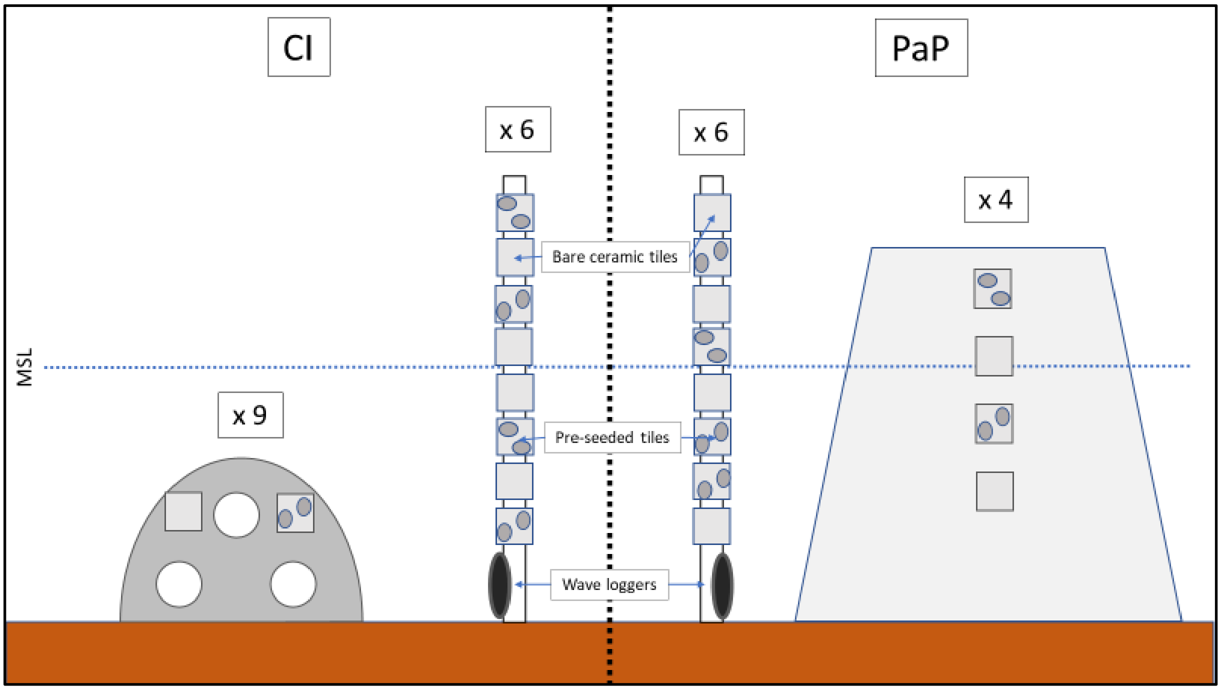

Figure 2. Tile field deployment scheme at Coffee Island (CI) and Point aux Pins (PaP). Bare and pre-seeded tiles will be deployed on PVC poles at various heights (inundation periods) and directly on to breakwater structures (CI: bagged shell, ReefBall, ReefBLK; PaP: WAD).

Sharing research results

My lab, the Baker Lab at the Dauphin Island Sea Lab, conducts extensive monitoring at Alabama living shoreline sites as part of a NOAA funded project, RESTORE Living Shorelines. We are in regular communication with project partners at the Alabama Chapter of The Nature Conservancy (TNC), Alabama Department of Conservation and Natural Resources, and other stakeholders; I will communicate the results of this work with this network to reach restoration practitioners and coastal wetland managers throughout the region. In particular, TNC is frequently responsible for implementing and evaluating LS restoration across coastal Alabama. This research will help inform TNC on how their coastal marsh restoration activities might better accommodate oysters through siting and design decisions. Additionally, this research will be incorporated into my planned dissertation on evaluating the ecological impacts of LS restoration. My dissertation will be communicated to the scientific community at the Dauphin Island Sea Lab and the University of South Alabama, and to the greater scientific community through journal articles and scientific conferences. To reach a non-scientific audience, I will deliver a "Boardwalk Talk" on the topic of oysters, restoration, and field monitoring with the Alabama aquarium. I have previously delivered a Boardwalk Talk on the subject of tracking shoreline change (available at https://youtu.be/fjNCF_VTXXU). Finally, I plan to leverage the results of this project to apply for additional funding for a larger-scale project, determining the factors limiting oyster recruitment over multiple years at additional living shoreline sites.

Works Cited

1. Zu Ermgassen, P. S. E. *et al.* Historical ecology with real numbers: past and present extent and biomass of an imperilled estuarine habitat. *Proc. R. Soc. B Biol. Sci.* **279**, 3393–3400 (2012).
2. Dame, R. F. & Patten, B. C. Analysis of Energy Flows in an Intertidal Oyster Reef. *Mar. Ecol. Prog. Ser.* **5**, (1981).
3. Grabowski, J. H. *et al.* Economic Valuation of Ecosystem Services Provided by Oyster Reefs. *BioScience* **62**, 900–909 (2012).
4. Bilkovic, D. M., Mitchell, M., Mason, P. & Duhring, K. The Role of Living Shorelines as Estuarine Habitat Conservation Strategies. *Coast. Manag.* **44**, 161–174 (2016).
5. Smith, C. S. *et al.* Coming to Terms With Living Shorelines: A Scoping Review of Novel Restoration Strategies for Shoreline Protection. *Front. Mar. Sci.* **7**, 434 (2020).
6. Morris, R. L. *et al.* The application of oyster reefs in shoreline protection: Are we over-engineering for an ecosystem engineer? *J. Appl. Ecol.* **56**, 1703–1711 (2019).
7. Goelz, T., Vogt, B. & Hartley, T. Alternative Substrates Used for Oyster Reef Restoration: A Review. *J. Shellfish Res.* **39**, 1–12 (2020).
8. Morris, R. L. *et al.* Large-scale variation in wave attenuation of oyster reef living shorelines and the influence of inundation duration. *Ecol. Appl.* **31**, (2021).
9. Wellman, E. H. *et al.* Reef design and site hydrodynamics mediate oyster restoration and marsh stabilization outcomes. *Ecol. Appl.* **32**, 41 (2021).
10. Gancel, H. N., Carmichael, R. H., Du, J. & Park, K. Use of settlement patterns and geochemical tagging to test population connectivity of eastern oysters Crassostrea virginica. *Mar. Ecol. Prog. Ser.* **673**, 85–105 (2021).
11. Shumway, S. Natural Environmental Factors. in *The Eastern Oyster: Crassostrea virginica.* (eds. Kennedy, V., Newell, R. & Eble, A.) 467–513 (Maryland Sea Grant College, 1996).
12. Baker, S. M. & Mann, R. Effects of Hypoxia and Anoxia on Larval Settlement, Juvenile Growth, and Juvenile Survival of the Oyster *Crassostrea virginica*. *Biol. Bull.* **182**, 265–269 (1992).
13. Brown, K. M. & Stickle, W. B. Physical constraints on the foraging ecology of a predatory snail. *Mar. Freshw. Behav. Physiol.* **35**, 157–166 (2002).
14. Grabowski, J. H. Habitat Complexity Disrupts Predator–Prey Interactions but Not the Trophic Cascade on Oyster Reefs. *Ecology* **85**, 995–1004 (2004).
15. Johnson, K. D. & Smee, D. L. Predators influence the tidal distribution of oysters (*Crassostrea virginica*). *Mar. Biol.* **161**, 1557–1564 (2014).
16. Powers, S., Peterson, C., Grabowski, J. & Lenihan, H. Success of constructed oyster reefs in no-harvest sanctuaries: implications for restoration. *Mar. Ecol. Prog. Ser.* **389**, 159–170 (2009).
17. Belgrad, B. A., Combs, E. M., Walton, W. C. & Smee, D. L. Use of predator cues to bolster oyster resilience for aquaculture and reef restoration. *Aquaculture* **538**, 736553 (2021).
18. Scyphers, S. B., Powers, S. P., Jr, K. L. H. & Byron, D. Oyster Reefs as Natural Breakwaters Mitigate Shoreline Loss and Facilitate Fisheries. *PLOS ONE* **6**, e22396 (2011).