Aquaculture Gear Type Affects Growth of Eastern Oysters and Other Aquatic Species

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In contrast to historical, terrestrial farming operations, where we have focused on how to minimize negative impacts on the environment while optimizing crop yields first, oyster aquaculture can generate positive economic and ecological responses simultaneously, through water filtration, nutrient sequestration, and habitat creation though the magnitude to which these functions occur still requires further investigation. Eastern oysters (*Crassostrea virginica*) have been an important resource for communities along the east coast of the United States for centuries. Unfortunately, oyster populations have been greatly reduced in many places, with disease outbreaks (MSX and Dermo), water quality impairment, and overharvest often cited as drivers of modern population decline. The ability of oysters to thrive in many waterways along the U.S. east coast, including in estuaries of the Mid-Atlantic bight, has been further limited by chronic eutrophication from nutrient pollution and low spawning stock biomass. Following declines in wild oyster stocks, oyster gardening programs, artificial oyster reefs, and commercial oyster aquaculture operations have been established along the U.S. east coast, and specifically in Delaware, with goals of restoration and commercial crop production.

Oysters and associated aquaculture operations are known to provide ecosystem benefits to coastal waterways. One indirect benefit of oyster aquaculture that has garnered attention in the last two decades is the associated habitat value provided to fishes and invertebrates, such as shrimp and crabs, by oyster gear (Theuerkauf *et al.* 2022). Similar to the way that aquatic animals congregate around a dock or a three-dimensionally complex coral reef, oyster aquaculture cages are structures that can give animals a place to hide from predators, find food, or rest.

Multiple studies along the U.S. east coast and in Delaware have investigated the habitat value of some of these aquaculture gear for fishes and invertebrates, comparing gear types to each other or to other habitats present within an estuary (Dealteris *et al.* 2004, Marenghi *et al.* 2010). These studies have found that oyster aquaculture gear can support an array of species in relatively high abundances, providing comparable or sometimes superior habitat to other areas (e.g., natural seagrass bed, created oyster reef). Additionally, many species observed around aquaculture gear have direct commercial importance such as blue crabs (*Callinectes sapidus;* Figure 1), striped bass (*Morone saxatilis*), Atlantic menhaden (*Brevoortia tyrannus*), summer flounder (*Paralichthys dentatus*), tautog (*Tautoga onitis;* Figure 2), and black sea bass (*Centropristis striata;* Figure 3), among others. Oyster farms may therefore be supporting fisheries by providing short-term habitat to juvenile fishes and invertebrates; however, the degree to which these oyster farming activities create population-level impacts for fishes is largely unknown.

There are two general categories of oyster aquaculture gear used to grow oysters in commercial settings – cages that rest on the substrate, "bottom cages", and cages that float at the water's surface, "floating cages". Bottom cages have been used traditionally, while floating cage designs are relatively new and thus less studied than bottom cages on both the oyster and ecosystem service fronts. In order to further scientific understanding of the influence of these two general gear types on oysters and other estuarine biota, we compared oyster size metrics, oyster death rates, and abundance and diversity of fishes and invertebrates between bottom cages and floating cages. We hypothesized that oysters would grow at dissimilar rates between cage types, and that diversity and abundance of other estuarine biota would vary similarly between the two gears.

Our Methods

We placed four oyster aquaculture cages – two bottom cages and two floating cages – at a nearshore brackish site in southern Delaware to examine oyster growth and the response of the aquatic community (Figures 4 and 5). We put 60 live oysters in each cage, and monitored the oysters, fishes, and invertebrates at each cage on a weekly basis from June through September

2022. We measured oyster shell length (the end-to-end distance from the hinge) and oyster shell depth (the thickness/cup-shape of the oyster), which are important factors influencing marketability. Thus, oyster farmers are interested in understanding how both shell length and shell depth may be influenced by gear type. To assess the use of the aquaculture cages by fishes and invertebrates, we removed portions of the gear from the water thereby removing the fishes and invertebrates that were within the gear, and we also attached un-baited minnow traps for 24-hour periods to sample the animals that were around but not within the gear. We compared the influence of gear type on fishes or invertebrates by looking at abundance (number of organisms present) and diversity, quantified as species richness (number of unique species present) and Shannon diversity index (a metric that considers both the number of unique species present and how evenly represented those species are).

Influence of Gear Type on Oysters

We found that oysters in bottom cages were larger at the end of the study period in terms of both shell length and shell depth (Figure 6). We noticed that, despite random assignment, the oysters in the bottom cages were initially slightly longer than the oysters in the floating cages, so it is possible that the oysters in the bottom cages were intrinsically better growers. However, there was no significant difference in shell depth between the cage types to start, and shell depth was significantly greater in the bottom cages at the conclusion of the experiment suggesting that something other than intrinsic growth rates affected how oysters grew in the two cage types.

Beyond intrinsic growth rates, size differences in oysters between cage types may have occurred in response to wave-associated tumbling or differences in fouling. The floating oyster cages were attached to anchored lines in such a way that prevented them from drifting around or entirely flipping over during extreme wave action, but slack in the anchor lines to account for changes in water height over a tidal cycle did allow for near constant light rocking of the cages in the waves. During times of elevated wave height and increased wave frequency, the unattached oysters likely rolled around within their bags, and these small collisions with both the bags and other oysters may have resulted in minor chips to new growth that cumulatively resulted in smaller oysters over a months-long timescale. The submerged bottom cages appeared to experience less surface wave activity related to a decline in wave energy with depth and the weight of the bottom cages anchoring these cages to the substrate. Additionally, we noted, but did not directly measure, a relative increase in the presence of barnacle settlement, algal growth, and sediment coverage of the oysters within floating cages compared to oysters in the bottom cages despite identical weekly cleaning routines. We did not detect any significant differences in oyster mortality between the cage types, but the presence of other filter-feeding organisms (i.e., barnacles) and materials covering the oysters in the floating cages may have prohibited maximum oyster growth through local competition or other inhibitory means.

Influence of Gear Type on Fishes and Invertebrates

When examining trends in the fishes around the oyster aquaculture cages, we noticed that there were some stark differences between cages of the same type (e.g., between the two floating cages). Abundance and diversity of fishes was lower at one of the floating cages than the other three cages (Figure 7), and we believe that those findings may be influenced by characteristics of the surrounding environment. The substrate directly underneath the floating cage with lower fish abundance and diversity was an open, sandy area with little to no submerged aquatic vegetation or other cover. The second floating cage was initially placed in similar conditions to the first, but it became surrounded by dense growths of sea lettuce (*Ulva lactuca*) over the progression of the summer months. The two bottom cages were in sandy areas with low to moderate vegetation cover. In comparison to the benthic-oriented bottom cages and the vegetation-surrounded floating cage, the sandy-area floating cage may have represented a predation risk for young fishes which must cross an open water column to reach the floating structure. Many fishes prefer to avoid open water to reduce risks associated with predation from larger fish or birds, so it is likely that fewer fish chose to spend time around this sandy-area floating cage. Interestingly, while the sea lettuce growth around the vegetation-surrounded floating cages led to more total fishes around the cage, the diversity of fishes there was intermediate and not quite as high as the bottom cages. Vegetation cover appears to provide a pathway that encourages some, but not all, fish species to travel higher in the water column to reach floating cages.

When looking at trends in invertebrates between the oyster aquaculture cages, we saw that abundance of total invertebrates present in the floating cages was higher than in the bottom cages (Figure 8). This was attributed to high numbers of grass shrimp (*Palaemon sp.*) at the floating cages (Figure 9), which is in contrast to lower fish abundance at floating cages unless additional vegetative cover was present. One potential explanation for high abundance of grass shrimp at the floating cages is differential food availability or protection provided by increased algal growth on the floating cages which receive more sunlight than the bottom cages. Previous work from another group has found that macroalgal growth on shellfish aquaculture gear can support high abundances of motile invertebrates (Powers *et al.* 2007). While the sandy-area floating cage did support high numbers of grass shrimp, this cage is likely not an accessible habitat readily used by a wide variety of species based on lower invertebrate diversity at this cage. We believe that this may be due to limitations of some species which would prevent them from swimming up in the water column. For example, hermit crabs or non-swimming crabs might find it difficult to reach a floating cage which does not have additional vegetative structure nearby. Grass shrimp in contrast are able to swim in the water column so they would not be limited in this way.

Plans for Future Work

Our experiment has demonstrated how different aquaculture gear designs variably influence oyster growth and the ecosystem services provided by oyster farms using these gears, thereby supporting our initial hypotheses. Bottom cages supported faster oyster growth in both shell length and shell depth, as well as higher levels of abundance and diversity of fishes. Our work has identified new questions that will need to be explored in order to fully understand the influence of gear type on oysters and other animals. For example, how do rates of fouling by barnacles, algae, and sediment change with depth and oyster bag mesh size? What influence might these fouling organisms or sediment have on oyster growth in a controlled setting? Would low levels of fish abundance and diversity trends at isolated floating cages continue with additional replication at other sites? Our project demonstrated variance in the growth of eastern oyster between cage types, while documenting some of the key habitat provisioning provided by aquaculture farming. We look forward to continuing to explore how anthropogenic activities such as oyster farming affect coastal environments in the future.

Notes

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Acknowledgments

We thank members of the University of Delaware-Lewes campus community who played a crucial role in data collection including Ms. Lenna Wood, Ms. Madison Windsor, Mr. Anthony O’Toole, Ms. Kaylin Regan, Ms. Caroline Bowers, Mr. Nicholas Whaley, Mr. Sam Hankinson, Ms. Maddie Reifsteck, and Mr. Randy Feris. Additionally, we would like to recognize Dr. Adam Marsh for statistical advisement of the analyses for this project and Steve Friend for his guidance on the installation and operation of the oyster cages.

References

Dealteris, J.T., B.D. Kilpatrick, and R.B. Rheault. 2004. A comparative evaluation of the habitat value of shellfish aquaculture gear, submerged aquatic vegetation and a non-vegetated seabed. Journal of Shellfish Research 23(3):867–874.

Marenghi, F., G. Ozbay, P. Erbland, and K. Rossi-Snook. 2010. A comparison of the habitat value of sub-tidal and floating oyster (*Crassostrea virginica*) aquaculture gear with a created reef in Delaware's Inland Bays, USA. Aquaculture International 18(1):69–81. https://doi.org/10.1007/s10499-009-9273-3

Powers, M.J., C.H. Peterson, H.C. Summerson, and S.P. Powers. 2007. Macroalgal growth on bivalve aquaculture netting enhances nursery habitat for mobile invertebrates and juvenile fishes. Marine Ecology Progress Series 339:109–122. https://doi.org/10.3354/meps339109

Theuerkauf, S.J., L.T. Barrett, H.K. Alleway, B.A. Costa-Pierce, A. St. Gelais, and R.C. Jones. 2022. Habitat value of bivalve shellfish and seaweed aquaculture for fish and invertebrates: Pathways, synthesis and next steps. Reviews in Aquaculture 14(1):54–72. https://doi.org/10.1111/raq.12584

Figures:

Figure 1: Juvenile blue crab (*Callinectes sapidus*) captured in one of the oyster aquaculture cages. Photo by Timothy Smoot.

Figure 2: Juvenile tautog (*Tautoga onitis*) captured in one of the oyster aquaculture cages. Photo by Timothy Smoot.

Figure 3: Juvenile black sea bass (*Centropristis striata*) captured in one of the oyster aquaculture cages. Photo by Timothy Smoot.

Figure 4: A map of the study site. Four oyster aquaculture cages were situated in an estuarine boat basin connected to the Delaware Bay, USA.

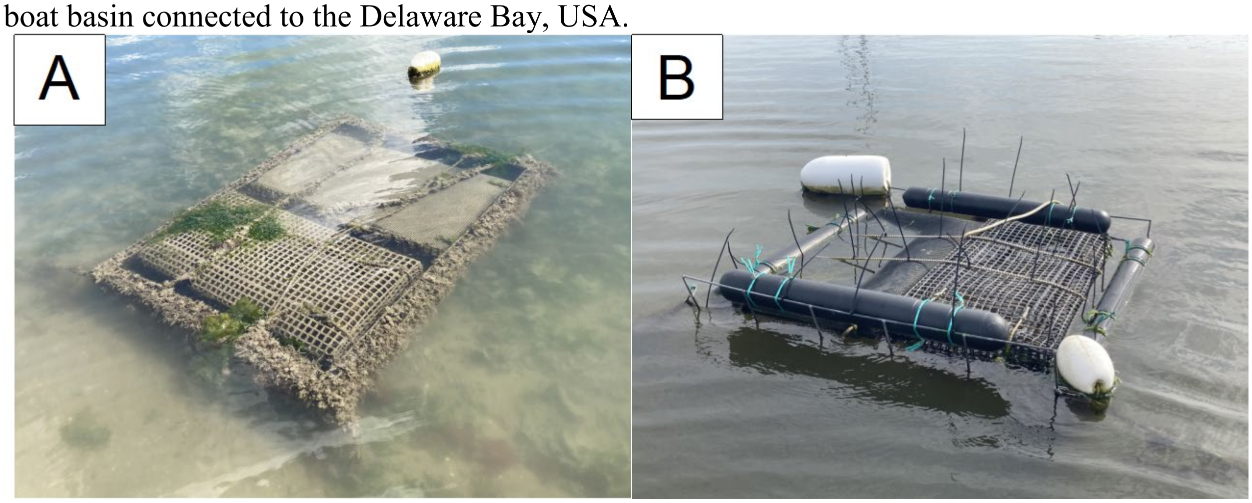

Figure 5: Oyster aquaculture gear types used in this study include (A) on-bottom cages that sit on the substrate and (B) floating cages which elevate the oysters to just below the water’s surface.

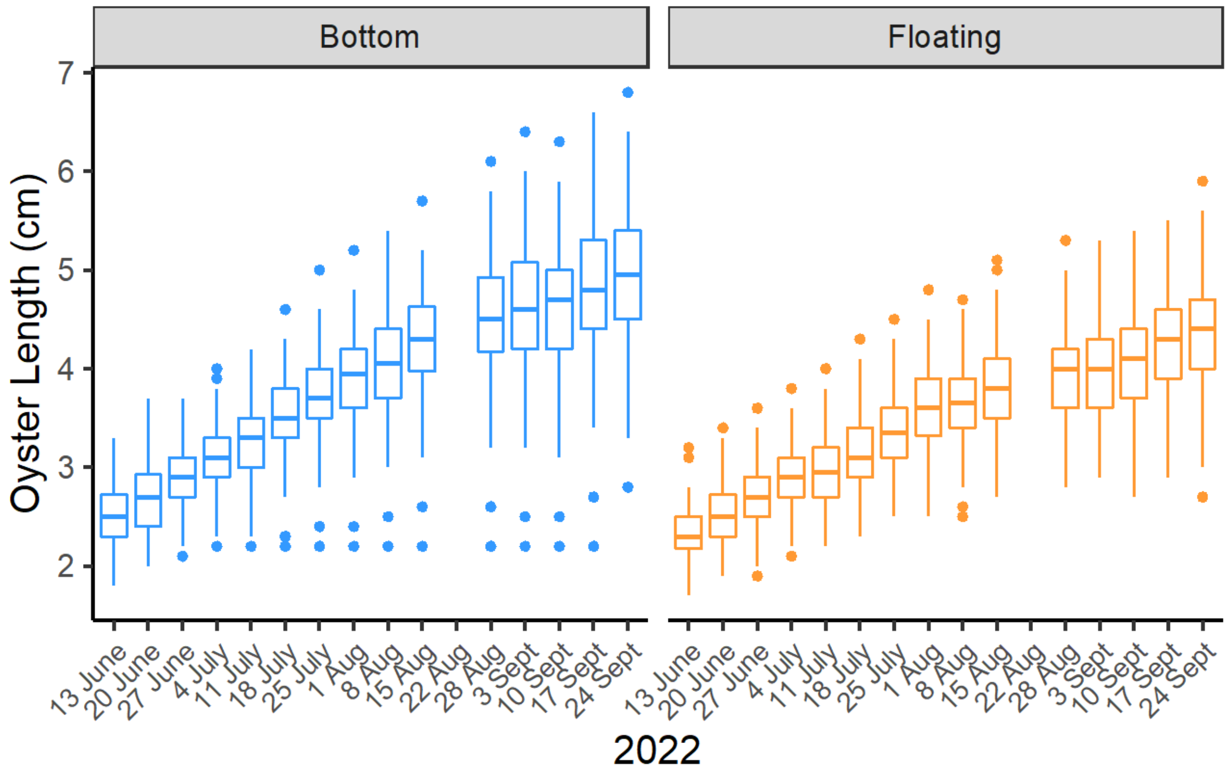

Figure 6: Oyster length over time in the bottom and floating oyster aquaculture cages.

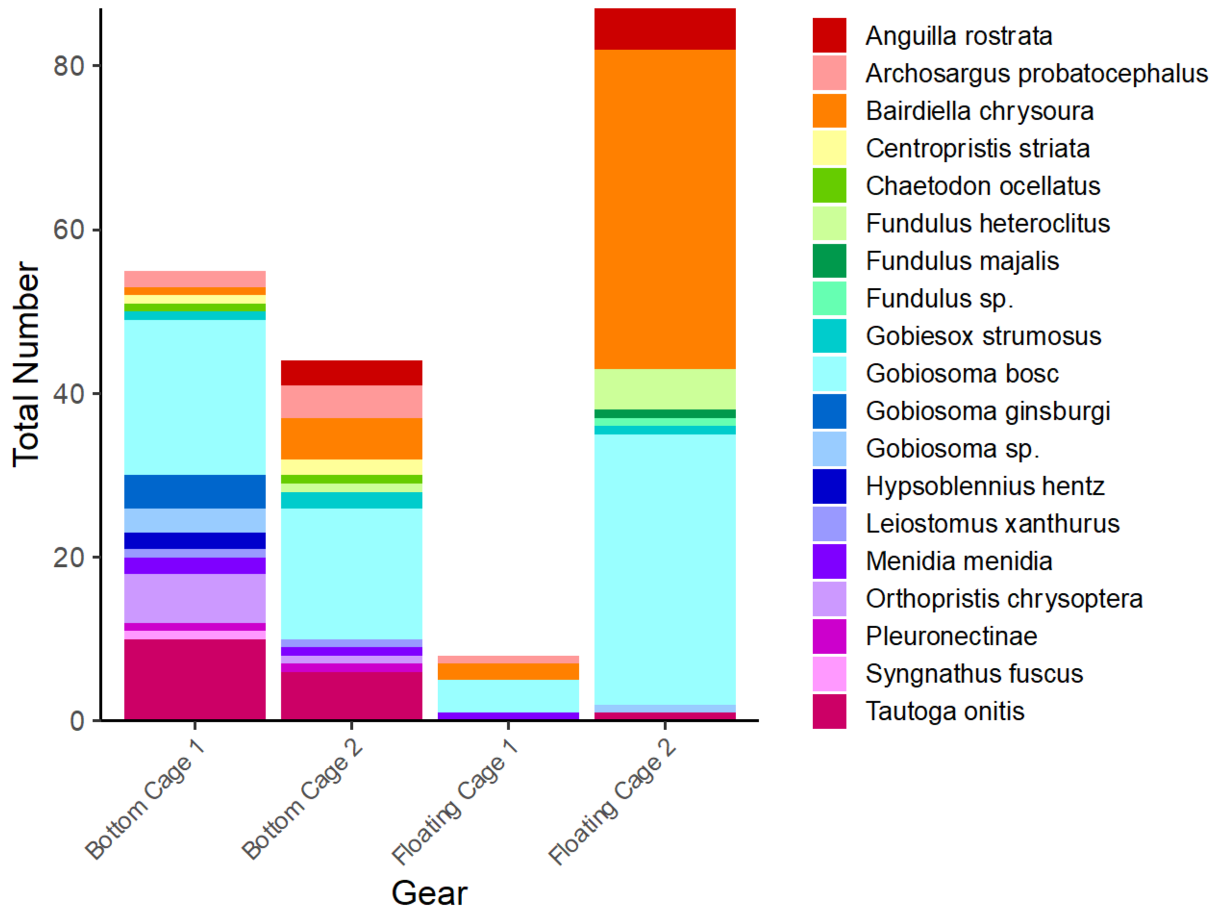

Figure 7: Cumulative counts of individual fishes captured from within and around each oyster aquaculture cage from June 14 – September 25, 2022 in a Mid-Atlantic estuary.

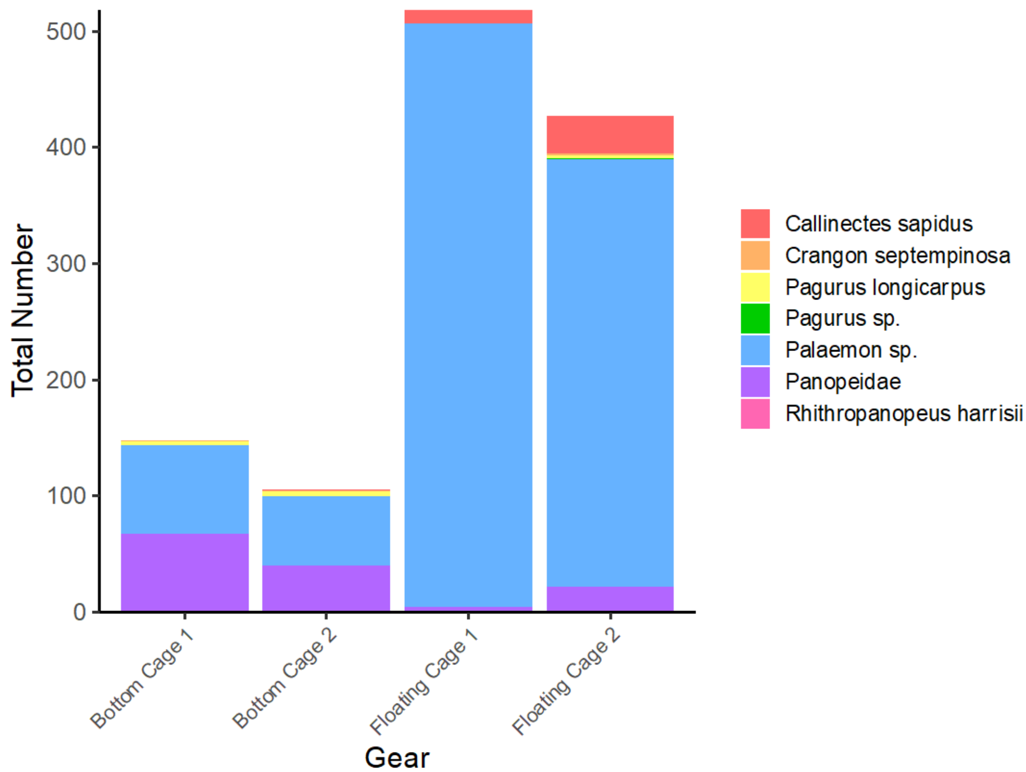

Figure 8: Cumulative counts of individual motile invertebrates captured from within and around each oyster aquaculture cage from June 14 – September 25, 2022 in a Mid-Atlantic estuary.

Figure 9: Grass shrimp (*Palaemon sp.*) captured in one of the oyster aquaculture cages. Photo by Timothy Smoot.