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Barriers to oyster recovery in Hudson River Estuary: Billions of larvae with no place to go

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Abstract (word limit - 200)

Interest in eastern oyster restoration in the Hudson/Raritan estuary (HRE) has been building in conjunction with water quality improvements near New York City. Restoration is motivated by the ecosystem services typically provided by a large oyster population. Multiple projects have tested the performance of post-settlement oysters in different parts of the HRE, or attempted to assess available habitat. Only one study tested whether oyster larvae can survive to settlement (to produce juvenile oyster "spat"), and that effort in Jamaica Bay found larvae but no local settlement. Larvae represent the critical dispersal stage of eastern oysters, but it also is the most vulnerable life cycle stage. Restoring a sustainable population requires that we understand environmental constraints on larval survivorship. In this project we continued systematic monitoring of newly settled oyster spat south of the only known wild population in the Hudson River. Oyster settlement in 2019 decreased to the south in a pattern similar to 2018. A net southward pattern of larval dispersal is expected, so our second objective was to experimentally test whether waste water treatment plant effluent increases oyster larval developmental abnormalities or mortality. No treatment effect was observed, but logistical challenges prevented sufficient testing to support a conclusion.

Three Summary Points of Interest

1. Research on the feasibility of oyster restoration in the Hudson River Estuary needs to focus more on the most vulnerable oyster life stage: larvae
2. Annual reproduction and local larval settlement is very consistent from the remnant wild oyster population in Tappan Zee/Haverstaw Bay, but continued monitoring confirms that this "ecosystem service" does not propagate southward to the lower Hudson River Estuary.
3. Preliminary experiments testing larval survivorship in dilutions of waste water treatment plant effluent showed no significant effect, but were ultimately inconclusive due to logistical constraints.

Keywords: Crassostrea virginica, eastern oyster restoration, larval survival, settlement, spat recruitment

Barriers to oyster recovery in Hudson River Estuary

Introduction

Interest in oyster restoration in the Hudson/Raritan estuary (HRE) has been building in conjunction with water quality improvements near New York City. Restoration is motivated by the ecosystem services typically provided by a large oyster population; filter feeding of algae helps cycle nutrients from the water column to the benthos, and cycles of oyster recruitment and growth continually accrete a complex reef structure that provides habitat for hundreds of other species (Grabowski et al. 2012). Multiple projects have tested the performance of oysters in different parts of the HRE to assess the potential for restoration (Levinton et al. 2011; Levinton et al. 2013; Hoellein and Zarnoch 2014; Lodge et al. 2015; McFarland and Hare 2018). Others have attempted to quantify the availability of suitable habitat (Medley 2010). These studies have been important for building oyster restoration capacity, for learning about environmental hotspots and cold spots for oyster growth and survivorship, and for the community benefits of associated outreach and education. However, one of the biggest barriers to oyster recovery may involve a question nobody has even asked: can oyster larvae survive in the water column and recruit to the lower estuary?

Based on Hare Lab studies since 2012, and other studies before that (Medley 2010; Carthan and Levinton 2013), there are two locations in New York City and the Hudson River Estuary that get large sets of wild oyster recruitment. In the East River, connecting Long Island Sound with the Hudson River, some settlement occurs at the mouth of the Bronx River in most years with occasional abundant recruitment. However, average longevity is low (2-3 years) relative to recruitment pulses so there is only a standing stock of wild-set adult oysters occasionally. In contrast, an extensive but isolated mixed-age population of wild oysters persists near the Tappan-Zee bridge, Haverstraw Bay area (TZ-HB; AKRF report to NY Thruway Authority). The low average salinities in this area (0 – 10 psu) are considered marginal habitat in most published literature on *C. virginica* (Butler 1949), but in the Hudson River this population consistently produces a large recruitment pulse (McFarland and Hare 2018; Levinton et al. 2011). For the first time in 2018 we collaborated with The Nature Conservancy and Billion Oyster Project to monitor oyster settlement (recruitment) simultaneously all along the Hudson River in order to spatially compare recruitment intensity. Results showed a dramatic diminution of recruitment at sites south of (downriver of) the TZ-HB population. When oyster larval dispersal has been modeled in the Chesapeake Bay and Delaware Bay estuaries, a net downstream movement toward the ocean was found (North et al. 2008; Narváez et al. 2012). Why isn't the TZ-HB population expanding downstream given the water quality improvements seen in NYC since passage of the Clean Water Act (NYCDEP 2012)?

To address this question we (1) replicated and expanded our 2018 oyster recruitment monitoring and (2) conducted preliminary experiments testing larval survivorship in dilutions of waste water treatment plant (WWTP) effluent.

WWTP effluent cumulatively represents 11% of the total river flow on an average dry day in New York City (Pochodylo and Helbling 2016; Cantwell et al. 2018). In addition, untreated storm water and sewage overflows get discharged to HRE waters through combined sewer outfalls (CSO), and storm water also is discharged via municipal separate storm sewer system (MS4) outfalls. Collectively, storm water and CSO discharges add $30x10^7$ m^3 annually of contaminated water to New York City waters, potentially including oils, pesticides, heavy metals, detergents, solvents, flame retardants, pathogens and sediment in addition to human and animal waste (NYCDEP, 2016).

Sewage treatment removes biosolids and associated pollutants, but generally does not remove water-soluble chemicals. Personal care products and medicines such as antibiotics, birth control steroids, and other pharmaceuticals largely persist through sewage treatment. Their near-constant supply to the environment via WWTP effluent, albeit at low levels due to dilution, has the potential to elicit cumulative impacts that would be difficult to trace (Daughton and Ternes 1999). An important recent study mapped the concentration of pharmaceuticals and wastewater tracers (sucralose and caffeine) at 16 sites along the Hudson River (Cantwell et al. 2018). They found that many of the study compounds were present throughout the Hudson River Estuary, with concentrations best explained by wastewater discharge rates and proximity of sampling to WWTP discharge sites. Notably, the observed proportion of pharmaceuticals spiked above 90% near three WWTP outfalls where many individual pharmaceutical concentrations also were unusually high, including the Yonkers WWTP at river mile 28.2 (just downstream of the TZ-HB oyster population).

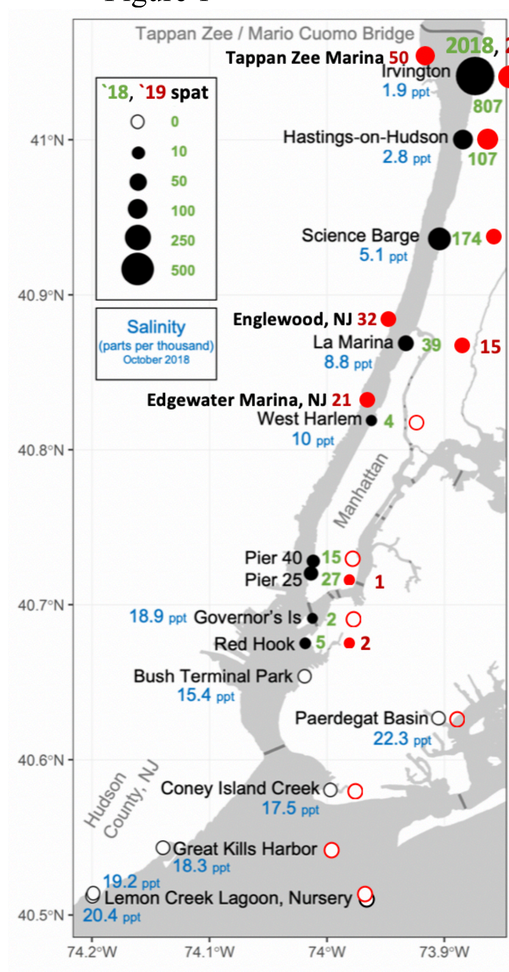
There are two studies that have inferred demographic and evolutionary consequences from wastewater effluent. In the Southern California Bight, a species of bat star (*P. miniata*) with long-lived larvae (6-10 weeks in the plankton) showed population genetic differentiation associated with proximity to sewage effluents and storm water (Puritz and Toonen 2011). They concluded that treated sewage effluent had generated a long-term barrier to larval dispersal, thereby disrupting previous patterns of connectivity. Similar patterns were observed in *Mytilus* mussels based on a nested sampling design that compared harbor, WWTP and reference sites at multiple locations within the Baltic Sea (Larsson et al. 2016). Genetic differentiation was found between WWTP sites compared with proximate reference sites, but the same was not true for harbor sites. The authors hypothesized that the genetic differences result from viability selection each generation, depending on the location where larvae settle. As far as we are aware, these are the only studies that have used genetic markers to test for these population-level effects from wastewater discharges.

Results & Discussion

To measure the extent to which the Tappan Zee/Haverstraw oyster population contributes to wild spat recruitment in the lower HRE, systematic measurements of spat recruitment were made by the Hare Lab at Cornell in collaboration with The Nature Conservancy and the Billion Oyster Project (BOP). Clean bivalve shell from the BOP shell recycling program were bagged into uniform size polypropylene bags, then deployed at 15 sites along the HRE shores (sites shown in Figure 1) for oyster larvae to settle on during the reproductive season. In 2019 the bags were deployed in August and retrieved in September, slightly earlier than in 2018.

In both 2018 and 2019 the majority of wild spat were found close to the Tappan Zee/Haverstraw oyster population. In 2018 there was a rapid decline in spat abundance south of Irvington, and another step down below Yonkers (Science Barge). Spat abundance was less overall in 2019, with a more gradual decrease southward.

Figure 1



Toxicology experiments used wastewater treatment plant effluent. Adult broodstock were collected from experimental cages maintained at different regions of the estuary. After spawning, early embryos were exposed to a dilution series (an

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experimental design similar to His et al. 1997). Treated, dechlorinated effluent was obtained from a WWTP, then diluted with sea water to 90%, 50%, 25%, 12.5%, and 6.25% by volume (= treatments) and compared with a 0% effluent control. Seawater for the control and dilutions was either obtained from the TZ-HB region of the Hudson River or made from Crystal Sea Marinemix®. WWTP effluent samples were stored in brown glass bottles on ice and transported to Cornell for initial use within 36 hours. Acute toxicity testing followed EPA guidelines for whole effluent testing (WET, USEPA 2002). Salinity in effluent dilutions was standardized using Crystal Sea Marinemix® (equalizing with filtered seawater control) and temperature was maintained at the ambient broodstock temperature at the time of collection.

Experiment 1 on June 22 used oysters transported to Ithaca from Jamaica Bay. After attempting and failing to induce spawning of these oysters, they were opened for strip-spawning but none had mature gonads.

Experiment 2 on July 24 used oysters from both northern and southern HRE waters. WWTP effluent came from the Ithaca facility. Seemingly mature gametes were "stripped" from adult oysters (dissected out) and fertilized in-vitro. Effluent treatments were set up for two cohorts; 4 hour embryos and 6-day old D-larvae. Both experiments yielded preserved samples from 24 hour treatments that were counted during the Fall semester.

Experiment 3 on August 8 was the only one where we succeeded in getting WWTP effluent from Yonkers, albeit diluted in Hudson River receiving waters, with the help of RiverKeeper. During this experiment the Hare Lab environmental chamber responded to a power disruption by losing its temperature set point, compromising the experiment. However, we did learn that working with effluent receiving waters is much more difficult than straight effluent because of all the microorganisms (and potentially bivalve larvae) that are collected with the sample, greatly complicating microscope analysis of experimental results.

Counts from the July experiment yielded the following results. In all cases we used Nile Red stain to distinguish between live and dead individuals under a dissecting microscope. Many embryos seemed to survive even the highest effluent treatment, so we tested for developmental effects by measuring the ratio of "normal" embryos (given typical eastern oyster developmental rates) versus underdeveloped fertilized eggs. There was a lot of variation in this ratio among replicates and the regression across treatments showed no significant effect of effluent on development.

Figure 2a - embryos

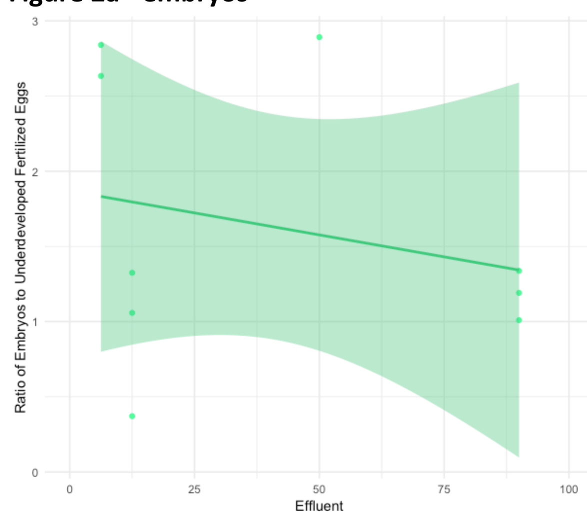
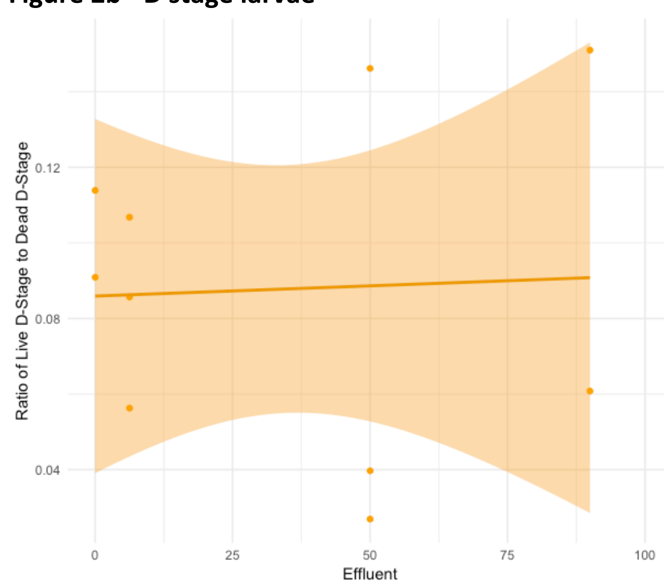


Figure 2b - D stage larvae



These results are not sufficient to support an overall conclusion (lack of replication). However, considering WWTP effluent alone (as done here

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with no additional stressors) there does not appear to be a strong impact on early oyster larval viability or development, at least from Ithaca effluent. This is contrary to some reports in the literature, but may reflect variation in methods, heterogeneous effluent constituent, or a reporting bias in the literature. One of our goals was to evaluate the feasibility of performing these experiments in Ithaca. We proved that it is possible, but the logistics of getting spawn-ready "ripe" broodstock, given annual variation in the timing of oyster reproductive maturation, prevents proper scaling up and replication. Future pursuit of these questions will need to be collaborative with hatchery-based researchers.

Policy Implications

This work focused on oyster recruitment monitoring as a means of judging whether the dispersal larval stage is especially vulnerable to anthropogenic stressors that increase in the Hudson River as it approaches New York City. The effluent toxicology trials were an attempt to test one mechanism by which oyster larvae and other plankton could be stressed, as documented in other estuaries. Although our studies to date are not conclusive, there is a great need for understanding how anthropogenic stressors, individually and in combinations, may be limiting population and ecological recovery even while some water quality metrics (e.g. dissolved oxygen) slowly improve. Even for metrics we are monitoring and think we understand, such as dissolved oxygen and pH, there is inadequate monitoring and understanding of their interactive effects to properly shape policy (Tomasetti and Gobler 2020). What's more, the list of 'chemicals of emerging concern' keeps growing, and many of these do not get removed by current wastewater treatment technology. Due to inadequate research to understand incremental anthropogenic effects, there may be cumulative and growing degradation of species, populations and the environment right under our noses.

Outreach Comments

Outreach associated with the oyster recruitment monitoring focused on site-hosts that provided access to secure shoreline sites. The following site-hosts were all acknowledged on our public one-page summary of results: Irvington Boat Club, Hastings Community Assoc, Yonkers Science Barge (Groundwork), La Marina, Inwood Canoe Club, Ira Gershenhorn & Baylander, River Project, Red Hook Barge Museum, New York City Parks, Sebago Canoe Club, Princess Bay Boatmens Association, Richmond County Yacht Club, Kingsborough Community College. Beyond explaining our research to site hosts and sharing the summary, we provided educational programs at the Groundworks Science Barge in Yonkers.

Student Training

One beginning MS student, Hannah Hartung, got trained during involvement with both projects this year. In addition, one visiting undergraduate student from Columbia, Ana Caruso, gained experience with both research and outreach with these projects.

Publications/Presentations

Our one page summary of recruitment monitoring results is attached. Nothing published yet.

Additional final reports related to water resource research are available at
http://wri.cals.cornell.edu/news/research-reports

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