Surprising Abundant Mussel Beds in the Center of Boston Harbor in the Midst of a Regional Die-Back

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All data and code for this manuscript are available at http://github.com/jebyrnes/harbor_mussels

The rocky intertidal of the Gulf of Maine has long served as a petri dish for the generation and testing of Ecological Theory (Menge 1976, 1983, Lubchenco 1978, Bertness et al. 1999, 2002, Petraitis and Dudgeon 2004, Bryson et al. 2014). Perhaps most importantly, it has been used to show that physical forces have not only direct effects - setting limits to zonation, regulating predator abundances, etc. - but also a cascade of indirect effects. By reducing predation and predator abundances, high wave energy enables dense beds of mussels to escape consumption and achieve dominance. The resulting community stands in contrast to low wave energy sites favoring dominance by algae as consumers reduce mussel abundance. This paradigm has been shattered over the past few decades, however, as mussels throughout the Gulf of Maine have witnessed a precipitous >60% decline since the 1970s (Sorte et al. 2017, Petraitis and Dudgeon 2020) for still poorly understood reasons. Despite this loss, mussel recruitment remains strong in some years - although declining on average (Petraitis and Dudgeon 2015). These larvae must be coming from somewhere.

In the summer of 2021, the Stone Living Lab (SLL) began an intensive study of Rainsford Island in Boston Harbor, MA. The purpose of these surveys was to establish a baseline before members of the lab began working on implementing experimental nature-based engineering approaches to evaluate potential mitigation under changing climate conditions (e.g., sea level rise and increasing storm and wave intensity). The results of these larger scale *in situ* experiments are intended to provide transferable knowledge and serve as a model for Boston and other urban waterfronts throughout the world. Alongside whole-island surveys of substrates, the lab conducted detailed quadrat-based sampling of the intertidal and subtidal ROV surveys of mobile fauna on both Rainsford and three surrounding islands - Georges, Peddocks, and Gallops Island. These latter three were to serve as control sites in monitoring community change after large-scale installations of structures on the north and northeast shorelines of Rainsford Island. Together, these surveys showed that, despite region-wide declines in mussels, the rocky areas of these inner islands had large dense intertidal mussel beds.

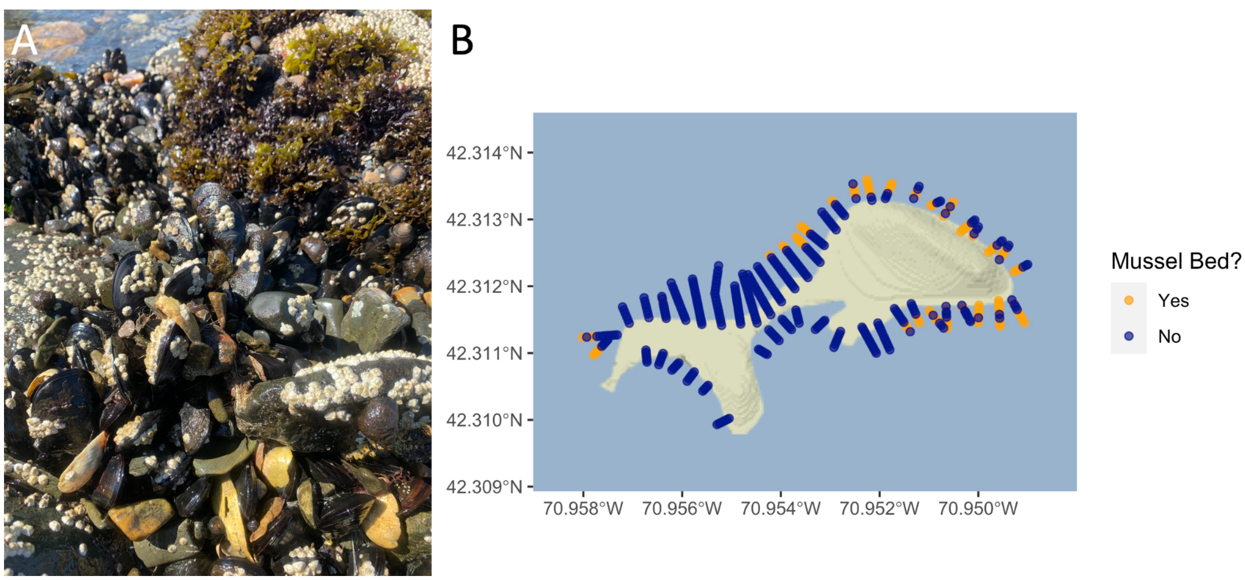

Figure 1. Mussel beds around Rainsford Island. A) A photograph taken along the edge of the northern bed in the mid-intertidal. B) Survey results from transects in the intertidal recording the presence of absence of mussel beds under survey points.

Briefly, to survey the extent of beds around Rainsford, in October of 2020, we walked 51 transects perpendicular to shore starting at the low tide mark, taking samples with a clam rake every 5m as far as was safe in waders in order to determine substrate type and mussel presence. To determine mussel density, we conducted intertidal surveys during spring tides in June 2021. We divided a 30m stretch of intertidal on the northeast side of each island into high, mid, and low zones and recorded percent cover of all sessile species in six 0.25m^2 quadrats per zone, with quadrats randomly placed within three 10m horizontal blocks to ensure even sampling (i.e., each zone-block receiving 2 randomly placed quadrats). To assess the abundance of predators that could move in with the tide, we conducted subtidal video surveys using a Blue Robotics BlueROV2. The ROV ran along 120m of chain marked in 5m intervals sunk at the 10m isobath offshore of intertidal sites. We recorded *Cancer* crab, green crab (*Carcinus maenas*), sea star, lobster (*Homarus americanus*), fish, and moon snail abundance in each interval, limiting field of view to 1m on either side of the transect, creating six 5x2m belt transects.

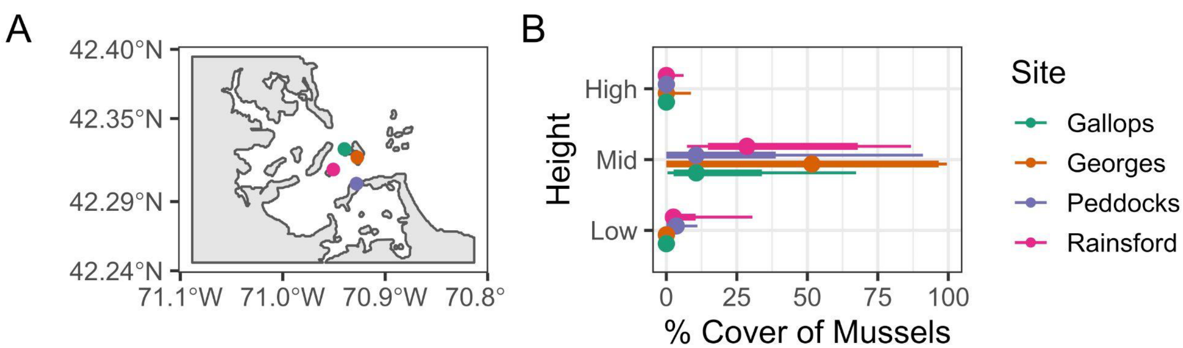

Figure 2. Map of the Boston Harbor islands highlighting A) sites surveyed and B) the percent cover of mussels in each zone on each island. Points indicate medians with the thick and thin bars highlighting the interval covering 66% and 95% of the data respectively

In our spatial survey, we found mussels around the entire east side of the island, wrapping from the north shore, around the end of the island, and covering the south shore as well (Fig. 1). Further, we found more beds on the rocky intertidal on the extreme east end. These were not areas of sparse mussels. Our quadrat surveys on Rainsford found plots with a median cover of 30% and up to ~87% cover in the mid-intertidal

(Fig. 2). Other islands were similar. While not quantified, on the northern end of Lovells Island, just to the east of surveyed islands but protected by the outer harbor islands, we walked the edge of a mussel bed during low tide that covered roughly 30,000 m^2. None of these sites were low in predator abundance (Fig. 3). Our subtidal surveys, which likely undercounted crabs given that we could not actively search crevices, showed an average of between 0.2-0.7 crabs per m^2. Curiously, in rocky intertidal surveys, the abundance of the predatory dog whelk, *Nucella lapullis*, was low (8 found on all surveys). However, the whelks we did find often measured 5-6cm in length - quite large relative to many populations studied (Etter 1989). Initial site surveys outside of quadrats matched with our quadrat observations for these important predators.

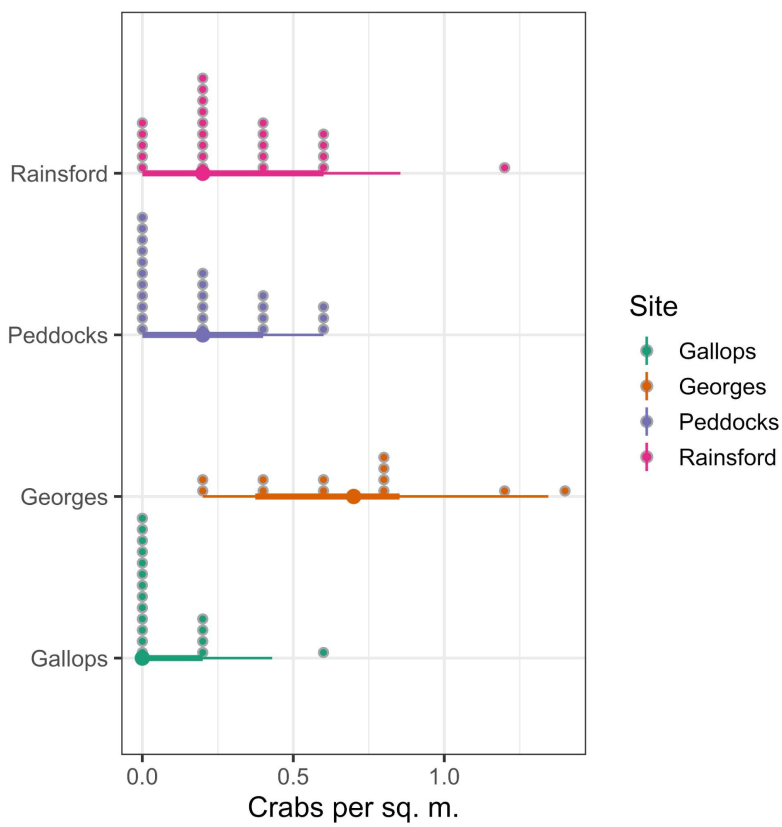

Figure 3. The abundance of crabs in the shallow subtidal from ROV data. Central points indicate medians with the thick and thin bars highlighting the interval covering 66% and 95% of the data respectively. Points above the bars are the raw data points themselves.

Given the decline of mussels throughout the Gulf of Maine, we were surprised to find such large seemingly healthy mussel beds. More surprising, these beds were all in areas relatively 1) sheltered from wave exposure and 2) had robust abundances of a major predator in the nearby subtidal - a predator that migrates in on high tide to consume mussels, although a diminished assemblage of intertidal whelk predators. Waves at these sites are reduced >70% in height relative to the outer harbor islands (calculated from the Massachusetts Coastal Flood Risk model from Bosma et al. 2015). The dominant paradigm in New England marine ecology is that these sites should be algal beds (Menge 1976, Lubchenco and Menge 1978, Bertness et al. 2002). While the high intertidal was often replete with *Fucus* and the lower often hosted a diverse mix of red algae, the presence of such large persistent mussel beds in these locations was surprising. How have these beds survived in the midst of massive decline? High flow rates are one potential answer. As any mariner will tell you, tidal currents between islands the inner Boston Harbor Islands are extremely strong. NOAA tides and currents show current speeds of up to 80-90 cm/s within certain constrictions within Boston Harbor during spring tides, while at the same time the nearby open coastline has velocities less than half in magnitude ("NOAA Tides and Currents" 2022). Additionally, highly detailed hydrodynamic modeling within Boston Harbor (Sustainable Solutions Lab, UMass-Boston, 2018), indicates current magnitudes on the order of 40-60 cm/s in the vicinity of Rainsford Island, compared to velocities at similar tidal cycles of 10-20 cm offshore of Boston Harbor. This would enhance both food and larval delivery (Palardy and Witman 2014), can be very beneficial for filter feeders such as mussels (Fréchette et al. 1989, Leichter and Witman 1997), and reduce efficacy of predators (Leonard et al. 1998). It does not, however, explain why these beds have persisted while those at the nearby monitored beds in Nahant have declined to 3-5% average cover (Sorte et al. 2016). Further, we were able to obtain intertidal photo quadrat data from the National Park Service's Boston Harbor monitoring program (Long and Mitchell 2015) on the more wave exposed outer harbor islands - Calf, Green, and Outer Brewster. These areas fit the traditional profile of what should be a mussel dominated habitat given their exposure to open ocean swell. On these transects, beds rarely get above 5% cover, save for a brief pulse in 2016 with a maximum cover in one plot of 17%, far less than we observed. These outer harbor island sites share a similar thermal and chemical environment to those we surveyed, at least allowing us to rule out those mechanisms, although they do possess higher wave exposure.

The ubiquity of the mussel beds we found throughout the harbor suggests some hope for the story of mussels in the Gulf of Maine. We need to better understand the role of hard substrate habitats in wave protected environments in high flow sites that sit in the middle of estuaries. While these are not the traditional sites ecologists have concentrated on, we suggest a greater need to understand their ecology for mussels. Further, the data of mussel bed locations often exists - albeit in the gray literature. Many states' marine resource management agencies have records of bed locations from environmental permitting (e.g., permit reports from Woods Hole Group show beds in Nauset Estuary(Woods Hole Group 2021) that are, to our knowledge, unexamined by academic ecologists). These permitting reports represent an untapped font of knowledge to understand when and where mussel beds have been able to remain resilient in the face of whatever has caused their die-off throughout the Gulf. This understanding may well open up new vistas in both the fundamental understanding of intertidal ecology in the Gulf of Maine and ecological strategies to resist or adapt to global change.

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