Five years of monitoring a bio-engineered living shoreline: comparison of oyster population development by reef technology.

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Living shoreline demonstration project (PO-148)

Five years of monitoring a bio-engineered living shoreline: comparison of oyster population development by reef technology

Final Oyster Monitoring Report (AWD-0001087) February 2022

Submitted to:

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Photo: Megan La Peyre, 2020

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1. PROJECT DESCRIPTION

The Living Shoreline Demonstration Project (PO-148) used five bio-engineered reef technologies (Reef Balls in two configurations; Figure 1) acting as breakwaters to protect vulnerable shorelines. While the primary goal is to attenuate wave energy, the sustainability and success of these products as “living” shorelines are based on their ability to enhance oyster habitat, enabling the reef to maintain elevation within the rapidly changing environment (i.e., sea level rise, subsidence). This report documents the recruitment, survival, and growth of the living components of the reef – oysters and other encrusting organisms (e.g. mussels, barnacles). This final technical report provides data from five years of monitoring (November 2017 – December 2021) of reefs located along the western side of Eloi Bay in Pontchartrain Basin, Louisiana (Figure 2). Monitoring goals included (1) assessment of annual oyster densities and population dynamics on the reefs, (2) assessment of annual density and diversity of other encrusting organisms, and (3) comparisons of outcomes by reef technology, exposure, and water quality. Detailed information on technologies used, construction design, and as-built elevations are available in Coast & Harbor Engineering (2016) Design Memorandum dated March 25, 2016, submitted to Louisiana Coastal Protection and Restoration Authority.

Figure 1. Photographs of the five reef technologies monitored: Oyster Break (OB), Reef Block (RBL), Wave Attenuating Device (WAD), Reef Ball (RFB2, RFB3 – based on number of rows), and Shore Jax (JAX). Information on each reef technology is available in Coast and Harbor Engineering (2016). Photos: D. Aguilar Marshall, 2019

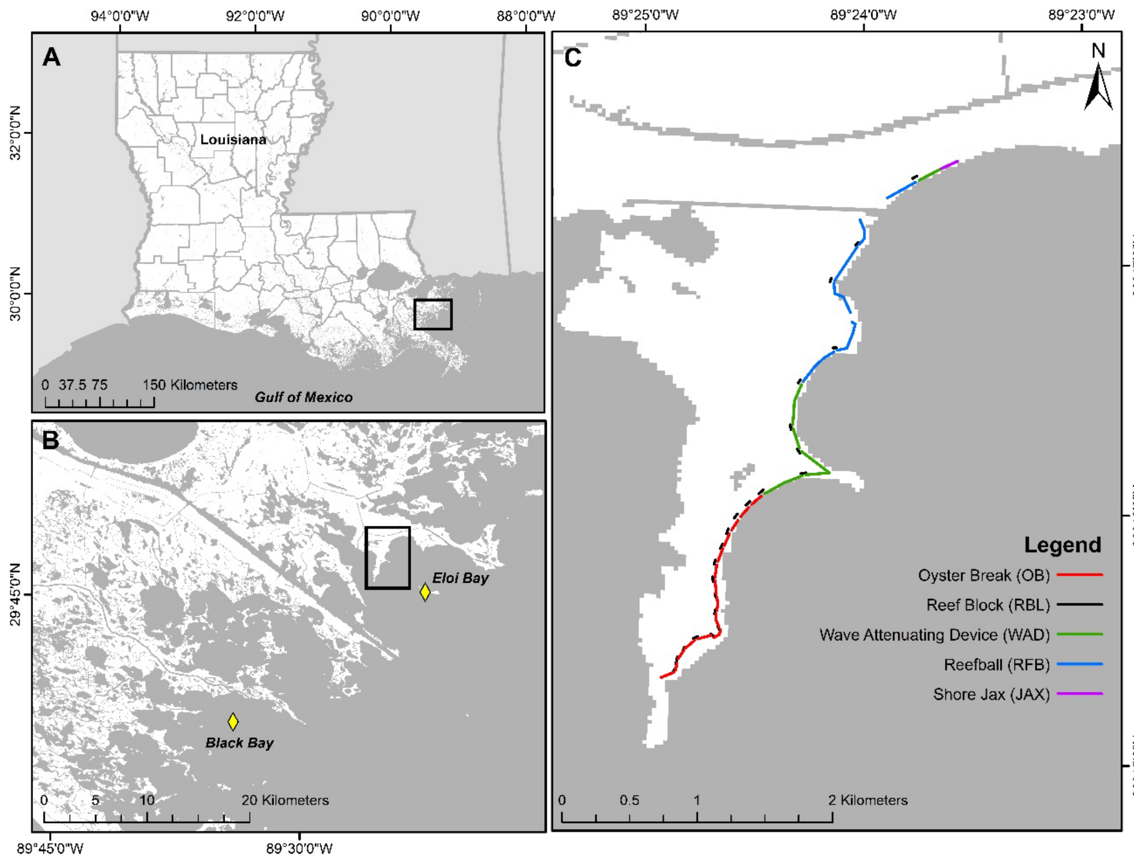

Figure 2. Locations of five bio-engineered reef technologies in Eloi Bay, Pontchartrain Basin, LA. Panel A is a Louisiana locator map. Panel B is a regional locator map. In Panel B, the yellow diamonds represent the Louisiana Department of Wildlife and Fisheries (LDWF) fisheries independent monitoring station 2055 (LDWF 2018; top right) and the U.S. Geological Survey (USGS) continuous data recorder 07374526 (https://waterwatch.usgs.gov/; bottom left) locations. Panel C depicts the approximate locations of the five reef technologies. Reefs were located off-shore of the marsh, in shallow water. Actual reef extents are available in the as-built surveys available from the Louisiana Coastal Protection and Restoration Authority (CPRA). Details about reef technologies, design, locations and engineering parameters can be found in Coast and Harbor (2016).

2. OBJECTIVES AND APPROACH

To examine the development of the biological component of these different bio-engineered reef technologies, density of oysters and encrusting organisms were monitored annually from 2017 through 2021 on each of the five reef technologies (Figure 1) following methods detailed below.

No continuous data recorder is found in close proximity (< 5 km) to the shoreline project. We examined data from three recorders located within a 20 km radius of the project. These stations include a U.S. Geological Survey (USGS) continuous data recorder (https://waterwatch.usgs.gov/; USGS 07374526), and two Coastwide Reference Monitoring Stations (CRMS 4457, CRMS 1024; CPRA 2021). We downloaded data from all three stations and compared discrete data points collected during our sampling to daily means from each station. Due to the complex hydrology in the region, no station tracked the shoreline site salinities consistently, and ultimately, we used the USGS data to provide an approximation of trends in the area. Water quality data from 1/1/2017 through 12/4/2021 were downloaded from the nearest continuous recorder (https://waterwatch.usgs.gov/; USGS 07374526) and plotted for salinity, temperature, and water level at the site. We also acquired Fisheries Independent Monitoring Program data from Louisiana Department of Wildlife and Fisheries (LDWF 2018) Station 2055 located in Eloi Bay approximately 5 km southeast of the bio-engineered reefs (Figure 2) and plotted their available salinity and temperature data. LDWF data provide only discrete monthly data points but are more reflective of the data at the site than the USGS recorder.

2.1. Quantify oyster density and population dynamics, and encrusting organism densities on five bio-engineered reef technologies

All oyster materials were sampled annually and are coded as follows (Figure 1): Oyster Break (OB), Reef Block (RBL), Wave Attenuating Device (WAD), Reef Ball (RFB2, RFB3 – based on number of rows), and Shore Jax (JAX). For the purposes of this work, the RFB2 and RFB3 technologies were pooled together as the configuration was less important than the material in determining recruitment and development of oyster populations. Sampling occurred in December or January of 2017, 2018, 2019, 2020, and 2021 during low water events to be able to see and count oysters and other encrusting organisms (Appendix Table A.1).

We used a random sampling design, stratified by windward (bay-facing) and leeward (marsh-facing) sides of the reef. Sampling approach varied slightly based on bio-engineered reef material, but in all cases we generated comparable measurements of oyster density and population demographics (shell height (mm)). Reefs were sampled visually using a 0.25 m^2 quadrat which was haphazardly placed on the reef. Due to low visibility and the various reef materials used, oyster density occurred in the top of the water column (to 25 cm), or on exposed reef, depending on water levels. Samples were not taken in the lower 0.5 m of the reef due to a lack of visibility and ability to sample. Within each quadrat, oysters were counted; any encrusting organisms were also counted and recorded by species. Individual oyster shell height was also recorded for all live oysters within the quadrat.

For each technology, a minimum of five samples were taken along the reef technology on the leeward and windward side of the reef depending on reef type and sampling conditions (5 to 9 samples x 2 reef sides = 10 to18 samples x 5 reef technologies x 5 years $\geq$ 250 samples). Methods replicated previous work with similar bio-engineered reef technologies in Louisiana (Melancon et al. 2013, La Peyre et al. 2017).

The densities (ind m^{-2}) of oysters (*Crassostrea virginica*) and the dominant encrusting organisms (hooked mussel (*Ischadium recurvum*), and barnacle (*Semibalanus balanoides*) were calculated from the data. Total density is defined as the mean density of each organism, for each reef technology, across both sides of the reef; leeward density is defined as the mean density of each organism for each reef technology on the leeward (shore facing) side of the reef; windward density is defined as the mean density of each organism for each reef technology on the windward (gulf facing) side of the reef. Analyses were developed to answer specific questions identified by the Louisiana Coastal Protection and Restoration Authority (CPRA):

(1) ***Did total oyster, hooked mussel or barnacle density differ by reef technology?*** To address this question, we examined total density by reef technology, blocking on year.
(2) ***Did leeward or windward oyster, hooked mussel or barnacle density differ by reef location (i.e., leeward, windward) across all reef technologies?*** To address this question, we examined leeward and windward densities by reef location, blocking on reef technology and year.
(3) ***Are there temporal trends in the total, leeward or windward oyster, hooked mussel or barnacle density?*** To address this question, we examined total, leeward and windward oyster density by reef technology and year.
(4) ***Did oyster demography vary by year and technology?*** To better understand the development and maintenance of the oyster populations, we examined oyster population distribution (shell heights) across years and reef technology.

In order to answer these specific questions, a series of tests were run to examine the data. Question (1) was examined using a repeated measures ANOVA (factor: reef technology) blocking on year, Question 2 was examined using a repeated measures (ANOVA) (factor: reef side), blocking on reef technology. Question 3 was examined using a two factor ANOVA (reef technology, year). All data were checked for normality and homogeneity of variance using Shapiro Wilkes. Significant differences were examined using Tukey's HSD post-hoc tests. A significance level of $p < 0.05$ was used.

2.2. Assess oyster recruitment and spat on five bio-engineered reef technologies

In 2018, recruitment was monitored using spat plates placed adjacent to reefs. Spat plates were placed at five locations at three water depths per location and were sampled with replacement in early June, mid-July, and late August. Upon retrieval, plates were taken to the laboratory at Louisiana State University's AgCenter and all encrusting organisms were identified, counted, and measured.

A separate project near the CPRA reefs collected data on recruitment using "oyster ladders". The oyster ladder measures and follows recruitment to measure mortality and growth at three different exposure levels in open (predator) and closed (predator-free) cages. The cages on the ladder were filled with ~20 clean oyster shells to serve as recruitment substrate. These oyster ladders were monitored at the same time as the spat plates by counting all live oysters on the shells and measuring their sizes. We also recorded predators and other organisms found within the cages. These oyster ladders, described in detail in Marshall and La Peyre (2020), were established in April 2018 and monitored through October 2019 and provided details on recruitment and survival relative to inundation or exposure periods.

3. RESULTS

3.1. Water quality

Over the past five-year period (1/1/2017 through 12/4/2021), based on the USGS continuous data recorder (07374526) overall mean ± SEM salinity was 6.9 ± 0.2 ppt with a range of 0.2 – 21.0 ppt (Figure 3). Mean salinity during the spawning season (April through November) for this five year period was 5.8 ± 0.2 ppt (Figure 3). Temperatures followed typical seasonal trends for this region with an overall mean ± SEM of 22.8°C ± 0.2 and a range of 5.0°C to 31.8°C (Figure 3). The year 2019 through mid-2020 had the most continuous low salinity compared to the other years assessed in this study (Figure 3).

Typical salinities on the reef during LDWF sampling were as much as 11.4 ppt higher than salinities recorded on the same day at the USGS data recorder. LDWF data from monthly sampling station 2055 also showed slightly higher salinity means than at the USGS data recorder, but there was no consistent relationship between the LDWF salinity data and the USGS salinity data over the sampling period. The establishment of nearby continuous data may prove valuable for evaluating future projects. Compared to the USGS continuous data recorder, which was distant from the reefs, examination of salinity recorded by LDWF monthly sampling station 2055, which was close to the reefs, indicates a higher mean salinity ± SEM for the past five years (14.7 ± 0.6 ppt) with a slightly larger range of salinities (3.4 – 26.9 ppt), and a higher spawning season salinity during April – November for all years combined (14.2 ± 0.8 ppt).

Based on the USGS continuous data recorder (07374526), water levels ranged from -0.73 m to 1.79 m (NAD83 with correction of -0.088 m) with an overall mean ± SEM of 0.33 ± 0.01 m (median 0.31 m). The maximum height of the five reef technologies varied, with RBL as the shortest (0.46 m), OB and RFB in the middle (0.76 m and 0.88 m, respectively), and WAD and JAX as the tallest (both at 1.07 m). Over the five-year period 1/1/2017 – 12/4/2021, the water level was ≥ 0.46 m (inundating the RBL technology) ~21 % of the time, ≥ 0.76 m (inundating the OB technology) ~5 % of the time, and inundated the remaining technologies less than 5% of the time. Based on previous literature, oysters are more likely to thrive with inundation between 50-100%. Using the 50% threshold, ~67% of RBL reef surfaces, ~40% of OB reef surfaces, ~34% of RFB reef surfaces, and ~29% of WAD and JAX reef surfaces were inundated at least 50% of the days during this study. These calculations are based on as-built data identifying reef height elevation. These estimates are based on living shoreline final as-built survey.pdf, from CPRA (Coast & Harbor Engineering, 2016) , and do not account for any settlement that may have occurred after these as-built surveys were taken, and thus may underestimate total inundation.

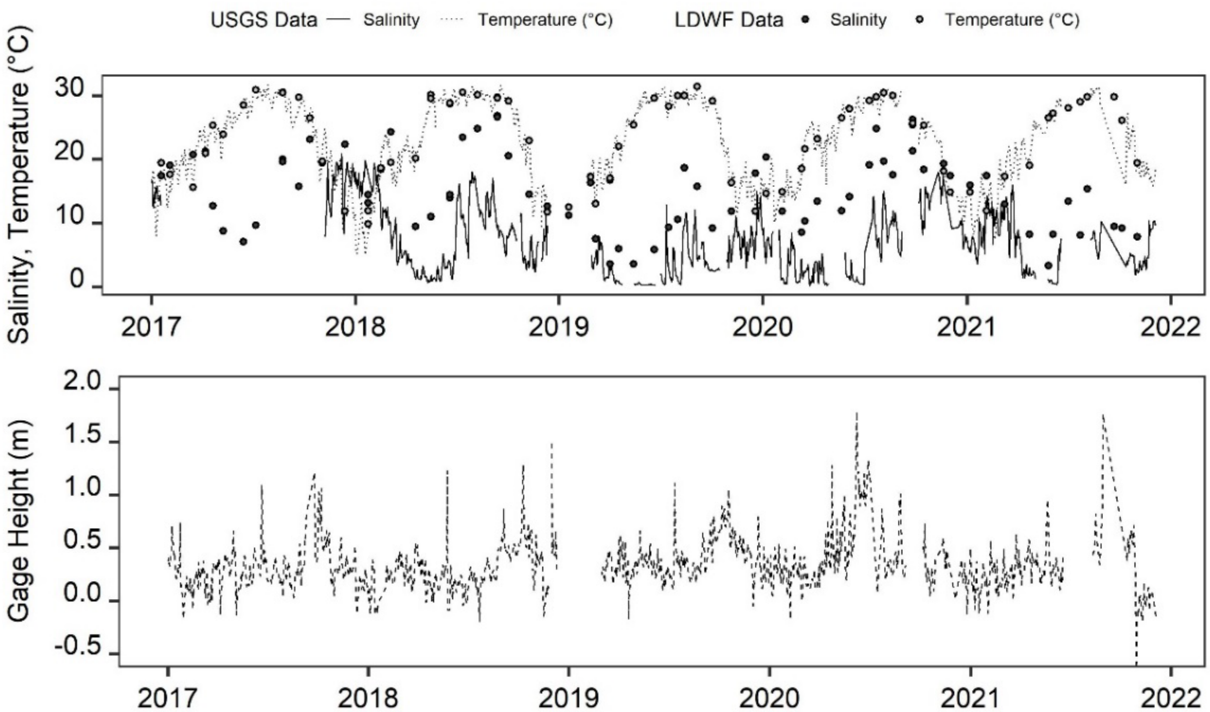

Figure 3. Salinity (ppt), temperature (°C), and water level data (m) from U.S. Geological Survey (USGS) continuous data recorder 07374526 (-0.29 m NAD88) for the full study period (1/1/2017 through 12/4/2021). Outlier data were removed for Temperature and Gage Height (NAD83); generally these outliers coincided with major storm events, potentially disrupting the recorders. Discrete monthly Louisiana Department of Wildlife and Fisheries (LDWF) (station 2055) salinity and temperature data are included and, while these represent only monthly data, are more representative of salinity at the reefs than the USGS recorder data.

3.2. Do oyster, mussel or barnacle density differ by reef technology, when all years and sample locations are combined?

With data from all five years and reef location combined, oyster and mussel density were significantly higher and similar on OB, RBL, RFB and WAD reef technologies as compared to JAX technology ($p < 0.001$; Figure 4). Oyster density varied from a low of 34.3 ± 4.8 ind m^{-2} on JAX, to a high of 119.5 ± 6.2 ind m^{-2} on RFB while mussel density varied from a low of 476.0 ± 67 ind m^{-2} to a high of 1,804.7 ± 216.7 ind m^{-2} on OB. With data from all five years and reef location combined, barnacle density was significantly higher and similar on OB, RFB, WAD and JAX reef technologies as compared to RBL technology (1-factor ANOVA, $p < 0.001$; Figure 4) with barnacle density ranging from 390.7 ± 448 ind m^{-2} on RBL to a high of 1,048.1 ± 135 ind m^{-2} on JAX.

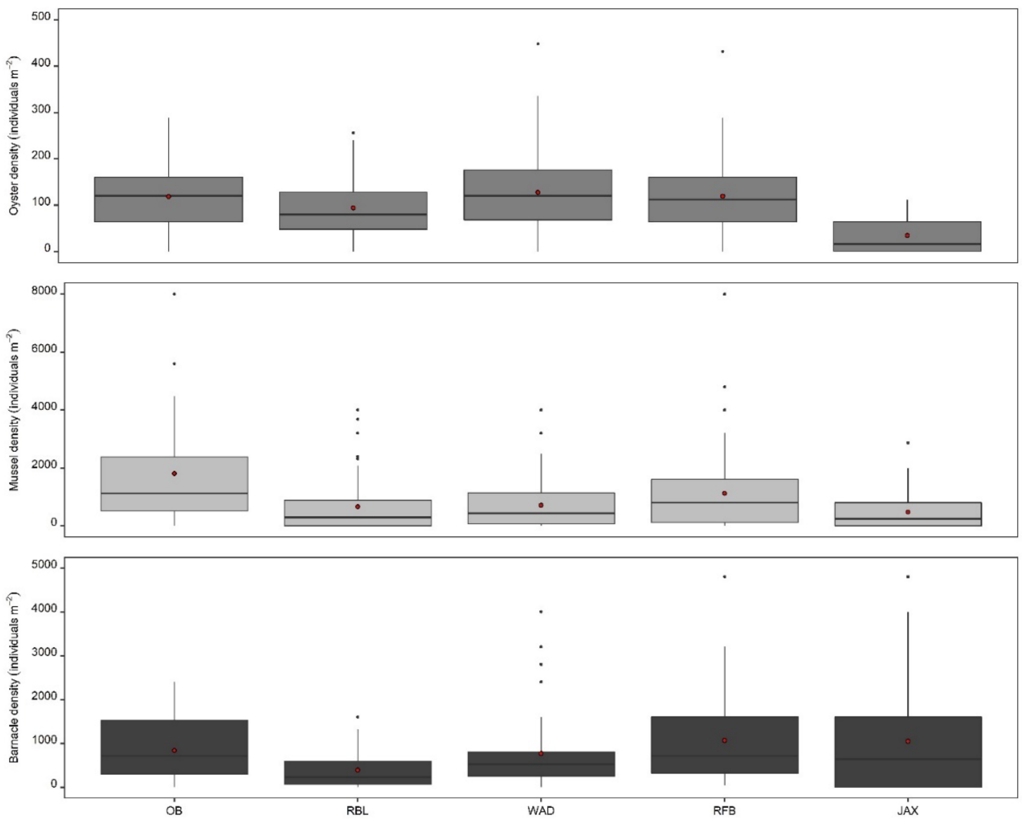

Figure 4. Oyster, hooked mussel, and barnacle density (ind. m^{-2}) on five reef technologies (OB, RBL, WAD, RFB, JAX) with all years (2017 – 2021) and reef sides (leeward, windward) combined. For each boxplot, the red circle indicates mean, whiskers represent first and fourth quartiles, the box represents second and third quartiles, and the horizontal line represents the median, with outliers depicted as single points. Oyster Break (OB), Reef Block (RBL), Wave Attenuating Device (WAD), Reef Ball (RFB2, RFB3 – based on number of rows), and Shore Jax (JAX).

3.3. Do oyster, mussel or barnacle density differ by side of reef (leeward, windward) across all years and technologies?

With all five years and technologies combined, oyster density was significantly higher on the leeward side of the reefs compared to the windward side ($p < 0.001$; Figure 5). Oyster density on the leeward side was 123.2 ± 4.8 ind m^{-2}, as compared to 78.0 ± 4.5 ind m^{-2} on the windward side. In contrast, both mussel density and barnacle density were significantly higher on the windward side of the reefs compared to the leeward side (mussel: $p = 0.001$; barnacle: $p = 0.03$). Mussel density on the leeward side was 775.8 ± 57.7 ind m^{-2}, as compared to 1,158.6 ± 103.3 ind m^{-2} on the windward side. Barnacle density on the leeward side was 749.1 ± 54.3 ind m^{-2}, as compared to 935.6 ± 63.9 ind m^{-2} on the windward side.

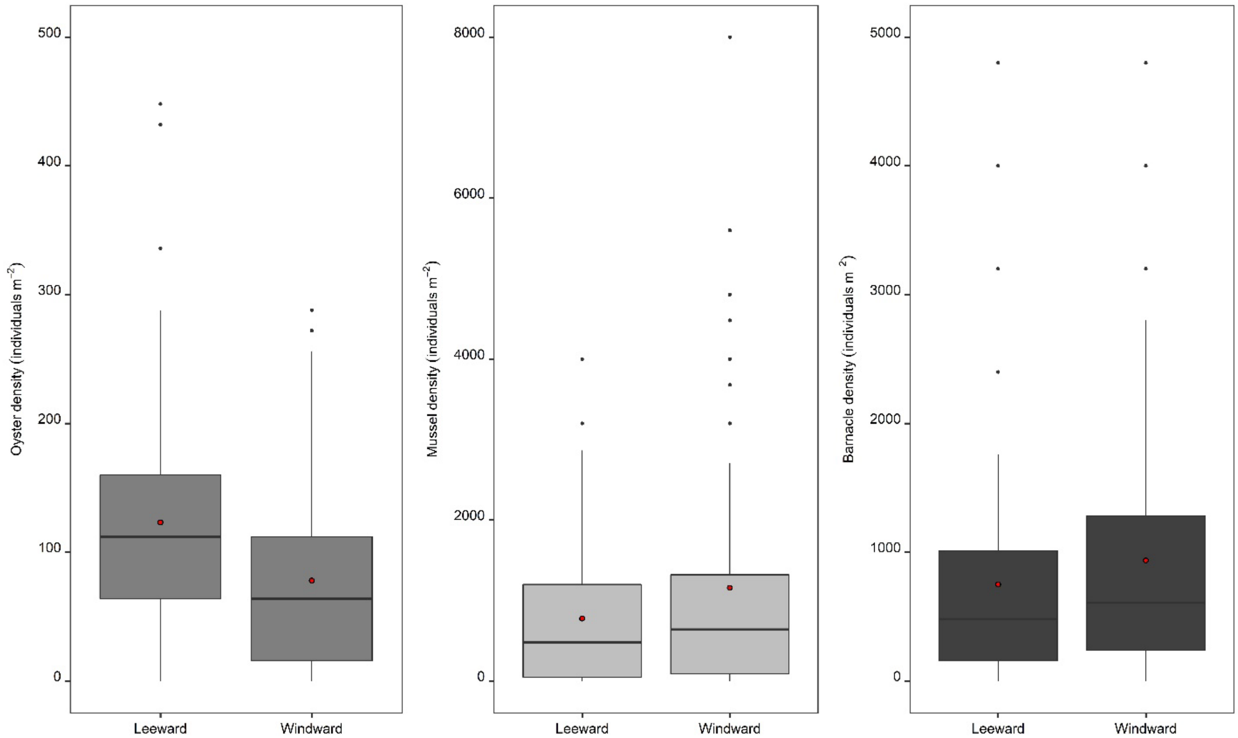

Figure 5. Oyster, hooked mussel, and barnacle density (ind. m^{-2}) on the leeward and windward sides of reefs with all years (2017 – 2021) and technologies (OB, RBL, WAD, RFB, JAX) combined. For each boxplot, the red circle indicates mean, whiskers represent first and fourth quartiles, the box represents second and third quartiles, and the horizontal line represents the median, with outliers depicted as single points. Oyster Break (OB), Reef Block (RBL), Wave Attenuating Device (WAD), Reef Ball (RFB2, RFB3 – based on number of rows), and Shore Jax (JAX).

3.4. Are there temporal trends in the total, leeward or windward oyster, hooked mussel or barnacle density?

3.4.1. Did total oyster, mussel and barnacle density differ by year, across the five technologies?

Oysters, hooked mussels, and barnacles were recorded across all reef technologies in all years, except on the JAX technology in 2017 (Figure 6). There was a significant interaction between reef technology and year for oysters ($p = 0.0171$), mussels ($p < 0.001$) and barnacles ($p < 0.001$). Oyster density ranged from 0 ind m^{-2} (JAX, 2017) to a high of 181 ± 14 ind m^{-2} (WAD, 2018). The interaction is largely explained by significantly lower densities on JAX across all five years, high density on WAD in 2018 and significantly lower density on RBL in 2017 compared to most other technologies and years (Tukey HSD, $p < 0.05$). The highest mussel density was on OB in 2017 (2,768 ± 810 ind. m^{-2}), whereas the lowest mussel density observed was on JAX in 2017 (0 ± 0 ind. m^{-2}) (Figure 7). The interaction is largely explained by higher density on the OB technology in 2017 than on all other technologies in most other years (Tukey HSD, $p < 0.05$). The lowest barnacle density observed was quantified on JAX in 2017 (0 ± 0 ind. m^{-2}), whereas the highest barnacle density was also on JAX but in 2019 (2,933 ± 274 ind. m^{-2}) (Figure 7). The interaction is largely explained by high density in 2019 on all technologies except RBL.

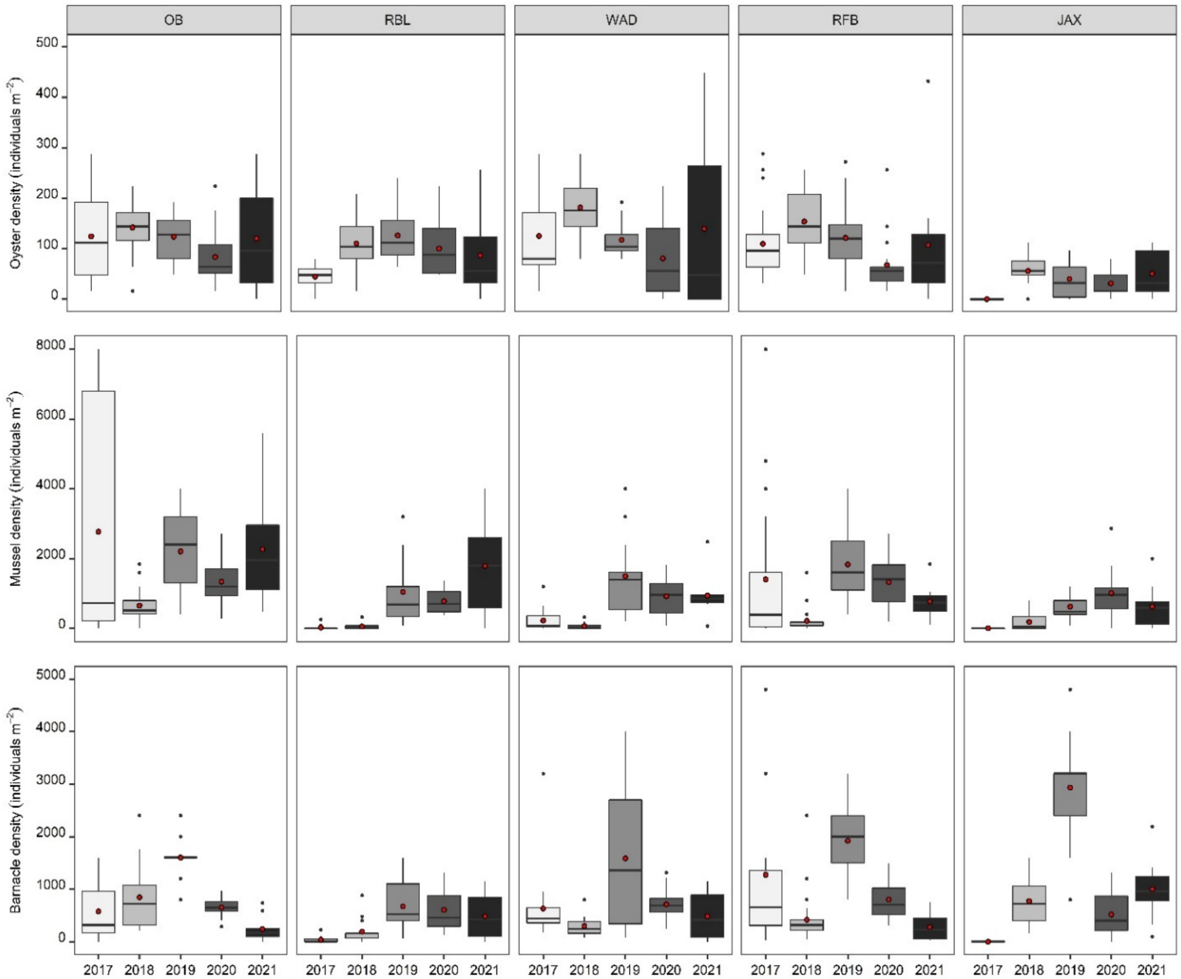

Figure 6. Oyster, hooked mussel, and barnacle density (ind m^{-2}) at five bio-engineered reef technologies from 2017 – 2021. For each boxplot, the red circle indicates mean, whiskers represent first and fourth quartiles, the box represents second and third quartiles, and the horizontal line represents the median, with outliers depicted as single points. Oyster Break (OB), Reef Block (RBL), Wave Attenuating Device (WAD), Reef Ball (RFB2, RFB3 – based on number of rows), and Shore Jax (JAX).

3.4.2. On the leeward side of reefs, do oyster, mussel and barnacle density differ by year, and technology?

On the leeward side of the reefs, there was a significant interaction between reef technology and year on oyster density (2-factor ANOVA, $p < 0.001$; Figure 7), mussel density ($p < 0.001$) and barnacle density ($p < 0.001$). The highest oyster density on the leeward side occurred on WADs in 2021 (272 ± 63 ind. m^{-2}), whereas the lowest oyster density was on JAX in 2017 (0 ± 0 ind. m^{-2}). The interaction is largely explained by low density on all technologies (except OB) in 2017 and low density on JAX in all years (Tukey HSD, $p < 0.05$). The remaining interactions are largely due to instances of high density on OB in 2017 and 2021, WAD in 2018 and 2021, and RFB in 2018 (Tukey HSD, $p < 0.05$).

For mussels, the highest mussel density on the leeward side was seen on RFB in 2019 (2,396 ± 234 ind. m^{-2}), whereas the lowest mussel density was on JAX and RBL in 2017 (0 ± 0 ind. m^{-2}). The interaction is largely explained by low density on all technologies (except OB) in 2017 and 2018 and by high density on RFB in 2019 and 2020 (Tukey HSD, $p < 0.05$). For barnacles, the highest barnacle density was on RFB technology in 2019 (1,956 ± 155 ind. m^{-2}), whereas the lowest barnacle density was on JAX in 2017 (0 ± 0 ind. m^{-2}). The interaction is largely explained by high density on OB, RFB, and JAX in 2019, especially compared to low density on RBL and JAX in 2017 and WAD and RFB in 2021 (Tukey HSD, $p < 0.05$).

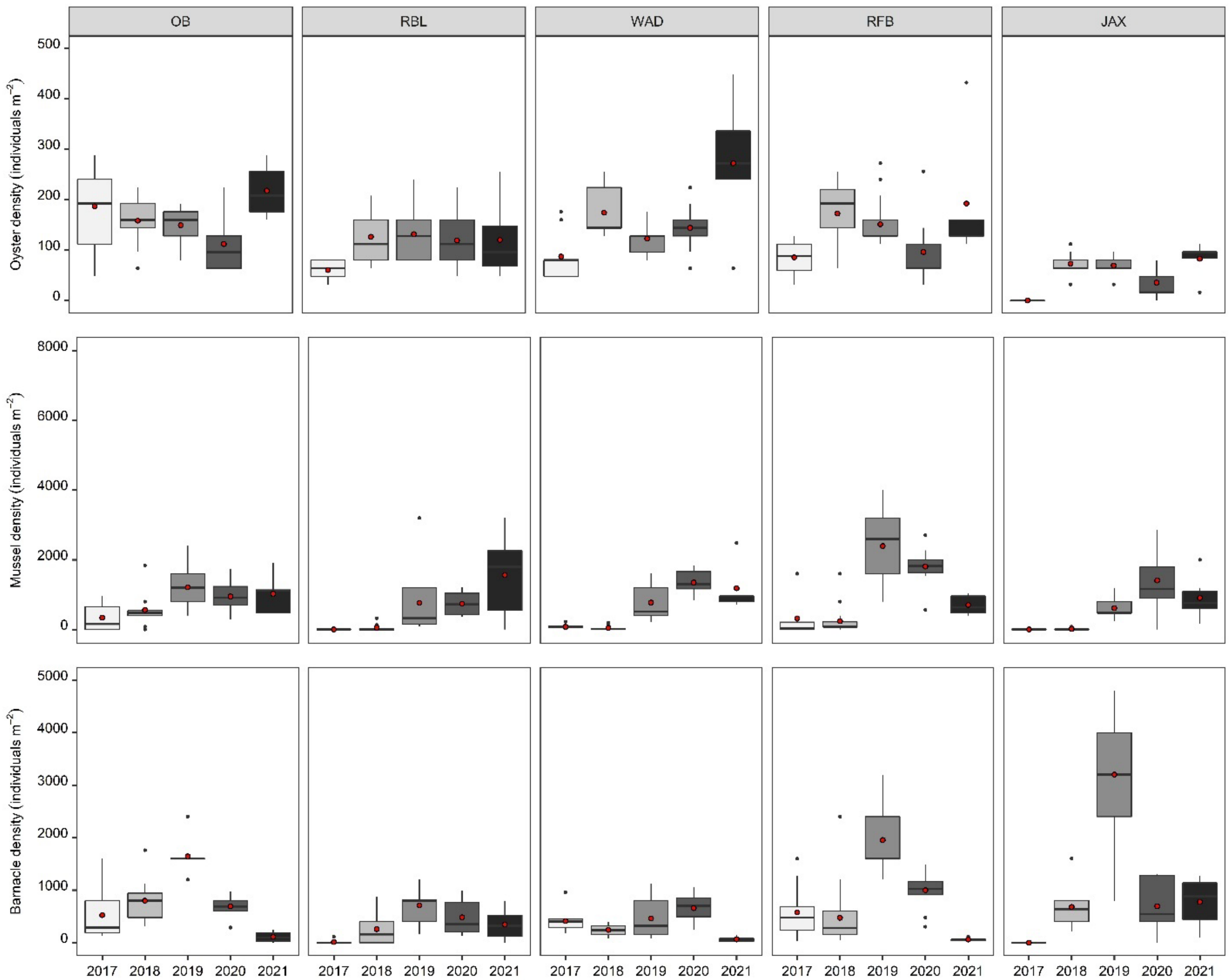

Figure 7. Oyster, hooked mussel, and barnacle density (ind. m^{-2}) on the leeward side of five bio-engineered reef technologies from 2017 – 2021. For each boxplot, the red circle indicates mean, whiskers represent first and fourth quartiles, the box represents second and third quartiles, and the horizontal line represents the median, with outliers depicted as single points. Oyster Break (OB), Reef Block (RBL), Wave Attenuating Device (WAD), Reef Ball (RFB2, RFB3 – based on number of rows), and Shore Jax (JAX).

3.4.3. On the windward side of reefs, do oyster, mussel and barnacle density differ by year, and technology?

On the windward side of the reefs, there was a significant interaction between reef technology and year for oyster density (2-factor ANOVA, $p < 0.001$; Figure 8), mussel density ($p < 0.001$) and barnacle density ($p<0.001$). For oysters, the highest oyster density was on WAD in 2018 (188 ± 22 ind. m^{-2}), whereas the lowest oyster density was on JAX in 2017 (0 ± 0 ind. m^{-2}). The interaction is largely explained by high density on all technologies except JAX in 2018 and on WAD and RFB in 2017, and low density on JAX across all years (Tukey HSD, $p < 0.05$). For mussels, the highest mussel density was on OB in 2017 (5,200 ± 1,139 ind. m^{-2}), and the lowest mussel density was on JAX in 2017 (0 ± 0 ind. m^{-2}). The interaction is explained by high density on OB in 2017, 2019, and 2021, high density on WAD in 2019, and high density on RFB in 2017 as compared to all other year and technology combinations (Tukey HSD, $p < 0.05$). For barnacles, the highest barnacle density was on WAD in 2019 (2,711 ± 265 ind. m^{-2}), whereas the lowest barnacle density was on JAX in 2017 (0 ± 0 ind. m^{-2}). The interaction is explained by high density on OB, WAD, RFB, and JAX in 2019 and RFB in 2017 (Tukey HSD, $p < 0.05$) in comparison to other year and technology combinations.

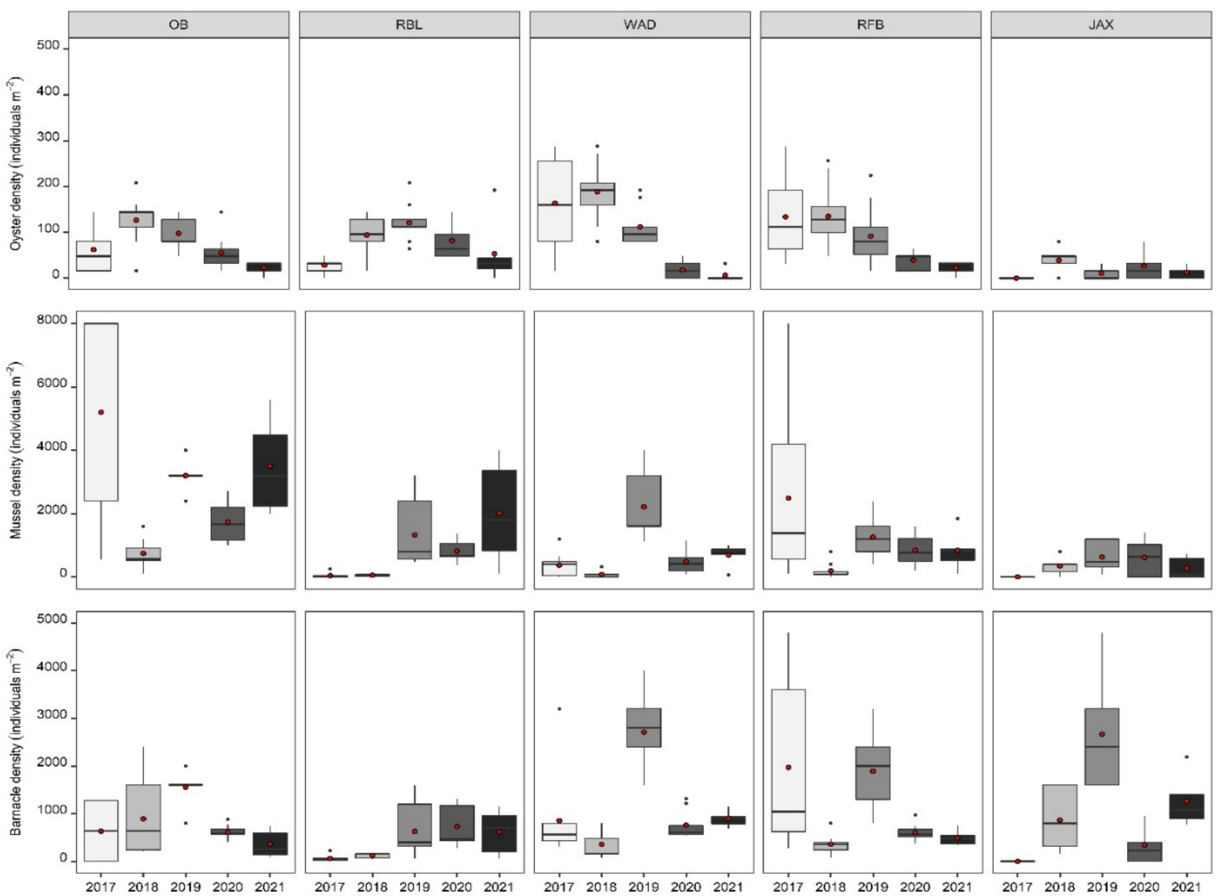

Figure 8. Oyster, hooked mussel, and barnacle density (ind. m^{-2}) on the windward side of five bio-engineered reef technologies from 2017 – 2021. For each boxplot, the red circle indicates mean, whiskers represent first and fourth quartiles, the box represents second and third quartiles, and the horizontal line represents the median, with outliers depicted as single points. Oyster Break (OB), Reef Block (RBL), Wave Attenuating Device (WAD), Reef Ball (RFB2, RFB3 – based on number of rows), and Shore Jax (JAX).

3.5. Did oyster demography vary by year and technology?

Oysters ranging from juvenile (> 25 mm) to market size (> 76 mm) were observed on each bio-engineered reef type for each year sampled, with the exception of 2017 JAX when no oysters were observed (Figure 9). The average shell height distribution was similar across reef technologies and between years, with the majority of the population in the 25-75 mm size range, reflecting new recruits every year and survival from previous years. The largest oyster recorded was 174.9 mm on the RFB technology in 2020.

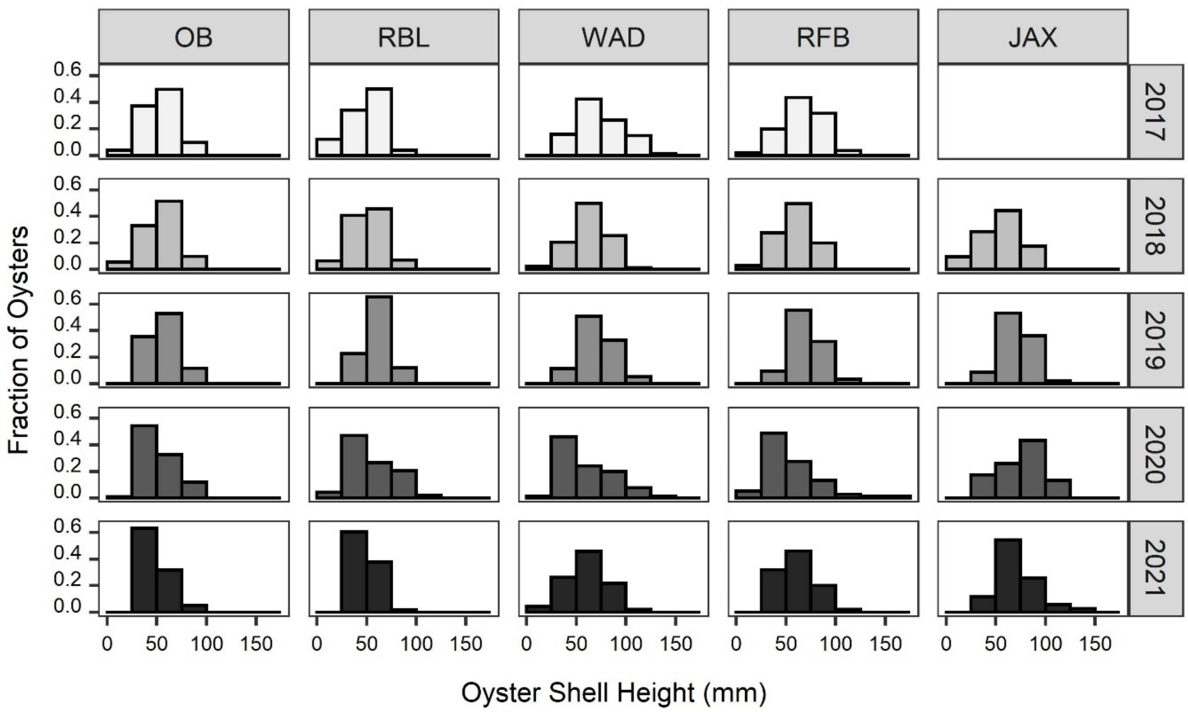

Figure 9. Oyster population shell height distribution by reef technology and year, binned by 25 mm sizes (n = 0 – 346 oysters). Percent of population within each bin is presented. Appendix Figure A.1 provides a similar figure, but using actual oyster counts (n) by size class, as opposed to percentages. Oyster Break (OB), Reef Block (RBL), Wave Attenuating Device (WAD), Reef Ball (RFB2, RFB3 – based on number of rows), and Shore Jax (JAX).

3.6. Oyster recruitment monitoring

Measurement of oyster recruitment through spat plates yielded few data points. In 2018, only two spat were counted on the recruitment plates placed in April 2018, although we know from oyster counts on the reefs that recruitment did occur. Spat plates need to coincide very closely with recruitment events as they can quickly foul and prevent spat from settling. In our case, many recruitment plates had 100% algae cover on the bottom and mid-water column tiles, while the top water-column plates, placed at a height equivalent to the top of the adjacent reefs, were often air-exposed, and not available for recruitment. Competition for space could also sometimes explain a lack of recruitment on the plates. In this case, barnacles were in high densities on the bottom-water column plates in the June and July sampling periods, although not in high densities at other dates and water column plates.

In 2019 river levels in Louisiana broke numerous flow records beginning early in the calendar year (Gledhill et al. 2020). As a result, estuaries, including where these reefs were located, experienced unusually low salinities to the extent that oyster reproduction would be inhibited. At the reefs, salinity was below 10 ppt for most of the year with salinities over 10 ppt occurring for less than 20 days in August through December. Salinity remained below 5 ppt from late March through mid-July and was below 1 ppt for an extended period within this timeframe (Figure 3). As the placement of recruitment plates needs to coincide with potential recruitment periods and suitable conditions to minimize excessive fouling on the tiles (generally, salinities > 10 ppt and temperatures > 20°C), spat plates were not placed on the reefs in 2019. This resulted in no spat counts through summer 2019; however, there is evidence of a late summer/early fall recruitment event captured through our oyster density survey in December 2019.

Although only located at one location along the reef project, the oyster ladders provide more insight into possible recruitment patterns. A few spat were recorded in June and July sampling events in 2018, particularly in the bottom locations, more significant numbers of spat were recorded in August 2018. More detailed analyses of these results are presented in Marshall and La Peyre (2020).

4. SUMMARY

All technologies experienced oyster recruitment and survival. Oysters survived on all reef technologies through 2021. All reef technologies recruited oysters by the second year (2018) of monitoring with oysters recruited every year thereafter, as evidenced by density patterns over time and consistent size distributions over time.

With the exception of the JAX technology, there was little difference in the total oyster density between reef technologies (Figure 4). JAX failed to recruit oysters the first year and oyster densities remained low from 2018 – 2021 in comparison to other reefs. JAX also had the lowest mussel densities but the highest barnacle counts. The lower oyster densities may be due to some feature of JAX reefs themselves (materials, surface, etc…), or, as with the exception of RBL, the reef technologies were not replicated across separate sections of the shoreline, reef location rather than reef technology may explain the observed lower density as JAX were located on one end of the test shoreline (Figure 2).

Oysters generally had higher densities on the leeward side of the reefs compared to the windward side, regardless of reef technology (Figure 5). Oysters initially recruited and survived on the windward side of all reef technologies in 2017 – 2018 before seeing a consistent decline in densities from 2019 – 2021. This may be due to higher wave energy on the windward side or increased competition from mussels and barnacles. It is possible that higher wave exposure combined with extreme low salinity in 2019 made oysters less competitive with mussels and barnacles that year, allowing them to take over the reefs.

As densities are similar across technologies (with the exception of the JAX technology), available surface area – specifically areas with inundation rates conducive to oyster recruitment and growth (50% - 100%; Marshall et al. 2020) – may ultimately determine overall oyster populations supported by different technologies. Using the 50% inundation threshold for oyster survival (i.e., Marshall and La Peyre 2020, and references therein), ~67% of RBL reef surfaces, ~40% of OB reef surfaces, ~34% of RFB reef surfaces, and ~29% of WAD and JAX reef surfaces were inundated at least 50% of the days during this study, and available for sustained oyster survival and growth. These calculations are based on as-built data identifying reef height elevation, but it is worth noting that available reef area for oyster recruitment may change over time as reef settlement occurs, as well as with subsidence or sea level rise altering inundation regimes.

From 2017-2021, these reefs recruited and supported oyster populations (Figures 6, 7, 8, 9). These reefs recruited and supported relatively stable oyster populations through the five year time period monitored, despite high variation in environmental conditions. Placement of a continuous data recorder for salinity and water level adjacent to these reef shorelines would significantly help in better predicting oyster survival and recruitment over the long-term. In addition, continuous salinity and temperature data for the reefs would help monitor potential reproductive events and potential mortality events. These oyster reefs, through continued growth and survival of adult oysters, may also contribute to their own persistence through reproduction and serve as sanctuaries for reproductive oysters, which may also help seed adjacent or connected natural reefs in the region (i.e., Marshall et al. 2020).

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APPENDICES

Table A.1. Chronological summary of work performed during five years of monitoring oyster populations on a bioengineered living shoreline in Louisiana, USA.

Year	Month	Description
2017	Dec	Sampled oysters and encrusting organisms; entered data; developed figures
2018	Apr	Prepared tiles, equipment for Task 3 deployment, deployed first set
	Jun	Exchanged tiles, counted tiles, cleaned, and entered data
	Jul	Exchanged tiles, counted tiles, cleaned, and entered data
	Aug	Exchanged tiles, counted tiles, cleaned, and entered data
	Sep	Collated data, wrote and prepared Annual Report #1
	Dec	Sampled oysters and encrusting organisms; entered data; developed figures
2019	Aug	Assessment of reefs; download of data
	Sep	Collated data, wrote and prepared Annual Report 2020
	Dec	Sampled oysters and encrusting organisms; entered data; developed figures
2020	Dec	Sampled oysters and encrusting organisms; entered data; developed figures
2021	Jan	Collated data from all sampling, wrote and prepared Annual Report 2021
	Dec	Sampled oysters and encrusting organisms; entered data; developed figures
2022	Jan	Collated data from all sampling, wrote and prepared Annual Report 2022

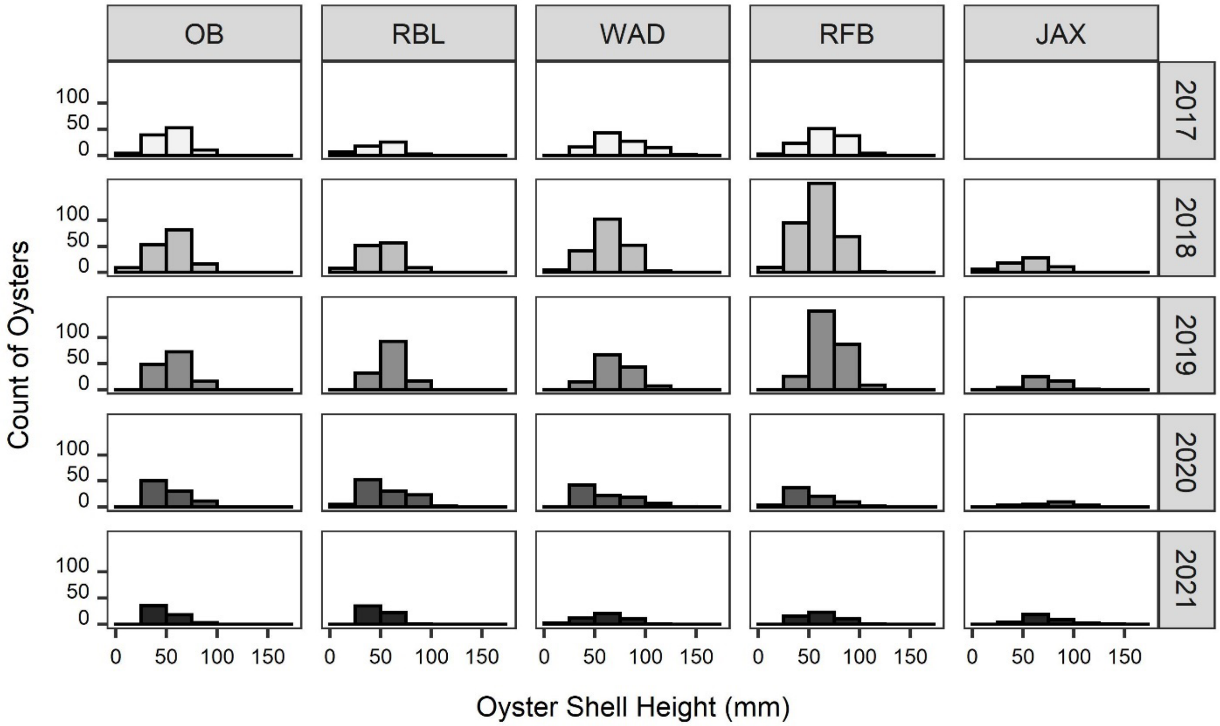

Figure A.1. Oyster population shell height distribution by reef technology (OB, RBL, WAD, RFB, JAX) and year (2017-2021) in Louisiana, binned by 25 mm shell height sizes. Count of population within each bin is presented. Oyster Break (OB), Reef Block (RBL), Wave Attenuating Device (WAD), Reef Ball (RFB2, RFB3 – based on number of rows), and Shore Jax (JAX).