State of Louisiana

Coastal Protection and Restoration Authority of Louisiana (CPRA)

2017 Operations, Maintenance, and Monitoring Report: Final Closeout Report

for

Bio-engineered Oyster Reef Demonstration Project (LA-0008)

State Project Number LA-0008
Priority Project List 17

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2017 Operations, Maintenance, and Monitoring Report
for
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Preface

This report includes monitoring data collected through January 2017.

The 2017 report is the 2nd and final report in a series of two reports. This 2017 OM&M report is the final closeout report of this five-year demonstration project.

I. Introduction

The Bioengineered Oyster Reef Demonstration (LA-0008) project was proposed on the 17th project priority list of the Coastal Wetlands Planning, Protection, and Restoration Act (CWPPRA) and is co-sponsored by the National Oceanic and Atmospheric Administration/National Marine Fisheries Service (NOAA/NMFS) and Louisiana's Coastal Protection and Restoration Authority (CPRA). It is located on the Gulf of Mexico shoreline in southeast Cameron Parish on the Rockefeller Wildlife Management Area and Game Reserve (Rockefeller Refuge) (Figure 1). The total length of this shoreline protection demonstration project is approximately 565 ft (172.2 m) long and is comprised of two, 215 ft (65.5 m) long sections separated by a 130 ft (39.6 m) long gap.

Both historically and recently, the Gulf of Mexico shoreline along Rockefeller Refuge has retreated at a high rate. The Barrier Island Comprehensive Monitoring Program (BICM) reported that the Rockefeller Refuge shoreline eroded 34.9 ft/yr (10.6 m/yr) from 1884 to 2005 and 52.4 ft/yr (16.0 m/yr) from 1999 to 2005 which were the highest rates west of the Atchafalaya River (Martinez et al. 2009; Fig. 2). From Feb 2010 to Mar 2013, the shoreline eroded 42.0 ft/yr (12.8 m/yr) along the Control reach of LA-0008 (HDR 2011). The beach along Rockefeller Refuge has diminished to a thin layer of shell hash over old marsh platform, and the waves wash ashore onto the marsh. The shell hash is reworked by waves and rolled onto the marsh vegetation along the shoreline where it smothers the vegetation. The soil weakens as the roots die, and the waves erode the shoreline as the shell hash is rolled further inland by the waves. This pattern is exacerbated in the mid-winter to late spring during higher water levels when persistent south winds feed frontal passages to the north (Pers. Comm. P. Trosclair, LDWF Rockefeller Manager). In addition, the water bottoms along the shoreline are old marsh platform and have very low weight bearing capacity. A geotechnical report for the Rockefeller Refuge Gulf Shoreline Stabilization Demonstration Project (ME-18) classified the top 20 feet of soil as very soft clay with an allowable bearing capacity of 290 pounds per square foot (psf) (Fugro Consultants LP 2004) which is too weak to support the weight of rock used in traditional breakwaters (CHE 2009).

To address shoreline erosion issues along the weak soils of the Rockefeller Refuge coastline, LA-0008 is testing the Oysterbreak™ system patented by Oyster Restoration Advancement Technologies, L.L.C. (ORA Tech). The Oysterbreak system is wave break composed of interlocking, concrete rings designed to provide habitat for oyster colonization; the rings are 5 feet in diameter, 6 inches wide, and 20 inches tall. The Oysterbreak is less dense than traditional rock rip-rap breakwaters because of the void space of the rings. Also, the more the structure is above the water, the heavier it is as it loses buoyancy from the water; therefore,

Figure 1. The Bioengineered Oyster Reef Demonstration Project (LA-0008) consists of two Oysterbreak segments on the Gulf of Mexico coast of Rockefeller Wildlife Refuge. The segments are each 215 feet long with a 130 feet gap in between. Oysterbreak – West is composed of OysterKrete, and Oysterbreak – East is composed of standard weight concrete.

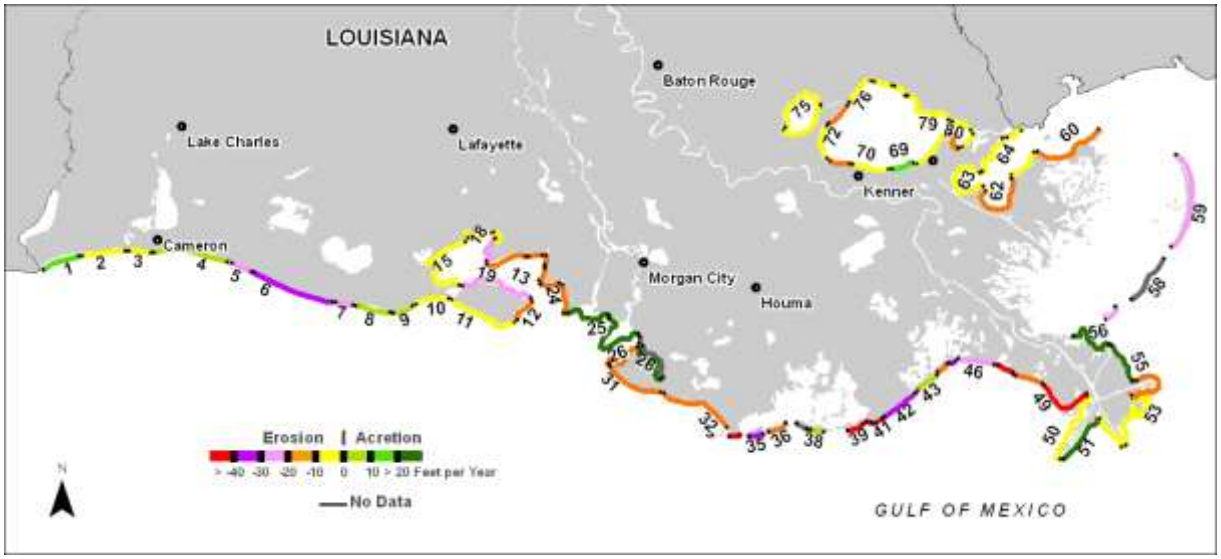


Figure 2. Shoreline movement rates across Louisiana from the mid-1880s to 2005 analyzed by BICM (from Martinez et al. 2009)**.** Reach six is the Rockefeller Refuge shoreline.

the Oysterbreaks were built wide (42 feet wide at the base) to compensate for not being able to build tall. Secondary design consideration was to provide oyster habitat for reef colonization which may increase wave attenuation by closing the void space and offsetting elevation deficits as the reef segments settle. In addition, the design includes a comparison of OysterKrete© versus standard weight concrete to test for differences in oyster colonization between different construction materials. OysterKrete is a concrete designed by ORA Tech to attract oyster colonization and improve survival.

The State of Louisiana's Master Plan (CPRA 2012) identified Gulf Shoreline Protection (Calcasieu River to Rockefeller, 004.SP.05a) "through rock and low wave-action breakwaters … to preserve shoreline integrity and reduce wetland degradation from wave erosion" (CPRA 2012). The LA-0008 demonstration project will contribute information towards determining the best type of low wave-action breakwaters. As per the LA-0008 fact sheet, the goals of the LA-0008 demonstration project are to test and to evaluate if the Oysterbreak is a cost-effective technique for protecting poor load bearing reaches of Gulf of Mexico shoreline (LCWCRTF 2009).

II. Maintenance Activity

a. Project Feature Inspection Procedures

The Bioengineered Oyster Reef Demonstration Project (LA-0008) consists of two, 215 ft concrete structures separated by a 130 ft gap. The Oysterbreak structures were constructed on a one foot thick "marine mattress" comprised of crushed limestone between sheets of geofabric. The Oysterbreak structures are composed of interlocking, concrete rings; the rings are 5 feet in diameter, 6 inches wide, 20 inches tall, and weigh 2,200 pounds. Extra marine mattresses were placed adjacent to the Oysterbreaks within the gap prevent potential scouring. Rings on Oysterbreak to the west (OBW) were made of OysterKrete which is a concrete designed by ORA Tech to attract oyster colonization and improve survival. Rings on Oysterbreak to the east (OBE) were made of standard weight concrete (4000 lb mix). An OysterKrete ring cost $10 more than the Standard Weight ring to fabricate for a total difference of $6,210 between the structures (Table 1). The OysterKrete Oysterbreak construction cost was $731,415 total and $3,401.93 per linear foot; the Standard Weight Oysterbreak construction cost was $725,205 total and $3,373.05 per linear foot.

Table 1. Original and As-built quantities of materials used for construction of the Bio-engineered Oyster Reef Demonstration (LA-0008) were copied from the project completion report (CHE 2012). "Original" quantities reflect material used for the Oysterbreaks. The term "Standard Weight" replaces "Normal Weight" throughout the report.

Item No.	Item Description	Original Quantity	As-built Quantity	Unit	Unit Cost	Original Cost	As-built Cost
1	Mobilization	1	1	LS	$79,000.00	$ 79,000.00	$ 79,000.00
2	Construction Surveying	1	1	LS	$36,000.00	$ 36,000.00	$ 36,000.00
3	Oysterbreak Armor Unit (Oysterkrete) - Fabricate and Deliver	621	631	EA	$ 620.00	$ 385,020.00	$ 391,220.00
4	Oysterbreak Armor Unit (Normal Weight Concrete) - Fabricate and Deliver	621	629	EA	$ 610.00	$ 378,810.00	$ 383,690.00
5	Oysterbreak Armor Unit - Install	1,242	1,260	EA	$ 90.00	$ 111,780.00	$ 113,400.00
6	Marine Mattress	18,060	18,480	SF	$ 23.50	$ 424,410.00	$ 434,280.00
7	Navigation Aids	4	4	EA	$10,400.00	$ 41,600.00	$ 41,600.00
8	Credit for Marine Mattress Geotextile Material	0	1	LS	$ (619.18)	N/A	$ (619.18)
	Total					**$1,456,620.00**	**$1,478,570.82**

No operations, maintenance, repair, and/or rehabilitation were planned for this demonstration project.

b. Inspection Results

Although official Operations and Maintenance (O&M) inspections were not conducted, observations were made during Monitoring. Both Oysterbreak structures appeared stable through 5 years after construction. The third ring from the west along the front, seaward row

of the Standard Weight Oysterbreak was damaged by unknown causes within the first year after construction and crumbled by 2014. Other minor cracking was observed on other rings, but no other broken rings were observed. The top layer of geofabric on the marine mattress became unwoven in some placed but was held in place by the Oysterbreak structures.

c. Maintenance Recommendations

No maintenance, repair, and/or rehabilitation were planned for this demonstration project.

d. Maintenance History

No maintenance, repair, and/or rehabilitation were planned for this demonstration project.

III. Operation Activity

a. Operation Plan

There are no water control structures associated with this project that require manual operation; therefore, no Structural Operation Plan was required.

b. Actual Operations

No active operations were associated with this project.

IV. Monitoring Activity

a. Monitoring Goals

The goals of LA-0008 are to:
1. Reduce shoreline erosion behind the reef segments.
2. Determine which construction material (OysterKrete v Standard Weight Concrete) performs better towards reaching Goal 1.

The objectives of the Bioengineered Oyster Reef Demonstration project are:
1. Reduce wave transmission reaching the shoreline by 50%.
2. Provide habitat for oyster settlement.

b. Monitoring Elements

i. <u>Topographic and Bathymetric Surveys</u>

A series of topographic and bathymetric elevation surveys were conducted over time in the Oysterbreak area and the control area. Elevation changes of the Oysterbreaks, marsh, and water bodies both landward and seaward of the reef positions were tracked along survey transects perpendicular to the shoreline. Elevation data were collected at a minimum of 5 ft intervals to define distinct morphologic features. Transects start 100 ft landward from the averaged shoreline contour continuing into the Gulf of Mexico (Figure 4):

- 11 transects at the control area, 1,200 ft into the Gulf of Mexico on 200 ft spacing
- 24 transects the Oysterbreak area, 5 extending 2,000 ft into the Gulf of Mexico.

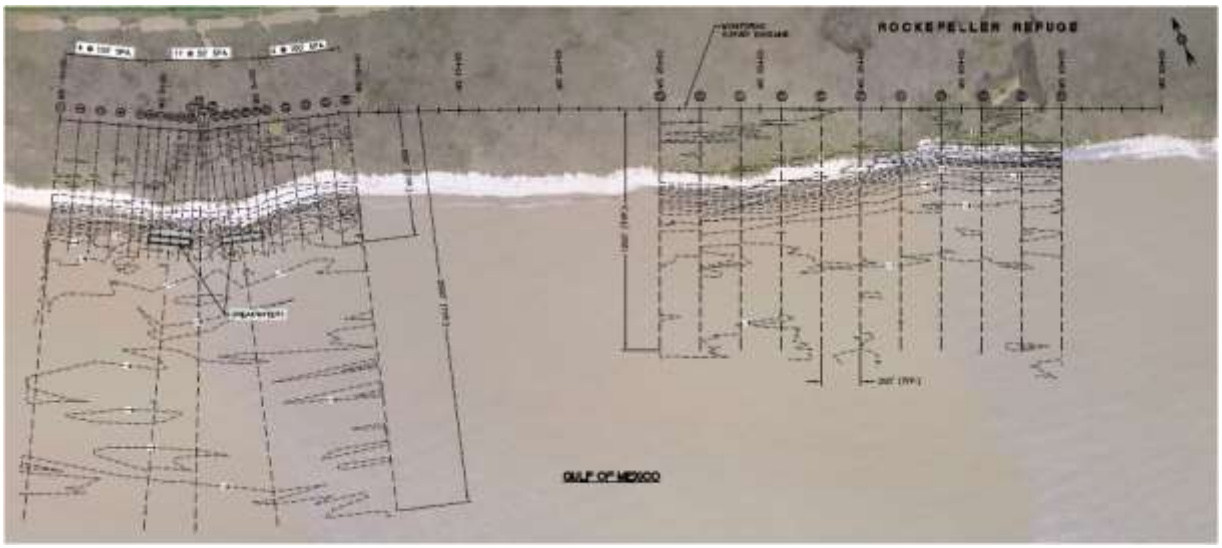


Figure 3. Approximate locations of topographic and bathymetric survey transects for the Bioengineered Oyster Reef Demonstration project (LA-0008). The aerial photography was taken on March 24, 2012.

Elevation surveys were conducted by survey contractors for preconstruction in October 2011, as-built in February 2012, and post construction Year 1 in July 2013, Year 2 in July 2014, and Year 4 in August 2016. The on land portion of three easternmost transects were not surveyed in Year 4. Survey report and drawings as deliverables from the contractors are available in Appendix#. Horizontal data was collected in the northing and easting coordinate set in Louisiana Stat Plane – South Zone NAD83; vertical (elevation) data was collected in feet NAVD88. The final survey was conducted in Geoid 12A for NAVD 88 elevations to be on the same plane as water level data collected at CRMS0600-H01. The contractor, T. Baker Smith, also converted the previous surveys to Geoid 12 A for elevation so that all of the surveys are on the same elevation plane. All of the previous surveys used 6.05 feet NAVD88 for the reference benchmark (ME18-SM-01) and a correction factor of -0.696 feet was applied to convert all elevation to Geoid 12A; see Section 4.3 of the 2016 elevation survey for more details (Appendix A). For use in ArcGIS (soil elevation changed dynamics and shoreline change), horizontal coordinates were converted to Universal Transverse Mercator (UTM) – Zone 15R in meters and vertical data were converted to meters NAVD88 Geoid12A.

Oysterbreak movement and water-level inundation

Elevations of the top row of rings on the landward and seaward edges of the structures presented in ft NAVD88, Geoid 12A, were gathered from survey report delineations and/or corresponding points on the survey transects mapped in ArcGIS for each time period and slopes were calculated. Elevations of the landward and seaward edges and slopes were averaged for each structure. The average structure elevations were plotted over time, and structure elevations and slope rates for each time period of interest were calculated to describe and compare vertical structure movement over the life of the project. Hourly water level elevations (ft NAVD88, Geoid 12A) from the nearest water level gauge open to Gulf of Mexico, CRMS0600-H01 (~17 miles west of LA-0008, a third of a mile up the mouth of Rollover Bayou), and structure crest elevations were plotted for the monitoring period, February 2012 through August 2016. Structure crest elevations were extrapolated between survey dates to calculate structure crest inundation/exposure percentages used in the Wave and Oyster Monitoring.

Soil elevation dynamics (elevation and volume change)

To assess soil elevation dynamics, elevations of the survey transects were uploaded to ArcGIS to construct elevation grids of each area for each survey date. Soil volume change over time was calculated from the differences in elevation grids between time periods of interest (between survey dates and overall, Preconstruction to Year 4) for each designated area. The inland to seaward extent of Oysterbreak and Control areas, 475 ft (144.8 m), was delineated by the inland most point of the Year 4 (August 2016) shoreline in the Control area to 50 ft (15.2 m) seaward of the structures. The width of the Oysterbreak area, 690 ft (210.3 m) was determined by adding half of the width of the gap between structures, 65 ft (19.8 m) to the outward ends of the structures; the width of the Control area was the western 1,000 ft (304.8 m) of the Control survey area. The Oysterbreak area was further subdivided into areas that focused on the middle 150 ft (45.7 m) of the structures and the 130 ft (39.6 m) wide gap between the structures; the middle of the structures was selected to minimize edge scour effects. Because of uncertainties involved with data conversions, more attention should be

paid to the data trends than the specific quantities. To standardize comparisons among different sized areas, soil volume change was calculated on a volume by area by time basis (m^3/ha). Cumulative soil volume change for each area was plotted over time. Soil elevation change for each time period was mapped in ArcGIS and soil volume change rate was calculated (m^3/ha/y) to standardize comparisons of different time increments.

Shoreline movement

To assess shoreline movement, a line feature was created in ArcGIS through the highest point along each survey lines to delineate the shoreline crest for each time period. Change rates for time intervals were calculated using Digital Shoreline Analysis System (DSAS) version 4.0, an ArcGIS application (Thieler et al. 2009). DSAS Transects spaced 5 m apart were established for the shoreline reaches, and change distance (m) and rates (m/y) were calculated between dates of interest for each transect. The DSAS transects were grouped by shoreline reaches of interest of the areas used for soil volume change: the Oysterbreak area, immediately behind the middle 150 feet of each Oysterbreak, the gap between the breaks, and the Control area. Cumulative shoreline movement for each shoreline reach calculated from the change distances was plotted over time. Shoreline movement along DSAS transects for each time period was mapped, and shoreline change rates were calculated for each area to standardize comparisons of different time increments.

ii. <u>Wave Attenuation</u>

The capacity of the Oysterbreak reef segments to dissipate waves was assessed by comparing wave transmission nearshore behind each Oysterbreak and from the control area.
Four gauges were deployed during to collect wave height data:

- 1 gauge seaward of the reef section at the -6 ft NAVD88 contour to measure incoming waves
- 1 gauge behind each Oysterbreak section (2 gauges) to measure broken waves
- 1 gauge in the control area to measure unbroken waves at a similar distance from the shoreline as the gauges behind the breaks.

Wave monitoring was conducted soon after construction in 2012 (07/08/2012 to 08/06/2012) and two years after construction in 2014 (04/10/2014 – 05/08/2014) (Table 1). Wave gauge deployment/retrieval, data collection, data processing, and preliminary data interpretation was conducted by T. Baker Smith, Inc. The gauges measured water level at frequency of 10Hz (10 times per second) for 20 minute "bursts" starting every half hour. The water levels are synthesized to derive an average water elevation (ft NAVD88, Geoid09), significant wave height (Hs, ft), and wave period (Tp, sec) for each 20 minute “burst”. See Appendix B – Wave Monitoring Reports for more details about the wave gauges, data collection, and data processing methodologies.

Processed data was analyzed and interpreted by the Coastal Protection and Restoration Authority of Louisiana - Lafayette Regional Office. Water level data collected in Geoid 09 was converted to Geiod 12A with a -0.46 feet correction. Wave data were initially screened by significant wave height (Hs) and water level (WL) of incoming waves to remove no wave

or suspect wave conditions; waves with Hs < 0.5 ft and WL < -0.5 ft NAVD88 Geoid12A at the seaward wave gage were omitted. Data from 2012 and 2014 were analyzed separately because of differences in sensor elevations (bottom of rod for wave staffs) (Table 1). A scatter plot of Hs for incoming (seaward) and nearshore (OysterKrete, Standard Weight, and Control) waves was plotted for each time period to compare overall relationships. The erosive energy of waves on the shoreline was quantified by the transmission coefficient (Kt) which is the proportion of Hs transmitted from a seaward point to a point near the shoreline: Kt = Hs nearshore / Hs offshore; the greater the value, the more wave height was transmitted. Kt for each nearshore location were grouped by water elevations and significant wave heights of the incoming waves in half-foot intervals and graphed for 2012 and 2014.

Table 2. Wave gage types and sensor elevations deployed at LA-0008 in summer 2012 and 2014. Sensor elevations were collected in Geoid 09 and converted to Geoid 12A by -0.46 ft. OBW and OBE are Oysterbreak – West and East, respectively.

Wave Gage			Sensor Elevation (ft, NAVD88, Geiod 12A)	
Location	TBS ID	Type	2012	2014
Offshore	P04	Pressure	-6.409	-5.985
Control	P03	Pressure	-2.070	-2.740
OBW	S02	Wave Staff	-0.998	-0.505
OBE	S01	Wave Staff	-1.021	-0.570

iii. <u>Oyster Monitoring</u>

Oyster and biological encrustation is monitored to (1) quantify the oyster settlement and colonization on the Oysterbreak segments and (2) compare OysterKrete against standard weight concrete in its ability to enhance settlement and colonization of oysters on the Oysterbreak reef segments. Three elements of oyster monitoring were conducted over the course of the project: oyster recruitment, biological accumulation, and oyster population density. Monitoring of oyster larvae (spat) recruitment to cylinders composed of the different ring materials and preliminary biological accumulation on rings was conducted form February 2012 – October 2013. The oyster recruitment monitoring was conducted by Dr. Earl Melancon of Nichols State University as a subcontractor to T. Baker Smith, Inc.; the full report is in Appendix C-i. Oyster colonization and population assessments of the Oysterbreaks were monitored from spring 2015 through winter 2016. The oyster recruitment monitoring was conducted by Dr. Earl Melancon through a contract with Nichols State University; the full report is in Appendix C-ii. Methods and results from the reports are summarized in this report.

Oyster recruitment and early colonization

The amount of oyster larvae (spat) and other organisms that attach to spat settlement surfaces (cylinders composed of the different concrete types used to construct the reef rings) were planned to be quantified in two sets over two years. The initial set of spat cylinders was deployed soon after the reef construction on April 19, 2012 and retrieved on March 13, 2013. Each spat cylinder composed of either OysterKrete or standard weight concrete was suspended vertically in a weighted cage with a standard spat plate attached to the underside of

the top of the cage. The cages were deployed on the gulf bottom around the perimeter of the Oysterbreaks. Unfortunately, the unprotected cages along the seaward edge and between the reefs were destroyed by gulf conditions prior to retrieval. Cages protected by the reef either settled into the gulf bottom or experienced varying amounts of sedimentation that affected the cylinders. The remaining cylinders were not suitable for density comparisons between the cylinder types; however, enough oysters were present for shell length frequency analysis which is used to interpret the timing of oyster recruitment by determining the modal length. The modal length is the peak size range within the size frequency histogram. The second set of oyster spat monitoring was deployed on March 13, 2013 and retrieved on October 28, 2013. Based on previous experience, the five cages were deployed only along the protected, landward side of the two reefs for a total of 10 cages. For additional weight, a pair of cylinders was placed vertically in each cage along with a pair of settlement plates attached to the underside of the top of the cage. Each cage was wedged between two bottom rings on the marine mattress and tethered to PVC pipe. Shell length frequency analyses were conducted for the spat plates and the cylinders to describe the recruitment trend. Oyster and barnacle density were compared between cylinder types.

Biological encrustation on the Oysterbreaks was sampled from the top layer of rings on March 13, 2013 and Oct 28, 2013 during low water levels. Two rows of rings, windward to leeward, were chosen to represent different elevations along each reef; five sample locations were randomly chosen on each row. Because the reefs were constructed at slightly different elevations, collecting comparable rows of rings representing tidal inundation was a challenge. Higher rows of rings were sampled on the lower, OysterKrete Oysterbreak than the higher standard weight Oysterbreak in an attempt to match water levels on each Oysterbreak; however, sampling was limited by water inundation throughout the day of sampling. Sampling consisted of scraping encrusted material within a $1/16^{th}$ m^2 quadrat off the top surface of a ring. Oysters shell lengths were measured to develop population shell length frequency for each Oysterbreak during both time periods to assess oyster growth. Overall biomass per row sampled for each Oysterbreak was determined from the March 2013 data set. Mean shell length and the shell size distribution by row for each Oysterbreak were calculated from the October 2013 data set.

Final oyster colonization

Oyster sampling consisted of scraping encrusted material within a 0.32 m^2 quadrat off the top surface of a ring; 83 quadrat samples were collected from the OBW-OysterKrete, and 85 quadrat samples were collected from the OBE-Standard Weight along with 6 samples collected from the bottom row on the leeward side of the OBE (row 8B8). Percent coverage and vertical height (distance above ring surface) was estimated from each quadrat prior to scraping. Oysters were scraped from the quadrat area and delivered to the laboratory for processing. The number of oysters was counted in each sample to determine oyster population densities. Oysters shell heights (distance from the hinge to the most distal linear edge of the shell) were measured to develop population shell length frequency for each Oysterbreak to assess oyster growth. The elevation (m NAVD88, Geoid 12A) on the ring surface of each quadrat location was surveyed.

c. Monitoring Results and Discussion

i. <u>Topographic and Bathymetric Elevation Dynamics</u>

Oysterbreak movement and water-level inundation

The planned crest elevation of the Oysterbreaks was 0.4 ft NAVD88, Geoid 12A (1.1 ft NAVD88 Geoid 03 used in planning) to match mean sea level of the Gulf of Mexico in this area during the planning phase of LA-0008; due to natural water bottom variability, however, the OysterKrete (OK) Oysterbreak to the West (OBW) was constructed to an average crest of 0.35±0.12 ft NAVD88 while the Standard Weight (SW) Oysterbreak – East (OBE) was constructed to a higher average crest of 0.82±0.67 ft NAVD88. The OBW was more uniform in elevation and had a flatter slope (0.041 ft/ft) when constructed. The OBE was less uniform in elevation as the eastern side was lower than the western side; it also had a sharper landward to seaward slope (0.045 ft/ft) when constructed (Figs. 4 and 5). From the end of construction in February 2012 to August 2016, the Oysterbreak structures settled ~0.20 ft (0.04 ft/yr), overall, which is within the range of error within and between elevation surveys. The landward edge of the OBW settled the least, 0.12 ft, while seaward edge of the OBW settled 0.24 ft as the west side settled half as much as the east side. The landward edge of the OBE settled 0.20 ft while the seaward edge of the OBE settled 0.24 feet. The landward edge of OBE settled more on the higher, west side (0.24 ft) than the lower, east side (0.10 ft). The seaward edges of both Oysterbreaks, which receive the waves, settled more than the landward edges, overall; and, the seaward edges settled more on the gap end of the Oysterbreaks which were also initially constructed higher (Fig. 4).

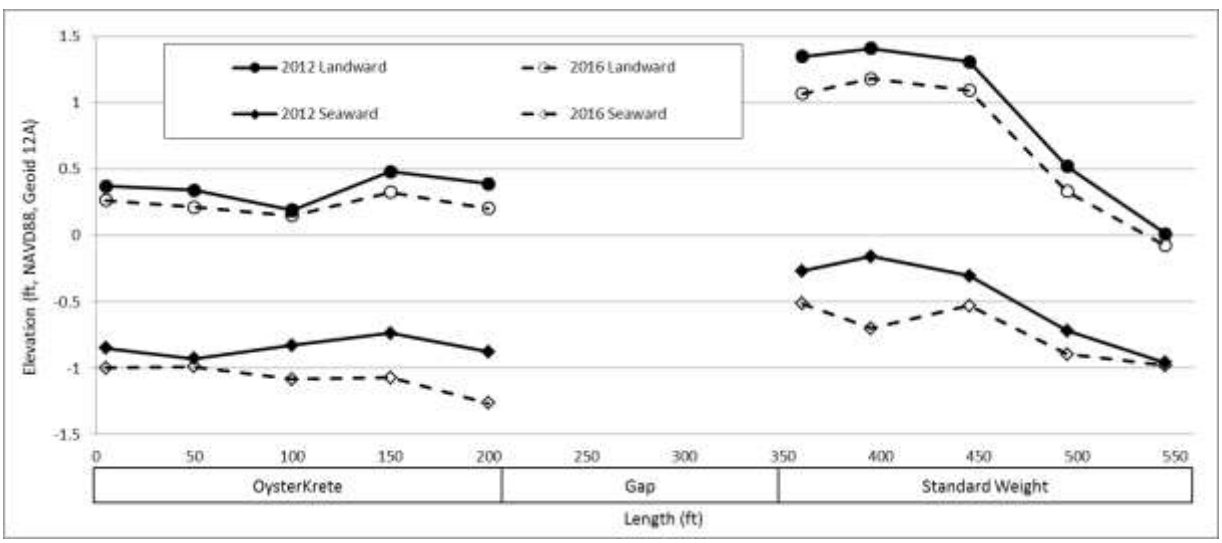


Figure 4. Elevation profiles of the top row of rings along the landward and seaward edges were surveyed for As-built construction in February 2012 and 4.5 years post construction in August 2016. Elevations were plotted to demonstrate the shapeliness of the Oysterbreaks and amount of settling. Note difference in axes scales.

Figure 5. A series of Google Earth images from an "eye altitude" of 550 feet compiled from 2010 – 2017 shows changes before and after LA-0008 Oysterbreak installation. Note the elevation difference between Oysterbreak - West composed of OysterKrete© (lower) and Oysterbreak - East composed of standard weight concrete (taller) based on relative water levels. Also, note the changes in the tombolo behind Oysterbreak - East that formed during construction in January 2012.

The difference between crest elevations (0.47 ft) causes water inundation differences between the Oysterbreaks, especially when the crest elevations are close to average sea level (Fig. 5). Over the project life, the mean water elevation at CRMS0600 was 0.73 ft NAVD88 Geoid 12A. CRMS0600 is the closest water level gauge to LA-0008 that is open to the Gulf of Mexico, but it is about 0.25 miles up a bayou; therefore, water levels are typically a little higher in the marsh drainage than in the Gulf. Based on CRMS0600, the OBW (OysterKrete) was completely submerged 72.7% of the time while the east OBE (Standard Weight) was completely submerged 56.8% of the time (Fig. 6). The Oysterbreaks only settled ~0.20 feet over the 4.5 year monitoring period (0.04 ft/yr); the OBE settled 26% more than the OBW

because the higher, OBE was above the water 58% more time than the OBW and less buoyant.

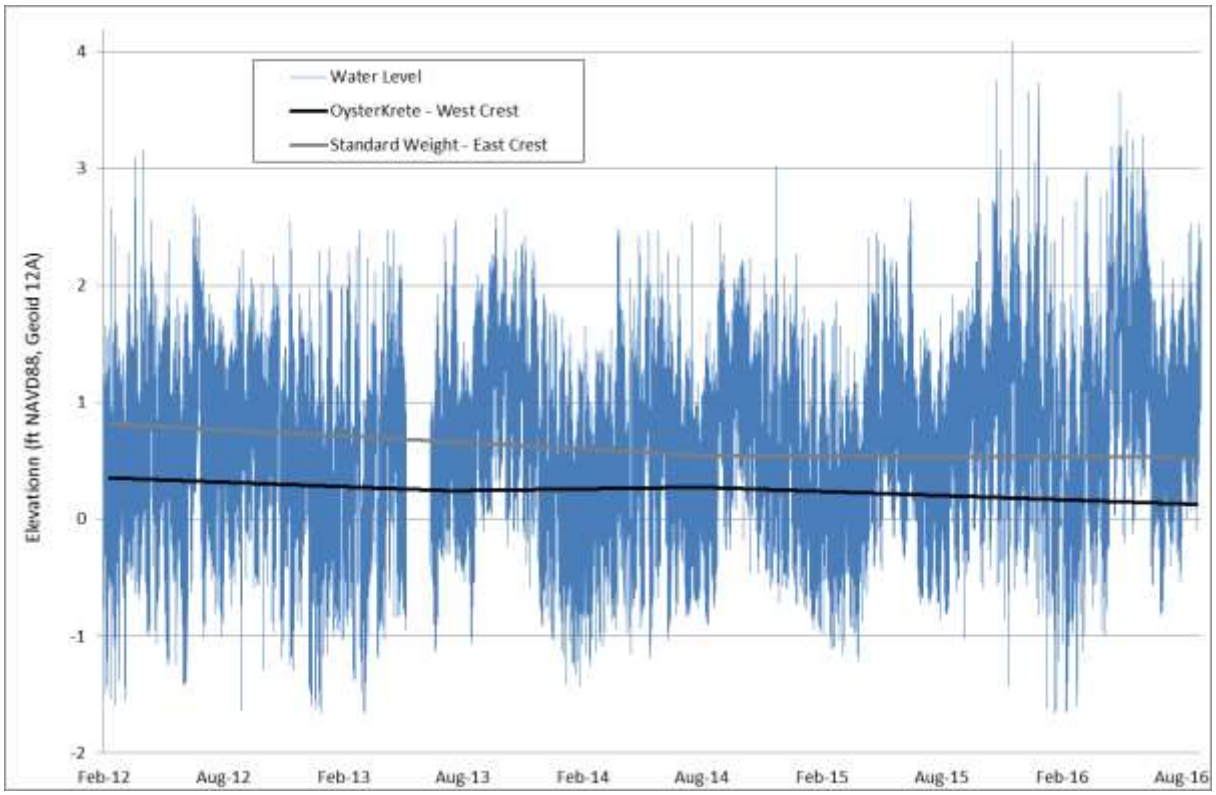


Figure 6. Water elevation collected from nearby CRMS0600-H01 and crest elevations of the West-OysterKrete and East-Standard Weight Oysterbreaks over the LA-0008 monitoring period. Note the difference in crest elevations and the corresponding difference in water inundation between the Oysterbreaks.

Soil elevation dynamics (elevation and volume change)

Cumulative soil volume change on an area basis (m^3/ha) was plotted over time to compare the Oysterbreak area to the Control area and compare sections within the Oysterbreak area (the structures and the gap) (Fig. 7). Soil surface elevation change was mapped and soil volume change was calculated overall from the preconstruction survey conducted in October 2011 through 4.5 years post construction in August 2016 (Fig. 8) and incrementally (Figs. 9-12). Preconstruction was included because a tombolo formed behind the OBE (Standard Weight) during the construction period. From 6 months preconstruction to 4.5 years after construction, the Oysterbreaks reduced soil loss by 43% relative to the Control area (Figs. 7 and 8). The Oysterbreaks reduced soil loss by ~60% through 2.5 years after construction (Figs 5, 7, 9-11), but the adjacent soil loss overwhelmed the small Oysterbreak area (560 linear feet) as more water current was able to flow behind the protruding structures (Figs. 5, 7 and 12). Within the Oysterbreak area, the OBE (Standard Weight) lost 17% less soil than the OBW (OysterKrete) (Figs. 7 and 8). The OBE was aided by the tombolo for the first couple of years (Figs. 5, 7, 10, and 11) but had the greatest volume loss of all areas during the final time increment (Figs. 5, 7 and 12). The gap between the Oysterbreak structures had similar soil volume loss as the

Control area throughout the life of the project despite the assumed protection by the structures.

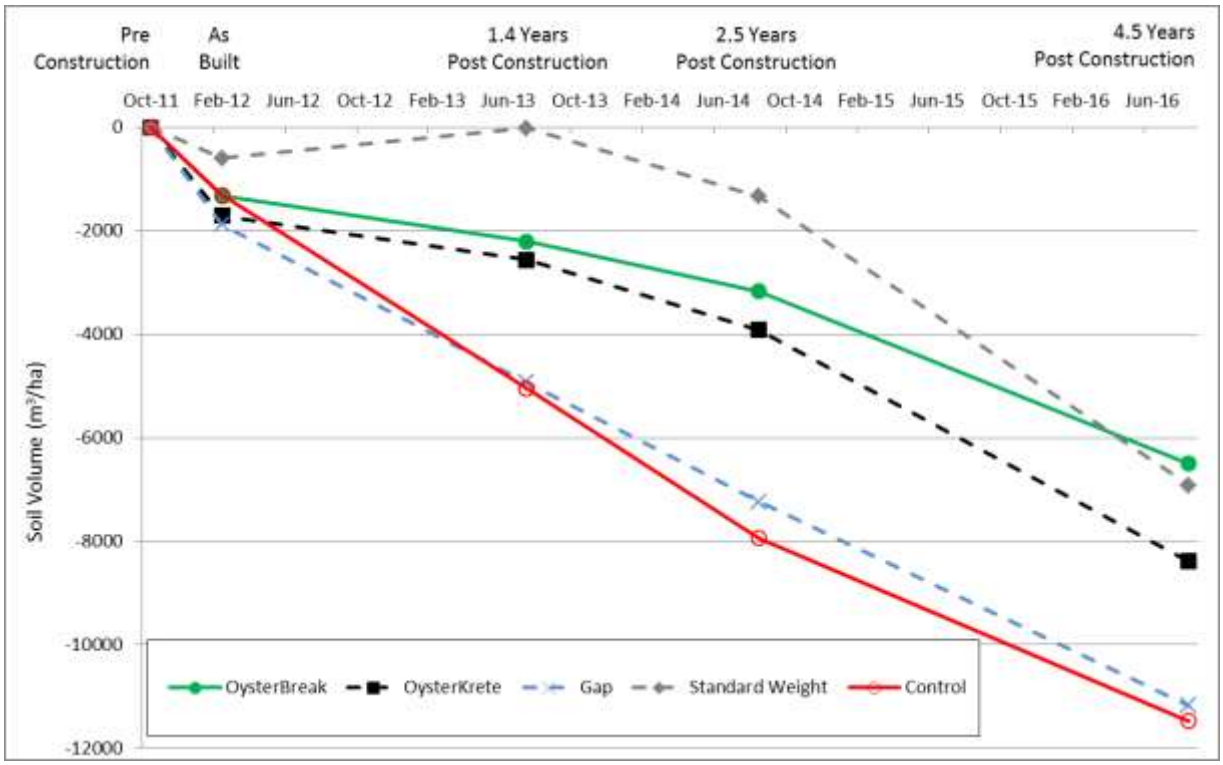


Figure 7. Cumulative soil volume change plotted from preconstruction (Oct 2011) to 4.5 years after construction (Aug 2016) in the LA-0008 Bio-engineered Oyster Reef Demonstration (LA-0008) project areas. The solid lines represent the overall comparison of the Oysterbreak to the Control area, and the dashed lines represent subareas within the Oysterbreak area: OysterKrete Oysterbreak – West, Gap, and Standard Weight Oysterbreak – East.

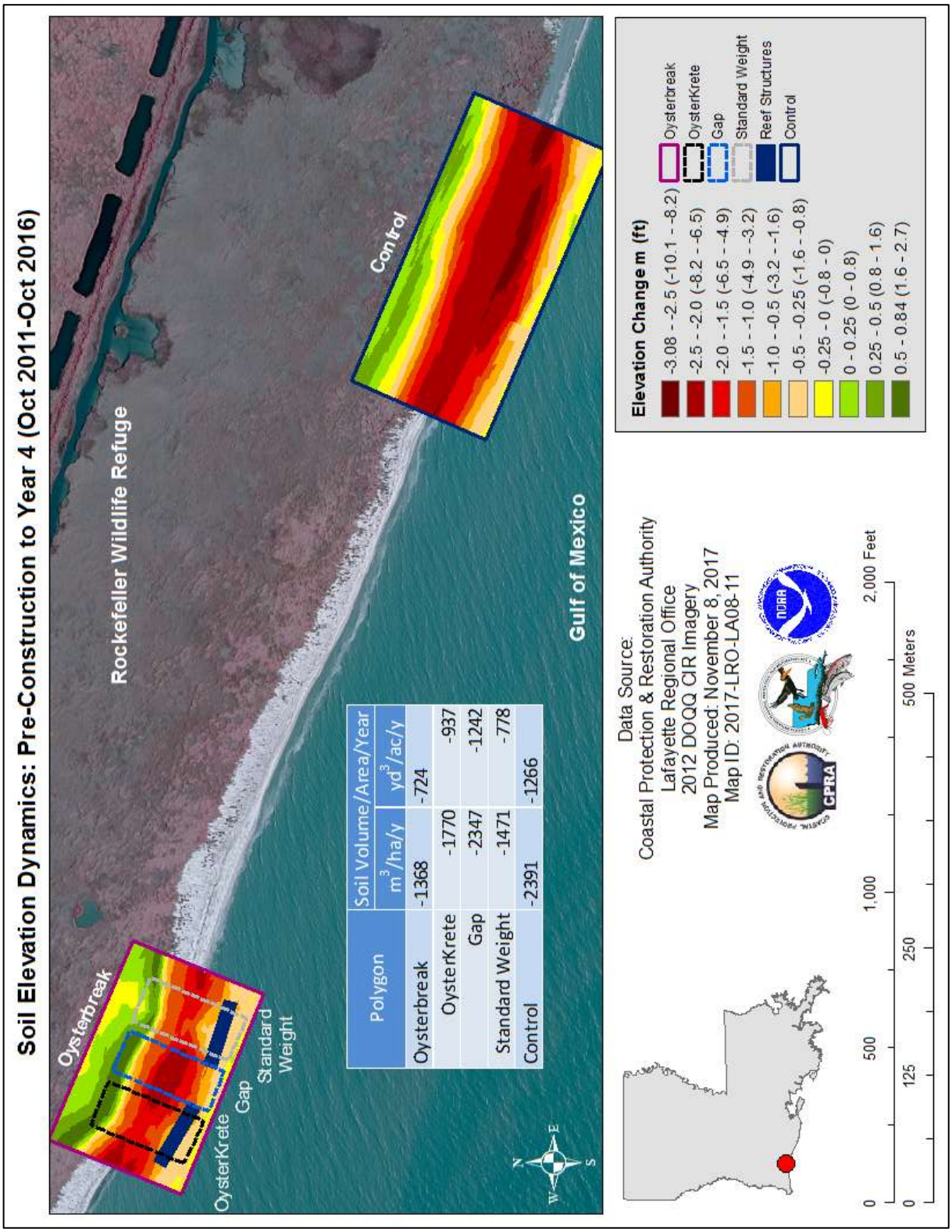
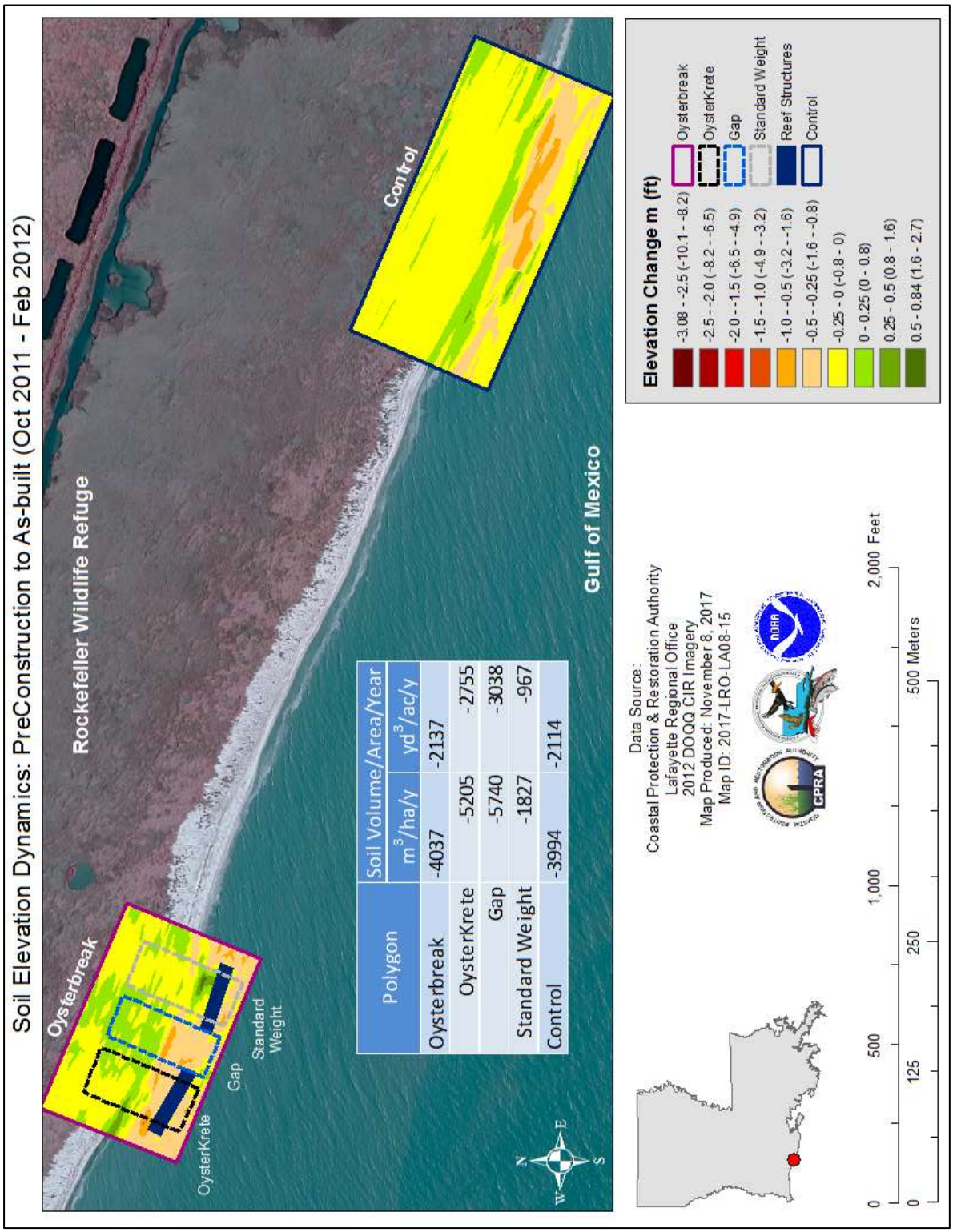


Figure 8. Soil elevation change was mapped and soil volume change calculated in the Oysterbreak and Control areas of the Bio-engineered Oyster Reef Demonstration Project (LA-0008) from preconstruction (October 2011) to 4.5 years after construction (August 2016).



Polygon	Soil Volume/Area/Year	
	$m^3/ha/y$	$yd^3/ac/y$
Oysterbreak	-4037	-2137
OysterKrete	-5205	-2755
Gap	-5740	-3038
Standard Weight	-1827	-967
Control	-3994	-2114

Figure 9. Soil elevation change was mapped and soil volume change calculated in the Oysterbreak and Control areas of the Bio-engineered Oyster Reef Demonstration Project (LA-0008) from preconstruction (October 2011) to end of construction (February 2012). Soil volume change values were extrapolated 6 months of data and may be overestimated.

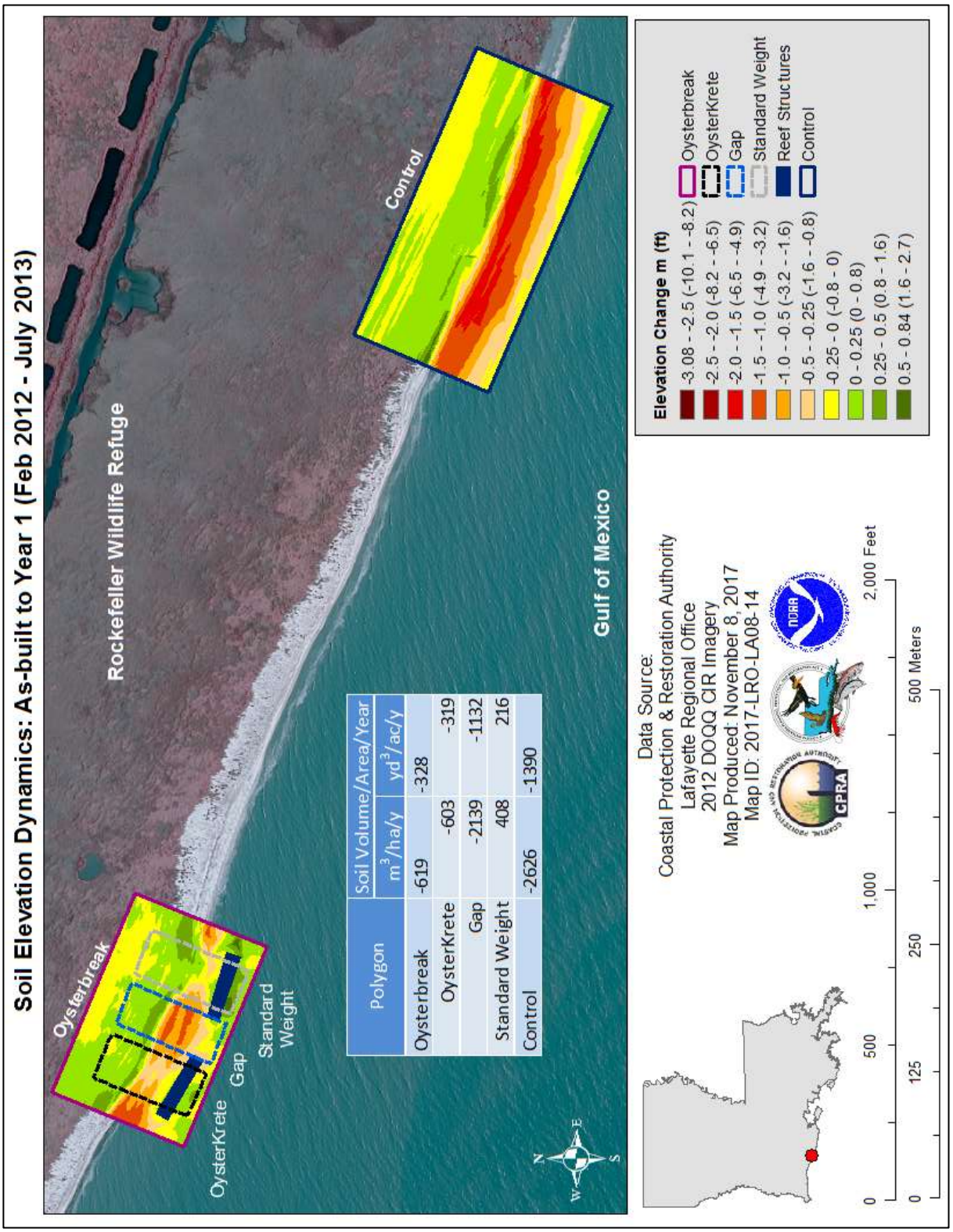


Figure 10. Soil elevation change was mapped and soil volume change calculated in the Oysterbreak and Control areas of the Bio-engineered Oyster Reef Demonstration Project (LA-0008) from end of construction (February 2012) to 1.4 years after construction (July 2013).

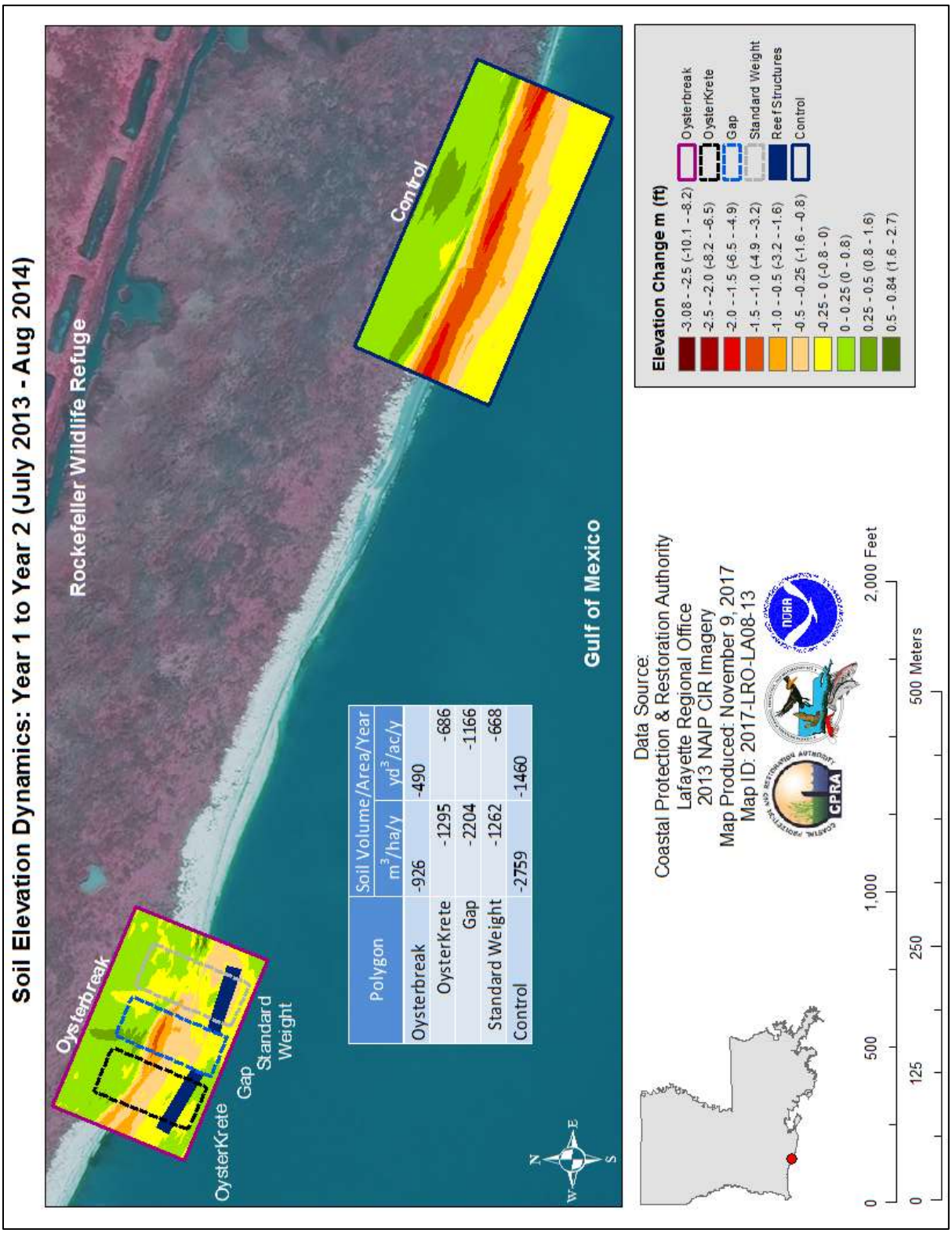


Figure 11. Soil elevation change was mapped and soil volume change calculated in the Oysterbreak and Control areas of the Bio-engineered Oyster Reef Demonstration Project (LA-0008) from 1.4 years (July 2013) to 2.5 years (August 2014) after construction.

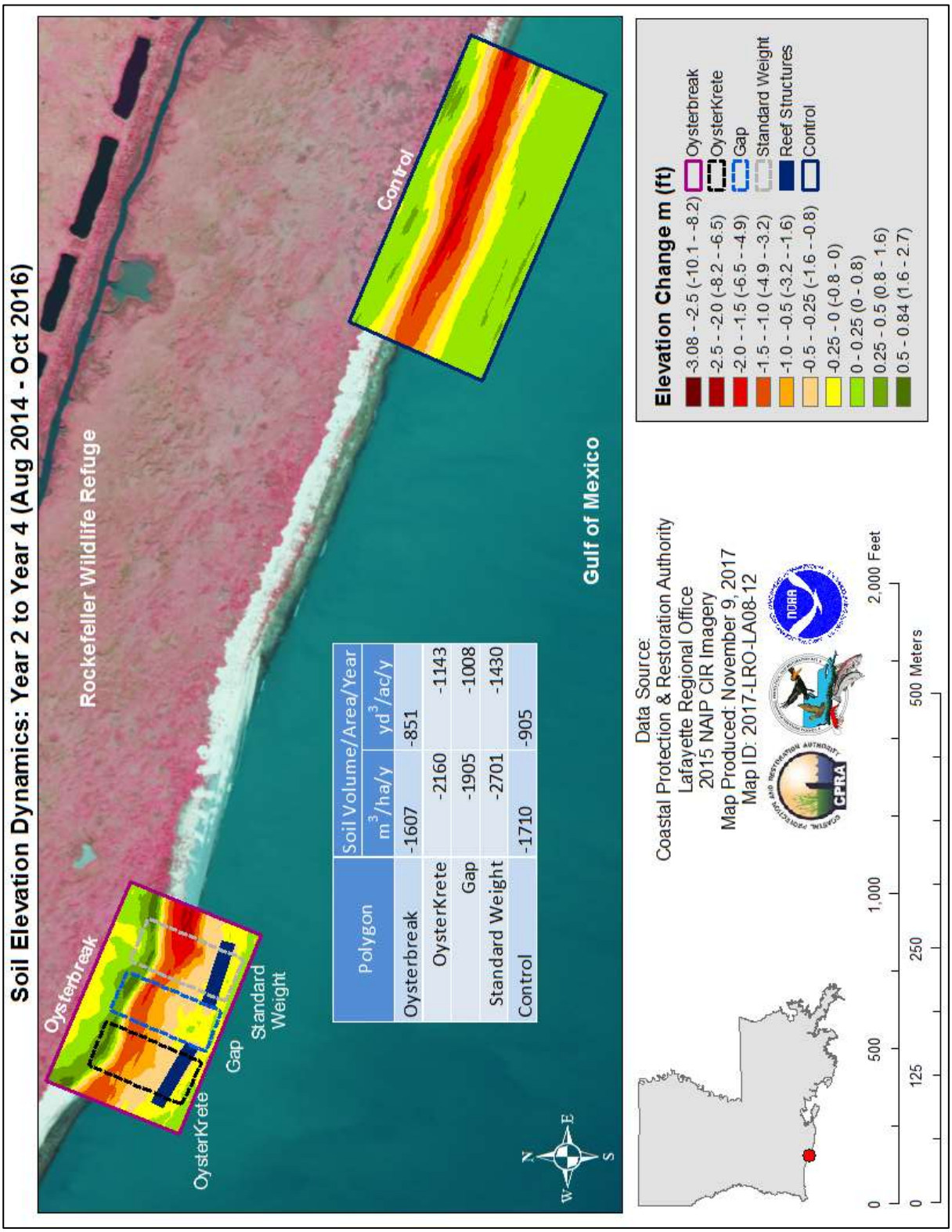


Figure 12. Soil elevation change was mapped and soil volume change calculated in the Oysterbreak and Control areas of the Bio-engineered Oyster Reef Demonstration Project (LA-0008) from 2.5 years (August 2014) to 4.5 years (August 2014) after construction.

Shoreline movement

Cumulative shoreline change was plotted over time to compare the Oysterbreak area to the Control area and compare sections within the Oysterbreak area (the structures and the gap) (Fig. 13). Shorelines were mapped and change rates were calculated from the preconstruction survey conducted in October 2011 through 4.5 years post construction in August 2016 (Fig. 14) and incrementally (Figs. 15-18). Preconstruction was included because a tombolo formed behind the OBE-Standard Weight during the construction period. From 6 months preconstruction to 4.5 years after construction, the Oysterbreaks reduced soil loss by 53% relative to the Control area (Figs. 13 and 14). The Oysterbreaks reduced shoreline loss by ~73% through 2.5 years after construction (Figs. 13, 15-17), but the adjacent shoreline loss overwhelmed the small Oysterbreak area (560 linear feet) as more water current was able to flow behind the protruding structures (Figs. 5, 13 and 18). Within the Oysterbreak area, shoreline loss behind the OBE-Standard Weight ended up similar to that of the OBW-OysterKrete (Figs. 13 and 14). Aided by the tombolo, shoreline loss was 54% less behind the OBE than the OBW for the first couple of years (Figs. 5, 13, 16, 17), but shoreline loss was greater behind the OBE during the final time increment as the tombolo washed away and may have been distributed along shorelines behind the OBW and gap (Figs. 5, 13, 18). Although greater shoreline loss occurred along the gap, shoreline loss there was more similar to the rest of the Oysterbreak area than the Control, unlike the soil volume change.

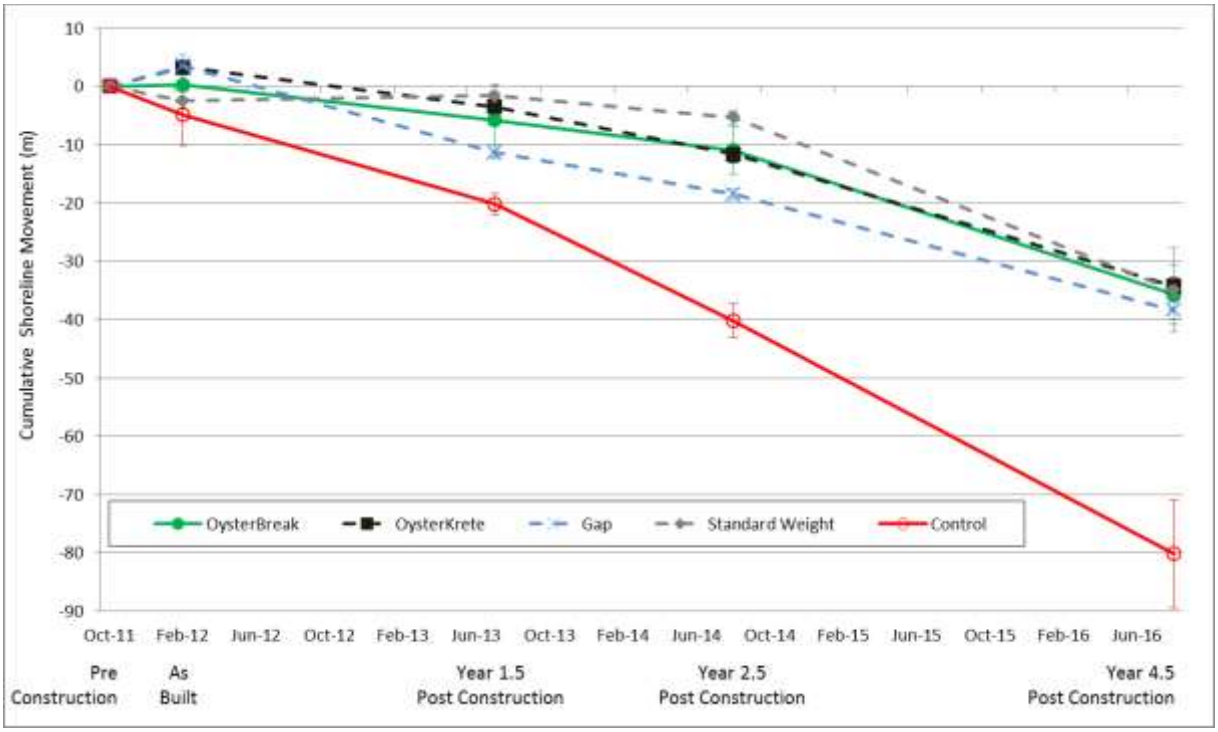


Figure 13. Cumulative shoreline change in the Bio-engineered Oyster Reef Demonstration Project (LA-0008) was plotted from six months preconstruction (October 2011) to 4.5 years after construction (August 2016). The OysterKrete, Gap between structures, and Standard Weight are within the Oysterbreak area.

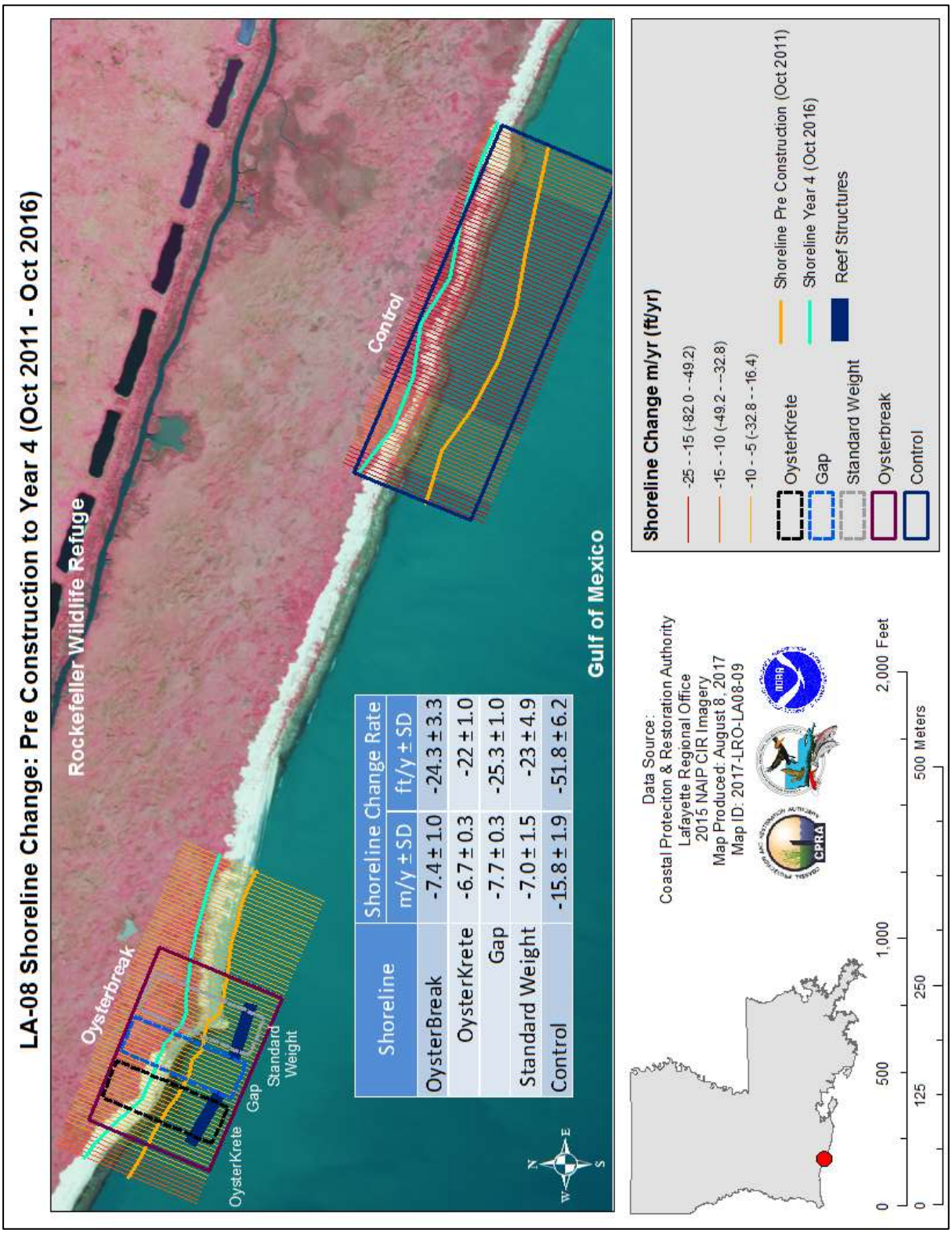
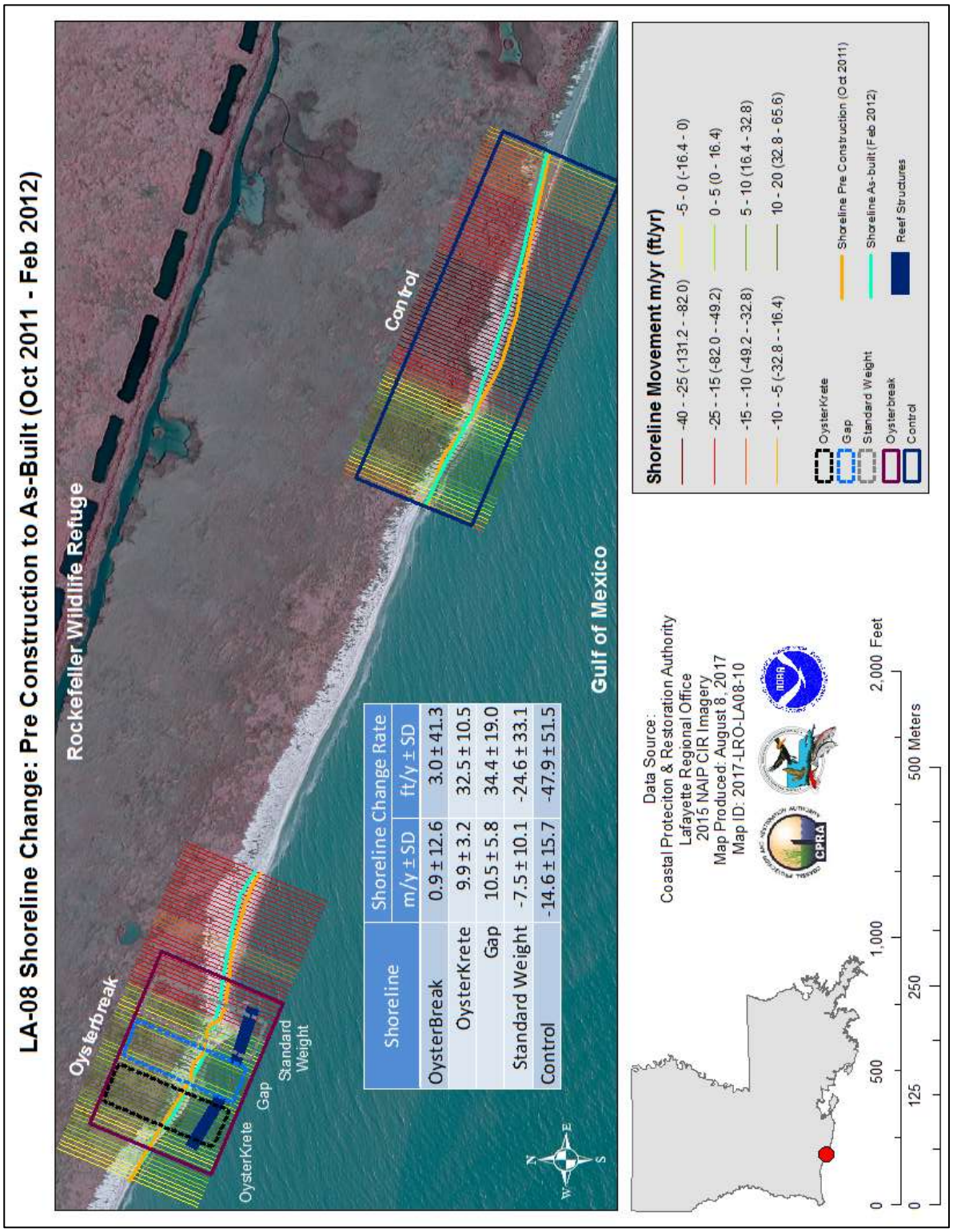


Figure 14. Shorelines were mapped and shoreline change calculated in the Oysterbreak and Control areas of the Bio-engineered Oyster Reef Demonstration Project (LA-0008) from preconstruction (October 2011) to 4.5 years after construction (August 2016).



Shoreline	Shoreline Change Rate	
	m/y ± SD	ft/y ± SD
OysterBreak	0.9 ± 12.6	3.0 ± 41.3
OysterKrete	9.9 ± 3.2	32.5 ± 10.5
Gap	10.5 ± 5.8	34.4 ± 19.0
Standard Weight	-7.5 ± 10.1	-24.6 ± 33.1
Control	-14.6 ± 15.7	-47.9 ± 51.5

Figure 15. Shorelines were mapped and shoreline change calculated in the Oysterbreak and Control areas of the Bio-engineered Oyster Reef Demonstration Project (LA-0008) from preconstruction (October 2011) to end of construction (February 2012). Soil volume change values were extrapolated 6 months of data and may be overestimated.

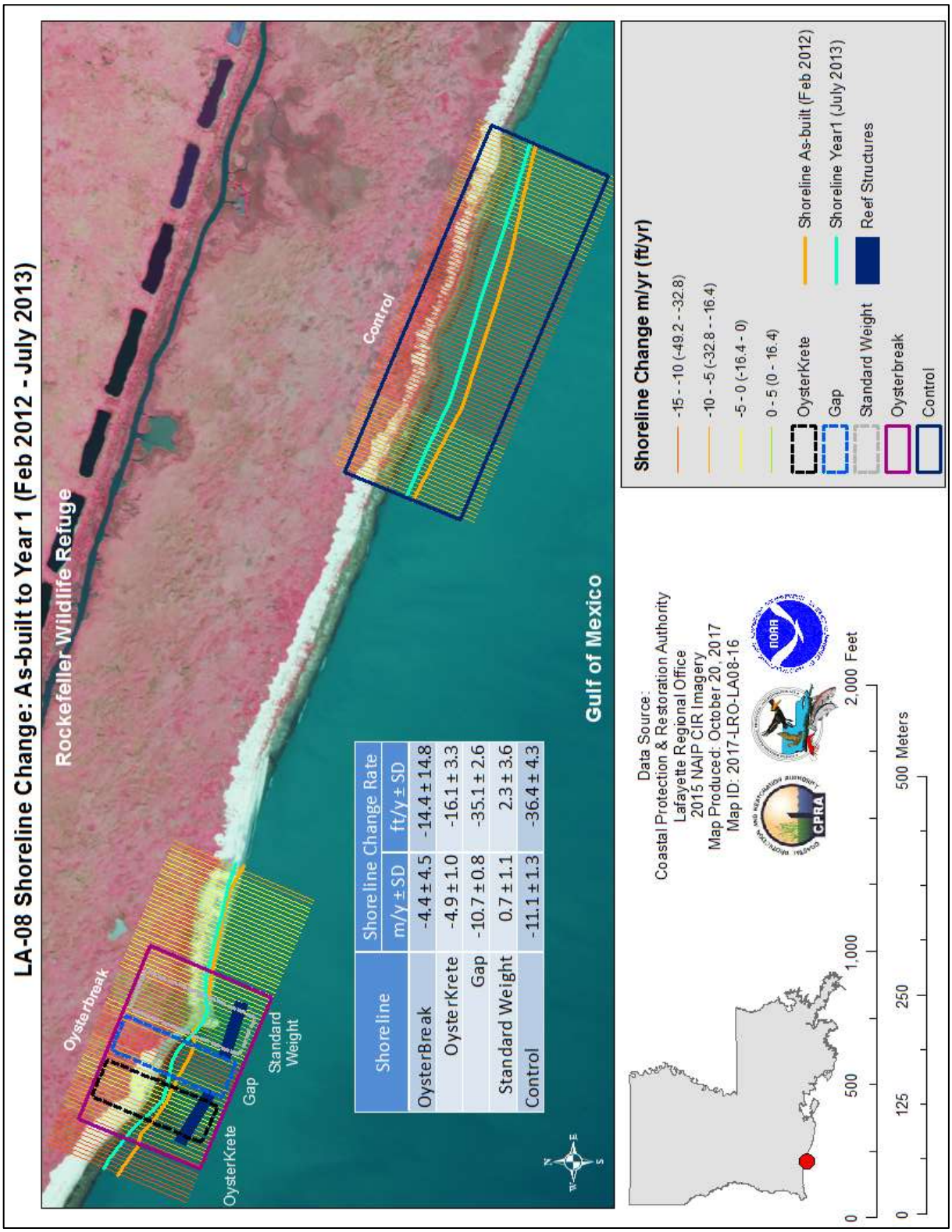


Figure 16. Soil elevation change was mapped and soil volume change calculated in the Oysterbreak and Control areas of the Bio-engineered Oyster Reef Demonstration Project (LA-0008) from end of construction (February 2012) to 1.4 years after construction (July 2013).

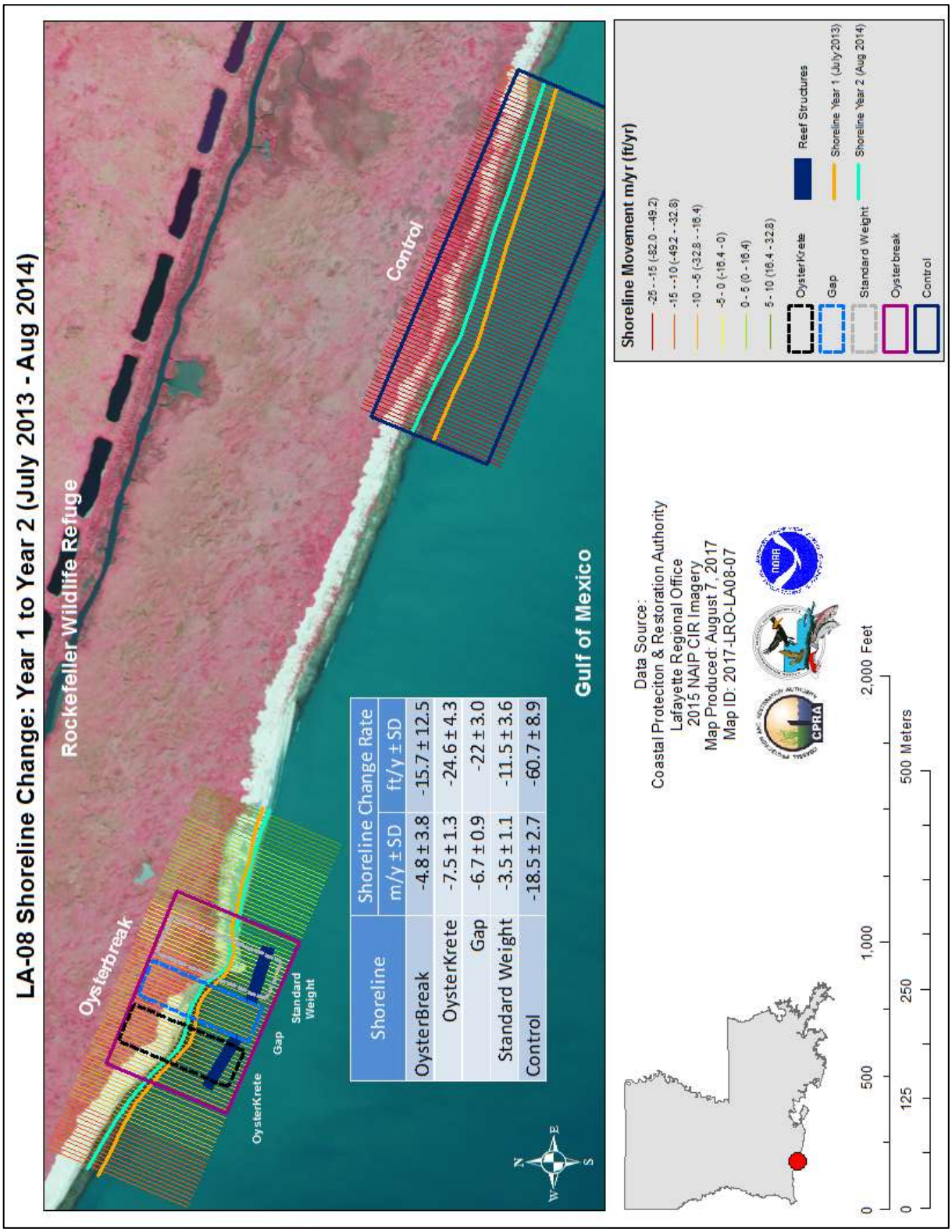


Figure 17. Shorelines were mapped and shoreline change calculated in the Oysterbreak and Control areas of the Bio-engineered Oyster Reef Demonstration Project (LA-0008) from 1.4 years (July 2013) to 2.5 years (August 2014) after construction.

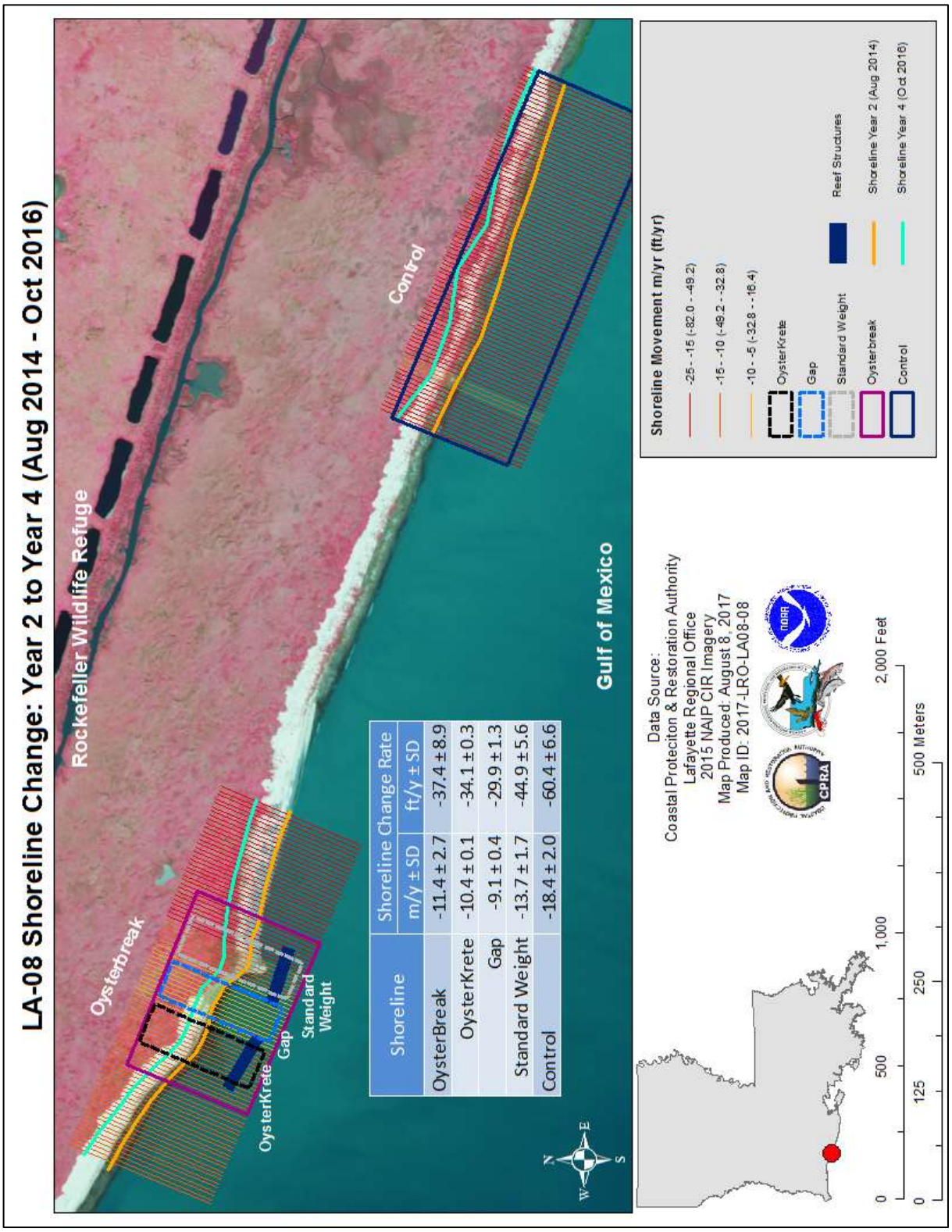


Figure 18. Shorelines were mapped and shoreline change calculated in the Oysterbreak and Control areas of the Bio-engineered Oyster Reef Demonstration Project (LA-0008) from 2.5 years (August 2014) to 4.5 years (August 2014) after construction.

ii. Wave Attenuation

The Oysterbreaks reduced wave heights from incoming waves compared to the Control in 2012 and 2014. Sensor elevations were 0.67 ft deeper at the Control in 2014 than 2012 and averaged 0.47 ft shallower at the Oysterbreak structures in 2014 than 2012 (Table 1); therefore, the 2012 and 2014 are presented separately although they have the same general patterns (Figs. 19 and 20). Overall in 2012, nearshore waves relative to offshore waves were reduced 30.6% as they approached the Control shore (natural bottom slope), 53.1% behind OBW (OysterKrete), and 67.9% behind OBE (Standard Weight). The difference in wave reduction between the Oysterbreaks is attributed to the crest height difference between the lower OBW and the higher OBE (Figs. 4-6).

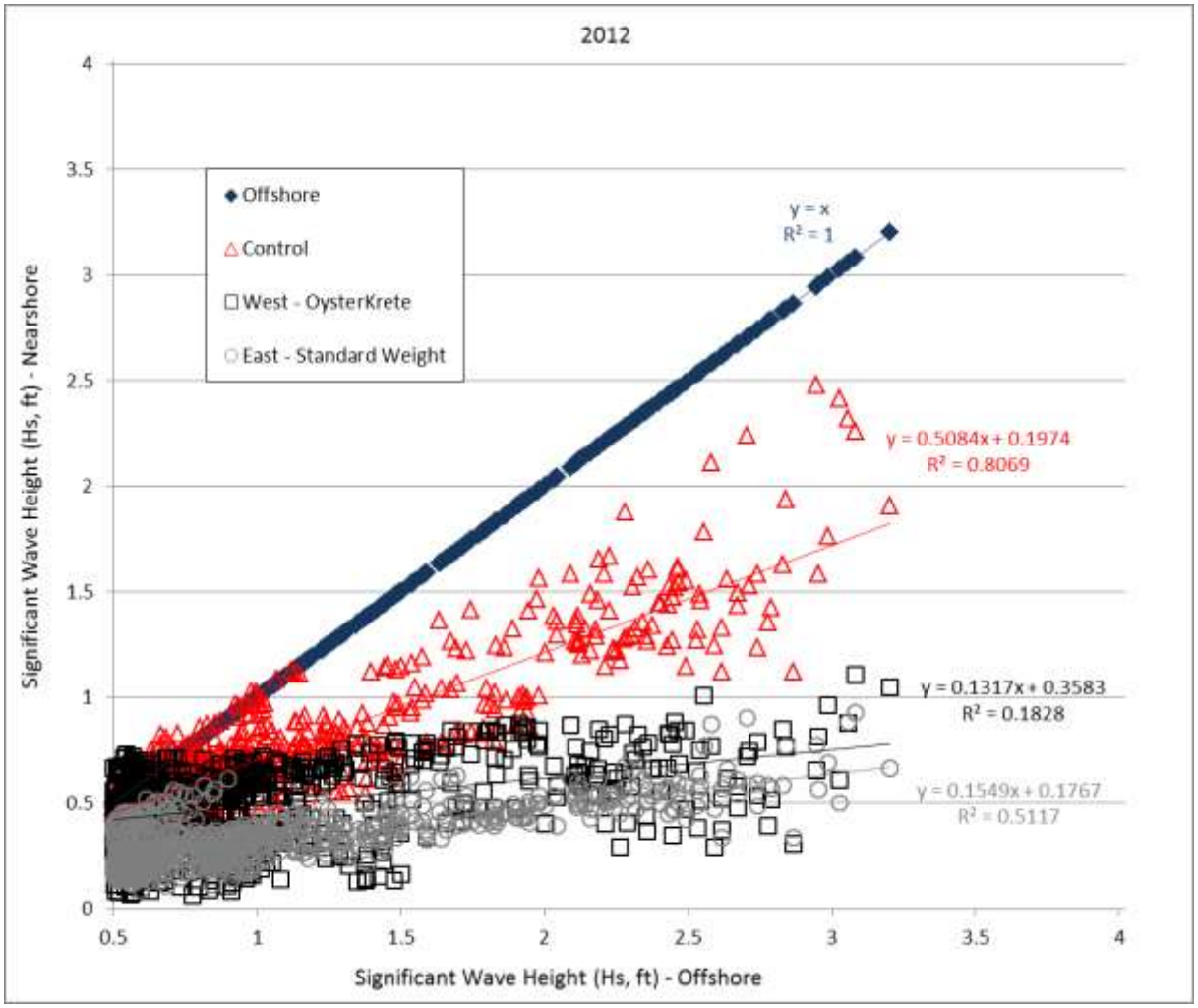


Figure 19. Significant wave heights (Hs) were recorded July 08, 2012 – August 06, 2012 from wave gauges deployed within the LA-0008 area soon after Oysterbreak construction. The offshore gauge measured the incoming waves (blue) while gauges behind the lower West and higher East Oysterbreaks and the Control measured waves remaining near the shoreline. Axes range was based on 2014 data for comparability (Fig. 20).

In 2014, nearshore waves relative to offshore waves were reduced 5.1% as they approached the Control shore (natural bottom slope), 61.7% behind OBW (OysterKrete), and 76.9% behind OBE (Standard Weight) (Fig. 20). The difference in wave reduction between the Oysterbreaks is attributed to the crest height difference between the lower OBW and the higher OBE (Figs. 4-6). The decline of wave reduction at the Control and the improvements behind the Oysterbreaks between 2012 and 2014 are attributed to differences in sensor elevations and larger waves coming from offshore in 2014 (mean Hs = 1.65 ft; max Hs = 4.01 ft) than in 2012 (mean Hs = 1.06; max = 3.20 ft). Settlement of the Oysterbreaks was minor (Fig. 6) and would have resulted in less wave reduction. Oyster colonization on the Oystebreaks was also minimal (See Oyster Monitoring below) and is not expected to have been a factor.

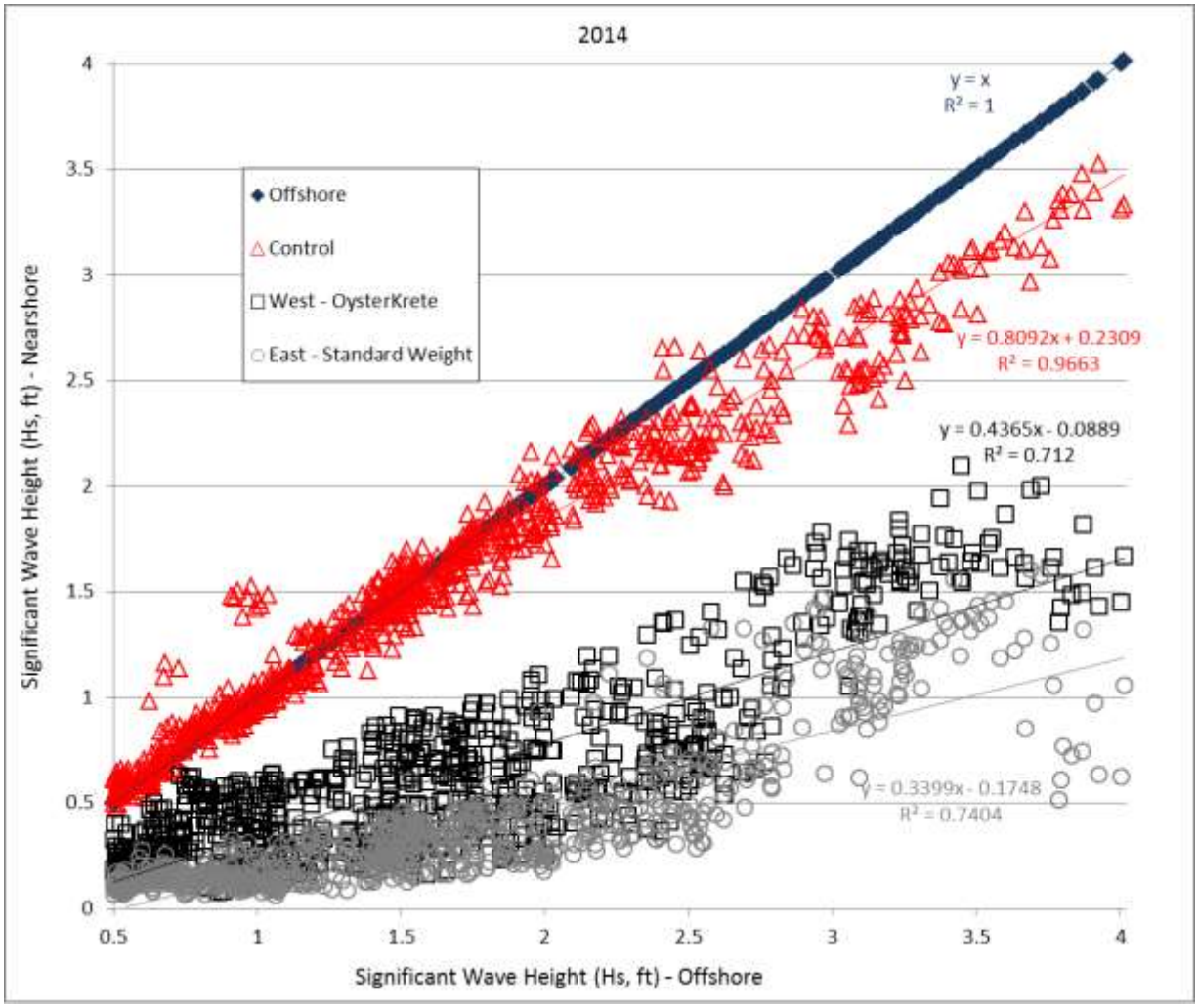


Figure 20. Significant wave heights were recorded April 10, 2014 – May 08, 2014 from wave gauges deployed within the LA-0008 area ~2 years after Oysterbreak construction. The offshore gauge measured the incoming waves (blue) while gauges behind the lower West and higher East Oysterbreaks and the Control measured waves remaining near the shoreline.

The proportion of wave height arriving to the nearshore location from an incoming wave, commonly referred to as the Wave Transmission Coefficient (Kt), is a standard metric to describe wave breaking; Kt < 1 indicates the wave height has decreased whereas Kt >1 indicates that wave heights have increased from offshore. Nearshore wave heights are determined by water level, incoming Hs, and the water bottom surface dictated by the natural slope of the Control and different crest elevations of the Oysterbreaks. For display purposes, the data are grouped by Hs within water levels of the incoming (offshore) waves in roughly 0.5 ft increments, and Kt is presented for the Control, Oysterbreak - West (OysterKrete), and Oysterbreak - East (Standard Weight). Data from 2012 and 2014 are presented separately (Figs. 21 and 22); although they follow the same general patterns, the 2014 data had different sensor elevations and a larger wave set discussed earlier. In the lower water levels (< 0 ft NAVD88, Geoid 12A), waves are reduced more by the Oysterbreak - West; waves disperse while going over and through the lower, less sloped Oysterbreak - East that is partially submerged at these water levels rather than deflecting around the taller, higher sloped Oysterbreak - East that is exposed at these water levels. When water levels partially submerged both Oysterbreaks (0 – 0.5 ft NAVD88), Kt is reduced similarly at both Oysterbreaks (Figs 21 and 22 A). During more typical water levels (0.5 -2.0 ft NAVD88), Kt is reduced more by the taller Oysterbreak - East; the difference in Kt lessens as the wave heights increase and overtop both Oysterbreaks (Figs 21 and 22). When both Oysterbreaks are substantially overtopped by water level (+2 ft NAVD88), both Oysterbreaks less effectively reduce Kt, but Kt is slightly more reduced by the Oysterbreak - East than Oysterbreak - West (Fig. 22 B).

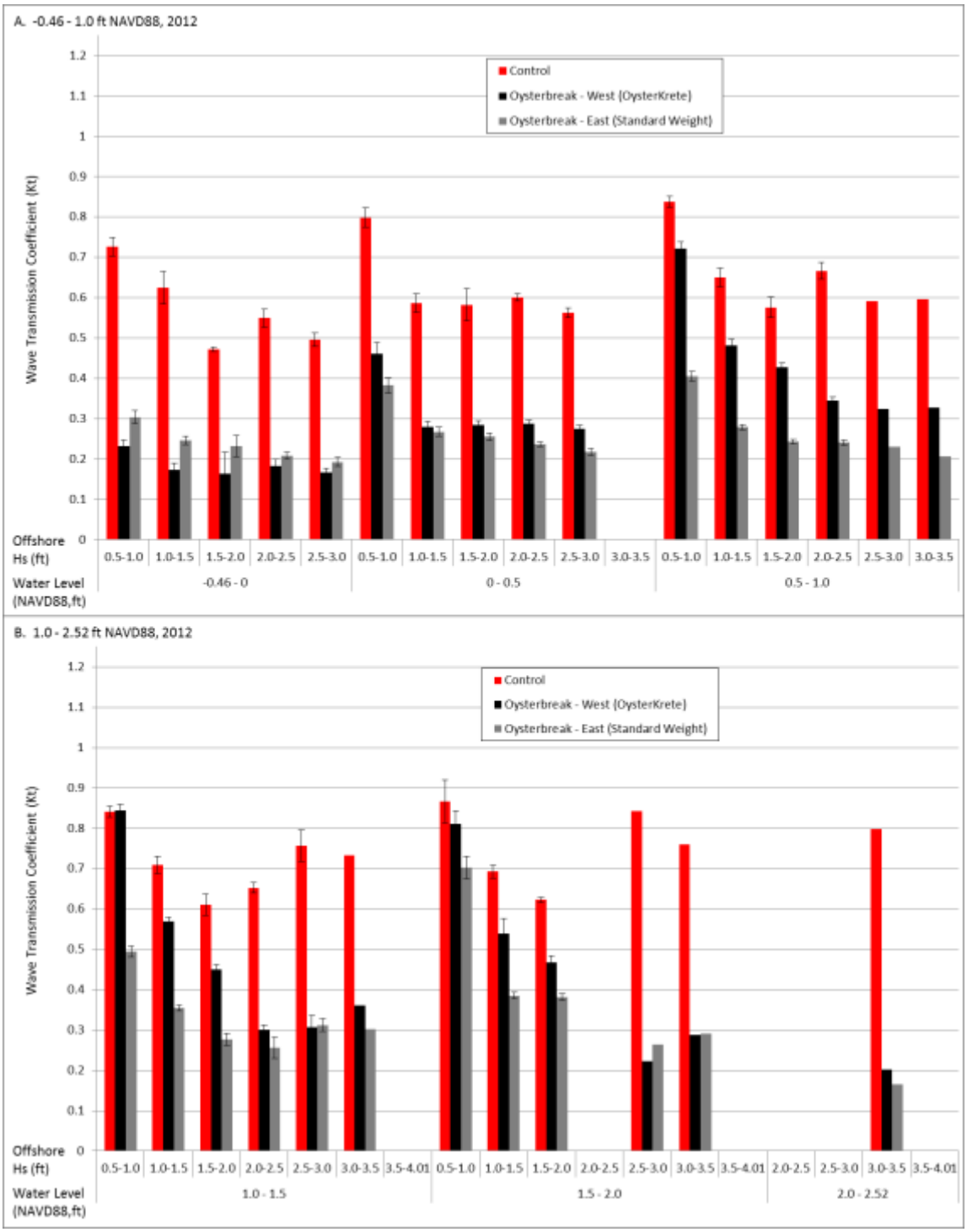


Figure 21. Wave transmission coefficients (Kt) collected in 2012 are grouped by incoming wave heights (Hs) within water level ranges in 0.5 ft increments. The bars represent different water bottom condition near the shoreline: the Control has a natural slope; Oysterbreak -West is lower and less steep; Oysterbreak - East is higher and steeper. The values are means and standard errors. Lower Kt values indicate more wave attenuation (reduction). The Offshore Hs of the x-axis matches the 2014 graph (Fig. 22) for comparability.

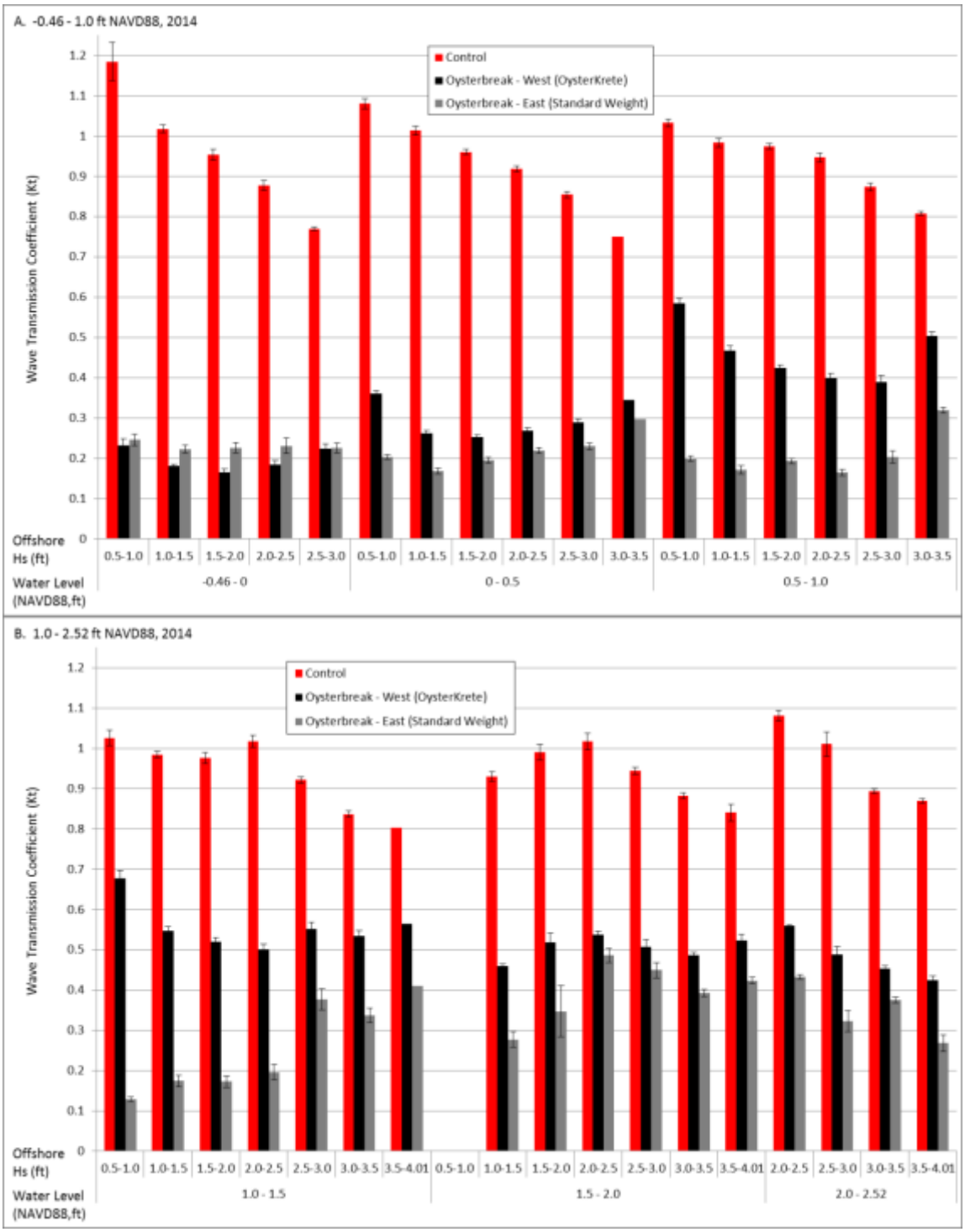


Figure 22. Wave transmission coefficients (Kt) collected in 2014 are grouped by incoming wave heights (Hs) within water level ranges in 0.5 ft increments. The bars represent different water bottom condition near the shoreline: the Control has a natural slope; Oysterbreak - West is lower and less steep; Oysterbreak - East is higher and more steep. The values are means and standard errors. Lower Kt values indicate more wave attenuation (reduction). The range of the y-axis matches the 2012 graph (Fig. 21) for comparability.

iii. Oyster Monitoring

The following results and discussion were extracted from oyster monitoring reports led by Dr. Earl Melancon contracted through T. Baker Smith, Inc, and Nicholls State University. See the reports (Appendix C) for a complete presentation of results. The following is a summary therein pertinent to the performance of the Oysterbreak overall each ring material type as oyster habitat in this Gulf exposed environment. Note that Oysterbreak – West (OBW) will be referred to as OysterKrete (OK) and Oysterbreak – East (OBE) will be referred to as Standard Weight (SW). Differences in graph formatting from previous sections will be apparent; please reference the legends.

Oyster recruitment and early colonization

This information is from the Bio-Engineered Oyster Reef Demonstration Project (LA-0008) Mid-Term Biological Assessment: February 2012 -2013; see Appendix C-1 for the full report.

Oyster settlement was assessed by collecting oyster spat from pairs of cylinders composed of the different concrete types and positioned along the shore side of the Oysterbreaks deployed from March 2013 to October 2013. Oyster spat settled on both construction materials and did not preferentially settle on the OysterKrete cylinders. Interpretation of the Oysterbreak comparisons is confounded by the depth and resultant tidal inundation behind the structures. Oyster spat were more abundant on standard weight cylinders than on OysterKrete cylinders behind the deeper OBW - OysterKrete (Fig. 23, 6-10), but there was no apparent difference between concrete cylinders behind the shallower OBE - Standard Weight (Fig. 23, 1-5).

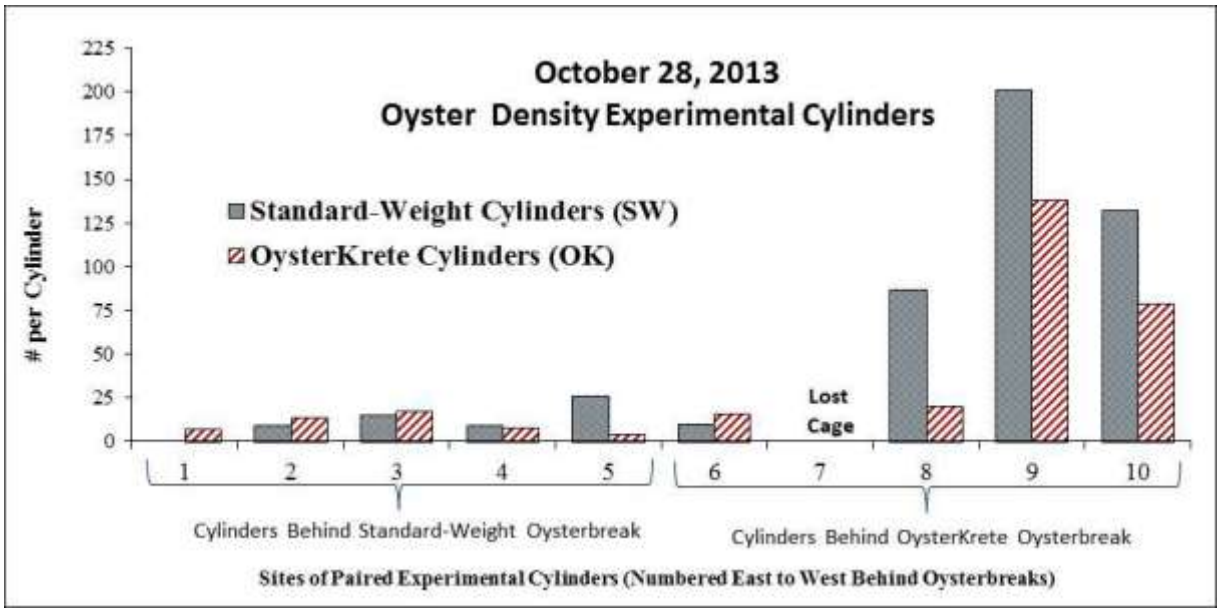


Figure 23. Oyster densities were collected from oyster spat settlement cylinders composed of the different construction cements on October 28, 2013. Note that cylinder pairs are numbered east to west rather than west to east. Graph copied from Appendix B – Figure 8.

For the initial set of spat monitoring cylinders (April 2012 - March 2013), spat from the Standard Weight cylinders had only a single nodal length peak of shell height at 5 – 9.9 mm whereas the OysterKrete spat had a longer nodal length peak at 10 – 14.9 mm and a smaller peak at 35 – 39.9 mm. The longer spat shell heights on the OysterKrete cylinders indicate greater growth, and the bimodal distribution indicates survival from an earlier recruitment event (Figure 24A). For the second set of oyster spat cylinders (March 2013 - October 2013), oysters on both cylinder types had a single nodal length of 5.9 – 9.9 and no shells longer than 25 mm, indicating one recruitment event (Figure 24B).

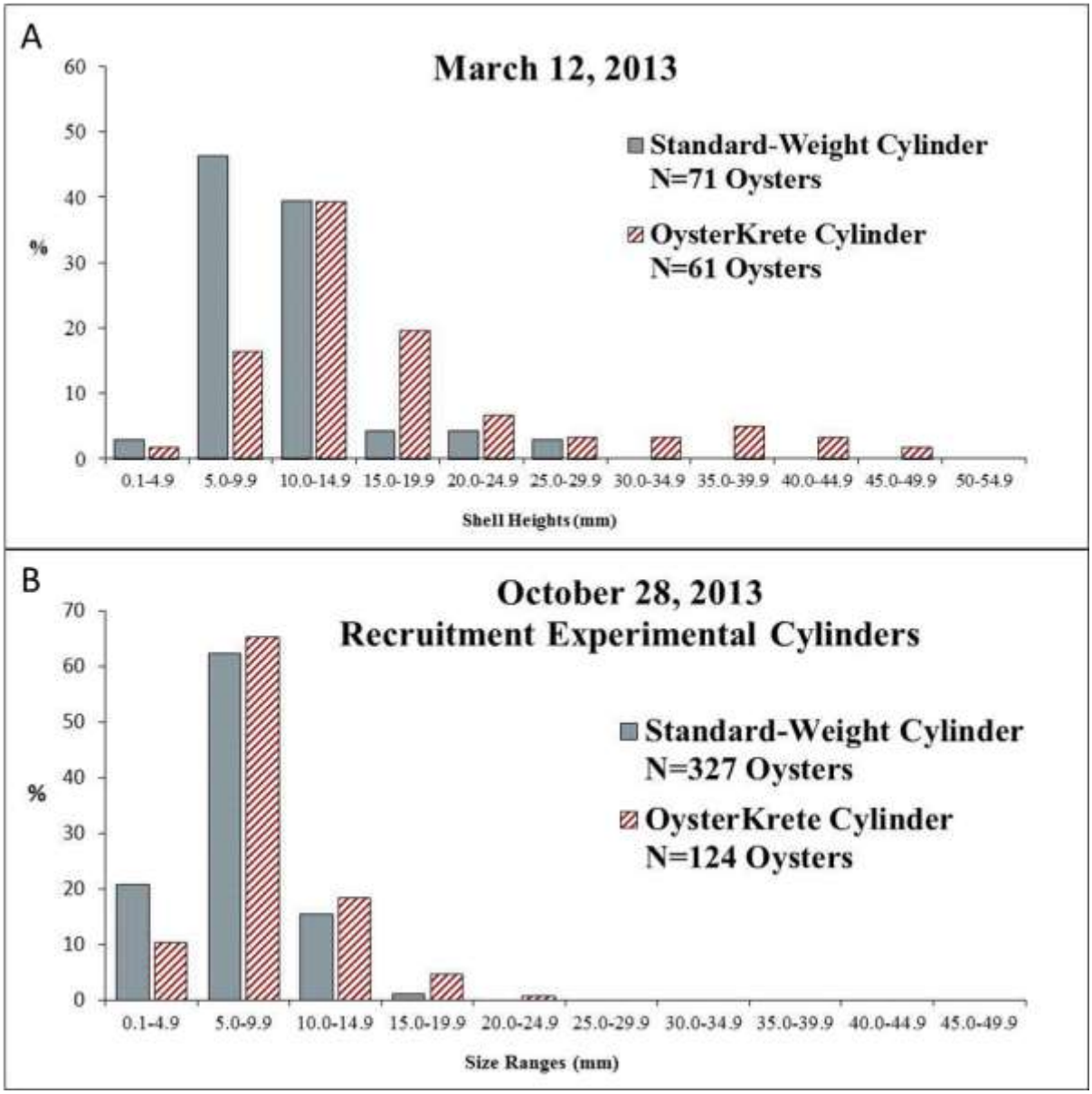


Figure 24. Oyster shell height frequency histogram were collected from oyster spat settlement cylinders composed of the different construction cements on (A) March 12, 2013 and (B) October 28, 2013 (graphs copied from Appendix B – Figures 5 and 7).

Oysters had established and grown on the Oysterbreaks by 20 months after construction. Oysters grew at a healthy rate from March to October 2013 on the intertidal portion of both OBE - Standard Weight (2.04 mm/month; Fig. 25A) and OBW (OysterKrete, 1.56 mm/month; Fig. 25B). The longer shell length on the Standard Weight rings may be a morphological adaptation of the oyster for clinging to a smoother surface. The oyster biomass did not statistically differ between the Oysterbreaks by October 2013.

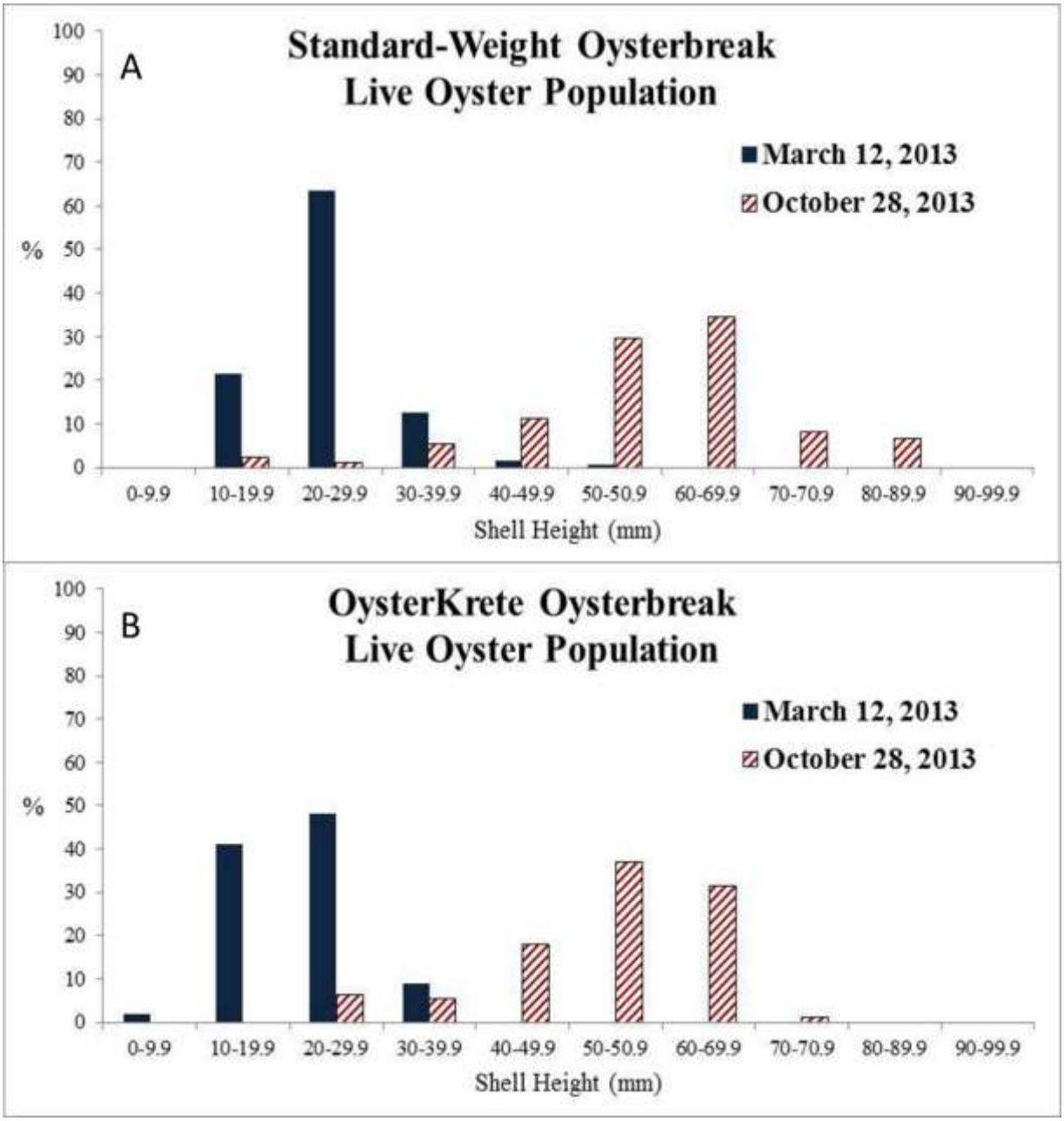


Figure 25. Oyster height frequency distributions collected from (A) Oysterbreak – East composed of standard weight concrete and (B) Oysterbreak – West composed of OysterKrete are compared between two time periods within 20 months of construction.

Final oyster colonization

This information is from the Oyster Assessment of Project LA-0008 OysterKrete Breakwater and Standard-Weight Breakwater: Rockefeller Wildlife Refuge, Louisiana see Appendix C-2 for the full report. The Oysterbreak layout will help describe feature and location terminology carried over from the report (Fig. 26).

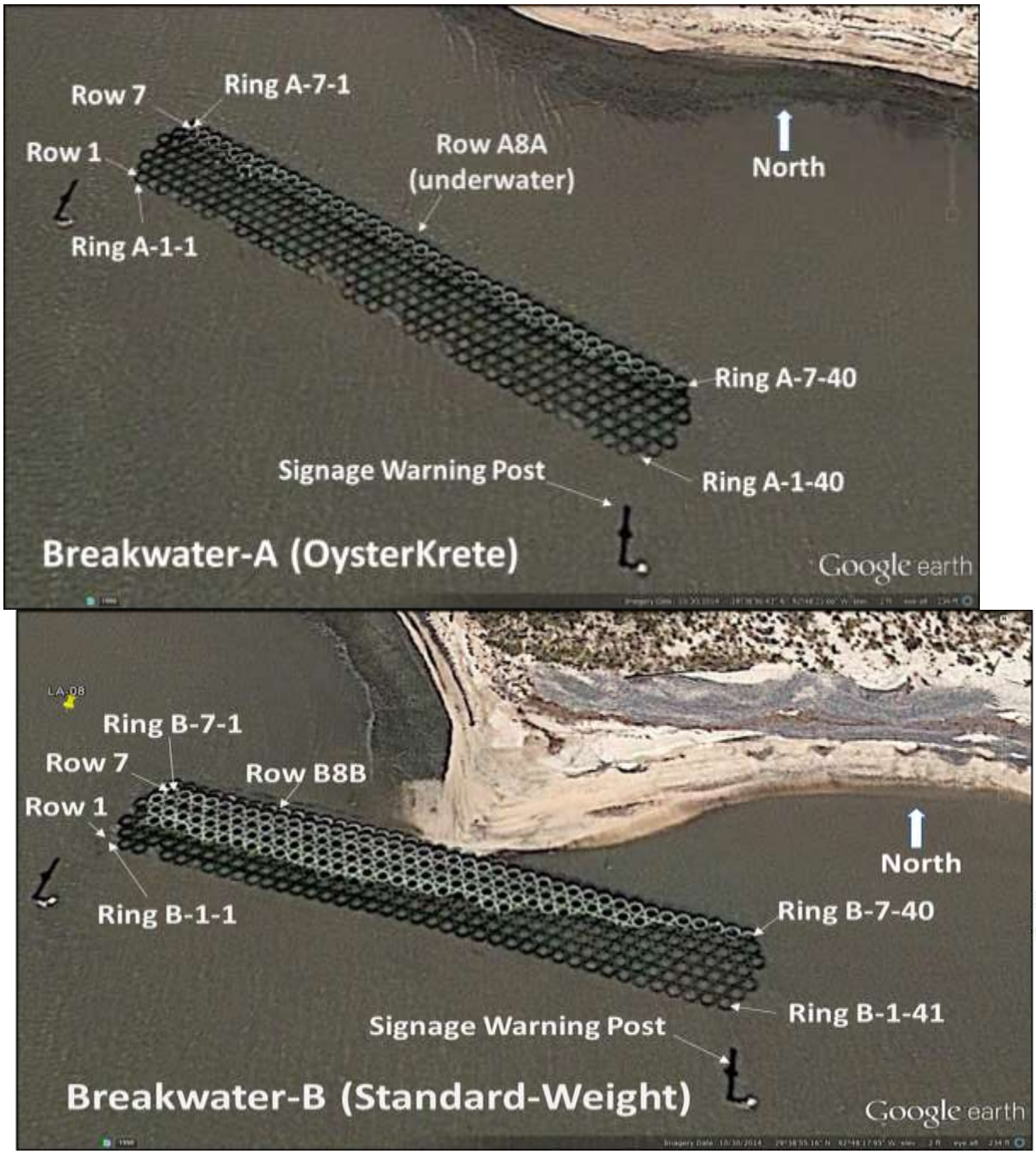


Figure 26. Aerial views of LA-0008 OysterBreaks (A) OysterKrete and (B) Standard Weight at low tide on were taken on October 30, 2014. Notation for rows and ring numbers are used throughout report.

Over the four years after construction, oysters recruited in sufficient numbers to potentially develop reef based on oyster reef development and active spat settlement (shell height < 20 mm) on the bottom row of rings on the leeward side of the Standard Weight Oysterbreak (row B8B) (Figs. 27 and 28). Multiple oyster cohorts were found on both Oysterbreaks with the year classes of 1- and 2-year old dominating. Oyster shell height is a proxy for age. On both Oysterbreaks, most oysters were in the 30 mm (< 1 yr. old, assumed to be fall/winter 2015 recruits) to 80 mm range (1-2 yrs. old, assumed to be spring/fall 2014 recruits). The Standard-Weight Oysterbreak (OBE) had a relatively good population percentage greater than 90-110 mm in shell length indicative of 3 years old. The OysterKrete Oysterbreak (OBW) had a few individuals >150 mm indicative of 4 year old oyster that would have settled soon after construction (Fig. 27). Most of the larger oysters (>90 mm) were on the higher-elevation rows that are still within the tidal frame (Fig. 28).

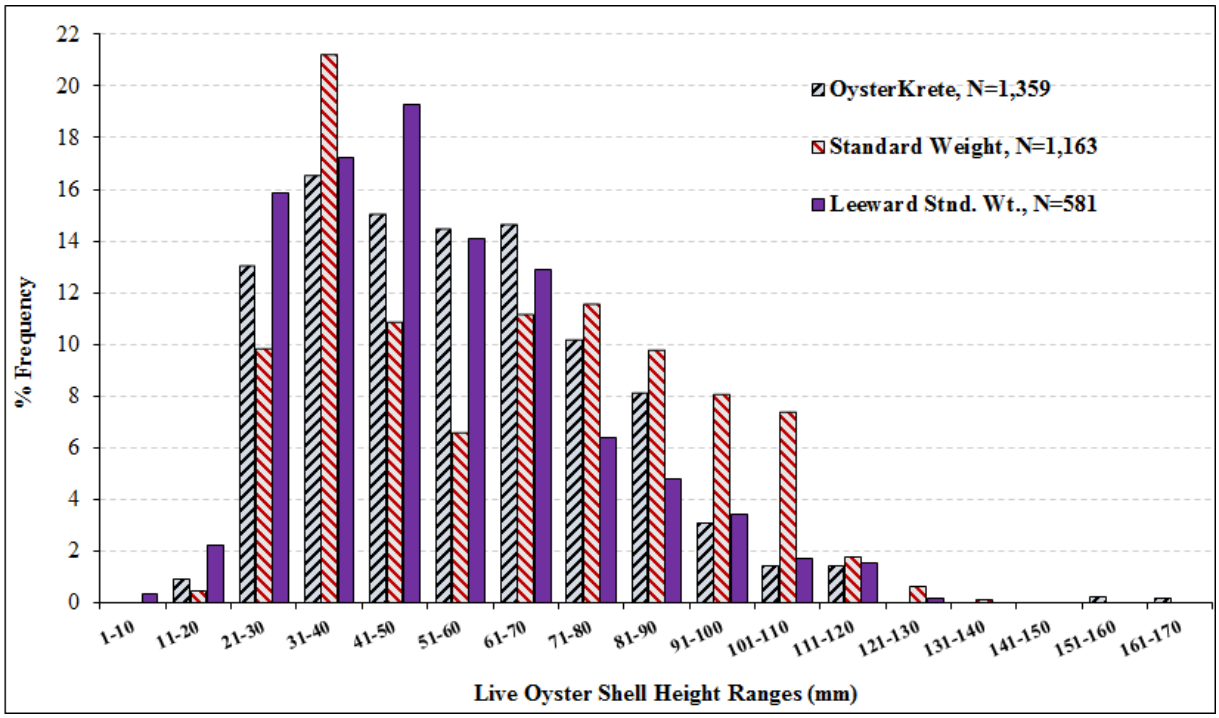


Figure 27. Live oyster shell height frequency distribution were collect from LA-0008 Oysterbreaks in January 2016 (about 4 years after construction). OysterKrete is Oysterbreak-West, Standard Weight is OysterBreak - East, and Leeward Stand. Wt. is row B8B.

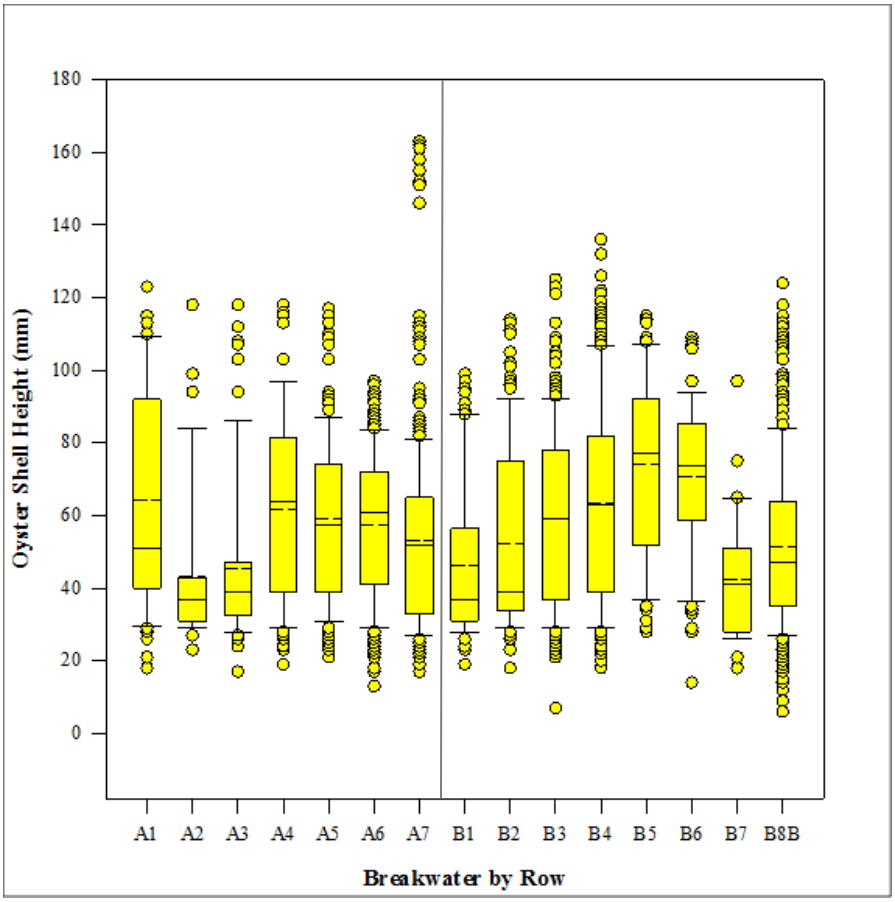


Figure 28. Live oyster shell heights were collected from the LA-0008 Oysterbreaks in January 2016 (about 4 years after construction). Distribution diagrams for each row depict the median (solid line) and mean (dashed line) values, 25% and 75% quartiles, and range of oyster shell heights. On the x-axis, "A" represents OysterKrete, "B" represents Standard Weight, and the numbers represent the rows of rings progressing seaward (1) to landward (7). B8B is the bottom row on the landward side of the Standard Weight Oysterbreak.

Unfortunately, the relatively good oyster size-frequency distributions did not translate into a consistently good oyster density distribution on the Oysterbreaks except for behind the Standard Weight Oysterbreak (Fig. 29). Oysters on the exposed, seaward-facing Oysterbreaks were sparsely populated and not sufficient for reef development (Figs. 30 and 31); these oysters had a rounded and low-profile shape to be more hydrodynamic and spread surface area on the rings. Oyster heights above the ring surface averaged less than an inch on both Oysterbreaks. Oysters inside the rings also had the same morphology but were a little more densely distributed (Fig. 32); as designed, water rushes along all surfaces of the rings as waves pass through the Oysterbreaks. Oysters on the leeward facing, bottom row of the Standard Weight Oysterbreak (B8B) were densely clustered with a much higher elevation profile and multiple angular shapes, typical of good reef structure (Fig. 33). Oyster heights above the ring surface averaged about 2 inches on row B8B.

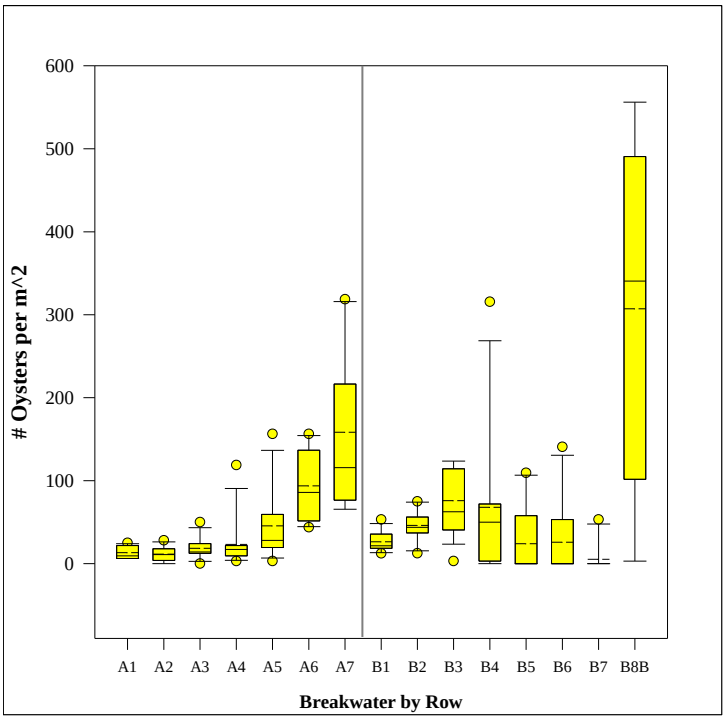


Figure 29. Live oyster density was collected from the LA-0008 Oysterbreaks in January 2016 (about 4 years after construction). Distribution diagrams for each row depict the median (solid line) and mean (dashed line) values, 25% and 75% quartiles, and range of oyster shell heights. On the x-axis, "A" represents OysterKrete, "B" represents Standard Weight, and the numbers represent the rows of rings progressing searward (1) to landward (7). B8B is the bottom row on the leeward side of the Standard Weight Oysterbreak.

Figure 30. Typical oyster colonization on the OysterKrete Oysterbreak was photographed four years after construction. Note the scattered distribution and rounded low-profile-shaped oysters which are characteristic of wave energy influences.

Figure 31. The east side of Standard Weight Oysterbreak was photographed in January 2016 during low-water conditions exposing the entire surface of the top layer of rings. The east end has lower elevation and, although sparse, has the highest density of oysters. Note the scattered distribution and rounded low-profile shaped oysters which are characteristic of wave energy influences.

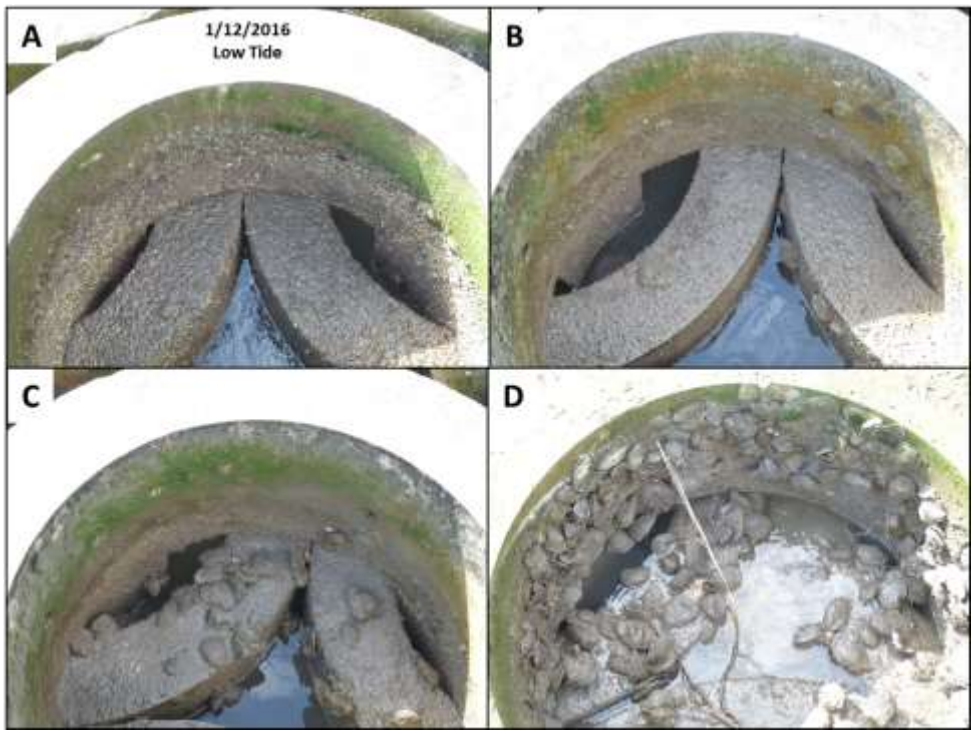


Figure 32. Oyster colonization was similar inside of hole of top layer of rings and bottom rings on Standard-Weight breakwater. Oysters in photos A and B are typical of low-elevation rings (rows B1-B3) which were typically sub-tidal. Oysters in photos C and D are typical of high-elevation rings (rows B4-B7).

Figure 33. A successful oyster reef structure exists on the leeward-facing, protected, bottom row (B8B) of the Standard Weight Oysterbreak four years after construction. Note the variety of sizes and fusion of oysters into complex shapes with good elevation profiles.

Oyster populations were not uniform across the Oysterbreaks as water inundation and wave energy greatly influenced how oysters recruited. A relationship between oyster density and ring elevation depicted that oysters typically increased until an elevation threshold of -0.33 ft (-0.1 m) NAVD88, Geoid 12A as limited by a lack tidal inundation; most of the rings above the elevation threshold were on upper rows of the Standard Weight Oysterbreak (Fig. 34). The remaining results will focus on the top surface of rings below the elevation threshold that have the capacity to support oysters. Four years after construction, the OysterKrete Oysterbreak had a mean population of 52±7 oysters/m^2 and 14±2 % coverage, the Standard Weight Oysterbreak had a mean population of 56±7 oysters/m^2 and 10±2 % coverage, and row B8B on the leeward side of the Standard Weight Oysterbreak had a mean population of 307±86 oysters/m^2 and 47±12 % coverage of oysters (Fig. 35 A and B). In a summary of oyster densities from other Louisiana living shorelines located in salinity ranges similar to LA-0008, two sites exceeded 500 oysters/m^2 just two years after construction and three sites had densities of 50-150 oysters/m^2 only one year after construction (LaPeyre et al. 2017). Four years after construction, artificial reef structures were 57±6 % covered by oysters in Terrebonne Bay, LA Melancon et al. (2013).

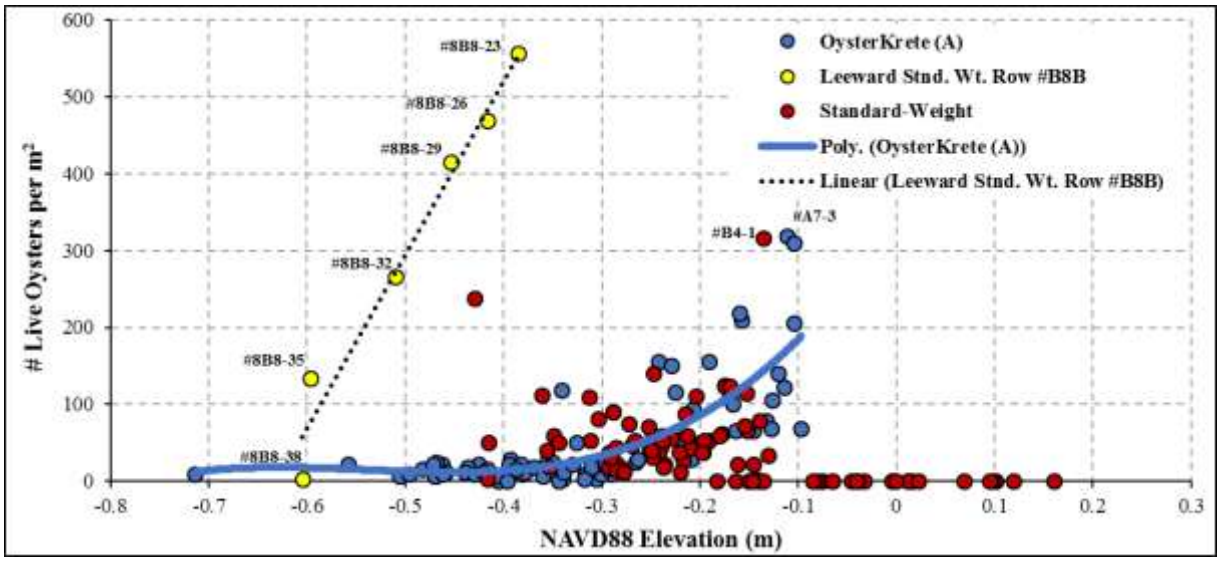


Figure 34. Oyster density is plotted against ring elevations for quadrat samples at the LA-0008 Site. The greater the elevation of the ring relates to less tidal inundation. A few individual rings identified with site number for reference.

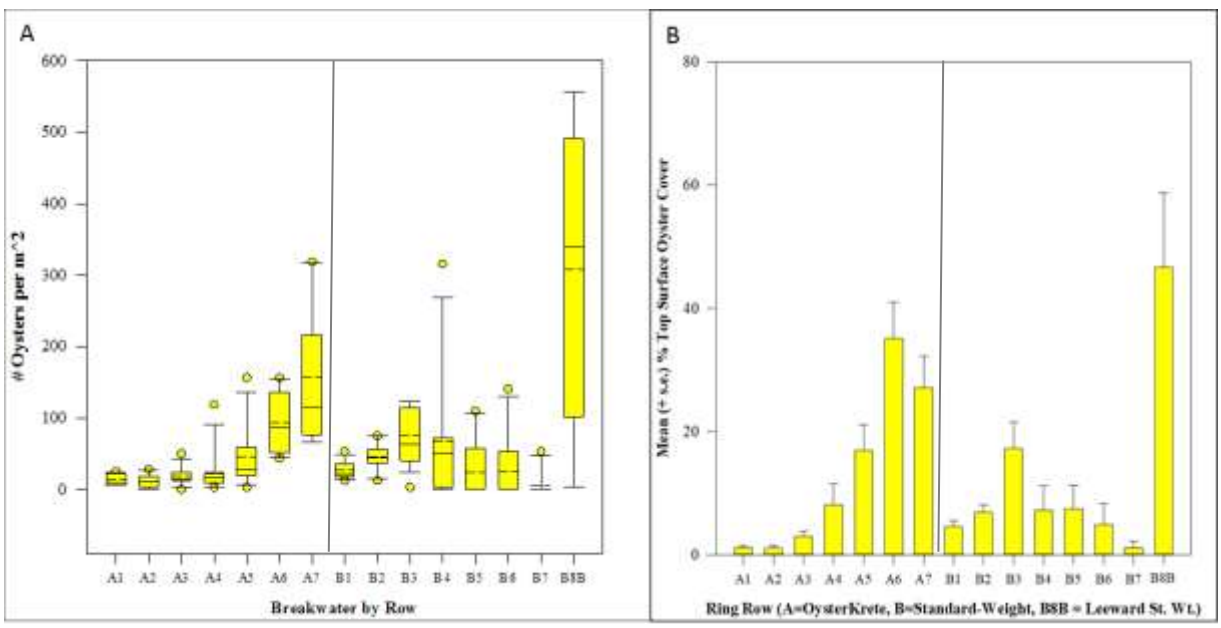


Figure 35. Oyster density (A) and percent cover (B) on top surface of OysterBreak rings within each row was assessed on January 2016. On the x-axis, "A" represents OysterKrete, "B" represents Standard Weight, and the numbers represent the rows of rings progressing windward (1) to leeward (7). B8B is the bottom row on the leeward side of the Standard Weight Oysterbreak.

Four years after construction, oysters on the Gulf-facing, wave-breaking plane of both Oysterbreaks were not sufficient to develop a reef. Oyster recruitment was related to

elevation, and oysters typically occurred in a one foot (-1.4 to -0.3 ft NAVD88, Geoid 12A) elevation band in the intertidal zone (Fig. 34). Within the viable elevation band, oysters were sparsely distributed and had a low-profile morphology to adapt to the harsh wave energy conditions. Areas above the elevation band were too removed from sufficient tidal inundation. The area below the elevation band is typically subtidal. Subtidal oysters are limited by predation, primarily by oyster drills. The oyster drills are common, predatory snails in subtidal, brackish and salt waters that do not receive long durations of low salinity pulses such as the gulf coast.

The only area on the Oysterbreaks with a healthy oyster reef was an area protected from direct wave impact on the leeward side of the Standard Weight Oysterbreak (row B8B). Row B8B is higher in elevation than the similarly protected row A8A on the leeward side of the OysterKrete Oysterbreak which does not have oyster reef formation (Fig. 36); greater predation pressure due to greater annual inundation at row A8A may be the reason for the difference in oyster populations.

Figure 36. The bottom row of the leeward side of the Standard Weight (left, row B8B) and OysterKrete (right, row A8A) Oysterbreaks protected from waves were photographed during very low water-levels in 2016. Note the difference in oyster reef formation four years after construction. The Standard Weight Oysterbreak averages 0.5 feet higher than the OysterKrete Oysterbreak. Water levels were higher in the left photograph; note water levels relative to the structures in the 02-01-2016 picture (OysterKrete is in the background).

See the full oyster monitoring report in Appendix C-2 for a more comprehensive summary of the oyster monitoring findings.

V. Conclusions

a. Project Effectiveness

As demonstrated by soil volume change and shoreline movement, LA-0008 effectively reduced nearshore and shoreline erosion behind the Oysterbreaks through two and half years after construction, but lost effectiveness by four and half years after construction. The higher, Oysterbreak – East composed of standard weight concrete has reduced shoreline erosion more than the lower, Oysterbreak – West composed of OysterKrete. The difference in shoreline erosion is attributed to differences in constructed elevations caused by water bottom conditions rather than construction materials. By four years after construction, coastal erosion adjacent to the Oysterbreaks overwhelmed the relatively small reach of protected shoreline.

The objective of reducing wave transmission reaching the shoreline by 50% was met by both Oysterbreaks after construction in 2012 and in 2014. The higher, Oysterbreak – East reduced wave transmission more than the lower, Oysterbreak – West.

Although sufficient oyster larvae were available for reef formation, both Oysterbreaks, OysterKrete and Standard Weight, failed to form oyster reef through four years after construction. Neither Oysterbreak was effective from the perspective of developing oyster reef with the ability to protect against erosion. A small oyster reef did develop on a small area of protected rings on the leeward side of the Standard Weight Oysterbreak but not on the exposed rings.

b. Recommended Improvements

Comparisons of the construction materials for all metrics were confounded by the difference in elevation of the Oysterbreaks, which is not easily avoidable in natural situations. Cement type comparisons for oyster monitoring would not have been confounded with structure elevation if the rings composed of different cement were mixed within the structures rather than having entire structures composed of separate materials.

c. Lessons Learned

Increasing the height of the structure to improve wave breaking potential should be considered in future planning. In terms of wave attenuation and shoreline erosion, the higher, Oysterbreak – East outperformed the lower, Oysterbreak – West, and both lost wave breaking efficiency when water levels and wave heights overtopped the crest elevation of the Oysterbreaks. The higher elevation portions of the OBE did settle more than lower elevations because of loss of buoyancy provided by the water; however, settlement for the higher portions was a low 0.24 feet over 4.5 years (0.05 ft/yr) which is anticipated to slow over time because of increased buoyancy due to increasing relative water levels.

Throughout the monitoring period, the gap between the Oysterbreaks eroded at a similar rate as the unprotected areas. Shortening the length of the gap relative to the length of the Oysterbreaks or not including gaps should be considered in future planning.

While the Oysterbreaks did not create reefs, they did function well as shoreline protection features. The Oysterbreaks demonstrated great stability throughout the 4.5-year monitoring period. Given that the extra wide (42') structures did not create a reef, future projects should consider reducing the width of Oysterbreaks and protecting longer reaches of shoreline. There are currently other Oysterbreak reefs installed in this region near Tigre Point (installed January 2013) and Chenier Au Tigre (installed August 2014) that appear to be stable and are protection shoreline based on GoogleEarth imagery. It is unknown if these structures have created reefs.

In active environments like the Gulf of Mexico, these oyster rings might support oyster reef development if used in concert with shoreline protection by installing a single row of oyster rings on the leeward side of shoreline protection features.

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APPENDIX A

Topographic/Bathymetric Elevation Survey
2016

(Field notes were removed from the original document)

BIO-ENGINEERED OYSTER REEF DEMONSTRATION PROJECT 4 YR. POST-CONSTRUCTION MONITORING SURVEY PROJECT NO. LA-08 SURVEY REPORT

PREPARED FOR:

COASTAL PROTECTION AND RESTORATION AUTHORITY OF LOUISIANA

STATE OF LOUISIANA
11-30-16
ADAM D. MECHE
License No. 5079
PROFESSIONAL LAND SURVEYOR

NOVEMBER 30, 2016

SUBMITTED BY:

T. BAKER SMITH
PROFESSIONAL CONSULTANTS SINCE 1913

BIO-ENGINEERED OYSTER REEF DEMONSTRATION PROJECT 4 YR. POST-CONSTRUCTION MONITORING SURVEY PROJECT NO. LA-08 SURVEY REPORT

Prepared for: C.P.R.A.
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BIO-ENGINEERED OYSTER REEF DEMONSTRATION PROJECT
4 YR. POST-CONSTRUCTION MONITORING SURVEY
PROJECT NO. LA-08
SURVEY REPORT

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SURVEY REPORT

BIO-ENGINEERED OYSTER REEF DEMONSTRATION PROJECT 4YR. POST-CONSTRUCTION MONITORING SURVEY PROJECT NO. LA-08

1.0 INTRODUCTION

Through the months of August and October 2016, T. Baker Smith, LLC (TBS) performed a 4 yr. post-construction monitoring survey of the Bio-Engineered Oyster Reef Demonstration Project (LA-08) under Contract Number 4400007054 with Coastal Protection and Restoration Authority of the State of Louisiana (CPRA). TBS provided topographic and bathymetric survey services to show the environmental effects of the demonstration project. TBS also provided elevation adjustments requested by CPRA to convert all the previous survey data to Geoid 12A. This work was outlined in *Monitoring Scope of Services, Bio-Engineered Oyster Reef Demonstration Project (LA-08)* dated May 16, 2016.

2.0 PROJECT OVERVIEW

This project is located along the coast of Rockefeller Wildlife Management Area and Game Preserve in Cameron Parish, LA and is funded through CWPPRA. This demonstration project is intended to dissipate wave energy and reduce coastal erosion. The project is also designed to create artificial habitat for oyster growth and eventual fishery sustainability. The federal sponsor is the National Marine Fishery Service and the local sponsor is CPRA under project priority list 17. The project consists of two breakwaters (215 ft. long by 42 ft. wide) constructed with OysterBreak Armor Units and a marine mattress under layer. One of the breakwater's armor units consists of normal weight concrete while the other uses OysterKrete, a proprietary concrete mix intended to attract oyster growth. TBS was contracted by CPRA to conduct monitoring surveys which will determine the performance of the breakwaters with respect to coastal morphology.

3.0 DATA COLLECTION SUMMARY

TBS conducted the 4-yr. post-construction surveys associated with the Bio-Engineered Oyster Reef Demonstration Project (LA-08) during August and October 2016. This included collecting topographic data using RTK GPS and bathymetric survey using a single beam fathometer coupled with RTK GPS. Thirty-five (35) transect lines were surveyed as outlined in the scope of services as shown below in Figure 1. A three person TBS survey crew utilized vehicles and boats to assist in the field work. After data collection, office personnel reviewed the data and prepared the data for submittal. The horizontal and vertical survey control used for this survey was "ME18-SM-01". The northing and easting coordinate is set in Louisiana State Plane – South Zone (U.S. Survey Feet) NAD83 horizontal datum of 420,724.93 ft. and 2,824,955.16 ft., respectively. The elevation of the monument is referenced to NAVD88 with an elevation of 5.43' using Geoid 12A. The "ME18-SM-01" survey datasheet is shown in Appendix A of this report.

3.1 TOPOGRAPHIC SURVEY

A TBS survey crew performed a topographic survey along 32 of the 35 transects. The last three easterly transects (33, 34, & 35) were omitted from the 2016 survey in an effort to reduce the scope and cost. Data points were collected using RTK GPS referenced to the monument stated above. The crew collected elevation data in 5 ft. increments along all transects. Morphological features such as the end of vegetation, shoreline escarpment crown, shoreline escarpment toe, Oysterbreak landward tow, Oysterbreak landward crown, Oysterbreak seaward crown, and Oysterbreak seaward toe and were delineated on the section sheets of the plan set. The topographic survey and bathymetric survey overlapped to ensure good quality of the data.

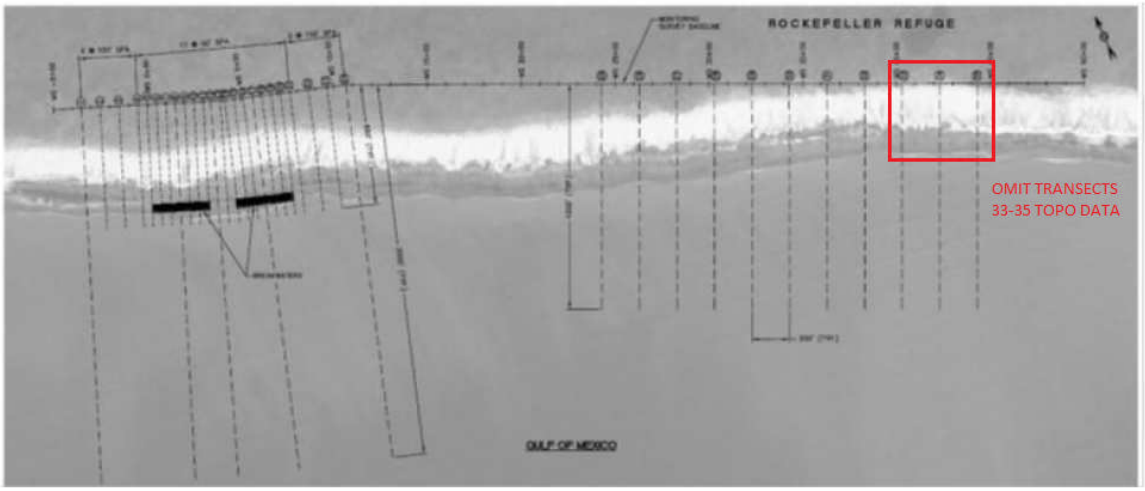


Figure 1. Transect Plan View

3.2 BATHYMETRIC SURVEY

The 35 transects were surveyed using a single frequency echo-sounder transmitting at 200 kHz. This sounder was interfaced with RTK GPS through an on-board navigation system. RTK GPS was used for real-time tide and heave corrections and centimeter level positioning. Positioning points were collected at 10 Hz. The data was then processed using HYPACK software for use in the submittals.

3.3 TRANSFORMING PRIOR SURVEY ELEVATION USING GEOID 12A MODEL

As discussed in Section 3.0, the 2016 Monitoring Surveys were performed using the "ME18-SM-01" benchmark with Geoid 12A. In order to ensure all previous comparison data is on the same elevation coordinate system, prior surveys performed for this project were converted from their original datum to Geoid 12A. Table 1 below shows the four previous survey events and the datum's used for each survey.

Survey Event	Monument (Geoid)	Geoid Model in Field Data Collector
2011 Pre-Construction Survey	ME-18-SM-01 (Geoid 03)	Geoid 03
2012 As-Built Survey	ME-18-SM-01 (Geoid 03)	Geoid 03
2013 Monitoring Survey	ME-18-SM-01 (Geoid 03)	Geoid 09
2014 Monitoring Survey	ME-18-SM-01 (Geoid 03)	Geoid 09

Table 1. Previous Survey Events for LA-08

The Preconstruction Surveys and As-Built Drawing surveys dated November 2011 and March 2012, respectively were surveyed by C.H. Fenstermaker & Associates, L.L.C. (Fenstermaker) using the "ME-18-SM-01" (Geoid 03) with a benchmark elevation of 6.05' according to the point file "Post-Construction Monitoring Survey Feb 2012.xls" provided by CPRA to TBS in March, 2016. The benchmark elevations for "ME-18-SM-01" in Geoid 03 and 12A are shown below in Table 2.

The Monitoring Surveys in 2013 & 2014 were performed by TBS using the same benchmark control as the Fenstermaker surveys with an elevation of 6.05'. However, during the 2013 & 2014 surveys TBS was unaware of the Geoid model used for the preconstruction and as-built surveys, so the Geoid 09 model was input into the field data collector instead of the Geoid 03 model. This proved to have a negligible effect on the data collected since the benchmark bared the values of Geoid 03 elevation of 6.05'.

Monument (Geoid)	Elevation (ft.)
ME-18-SM-01 (Geoid 03)	6.05
ME-18-SM-01 (Geoid 12A)	5.43

Table 2. ME-18-SM-01 Geoid Elevations

All four (4) data sets were converted to the most recent datum of NAVD 88, Geoid 12A by applying a uniform elevation adjustment of -0.696 feet. The methodology for the elevation adjustments is described below in Section 4.3.

4.0 METHODOLOGY

This survey was conducted in accordance with the guidelines and recommendations established in the Contractor's Guide to Minimum Standards revised March 2011 developed by the Coastal Protection and Restoration Authority of Louisiana. The survey was conducted and conformed to USACE standards as well. A three-person survey crew conducted survey work.

4.1 TOPOGRAPHIC SURVEY

Topographic data points were surveyed using a Trimble RTK GPS system using "ME18-SM-01" for horizontal and vertical control. Data points were collected every 5 ft. from the beginning of the transect seaward until the rodman of the survey crew could not safely survey without equipment/personnel being submerged. For some subaqueous portions of the cross sections, data was collected by taking hand soundings using a standard 25' Stadia Rod. RTK GPS was used for horizontal positioning of each sounding. The soundings were also referenced to an RTK GPS observed tide reading for elevation reduction.

The topographic survey data was downloaded from the data collector into the Trimble Business Center software for processing. The software allows for QA/QC of GPS data, and was used to check for instrument setup errors, antenna height errors, and other blunders. This data was exported to digital point files and then entered into AutoCAD Civil 3D for further processing. The topographic data was combined with the bathymetric data to produce 3D surface models and used to generate elevation contours for the final deliverable.

4.2 BATHYMETRIC SURVEY

The portions of transects requiring the use of a boat were surveyed on August 24, 2016 using "ME18-SM-01" as a benchmark for the RTK GPS which was interfaced with a single frequency echo-sounder operating at 200 kHz. The survey vessel ran the same 35

plan lines as specified in the scope of services and recorded depth at 10 Hz. The vessel heave was compensated by using tide corrections and tracking the vessel elevation in relation to the RTK base station. The wave climate during the August 24th survey was described as calm with occasional 0 to 1 ft. wave heights. The collected data was then processed for quality and accuracy using HYPACK software. Erroneous points were filtered by interpolation and verified against papers graphs written while the plan lines were surveyed. Once all the data was verified, the filtered data was then attached to the nearest plan line and data points were exported from HYPACK every 5 ft. along the plan line. These transects were then imported to AutoCAD to produce the 3D surface models and final submittals.

4.3 TRANSFORMING PRIOR SURVEY ELEVATION USING GEOID 12A MODEL

Upon initial review of the four previous surveys it became apparent that the surveys were all conducted using the same basis of control, "ME-18-SM-01" (Geoid 03). This control point possessed northing, easting and elevation values that can be seen below in Table 3. Although the TBS surveys from 2013 and 2014 were conducted with the setting of Geoid 09, it is believed that the control point values hold the survey to Geoid 03 rather than Geoid 09. With this being the case we set out to establish one uniform elevation shift for the four previous surveys.

HORIZONTAL/VERTICAL SURVEY MONUMENT CONTROL TABLE			
NAME	NORTHING	EASTING	ELVATION (NAVD88)
ME-18-SM-01	420,724.78	2,824,955.19	6.05

Table 3. "ME-18-SM-01" Preconstruction and As-Built Survey Control - Geoid 03

In order to convert the prior surveys from the Geoid model used at the time of survey to Geoid 12A an analysis of T. Baker Smith's 2013 survey data was conducted. We conducted a review of elevation changes as a result of applying different Geoid models in Trimble Business Center Software (TBC). Data values and CPRA published data sheets for benchmark "ME18-SM-01" were monitored while applying the different Geoid Models. Shifts due to the application of Geoid 03, 09, and 12A were reviewed. To do this the TBS 2013 field data was imported into a TBC project holding a Geoid 09 configuration. The control point was then edited to reflect an ellipsoid height of -24.029 meters as displayed in the "ME18-SM-01" (Geoid 09) data sheet prepared by John Chance Land Surveys, Inc dated July 2010. This data set was then transformed to Geoid 03 using TBC in order to observe the elevation of "ME18-SM-01". Once converted to Geoid 03, "ME18-SM-01" displayed an elevation of 6.09' resulting in a difference of .04' in comparison to the values held in the prior two surveys. The data set was then converted to Geoid 12A using TBC to again observe the elevation of "ME18-SM-01". Once converted to Geoid 12A, "ME18-SM-01" displayed an elevation of 5.46' resulting in a difference of .03' in comparison to the data sheet for "ME18-SM-01" (Geoid 12A) with an elevation of 5.43' prepared by C&C technologies, Inc dated April and June 2014. These results would lead to the belief that all four previous survey events were held in Geoid 03 and one uniform adjustment could be made from Geoid 03 to Geoid 12A.

Elevations upon all transects were converted to hold both Geoid 03 and Geoid 12A models in TBC. The difference in the two elevations at common surveyed observation points were established and then averaged. The average shift in elevation from Geoid 03 to Geoid 12A was -0.696 feet. This value was then deducted from each point on the previous surveys to enable the requested comparisons.

5.0 DISCUSSION

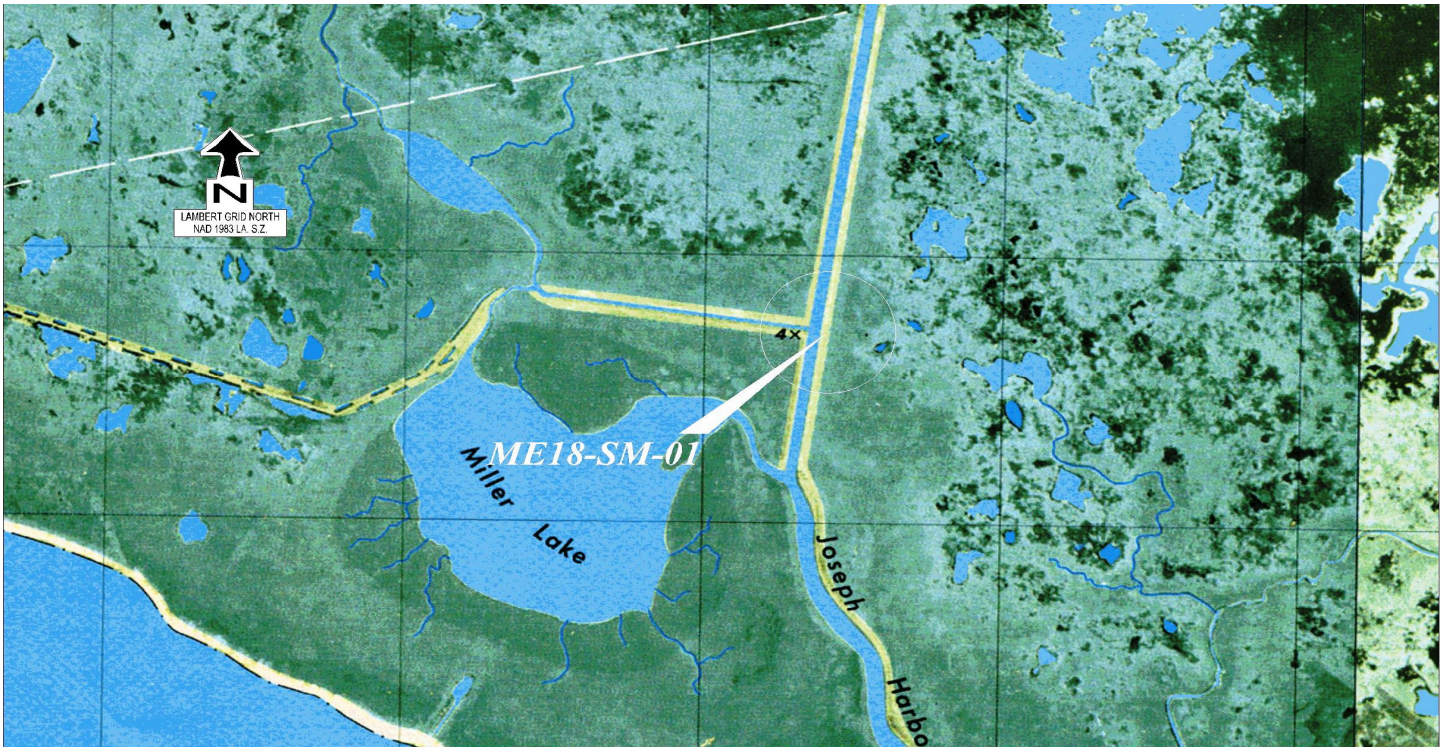
The 4 Yr. Post-Construction Monitoring Survey of Bio-Engineered Oyster Reef Demonstration Project (LA-08) occurred from August 23-25 and October 10, 2016. The work was completed without crew injury and a high regard for safety. All field data was

processed by TBS office personnel to produce elevation contours and cross sections as defined in the scope of services. The 2016 survey cross sections were superimposed onto the previous cross section surveys performed by TBS in 2013 and 2014 in order for CPRA or others to analyze the performance of the Oyster Reef breakwaters over the monitoring period.

APPENDIX A

Survey Monument Data Sheet

ME18-SM-01 (Geoid 12A)



VICINITY MAP Scale: 1" = 2000'

Reproduced from USGS "COW ISLAND" and "DEEP LAKE" Quadrangles

Station Name: "ME18-SM-01"

Monument Location: From the Rockefeller State Wildlife Refuge Headquarters near Grand Chenier, La., proceed easterly on State Hwy. 82 for 3.2 miles to a public boat launch on the right at Joseph Harbor Bayou. Then by boat, proceed southerly in Joseph Harbor Bayou for approximately 5.0 miles to a canal heading westerly and the monument on the east spoil bank of the canal intersection.

Monument Description: NGS Style Floating Sleeve Monument; datum point set on 9/16" stainless steel rods driven 56 feet to refusal, set in sand filled 6" PVC pipe with access cover and set in concrete flush with ground.

Stamping: "ME18-SM-01"

Set Date: June 2002

Monument Established By: John Chance Land Surveys, Inc

For: *Louisiana Department of Natural Resources, CRD*

NAD 83(2011) Geodetic Position
Lat. 29° 38' 56.599" N
Long. 92° 46' 06.777" W

NAD 83 (2011) Datum LSZ (1702) Ft
N= 420,724.93
E= 2,824,955.16

Adjusted NAVD88 Height (Geoid 12a)
Elevation = 5.43 ft / 1.655 m

Ellipsoid Height: -78.87 ft / -24.040 m
Geoid12a Height: -84.30 ft / -25.695 m

Surveyed by:
Lonnie G. Harper and Assoc., Inc.(2000)
Geoid 99 Elevation = 6.44 ft / 1.963 m
Ellipsoid Height = -78.51 ft / -23.931 m
Geoid 99 Elevation = -84.95 ft / -25.894 m

Note: Re-Surveyed and Re-Adjusted in April and June 2014

Adjusted Position Established by C&C Technologies, Inc. for Coastal Protection and Restoration Authority of Louisiana
Position Determined by GPS Network Adjustment

APPENDIX B

LA-0008 Wave Reports

APPENDIX B-i

Hydrodynamic Data Collection Report
2012

(Data from individual observations were removed from original document)

BIOENGINEERED OYSTER REEF DEMONSTRATION PROJECT
PROJECT NO. LA-08
HYDRODYNAMIC DATA COLLECTION REPORT

PREPARED FOR:

COASTAL PROTECTION AND RESTORATION AUTHORITY OF LOUISIANA

DECEMBER 12, 2012

SUBMITTED BY:

T. BAKER SMITH
PROFESSIONAL CONSULTANTS SINCE 1913

BIOENGINEERED OYSTER REEF DEMONSTRATION PROJECT
PROJECT NO. LA-08
HYDRODYNAMIC DATA COLLECTION REPORT

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BIOENGINEERED OYSTER REEF DEMONSTRATION PROJECT
PROJECT NO. LA-08
HYDRODYNAMIC DATA COLLECTION REPORT

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Digital Appendix

- Data Collection Report File (DOC & PDF Format)
- Project Processed Data (.CSV)

HYDRODYNAMIC DATA COLLECTION REPORT
BIOENGINEERED OYSTER REEF DEMONSTRATION PROJECT
PROJECT NO. LA-08

1.0 INTRODUCTION

This report details the first year of the post-construction wave monitoring work, conducted by T. Baker Smith, LLC (TBS), which was performed on the Bioengineered Oyster Reef Demonstration Project (LA-08). A series of gages were deployed in the summer of 2012, by TBS, for a period of one month to monitor the amount of wave attenuation due to the oyster reefs. The data was compiled, analyzed, and will be presented in this report. The data shows that the Bioengineered Oyster Reef Demonstration Project does reduce significant wave heights during high energy wave events.

2.0 PROJECT OVERVIEW

Two engineered oyster reef breakwaters were installed along the coastline of Rockefeller Wildlife Management Area and Game Preserve in Cameroon Parish, LA along the Gulf of Mexico. This is a demonstration project on the 17th Project Priority List of the Coastal Wetland Planning Protection and Restoration Act (CWPPRA). The breakwaters are being monitored to quantify the environmental effects on the surrounding coastline and wetlands. The monitoring will be conducted for a period of four years after installation and will include topographic surveys, bathymetric surveys, oyster monitoring, aerial photography, and spatial analysis. This portion of project monitoring consists of collecting wave data to observe the effects of wave attenuation due to the installed Oysterbreak reefs. A series of staff and pressure gages were installed in the vicinity of the breakwater collecting water levels over time. The water levels were analyzed and water surface elevation, significant wave height, and peak wave period were calculated as a function of time.

3.0 DATA COLLECTION SUMMARY

Wave Staff gages were placed on the landward side of each breakwater structure. Wave Staff gages were selected for the two breakwater sites because water depths between the

structure and shoreline are very shallow due to tombolo formation. Installation of a pressure gage at these two locations may have caused complications if the gage became un-submerged during low tide events.

In order to provide comparison of wave heights between the protected (Oysterbreak structures) and unprotected shorelines, a "control" gage was placed on an unaltered section of shoreline approximately 2700' east of the breakwater gages. At the control gage location, both a wave staff gage and a submerged pressure gage were placed at approximately the same distance from the natural shoreline as the two breakwater gages. The water depth at the control gage location was slightly deeper than the breakwater gage locations because of the relatively steep nearshore slope at this site. Because this site was located along an unprotected segment of shoreline, it was decided that the wave staff gage may become damaged during high energy wave events, especially considering that this location was in the nearshore surf zone subject to large breaking waves. It was therefore decided that a redundant pressure gage would also be installed to ensure continuous data was collected at this site. Upon retrieval of the gages, it was found that the wave staff gage at the control site was damaged by high surf. More specifically the gage was leaning and the grounding lug had become disconnected. However the pressure gage was found to be in an unaltered state and collected valid, continuous data throughout the deployment. The pressure gage data for the control location was used for further presentation and analysis in this report.

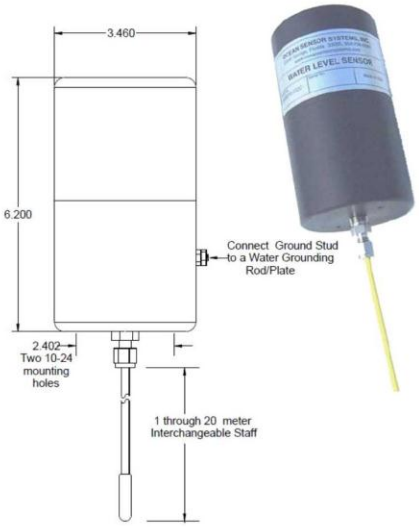
In order to obtain a record of untransformed, incident waves approaching each of the nearshore gages, an offshore (pressure) gage was placed at the -6 ft. contour. More specifically, the gage was placed 1730 ft. eastward of east breakwater gage, between the breakwater gages and the control gage, with the sensor reading at an elevation of -5.9498 ft. (NAVD88).

Each gage used in this deployment was configured to record water levels at a frequency of 10 Hz. for a period of 20 minutes starting every half hour, which provided 288,000 samples per day (48 bursts). The staff gages began collecting data, simultaneously, on July 3, 2012. Due to a period of rough weather, the pressure gages were deployed the following week and deployed during the morning of July 8, 2012. The gages were retrieved on August 6, 2012.

3.1 STAFF GAGES

The wave staff gages consisted of a 1 meter sensor rod attached to the bottom of a data recording and power unit. The recording and power unit was contained within a lockable box with a hole drilled in the bottom to accommodate the sensor rod. The lock box was then u-bolted to a galvanized pipe which was water-jetted securely into the mud. The sensor rod was reinforced with a small bracket connecting the lower portion of the rod to the galvanized pipe to prevent swaying of the sensor rod. Each galvanized pipe was placed shoreward and in roughly the center of each breakwater. The field crew was able to adjust and set the control boxes to approximately the same elevation. When the water elevation fell below -0.5 ft. NAVD88, the sensor did not record any data. However, because of the Oysterbreak structure and the shallow water depths, the incident wave heights approaching the shore during these periods of low water were negligible.

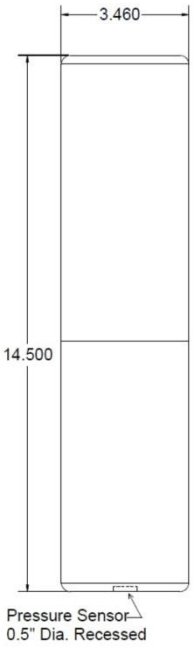
Gage	Northing (ft., NAD83)	Easting (ft., NAD83)	Top of Lock Box (ft., NAVD88)	Bottom of Rod (ft., NAVD88)	Mudline (ft., NAVD88)
East: 679412	420768.486	2813312.116	3.658	-0.538	-1.152
West: 679410	420929.002	2813027.895	3.586	-0.561	-1.374



3.2 PRESSURE GAGES

The pressure gages were deployed by attaching them to a large, metal sled which was anchored into the mud. The pressure gages are tubular shaped with the sensor placed in the center of the circular cap of one side of the gage. The tubular gage was then secured inside a box-shaped housing with the ends and gage caps exposed to the water. The box-shaped housing rested on top of a metal plate which rested on the bottom.

Gage	Northing (ft., NAD83)	Easting (ft., NAD83)	Sensor Elevation (ft., NAVD88)	Mudline (ft., NAVD88)
P01: Control	419696.862	2815845.470	-1.6102	-2.674
P05: Offshore	419969.840	2814849.528	-5.9498	N/A



4.0 DATA PROCESSING METHODOLOGY

The staff gages were deployed on July 2, 2012 at approximately 12:00 PM and 1:00 PM for gages 679412 and 679410, respectively. The Offshore (P05) Gage was deployed on July 8, 2012 at approximately 9:30 AM while the Control (P01) Gage was deployed at 10:00 AM. However, there was a difference between the "gage time" and "real time" on the control pressure gage. The control gage began taking readings in "real time" upon deployment, but the "gage time" indicated readings being taken 5:30 hours after actual deployment. This discrepancy should be noted if the raw data is subsequently processed.

The data was processed using MatLab, a numerical coding and programming environment was used to process the raw data into the requested formats of water surface elevation, significant wave height, and peak wave period. For the two Pressure gages, raw pressure observations were transformed into water heights (above the sensor) using atmospheric pressure readings at the time of deployment. Water densities were obtained from salinity values on a nearby gage in the Calcasieu Ship Channel. To obtain statistical wave heights and periods, a Spectral Density Analysis was performed on the time series data for each burst. A FFT (Fast Fourier Transform) analysis was performed to determine the frequency components of the

pressure signal. A Hann window function was also used to smooth the spectral density curves. The pressure response coefficient (Kp) was also applied to the data to correct for depth attenuation of pressure. Once the wave energy spectrum was developed for each burst, the zero moment wave height was computed as

$$H_s = H_{m0} = 4\sqrt{m_0}$$

Where m_0 is the zeroeth moment of a half amplitude squared spectrum and Hs is the average height of the upper 1/3 of all wave heights

The peak wave period, Tp, was calculated as the inverse frequency of the maximum spectral energy. The peak wave period was limited to 10 seconds to eliminate overestimation during calm, low energy days.

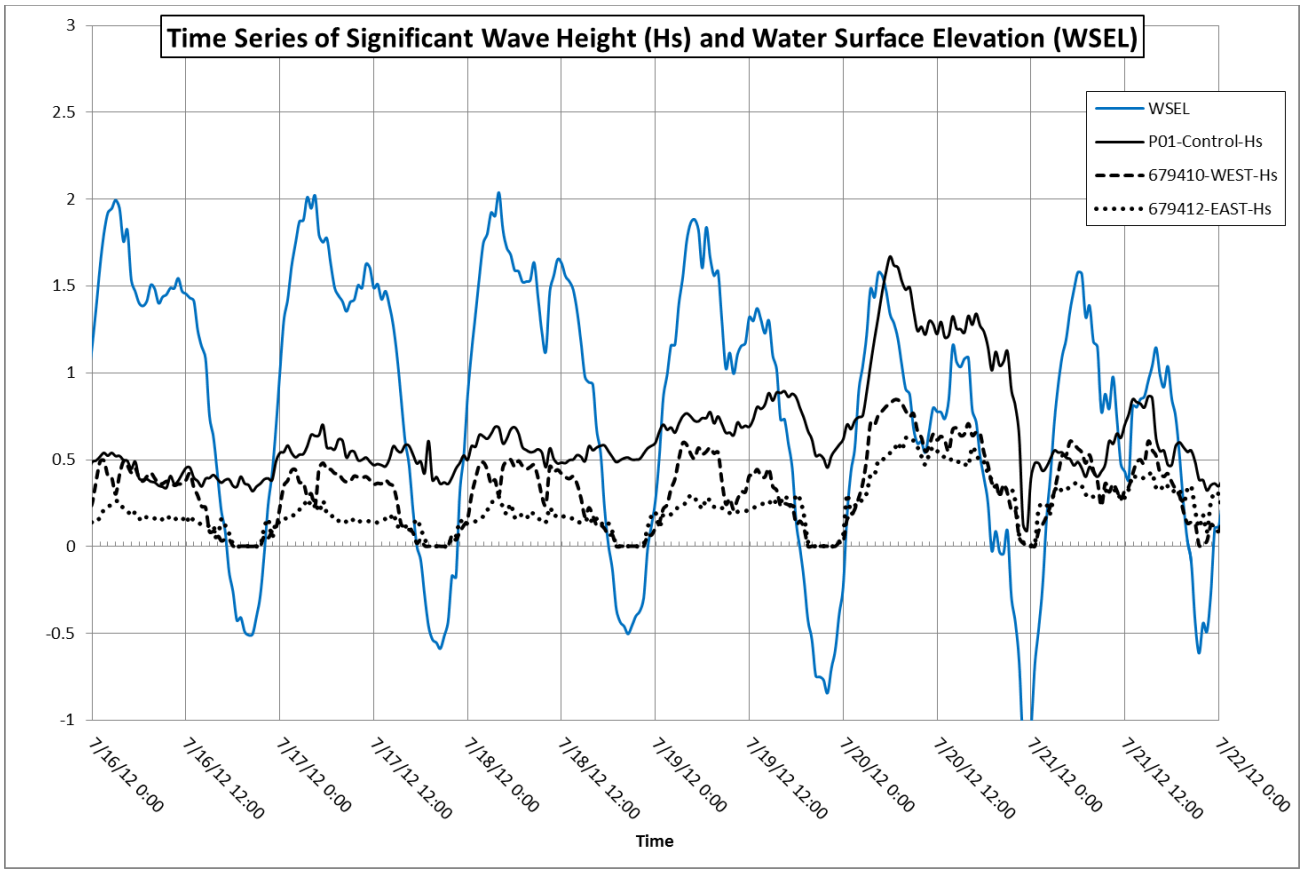
For the wave staff gages, waves were directly recorded on each staff as changes in water surface elevation. In order to obtain wave statistics for each burst, a zero crossing analysis was performed on the data in MatLab. This analysis defines each wave as the portion of the time series record between two successive zero downcrossings. Each wave is ranked and the Significant Wave Height was computed as the average height of the upper 1/3 of all wave heights in the record.

5.0 DISCUSSION

This particular gage deployment occurred during a period of relatively calm wave conditions in the northern Gulf of Mexico. The gages collected continuous, clean data during the period of deployment. Only three (3) high wave energy events occurred during the deployment. The initial analysis conducted by TBS reveals that during high wave energy events, the Bioengineered Oyster Reefs do decrease significant wave heights. It should be noted that wave height reduction between the control gage and the breakwater gages is significantly more pronounced during low-tide conditions. It was also observed that the West Oysterbreak Gage encountered higher significant wave heights compared to the East Oysterbreak Gage during high water levels. This may be attributed to the reef crest elevation of the West Oysterbreak being lower than East Oysterbreak, exposing higher waves heights to the West Oysterbreak compared

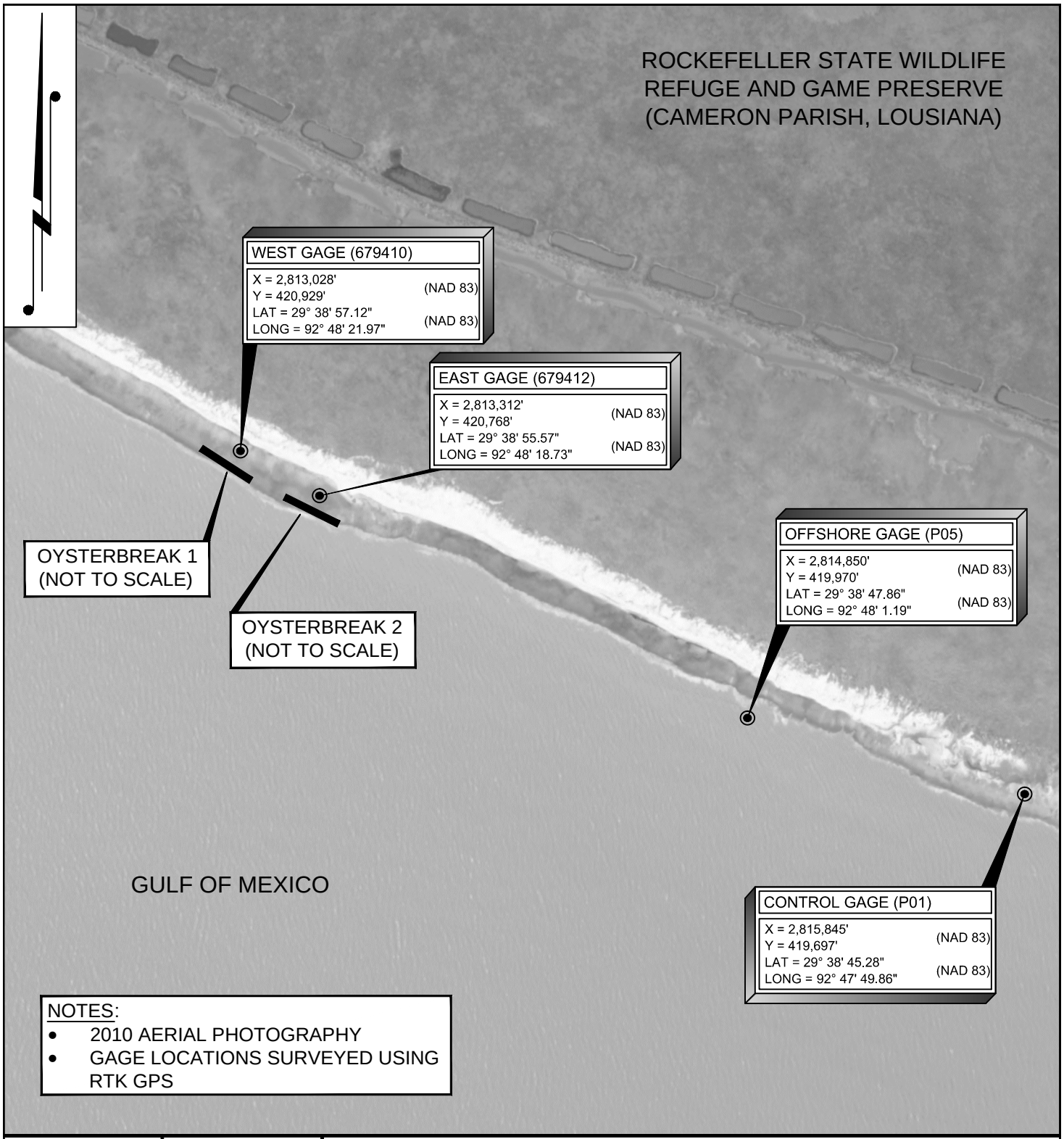
to the East Oysterbreak. This may be confirmed by conducting field surveys during future monitoring. Another observation of the data is that during lower water levels the Oysterbreak structures are more exposed to the waves, which provides more wave reflection and thereby reduces wave energy propagating across the structure.

For the high wave event on July 20, 2012, the reefs decreased the significant wave heights by approximately 60%. During the event on July 26, 2012, the reefs decreased the significant wave height by 41%, from an average wave height of 0.84 ft. to an average height of 0.50 ft. During the same event, the peak wave periods were decreased from a 5.28 sec. wave to a 4.12 sec. wave, a reduction of 22%. For the July 20, 2012 event, the peak wave periods decreased from a 4.57 sec. average wave to a 3.21 sec. average wave, a reduction of 30%.



APPENDIX 1

Project Map



DRAWN BY: WAC	APPROVED BY: BJK	GAGE LOCATIONS	
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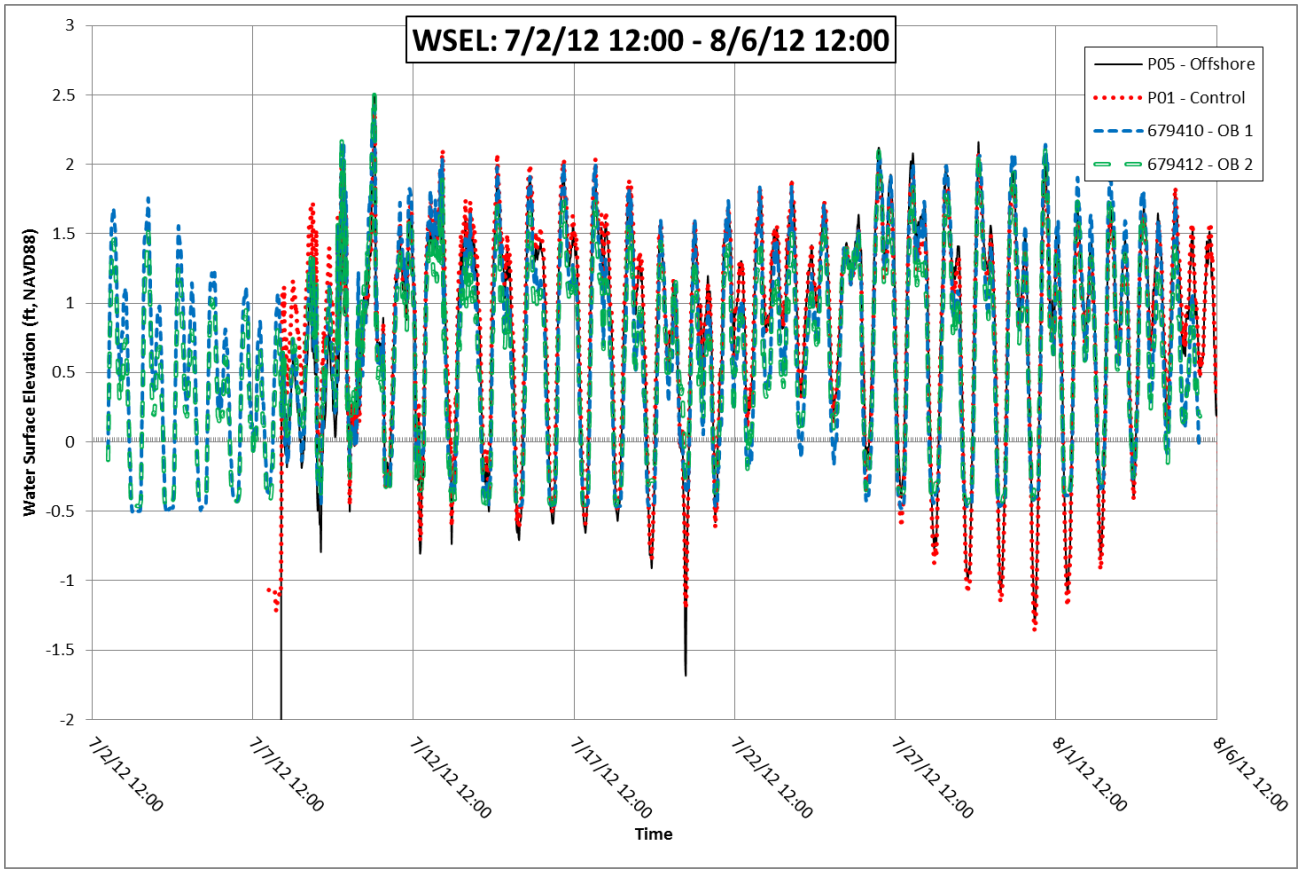
DRAWING NAME: GAGE LOCATIONS.DWG			
SHEET NO: 1 OF 1		BIOENGINEERED OYSTER REEF DEMONSTRATION PROJECT (LA-08)	
PROJECTION: PROJECTION GEO. DATUM: NAD83 | VERT. DATUM: NAVD88 US SURVEY FEET			
SCALE IN FEET 500' 250' 0' 500'	T. BAKER SMITH 1913 2013 A CENTURY OF SOLUTIONS 412 South Van Ave, Houma, LA 70363 (985)868-1050 - tbsmith.com	REV. NO: 00	REV. DATE: --/--/-- | REV. BY: ---
		REVISION DESCRIPTION: --	

APPENDIX 2

Water Surface Elevation Plots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P05 - Offshore
P01 - Control
679410 - OB 1
679412 - OB 2
Water Surface Elevation (ft, NAVD88)
3
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
7/2/12 12:00
7/7/12 12:00
7/12/12 12:00
7/17/12 12:00
7/22/12 12:00
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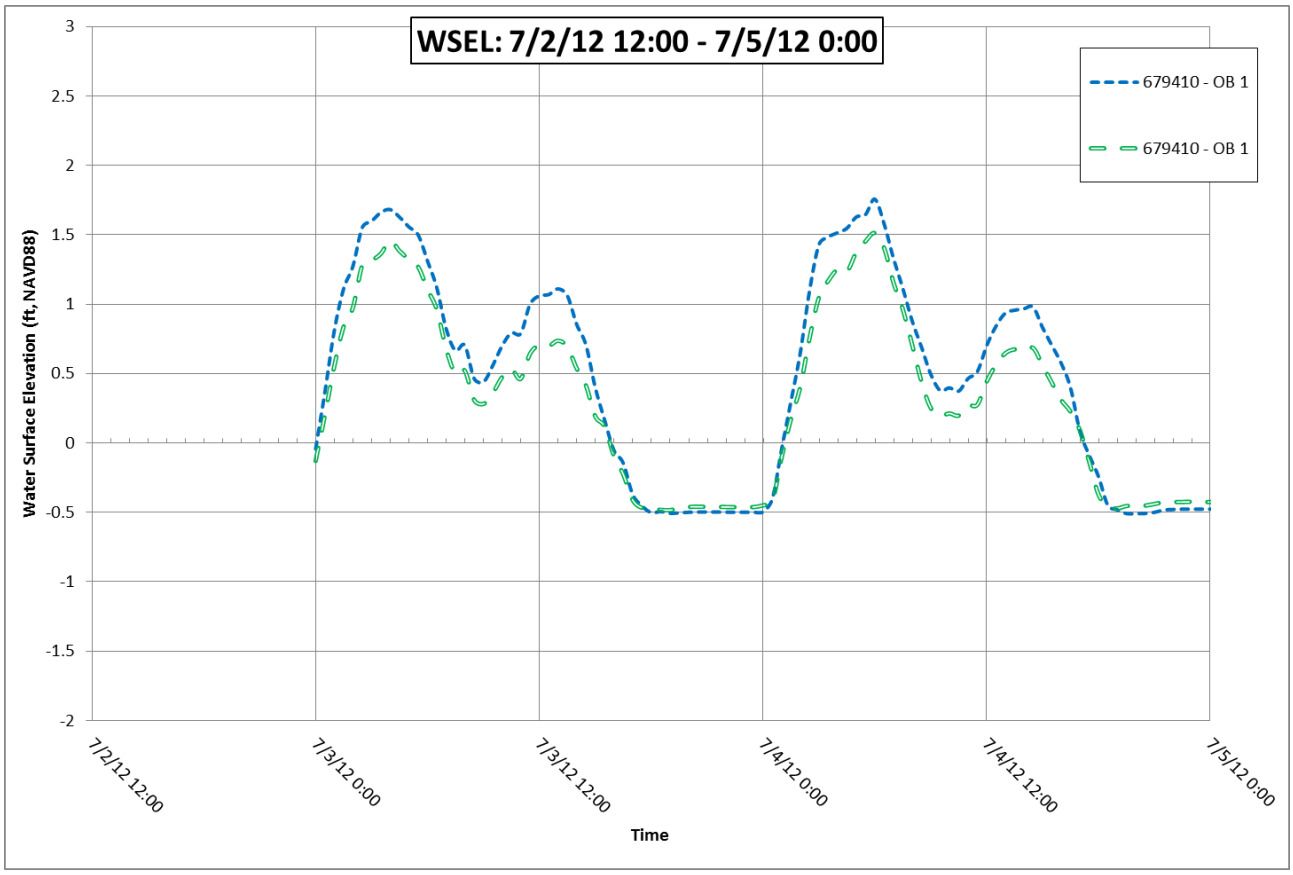
8/1/12 12:00
8/6/12 12:00
Time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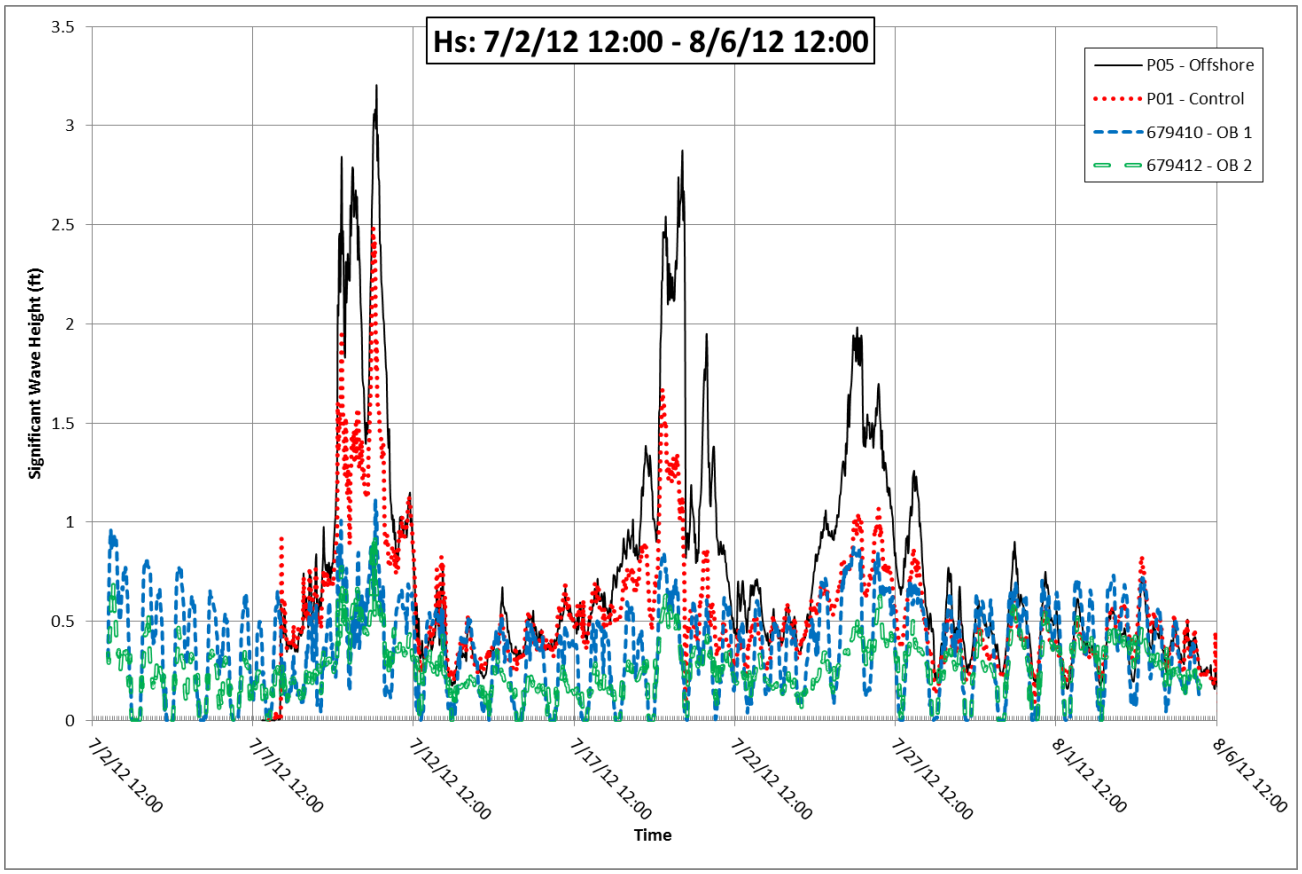
679410 - OB 1
679410 - OB 1
Water Surface Elevation (ft, NAVD88)
3
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
7/2/12 12:00
7/3/12 0:00
7/3/12 12:00
7/4/12 0:00
7/4/12 12:00
7/5/12 0:00
Time

APPENDIX 3

Significant Wave Height Plots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P05 - Offshore
P01 - Control
679410 - OB 1
679412 - OB 2
Significant Wave Height (ft)
3.5
3
2.5
2
1.5
1
0.5
0
7/2/12 12:00
7/7/12 12:00
7/12/12 12:00
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7/22/12 12:00
7/27/12 12:00
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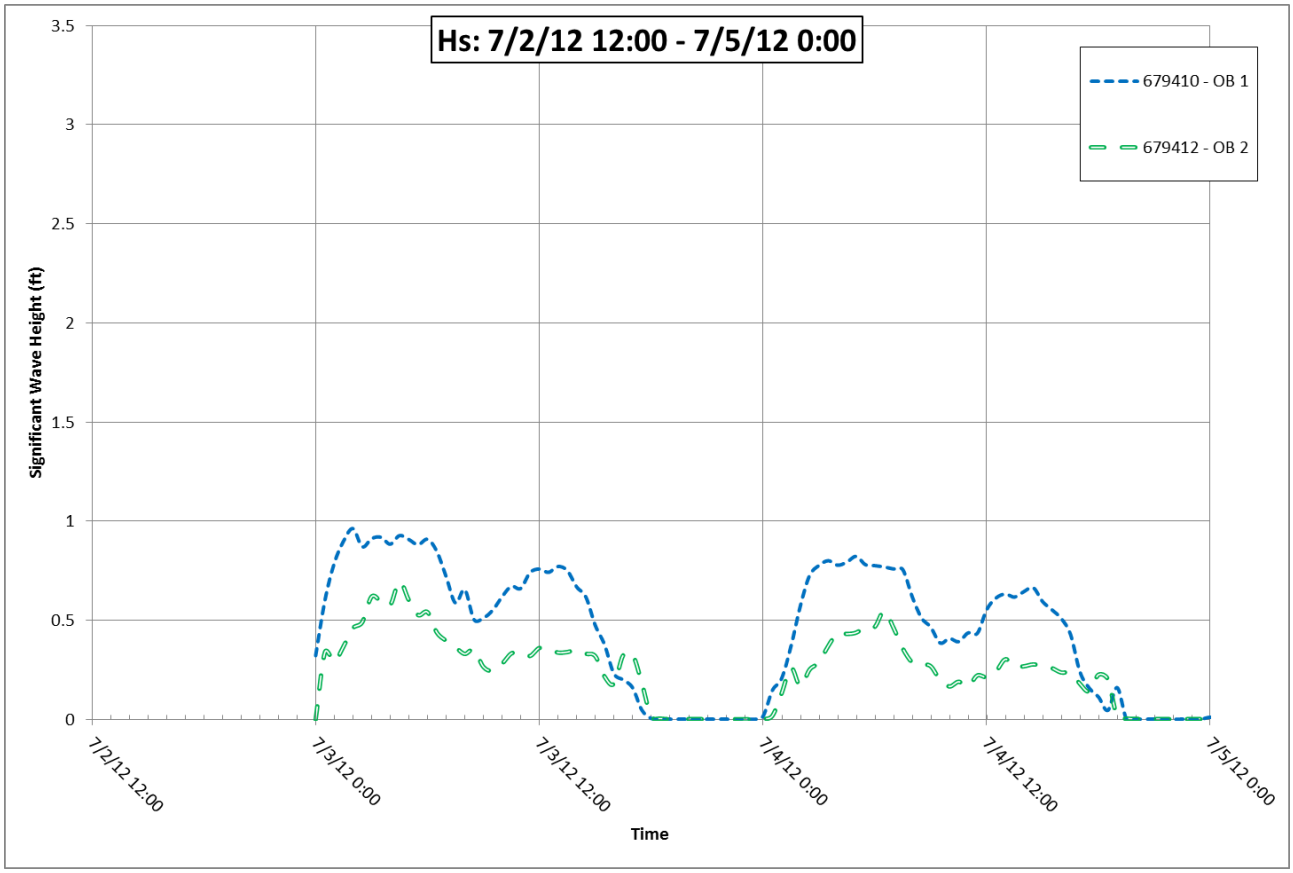
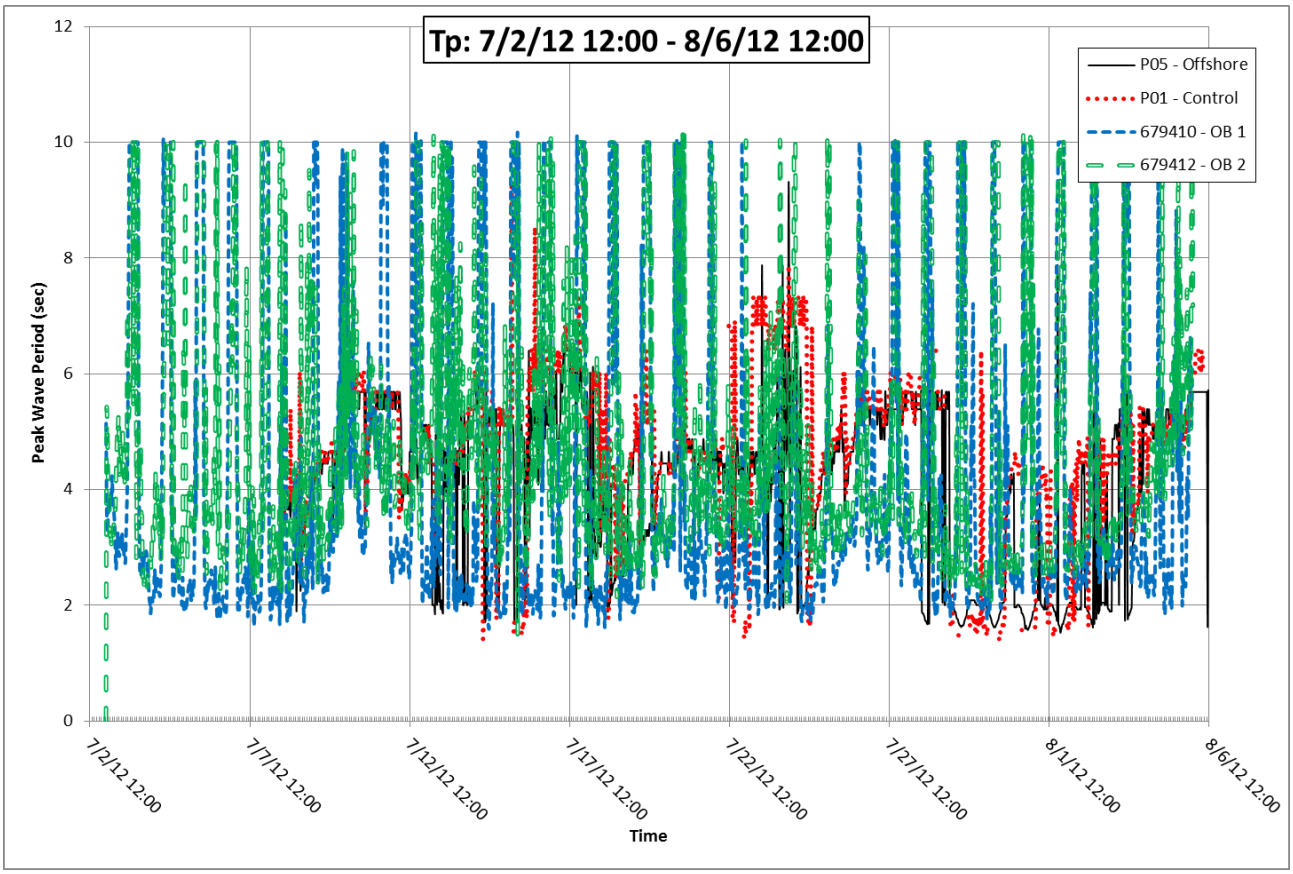
8/6/12 12:00
Time


Hs: 7/2/12 12:00 - 7/5/12 0:00
679410 - OB 1
679412 - OB 2
Significant Wave Height (ft)
3.5
3
2.5
2
1.5
1
0.5
0
7/2/12 12:00
7/3/12 0:00
7/3/12 12:00
7/4/12 0:00
7/4/12 12:00
7/5/12 0:00
Time

APPENDIX 4

Peak Wave Period Plots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P05 - Offshore
P01 - Control
679410 - OB 1
679412 - OB 2
Peak Wave Period (sec)
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4
6
8
10
12
7/2/12 12:00
7/7/12 12:00
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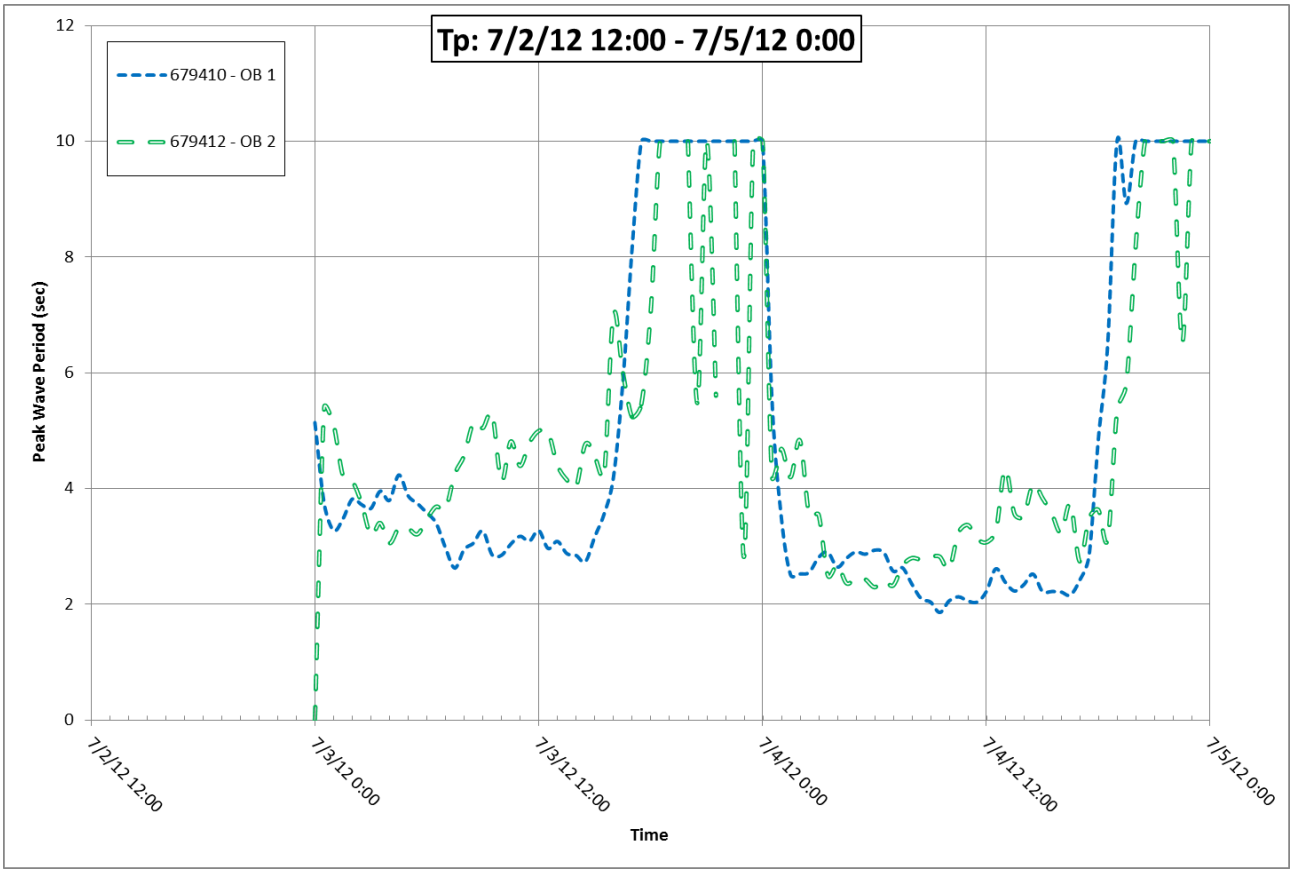
8/6/12 12:00
Time


Tp: 7/2/12 12:00 - 7/5/12 0:00
679410 - OB 1
679412 - OB 2
Peak Wave Period (sec)
0
2
4
6
8
10
12
7/2/12 12:00
7/3/12 0:00
7/3/12 12:00
7/4/12 0:00
7/4/12 12:00
7/5/12 0:00
Time

APPENDIX 7

Gage Installation Pictures

DANGER
UNDERWATER
OBSTRUCTION

APPENDIX B-ii

Hydrodynamic Data Collection Report
2014

(Data from individual observations were removed from original document)

BIOENGINEERED OYSTER REEF DEMONSTRATION PROJECT
PROJECT NO. LA-08
2014 HYDRODYNAMIC DATA COLLECTION REPORT

PREPARED FOR:

COASTAL PROTECTION AND RESTORATION AUTHORITY OF LOUISIANA

JULY 28, 2014

SUBMITTED BY:

BIOENGINEERED OYSTER REEF DEMONSTRATION PROJECT
PROJECT NO. LA-08
2014 HYDRODYNAMIC DATA COLLECTION REPORT

Prepared for: C.P.R.A.
Coastal Protection and Restoration Authority
Lafayette Field Office
P.O. Box 62027
Lafayette, LA 70596-2027

Submitted By: T. Baker Smith, LLC.
412 S. Van Ave.
Houma, LA 70363

BIOENGINEERED OYSTER REEF DEMONSTRATION PROJECT
PROJECT NO. LA-08
2014 HYDRODYNAMIC DATA COLLECTION REPORT

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<u>Digital Appendix</u>

- Data Collection Report File (DOC & PDF Format)
- Project Processed Data (.CSV)

2014 HYDRODYNAMIC DATA COLLECTION REPORT BIOENGINEERED OYSTER REEF DEMONSTRATION PROJECT PROJECT NO. LA-08

1.0 EXECUTIVE SUMMARY

This report details the second post-construction wave monitoring field data collection, conducted by T. Baker Smith, LLC (TBS), which was performed on the Bioengineered Oyster Reef Demonstration Project (LA-08). A series of gages, provided by Louisiana State University Department of Civil and Environmental Engineering (LSU), were deployed in the summer of 2014, for a period of one month, to monitor the amount of wave attenuation due to two prototype breakwaters. The data collected by wave staffs and pressure gages were compiled and analyzed, and the results are presented in this report.

2.0 PROJECT LOCATION

The breakwaters are located just offshore of the Rockefeller State Wildlife Refuge in Cameron Parish, LA at approximately 92.648649 North latitude and -092.805086 West longitude, or 31.45 miles southwest of Gueydan, LA. The site is typical for the western coastline of Louisiana, with sandy soils with emergent salt marsh behind the gradually sloping beach.

3.0 PROJECT OVERVIEW

Two engineered, oyster-promoting reef breakwaters were installed along the coastline of Rockefeller Wildlife Management Area and Game Preserve in Cameron Parish, LA in the Gulf of Mexico. The Bioengineered Oyster Reef Demonstration Project (LA-08) is a demonstration project on the 17th Project Priority List of the Coastal Wetland Planning Protection and Restoration Act (CWPPRA). These prototype breakwaters are being monitored to quantify the environmental effects on the surrounding coastline and wetlands. The monitoring program will be conducted for a period of four years after installation, and will include topographic surveys, bathymetric surveys, oyster monitoring, aerial photography, and spatial analysis. This portion of project monitoring consists of collecting wave data to observe the effects of wave attenuation due to the breakwaters. A series of staff and pressure gages were installed in the vicinity of the breakwaters to collect data over a one month period. The data were then analyzed and water surface elevation, significant wave height, and peak wave period were calculated as a function of time.

4.0 FIELD DATA COLLECTION

Wave heights and periods may be recorded by multiple types of instruments. This project utilizes two different types of instruments; wave staffs and pressure sensors. The wave staffs directly measure water levels and provide very precise results. However, wave staffs are more likely to be damaged in larger wave environments. Therefore, pressure sensors were selected for locations with an anticipated higher wave climate. Pressure sensors were mounted near the sea bed, allowing them to withstand high wave energy environments while recording water surface measurements accurately. Pressure sensors measure the static and dynamic components of the water pressure as the waves directly overhead pass by. This data then can be converted to water level readings, and ultimately be compared to the data obtained by the wave staffs. The following sections will detail the instrumentation deployed.

5.0 FIELD EQUIPMENT INSTALLATION METHODOLOGY

Wave staff gages "S01" and "S02" were placed on the landward side of each breakwater structure. Figure 1 depicts the location of these gages relative to the breakwaters. These locations were chosen to measure the amount of wave transmission through the breakwaters. Wave staff gages were selected as the instrumentation for the two breakwater sites because water depths between the structures and shoreline are shallow, due in part to a salient/tombolo formation behind the eastern breakwater. Installation of pressure gages at these two locations may have caused data loss if the gages were to become un-submerged during low tide events.

Figure 1: Staff Gages - Layout and Orientation

In order to provide comparison of wave heights between the protected (oysterbreak structures) and unprotected shorelines, a "control" gage "P03" was placed on an unaltered section of shoreline approximately 2700' east of the breakwaters. The water depth at the control gage location was slightly deeper than the breakwater gage locations because of the relatively steeper nearshore slope at this site. A pressure gage was selected for this location to allow for continuous data collection through all tidal fluctuations and to account for the potentially large wave heights that would have damaged wave staffs.

In order to obtain a record of untransformed, incident waves approaching each of the nearshore gages, an offshore (pressure) gage "P04" was placed approximately at the (-)6 ft. (NAVD88) contour. Specifically, the gage was placed 1730 ft. eastward of east breakwater gage, between the breakwater gages and the control gage.

Figure 2: Staff and Pressure Gages - Layout and Orientation.

Table 1 shows some of the specifications of the gages chosen for this deployment. Appendix F provides the full data technical specifications of the instruments as well. Each gage used in this deployment was configured to record water levels at a frequency of 10 Hz. for a period of 20 minutes starting every half hour, which provided 576,000 samples per day (48 bursts). Table 2 summarizes the sampling frequency. All four gages were set to start recording on April 8th, 2014 at 21:00 (9 PM) UTC (Coordinated Universal Time). This start time was set to ensure that each

gage was functioning before deployment and to provide a baseline reading before being submerged or installed. The staff gages "S01" and "S02" were deployed at approximately 16:00 (4PM) UTC on April 9th, 2014. The pressure gages "P03" and "P04" were deployed at approximately 18:00 (6PM) UTC on April 9th, 2014. All four sensors were then retrieved at approximately 18:00 (6PM) UTC on May 15th, 2014. Table 3 depicts the periods of observation for each of the gages.

Table 1: Instrument Property Summary

Instrument	Model	Range (Accuracy)	# of Units	Parameter
Wave Staff "S01" "S02"	Wave Logger: OSSI-010-004E	0-1 meter (±0.25%, 20-80% of full scale)	2	Wave Height, H_{mo} Peak Wave Period, *Tp* Water Level, *h*
Wave Gage "P03" "P04"	Wave Gauge: OSSI-010-003C	0-3 bars (±0.05% full scale)	2	Wave Height, H_{mo} Peak Wave Period, *Tp* Water Level, *h*

Table 2: Instrument Recording Intervals and Sampling Frequency

Instrument	Model	Parameter	Recording Intervals (min)	Recording Duration (min)	Sampling Frequency (Hz)
Wave Staff "S01" "S02"	Wave Logger: OSSI-010-004E	Water Level, m	30	20	10
Wave Gage "P03" "P04"	Wave Gauge: OSSI-010-003C	Pressure, P	30	20	10

Table 3: Observation Periods

	Deployment	
	Start Date	**End Date**
Wave Staff "S01" "S02"	16:00 (4PM) UTC April 9th, 2014	18:00 (6PM) UTC May 15th, 2014
Wave Gage "P03" "P04"	18:00 (6PM) UTC April 9th, 2014	18:00 (6PM) UTC May 15th, 2014

5.1 STAFF GAGES

The wave staff gages "S01" and "S02" consisted of a 1 meter sensor rod attached to the bottom of the data recording and power unit. The recording and power unit was contained within a lockable box with a hole drilled in the bottom to accommodate the sensor rod. The lock box was then u-bolted to a timber 4x4 which was water-jetted securely into the mud. The sensor rod was reinforced with small brackets connecting the lower portion of the rod to the 4x4 to prevent swaying of the sensor rod. Each 4x4 was placed shoreward and approximately in the center of each breakwater. The field crew was able to adjust and set the control boxes to approximately the same elevation. In an effort to fully capture the larger wave events, the bottom of the staff was set to approximately (-)0.05 ft. (NAVD88). Therefore, when the water elevation fell below (-)0.05 ft. (NAVD88), the sensor would not be able to measure the water level. However, due to the breakwaters and the shallow water depths attenuating wave energy, incident wave energy propagating through the breakwaters during periods of low water were negligible. Table 4 shows the recording elevations for each of the wave staffs. Figure 3 shows the wave staff and the dimensions. Figure 4 shows the wave staff installed inside the lockbox and deployed behind a breakwater.

Table 4: Wave Staff Locations and Elevations

Gage	Northing (ft., La. State Plane, NAD83)	Easting (ft., La. State Plane, NAD83)	Top of Lock Box (ft., NAVD88)	Bottom of Rod (ft., NAVD88)	Mudline (ft., NAVD88)
East: S01	420768.365	2813310.624	4.02	-0.045	-1.37
West: S02	420930.679	2813025.123	4.04	-0.11	-2.10

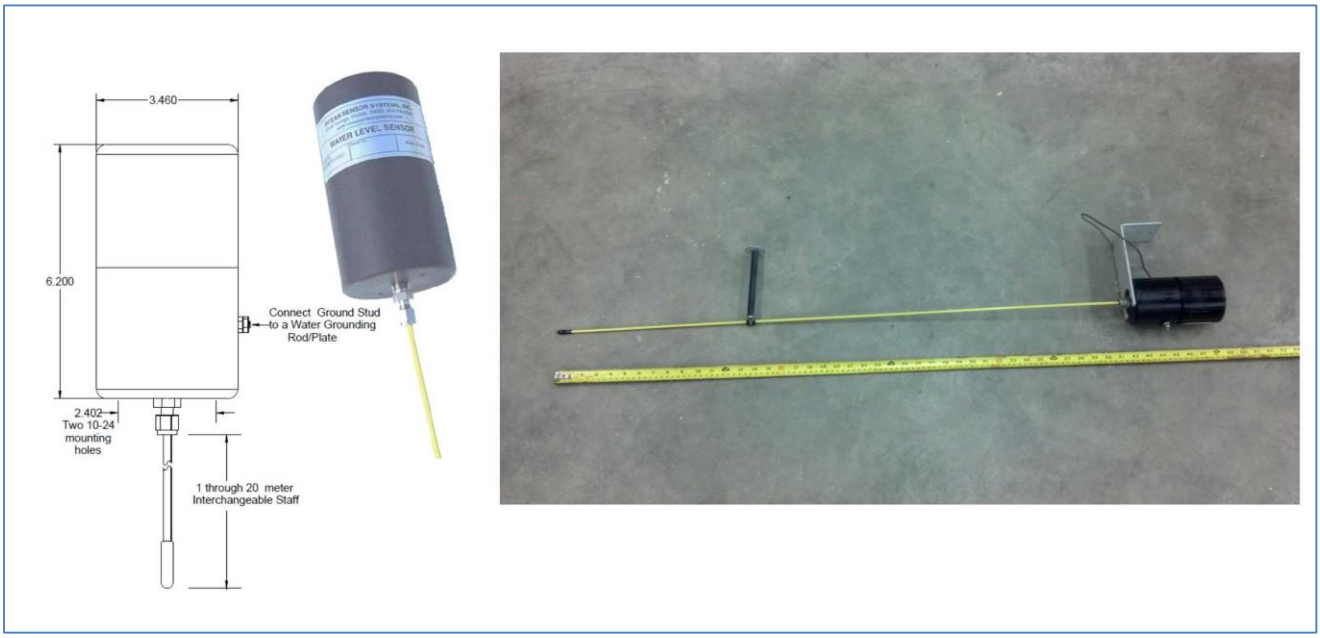


Figure 3: Wave Staff Gage Dimensions

Figure 4. Wave Staff and Lockbox

5.2 PRESSURE GAGES

The pressure gages were deployed by attaching them to a large, metal platform which was then anchored into the mud with a driven pipe. The pressure gages are tubular shaped with the sensor located in the center of the circular cap of one side of the gage. The tubular gage was then secured with U-bolts to the metal platform. The platform was then mated with the driven pipe with a collar on the underside of the platform, additional U-bolts were also installed on the platform to aid in retrieval. Tables 5 shows the location and elevations for the pressure gages. Figure 5 shows an image of the platform with the pressure gage installed.

Table 5: Pressure Gage Locations and Elevations

Gage	Northing (ft., La. State Plane, NAD83)	Easting (ft., La. State Plane, NAD83)	Sensor Elevation (ft., NAVD88)	Mudline (ft., NAVD88)
P03: Control	419756.897	2815908.836	-2.28	-3.07
P04: Offshore	419972.274	2814850.490	-5.525	-6.06

Figure 5: Pressure Gage mounted to Metal Platform

6.0 DATA PROCESSING

Coordinated Universal Time (UTC) was chosen as the time benchmark for this study. This allows for easier comparison to tide and water level readings from sources such as NOAA to aid in validating the processed data. For this report, unless explicitly specified as otherwise, time should be assumed to be in Coordinated Universal Time. For reference the difference between Coordinated Universal Time and Central Daylight Time is +5:00 hours. For example, 19:00 (7PM) in UTC corresponds to 14:00 (2PM) in CDT.

The staff gages "S01" and "S02" along with the pressure gages "P03" and "P04" were set to start recording on April 8th, 2014 at 21:00 (9 PM) UTC. This was done to verify functionality of the instruments and to provide baseline readings. The staff gages were deployed at approximately 16:00 (4PM) UTC on April 9th, 2014. The pressure gages were deployed at approximately 18:00

(6PM) UTC on April 9th, 2014. All four sensors were then retrieved at approximately 18:00 (6PM) UTC on May 15th, 2014.

6.1 THEORETICAL BACKGROUND

The data was processed using MatLAB, a numerical coding and programming environment. This program was used to process the raw data into the requested formats of water surface elevation, significant wave height, and peak wave period. The wave staffs recorded a direct observation of the water surface fluctuations and may be analyzed directly. For the two pressure gages, raw hydraulic pressure observations were transformed into water heights (above the sensor) using atmospheric pressure readings at the time of deployment. Pressure readings used for conversion were collected from NOAA Station 8768094 (Calcasieu Pass, LA.). The water level conversion process requires careful transformation due to the multiple components of hydraulic pressure (static and dynamic) during a wave cycle.

The staff gages were set to record water levels from the bottom of their staffs (approx. (-)0.075 ft. (NAVD88)) to the top of their staffs (approx. (+)3.21 ft. (NAVD88)). Therefore, when water surface elevations were below this range, the sensor was not able to record data. However, significant wave heights and water surface elevations never exceeded the upper recording limit of the wave staffs during the deployment. As mentioned previously, data collection was performed in bursts. Therefore, analysis was performed by treating each 20 minute burst of 10hz data as a standalone dataset of 12,000 readings. If more than 5% of a dataset recorded readings below 5 cm. (1.97 in.) on the wave staff, then that burst was disregarded for future analysis. Readings never exceeded the measurement upper limit. The resulting datasets that met this requirement were then analyzed using a Fast Fourier Transform (FFT) method which will be described next in the subsequent section.

Another method to analyze water level data on the wave staff data is to use a “zero-crossing method”. This method analyzes each wave as an independent data set. However, since the pressure signal obtained from the pressure sensors would need to be analyzed using the FFT method, the same analysis methodology was implemented for the wave staff datasets. This consistent analysis methodology allows for a direct comparison of H_{mo} (zeroth moment wave height) between the wave staffs and pressure sensors, so either method could have been applied to the water level data. Hs (Significant Wave Height) is defined as the average of the top third of all wave heights. In deep water, Hs (significant wave height) is very similar to H_{mo}. However, since the wave staffs are in shallow water, the difference between H_{mo} and Hs becomes much larger and can no longer be directly compared. For simplicity the plots and results found in this document, wave height is presented as Hs, but it should be noted that Hs is calculated from H_{mo}.

To obtain statistical wave heights and periods, a Spectral Density Analysis was performed on the time series data for each burst. A FFT analysis was performed to determine the frequency components of the pressure signal. A Hann window function was also used to smooth the spectral density curves. The pressure response coefficient (Kp) was also applied to the data to correct for depth attenuation of pressure. Once the wave energy spectrum was developed for each burst, the zero moment wave height was computed as:

$$H_{m0} = 4\sqrt{m_0}$$

where m_0 is the zeroeth moment of a half amplitude squared spectrum

The peak wave period, Tp, was calculated as the inverse frequency of the maximum spectral energy. The peak wave period was limited to 10 seconds to eliminate overestimation during calm, low wave energy days.

6.2 RAW DATA ADJUSTMENTS OR CORRECTIONS

The P03 gage was observed to have some "drift" in its mean values for data recorded during the second half of the observation period (approximately 14 days). The drift was found to only affect the overall mean water level values for each burst of data, therefore the individual water level data remained valid. This was the justification for the mean water level values for each burst in the P03 gage to be replaced with the mean water level values obtained from the staff gages during that corresponding burst. However, since the staff gages had gaps in the water level data (due to the water levels falling below the bottom of the wave staff), a cubic spline consisting of piecewise third-order polynomials was fitted to the existing points to generate the missing values.

The differences caused by adjusting the mean water levels in the P03 gage was analyzed. The adjustment has minor implications on the calculation of the wave heights. As mentioned above, the pressure gages recorded hydrostatic and an oscillating, dynamic pressure signals. Therefore, a pressure response coefficient must be calculated to account for the dynamic pressure effects on the total pressure signal. This coefficient is, basically, a function of water depth and wave length. Therefore, adjusted and unadjusted water surface levels or depth were used to generate a qualitative comparison of the coefficient. A 5% to 10% change in wave height resulted from analysis of the qualitative comparison. These differences were deemed acceptable for the purposes of this study. The same method was used to correct a slight sensor drift in the P04 sensor as well, which occurred toward the end of that dataset.

Another note is the staff gage data for the last week of the study period was omitted from the report, due to extreme variations observed in the water level observations. These variations were thought to occur from the brackets attaching the wave staffs to the 4x4 coming loose. The data

shows that the brackets came loose approximately 5-7 days towards the end of the deployment. However, four, full weeks of quality data were recorded, as required.

7.0 ANALYSIS AND DISCUSSION

TBS will not formulate an opinion on the precise effectiveness of the breakwaters, but will provide discussion of the resulting data and discuss observations made in the field during the monitoring event. The 2014 hydrodynamic monitoring event yielded quality wave statistics, which may be used to quantify the amount of wave attenuation due to the breakwaters during a typical springtime coastal wave climate in Louisiana.

Figure 6 is a graph which depicts offshore wave heights (Gage P04) as compared to nearshore wave heights (Gages S01, S02, and P03). The graph indicates a trend that larger wave heights (> 1.5 ft.) recorded at the control gage are slightly smaller as compared to the larger wave heights recorded at the offshore gage. This is attributable to the large, offshore wave energy being dissipated due to increased bottom friction, soil porosity caused by the interaction of a larger wave propagating through the surf zone, and wave breaking. However, the control gage and offshore gage recorded very similar wave heights for smaller waves, which is expected because these waves are not large enough to interact or "feel" the ground.

When comparing the staff gages to the offshore or the control gage, the staff gages recorded much smaller wave heights. This is attributed to the breakwaters greatly dissipating the incident wave energy, which is expected. However, the eastern staff gage recorded smaller wave heights as compared to the western staff gage. This may be a combination of several factors. The eastern staff gage was placed just west of a salient/tombolo formation forming behind the eastern breakwater. This morphological feature would have dissipated any wave energy generated from a south or easterly direction. Evaluation of the NOAA gage during the deployment showed that wind was generated from a southerly or easterly direction. This indicates that the combination of the breakwater and the salient/tombolo reduced the recorded wave heights behind the eastern breakwater. This is also indicative of predominant longshore sediment transport in the area, from east to west. For larger wave heights, the eastern and western gages recorded similar wave heights, indicating that wave energy was transmitting through the structures and the tombolo/salient formation equally.

Appendix A contains a drawing showing a plan view layout of the project with coordinates of the gages. Appendices B, C, D contains the water surface elevation, significant wave height, and peak wave period plots, respectively. Appendix E contains photographs taken during gage deployment and retrieval.

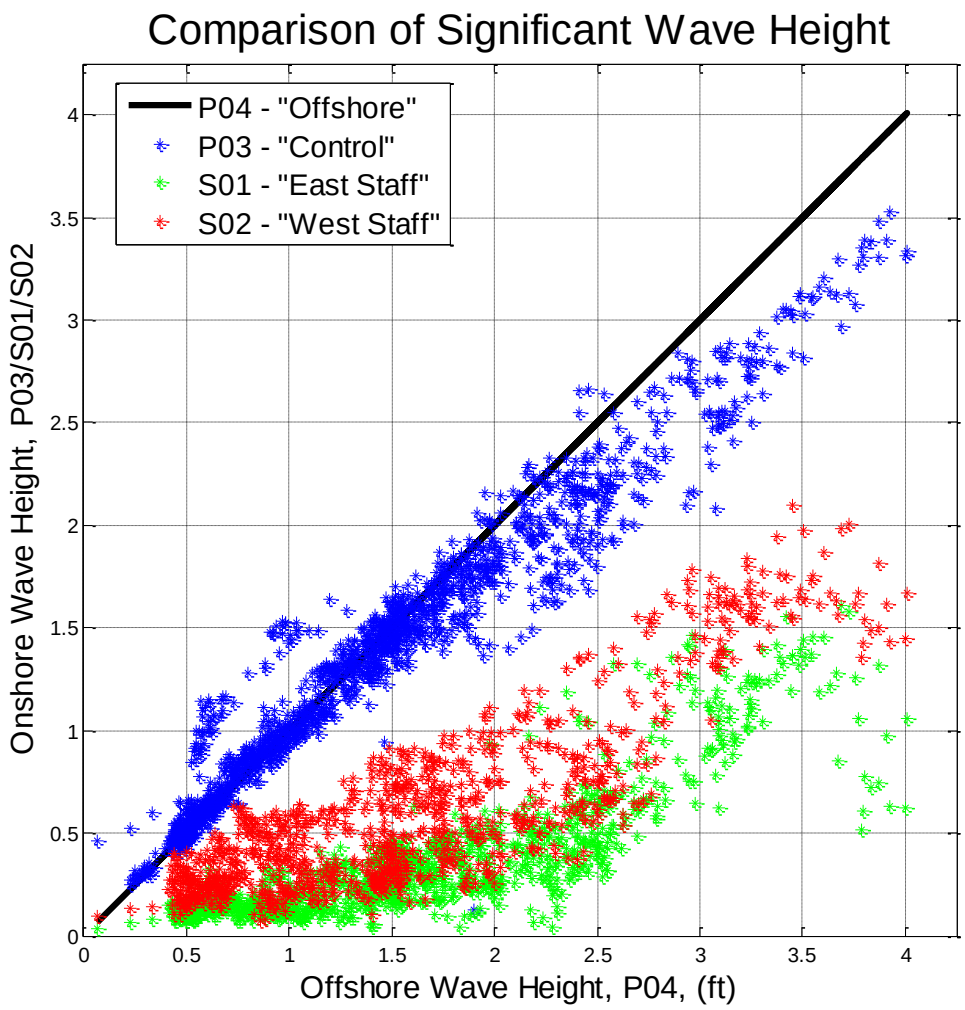
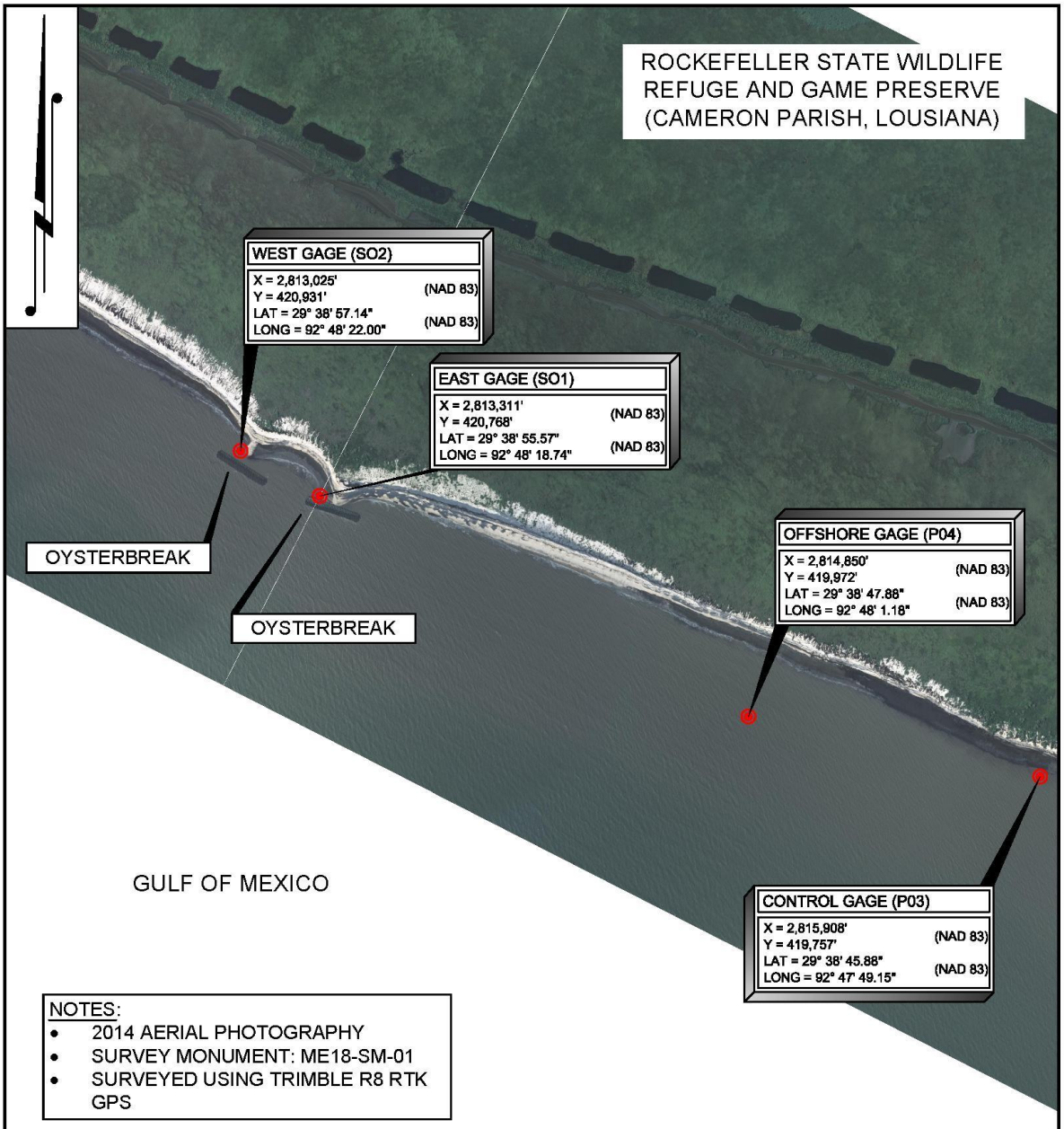


Figure 6: Comparison of Nearshore Wave Heights to Offshore Wave Heights

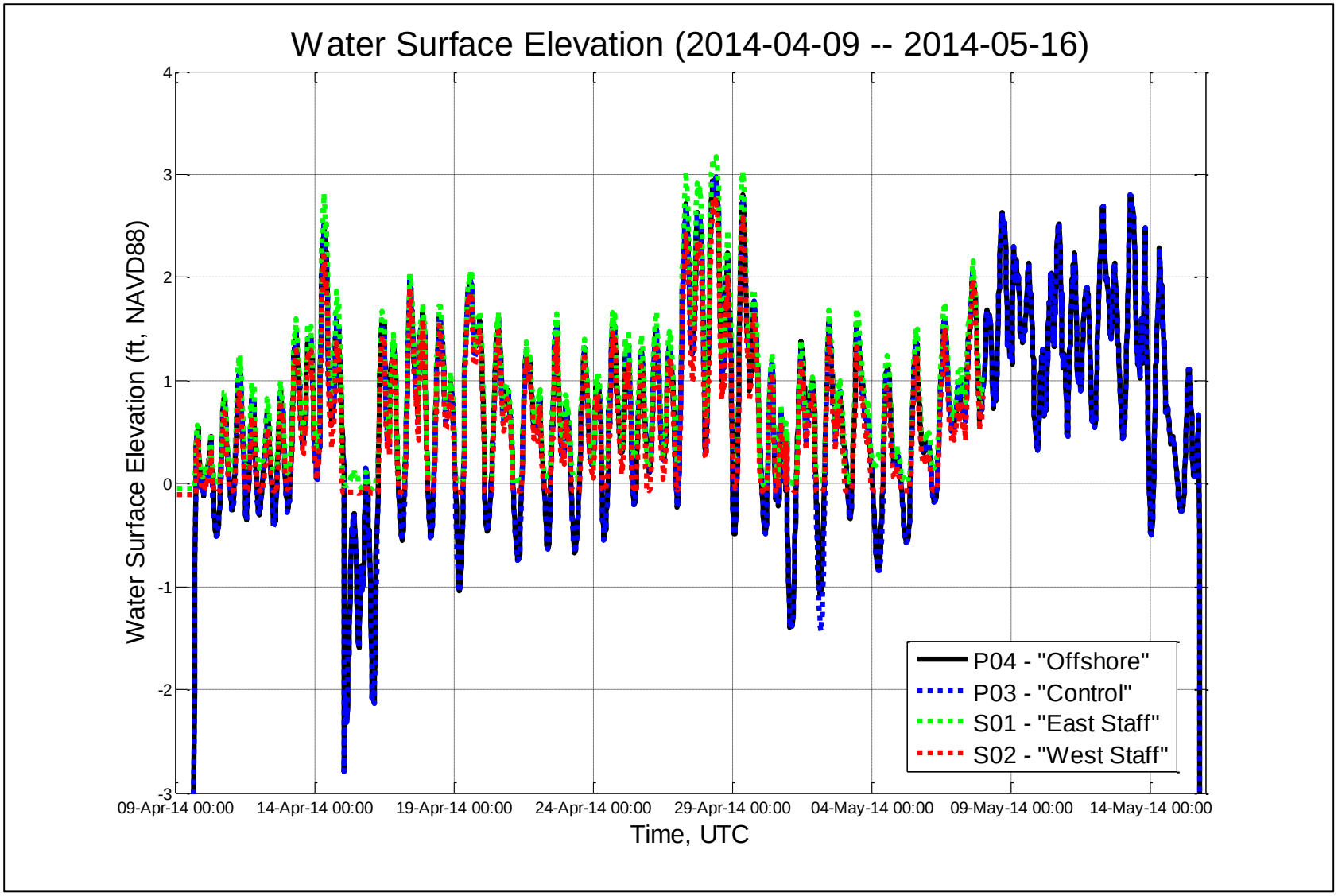
APPENDIX A

Project Layout


ROCKEFELLER STATE WILDLIFE
REFUGE AND GAME PRESERVE
(CAMERON PARISH, LOUSIANA)
WEST GAGE (SO2)
X = 2,813,025' (NAD 83)
Y = 420,931'
LAT = 29° 38' 57.14" (NAD 83)
LONG = 92° 48' 22.00"
EAST GAGE (SO1)
X = 2,813,311' (NAD 83)
Y = 420,768'
LAT = 29° 38' 55.57" (NAD 83)
LONG = 92° 48' 18.74"
OFFSHORE GAGE (P04)
X = 2,814,850' (NAD 83)
Y = 419,972'
LAT = 29° 38' 47.88" (NAD 83)
LONG = 92° 48' 1.18"
CONTROL GAGE (P03)
X = 2,815,908' (NAD 83)
Y = 419,757'
LAT = 29° 38' 45.88" (NAD 83)
LONG = 92° 47' 49.15"
OYSTERBREAK
OYSTERBREAK
GULF OF MEXICO
NOTES:
• 2014 AERIAL PHOTOGRAPHY
• SURVEY MONUMENT: ME18-SM-01
• SURVEYED USING TRIMBLE R8 RTK GPS
DRAWN BY: WAC
APPROVED BY: WAC
DATE: 6/23/14
JOB NO: 2012.0127
DRAWING NAME: GAGE LOCATIONS_EVENT 2.DWG
SHEET NO: 1 OF 1
PROJECTION: LOUISIANA STATE PLANE SOUTH ZONE
GEO. DATUM: NAD83 | VERT. DATUM: NAVD88
US SURVEY FEET
SCALE IN FEET
500' 250' 0' 500'
HYDRODYNAMIC MONITORING GAGE LOCATIONS
COASTAL PROTECTION AND
RESTORATION AUTHORITY OF LOUISIANA
BIOENGINEERED OYSTER REEF
DEMONSTRATION PROJECT
(LA-08)
T. BAKER SMITH
A CENTURY OF SOLUTIONS
412 South Van Ave, Houma, LA 70363
(985)868-1050 - tbsmith.com
1913
2013
REV. NO: 00
REV. DATE: --/--/--
REV. BY: --
REVISION DESCRIPTION:
--

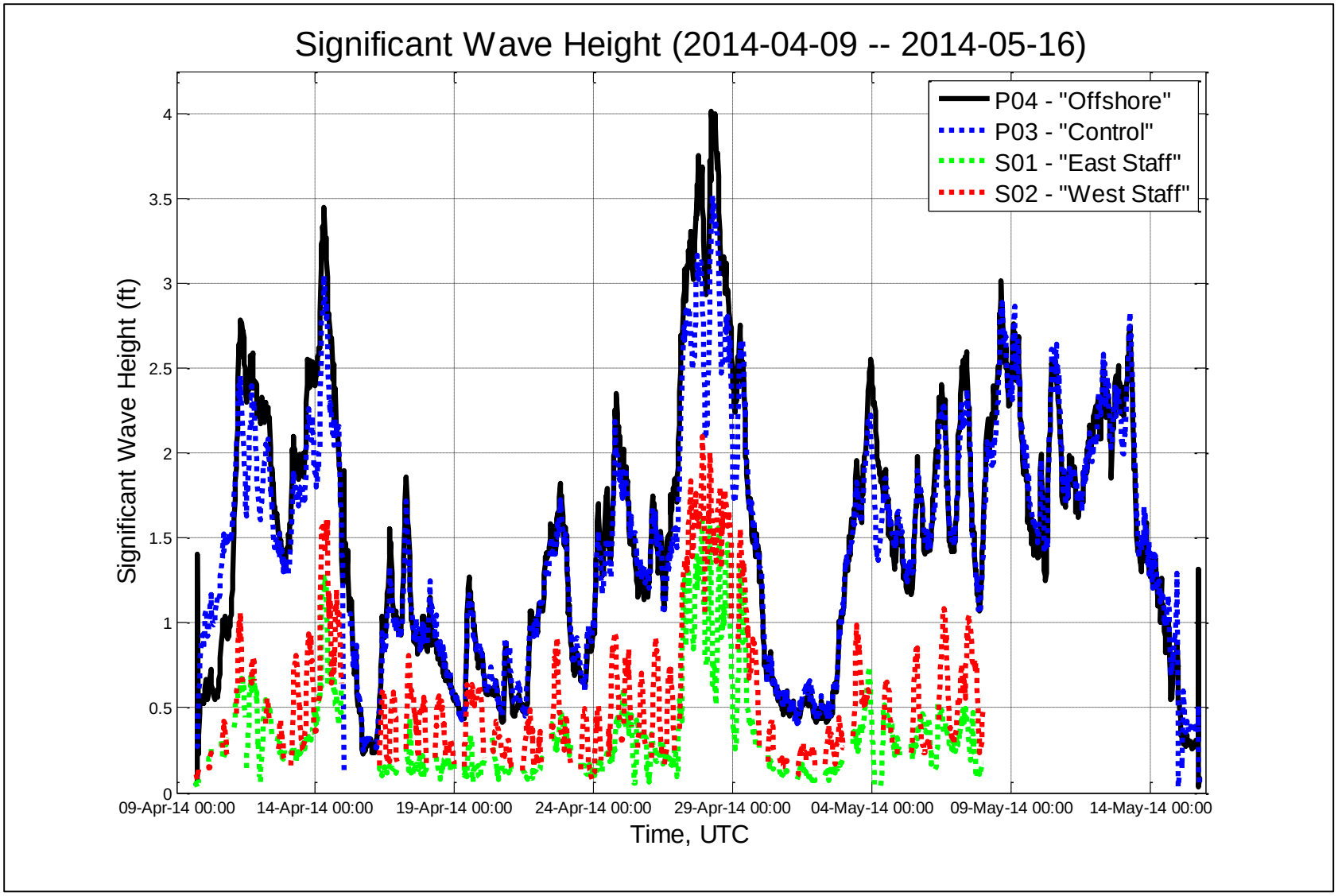
APPENDIX B

Water Surface Elevation Plots


Water Surface Elevation (2014-04-09 -- 2014-05-16)
Water Surface Elevation (ft, NAVD88)
4
3
2
1
0
-1
-2
-3
09-Apr-14 00:00
14-Apr-14 00:00
19-Apr-14 00:00
24-Apr-14 00:00
29-Apr-14 00:00
04-May-14 00:00
09-May-14 00:00
14-May-14 00:00
Time, UTC
P04 - "Offshore"
P03 - "Control"
S01 - "East Staff"
S02 - "West Staff"

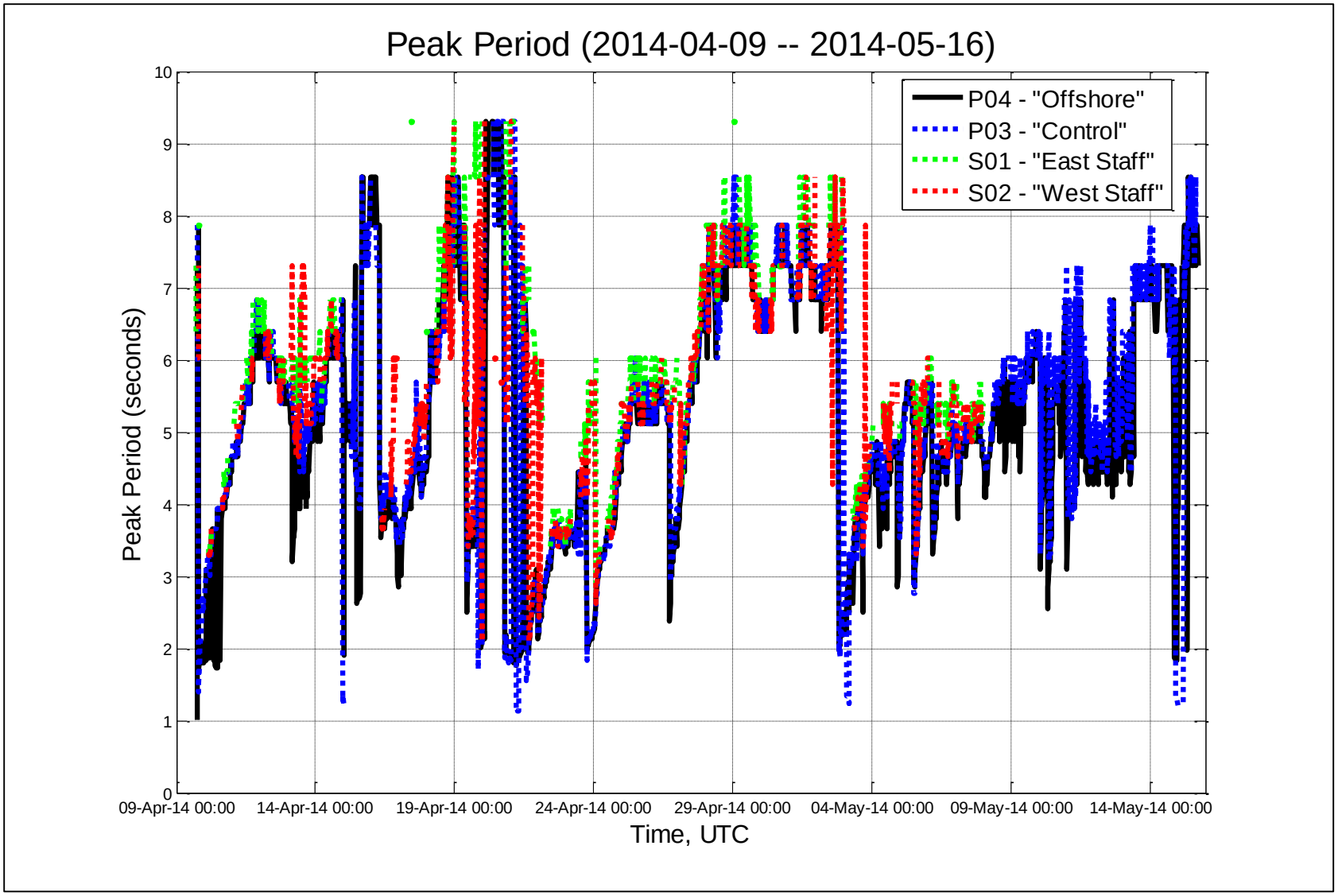
APPENDIX C

Significant Wave Height Plots


Significant Wave Height (2014-04-09 -- 2014-05-16)
P04 - "Offshore"
P03 - "Control"
S01 - "East Staff"
S02 - "West Staff"
Significant Wave Height (ft)
0
0.5
1
1.5
2
2.5
3
3.5
4
09-Apr-14 00:00
14-Apr-14 00:00
19-Apr-14 00:00
24-Apr-14 00:00
29-Apr-14 00:00
04-May-14 00:00
09-May-14 00:00
14-May-14 00:00
Time, UTC

APPENDIX D

Peak Wave Period Plots


Peak Period (2014-04-09 -- 2014-05-16)
P04 - "Offshore"
P03 - "Control"
S01 - "East Staff"
S02 - "West Staff"
Peak Period (seconds)
0
1
2
3
4
5
6
7
8
9
10
09-Apr-14 00:00
14-Apr-14 00:00
19-Apr-14 00:00
24-Apr-14 00:00
29-Apr-14 00:00
04-May-14 00:00
09-May-14 00:00
14-May-14 00:00
Time, UTC

APPENDIX E

Gage Installation Pictures

Figure 7: Deployment of Deepwater Marking Buoy (2014-04-09)

Figure 8: Deepwater Marking Buoy after Installation (2014-04-09)

Figure 9: Installed Wave Staff, "S01" East Staff (2014-04-09)

Figure 10: Recording "Top of Box" elevation of S01 East Staff Gage (2014-04-09)

Figure 11: S01 East Staff Gage Location Relative to Shoreline (2014-04-09)

Figure 12: Recording "Top of Plate" Elevation on P03 Control Gage (2014-05-15)

Figure 13. East Staff Gage with Salient/Tombolo Formation (2014-05-15)

Figure 14. West Staff Gage (2014-05-15)

APPENDIX F

Instrument Data Sheets

Ocean Sensor Systems, Inc.

Wave Gauge, OSSI-010-003B/C

A Self Logging/Self Powered Pressure Sensor

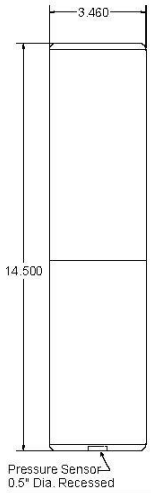
General Description

The OSSI-010-003B/C Wave Gauge combines a highly stable Pressure Sensor, a Compact Flash Card Data Logger, a rugged waterproof package and 12 or 28 C size Alkaline Batteries. A Low Power Microprocessor records up to 2 Gigabytes of data on a Compact Flash Card in an ASCII or Binary format with time and date. Then the Card is easily removed and can be read on any PC with a standard Compact Flash Card Reader. The Logger will collect months of continuous data or years of burst data. A serial port is provided as a user interface to configure and monitor the Wave Gauge. Standard pressure ranges are 0 to 1 Bar, 0 to 3 Bars and 0 to 10 Bars.

Features

- **Standard Compact Flash Card Data Storage**
- **Data storage up to 2 Gigabytes**
- **Standard Card Reader Compatible**
- **Power with 12 or 28 C Size Alkaline Batteries**
- **Flush Hastelloy Diaphragm**
- **ABS Plastic Housing Rated to 100 Meters**
- **Months of Continuous Operation**
- **Years of Burst Operation**
- **Rugged Sealed Waterproof Design**
- **Fully Programmable via RS232**
- **PC Interface Software**
- **Binary or ASCII Data Format**
- **Sample Rate From 2 Hz to 30Hz**
- **Burst or Continuous Sampling**
- **Accuracy ± 0.05% FS, 10 to 40** °C
- **Resolution 0.0033%FS**
- **Long Term Stability ± 0.05%FS**
- **Optional Water Temperature Logging**

Dimensions and Ordering Information



Pressure Range	Battery	Part Number
0 to 1 Bar (obsolete)	6 volt	OSSI-010-003B-01
0 to 3 Bars (obsolete)	6 volt	OSSI-010-003B-03
0 to 10 Bars (obsolete)	6 volt	OSSI-010-003B-10
0 to 1 Bar	18 volt	OSSI-010-003C-01
0 to 3 Bars	18 volt	OSSI-010-003C-03
0 to 10 Bars	18 volt	OSSI-010-003C-10
0 to 1 Bar Extended Case,	21 Volt	OSSI-010-003C-01E
0 to 3 Bars Extended Case	21 Volt	OSSI-010-003C-03E
0 to 10 Bars Extended Case	21 Volt	OSSI-010-003C-10E

Extended case for Dual 21V, 28 cell Battery Pack

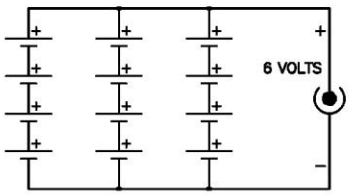
Ocean Sensor Systems Inc., Coral Springs FL, Tel. 954-796-6583 www.oceansensorsystems.com 1

Electrical Characteristics

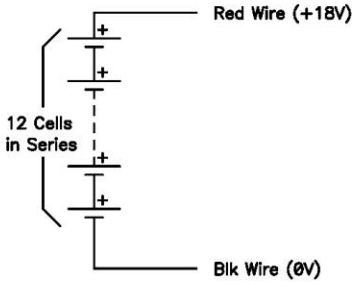
Parameter	Conditions	Min.	Typ.	Max.	Units
Battery Voltage	6 V, 12 cell battery	3.6	6.0	7.0	VDC
	18V, 12 cell battery (4)	9	18	35	VDC
	21V, 28 cell battery (3)	9	21	35	VDC
Temperature Range		-10		65	°C
Battery Drain, Sleep Mode	6 V battery Pack		3		mW
	18V battery Pack (4)		3.4		mW
	21 V battery Pack (3)		3.5		mW
Battery Drain	Sleep mode with RS232 Monitoring (1)		15.0		mW
Battery Drain, Continuous Sampling	6 V battery Pack		74.0		mW
	18V battery Pack (4)		65.2		mW
	21 V battery Pack (3)		66.2		mW
Battery Drain	Continuous Sampling with RS232 Monitoring (1)		90.0		mW
Battery Type, See schematic below	Alkaline 6V		12		C Cells
	Alkaline 18V		12		C Cells
	Alkaline 21V		28		C Cells
Battery Life Continuous Sampling	6 V battery Pack		2.5		Month
	18V battery Pack (4)		3.0		Month
	21 V battery Pack (3)		6.5		Month
Battery Life 25% Sample (2)	6 V battery Pack		8.5		Month
	18V battery Pack (4)		9.7		Month
	21 V battery Pack (3)		21.7		Month
Battery Life 10% Sample (2)	6 V battery Pack		16.7		Month
	18V battery Pack (4)		17.8		Month
	21 V battery Pack (3)		40.3		Month

(1) Powered up External Monitoring PC connected to RS232 Serial port.
(2) Industrial Alkaline Batteries 12 C cells totaling 102 Watt hr. Typ. or 28 calls totaling 238 Watt hr. Typ.
(3) Only available with the extended Wave Gauge case (Identified with the letter E at the end of the Wave Gauge part number)
(4) Version C Wave Gauge only

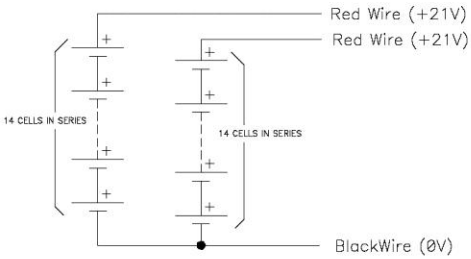
The 6V 12 alkaline C cells are connected in a Series, parallel arrangement.



The 18V 12 alkaline C cells are connected in a Series.



The 21V 28 alkaline C cells are connected in two groups of 14 cells connected in series.



Data Characteristics, Pressure

Parameter	Conditions	Min.	Typ.	Max.	Units
Pressure Numeric (4) Format & Units	OSSI-010-003C-01			+.99999	Bars
Pressure Numeric Format & Units	OSSI-010-003C-03			+3.0000	Bars
Pressure Numeric Format & Units	OSSI-010-003C-10			+9.9999	Bars
Data Accuracy (1)(2)(3)	10 to 40 °C			0.05	±% FS
Data Accuracy (1)(2)(3)	-10 to 65 °C			0.1	±% FS
Data Resolution			0.0033		% FS
Long Term Stability	OSSI-010-003C-01		0.0005		Bar
Long Term Stability	OSSI-010-003C-03, -10		0.05		% FS

(1) Linearity + Hysteresis + Repeatability + Temperature Coefficients + Zero + Span Tolerance
(2) Accuracy and Resolution are valid for Basic Pressure Range
(3) Linearity: Best Straight Line
(4) The 1 bar unit data format when over full scale (greater than +.99999) reads 1.00000 to 1.25000

Data Characteristics, Temperature

Parameter	Conditions	Min.	Typ.	Max.	Units
Temperature Numeric Format & Units	0 to 62.4375 °C			+999	counts
Temperature Data Resolution	Per count from 0°C		0.0625		°C
Temperature Accuracy	-10°C to 65°C			1.25	± °C

Timing and Interfacing Characteristics

Parameter	Conditions	Min.	Typ.	Max.	Units
Sample Frequency	Programmable	2		30	Hz
Serial Baud Rate			9.6		Kbaud
Flash Card Size	FAT16 format	64		2000	Mbytes
Sample Capacity 2000 Mbyte Flash Card	Binary IEEE 754 ASCII data			468 232	Msamples
Sample Burst Time	Programmable	1		60	minutes
Sample Burst Interval	Programmable	1		60	minutes
New File Interval	Programmable	1		255	days
Real Time Clock Accuracy				20	ppm

Battery Life Calculation:

Battery life is a function of Burst Time and the Burst Interval. It may be calculated with the following formula.

Calculate Drain power first: Dp = Sl + (Fs * (Bt / Bi))
Where Dp = Drain power in mW
Bt = Burst Time in minutes
Bi = Burst Interval in minutes

Power used with the 6V 12 Cell Battery Pack:
Fs = Power used during sampling = 74mW
Sl = Power used during sleep time = 3.0mW

Power used with the 18V 12 Cell Battery Pack:
Fs = Power used during sampling = 65.2mW
Sl = Power used during sleep time = 3.5mW

Power used with the 21V 28 Cell Battery Pack:
Fs = Power used during sampling = 66.2mW
Sl = Power used during sleep time = 3.5mW

Now Calculate Battery Life: Bl = Bc / Dp
Where Bl = Battery Life in Hours
Bc = Battery Capacity in mWhr = 100,200mWhrs typ. for 12 C size alkaline batteries
Bc = Battery Capacity in mWhr = 233,800mWhrs typ. for 28 C size alkaline batteries
Dp = Drain Power in mW

Ocean Sensor Systems, Inc.

Wave Logger, OSSI-010-004

A Self Logging/Self Powered Wave Staff

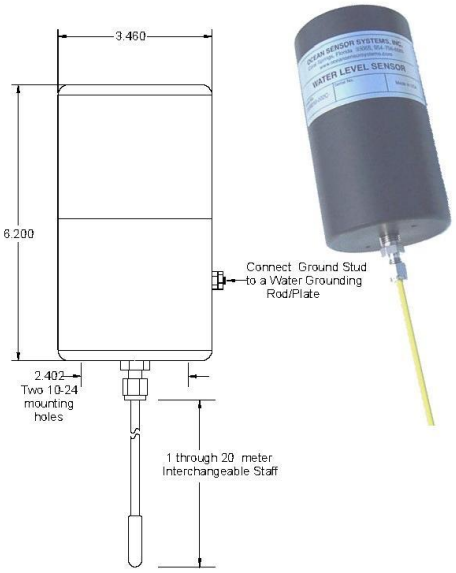
General Description

The OSSI-010-004 Wave Logger combines the high performance Wave Staff circuit, a Compact Flash Card Data Logger, a rugged waterproof package and 4 C size Alkaline Batteries. A low power microprocessor stores the data on a Flash Card in an ASCII or Binary format with time and date. Then the Card is easily removed and can be read on any PC with a standard Flash Card Reader. The Logger will collect months of continuous data or years of burst data. The Wave Staff circuit is temperature stable providing repeatable measurements to better than 0.1%. The Wave Logger is easily programmed via a PC serial port using our Wave Logger Interface Software or a Hyper Terminal program.

Features

- **Compact Flash Card Data Storage up to 2 GB**
- **Standard Card Reader Compatible**
- **4 C Size Alkaline Batteries**
- **Months of Continuous Operation**
- **Years of Burst Operation**
- **Rugged Sealed Waterproof Design**
- **Interchangeable Teflon Staff up to 20 meters**
- **Fully Programmable via RS232**
- **PC Interface Software**
- **Binary or ASCII Data Format**
- **Sample Rate Up to 30Hz**
- **Burst or Continuous Sampling**
- **Accuracy ± 0.25%, 20-80% of Full Scale**
- **Linearity 0.25%, 20-80% of Full Scale**
- **Resolution 0.025%**
- **Accuracy ± 1.0%, 0-100% of Full Scale**
- **Optional Air Temperature Logging**

Wire Configuration and Dimensions



Item Description	Staff Type	Part Number
1 Meter Staff	Teflon Coated Rod	OSSI-010-004-1
1.5 Meter Staff	Teflon Coated Rod	OSSI-010-004-1.5
2 Meter Staff	Teflon Coated Rod	OSSI-010-004-2
3 Meter Staff	Teflon Coated Rod	OSSI-010-004-3
4 Meter Staff	Teflon Coated Rod	OSSI-010-004-4
5 Meter Staff	Teflon Coated Rod	OSSI-010-004-5
6 Meter Staff	Teflon Coated Cable	OSSI-010-004-6
7 Meter Staff	Teflon Coated Cable	OSSI-010-004-7
8 Meter Staff	Teflon Coated Cable	OSSI-010-004-8
9 Meter Staff	Teflon Coated Cable	OSSI-010-004-9
10 Meter Staff	Teflon Coated Cable	OSSI-010-004-10
11 Meter Staff	Teflon Coated Cable	OSSI-010-004-11
12 Meter Staff	Teflon Coated Cable	OSSI-010-004-12
13 Meter Staff	Teflon Coated Cable	OSSI-010-004-13
14 Meter Staff	Teflon Coated Cable	OSSI-010-004-14
15 Meter Staff	Teflon Coated Cable	OSSI-010-004-15
16 Meter Staff	Teflon Coated Cable	OSSI-010-004-16
17 Meter Staff	Teflon Coated Cable	OSSI-010-004-17
18 Meter Staff	Teflon Coated Cable	OSSI-010-004-18
19 Meter Staff	Teflon Coated Cable	OSSI-010-004-19
20 Meter Staff	Teflon Coated Cable	OSSI-010-004-20
Standard operating temperature range is -10 °C to +65 °C add suffix T to Wave Staff part number for special -40 °C to +65 °C version		

Ocean Sensor Systems Inc., Coral Springs FL, Tel. 954-796-6583 www.oceansensorsystems.com 1

Electrical Characteristics

Parameter	Conditions	Min.	Typ.	Max.	Units
Battery Voltage		3.6		10	V
Battery Drain	Sleep mode		3		mW
Battery Drain	Continuous 20Hz Sample		6.8		mW
Data Accuracy	20-80% of Full Scale			0.25	±%
Data Accuracy	0-100% of Full Scale			1.0	±%
Data Resolution	Percent of Full Scale			0.025	%
Data Linearity	Percent of Full Scale			0.25	%

Data and Timing Characteristics

Parameter	Conditions	Min.	Typ.	Max.	Units
Sample Frequency (Note 1)	Programmable	2		30	Hz
Serial Baud Rate			9.6		Kbaud
Water Level Data	1 thru. 11 Meter Staffs, 0% to 100% Full Scale	0000		4095	counts
Temperature Resolution	Per count from 0°C		0.0625		°C
Temperature Accuracy	-10°C to 65°C -40°C to 65°C			1.25 2.15	± °C
Flash Card Size	FAT16 format	64		2000	Mbytes
Sample Capacity 2000 Mbyte Flash Card	Binary data ASCII data			936 388	Msamples
Sample Burst Time	Programmable	1		60	minutes
Sample Burst Interval	Programmable	1		60	minutes
New File Interval	Programmable	1		255	days
Real Time Clock Accuracy				20	ppm

Note 1: 20Hz maximum when Serial Data Output and Compact Flash Card are both enabled.

Battery Life:

Battery life is a function of Sample Frequency, Burst Time and the Burst Interval. It may be calculated with the following formula.

Calculate Drain power first: Dp = Sp + (Fp * (Bt / Bi))

Where Dp = Drain power in mW
Bt = Burst Time in minutes
Bi = Burst Interval in minutes
Fp = Power used per programmed Sample Frequency in mW as follows.
2Hz= 6.5mW, 5Hz=6.7mW, 10Hz= 6.9mW, 20Hz=7.2mW, 30Hz=7.5mW
Sp = 3mW, Power used during sleep time in mW

Now Calculate Battery Life: Bl = Bc / Dp

Where Bl = Battery Life in Hours
Bc = Battery Capacity in mWhr, 34,000mWhrs typ. for 4 C size alkaline batteries
Dp = Drain Power in mW

APPENDIX C

Oyster Monitoring Reports

APPENDIX C-i

Oyster Spat and Early Colonization

Bio-Engineered Oyster Reef Demonstration Project (LA-08) Mid-Term Biological Assessment February 2012-October 2013

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SUMMARY

The analyses from this mid-term data presented in this report, 2-years post construction, gives an opportunity to perform a basic assessment as to success of oyster colonization, survival and potential for reef development, but should not be interpreted as an assessment that one type of oysterbreak is better than the other. A more complete and robust assessment will be conducted in year four (4), the final contractual biological assessment year. The purpose of this interim report is to document the status of oyster reef development and to discuss observed environmental issues that must be addressed in the final assessment of success or failure. The interim assessment based on the 2-year data set and our observations are as follows:

- Mean oyster density per $0.0625m^2$ ($1/16\ m^2$) was similar between the Standard-Weight oysterbreak and the OysterKrete™ oysterbreak in October 2014. The mean density assessment is based on quadrat oyster data from top-tier rows #2 and #7 on the Standard-Weight oysterbreak, and rows #4 and #7 on the OysterKrete oysterbreak. This result is based on using top-tier-only rings with comparable-water depths. *Water depth, i.e., tidal depth, is a factor that must be used when comparing the two types of oysterbreaks. Water depth is explained below in other bullets.*

- Based on paired experimental cylinders, one a Standard-Weight (SW) and the other an OysterKrete (OK), there was no statistically significant difference between them in ability to recruit oyster spat, i.e., oyster densities were similar after deployment on March 2, 2013 and retrieval on October 28, 2013. *This experimental cylinder results is a mid-term data set for general interpretation of oyster activity at the sites, but should not be used for direct comparisons to the actual oysterbreaks which have diverse habitats, multiple tidal depths across the structures, and are subjected to harsher wave and other environmental activities.*

- Oyster shell heights on the top-tier rings between the two oysterbreaks are similar. By October 2013, oysters had grown on the OysterKrete oysterbreak to a modal height of 50-59.9 mm from a March 2013 modal height of 20-29.9 mm. Oysters have grown on the Standard-Weight oysterbreak from a modal height of 20-29.9mm in March 2013 to a modal height of 60-69.9mm. (*Oyster shell height* is *the measured distance from the shell hinge to most distal edge of the shell lip; sometimes in the lay community it is referred to as "length of shell"*).

- Based on oyster shell-height frequency analyses, the fall oyster recruitment event and survival appears to be more prevalent than the spring recruitment event.

- Collecting comparable oyster data from the two oysterbreaks is a challenge since there is a definite difference in tidal inundation, both within and between structures. The Gulfward edge of each oysterbreak is deeper, as expected, but the OysterKrete oysterbreak is in deeper water than the Standard-Weight Concrete oysterbreak. This water depth difference may be overcome by assessing specific rows of rings with similar depths on each oysterbreak when it is time to determine success or failure.

- Predation of oysters will be a factor in the success or failure of the oysterbreaks to develop and sustain an oyster reef. Predation in a relatively high salinity environment, such as in the coastal habitat where the oysterbreaks were placed, is tidal influenced. There is an abundance of the oyster predator, *Stramonita haemastoma*. This snail is considered the dominant predator on oysters greater than 10mm in shell height in Louisiana waters. Based on the presence of snails, the most likely habitat for oyster reef development will be the top-tiered rings on the oysterbreak since those rings are more intertidal than the lower-tiered rings beneath.

- Oysters usually remain in the water column for about 2-3 weeks during the late spring through early fall, and during this time are at the mercy of the prevailing currents. The closest known concentration of oysters spawners with a reef-type complex is in a bayou approximately 4.1 Kilometers (2.2 Nautical Miles) to the east. Initial recruitment of larvae may be coming primarily from this area since longshore currents predominantly flow east-to-west along the Louisiana coast. It is possible that as oysters recruit to the structures, they too will spawn and aid in new recruitment to the structures, if currents allow.

- Barnacles, mostly if not all *Balanus sp*., are abundant on the oysterbreaks. In the October 2014 survey barnacles were 35 times denser than oysters. Barnacles compete for space with oyster larvae, especially during early colonization. Over time, as oysters settle on the oysterbreaks, barnacles should become less of a factor and reef development is still possible.

- The Gulf ward edge of each oysterbreak, and therefore the deepest part of each oysterbreak, is encrusted with blue-green algae that will most probably remain year-round, but may not hinder oyster spat recruitment.

- The Gulf ward edge of each oysterbreak in the March 2013 assessment was covered with the filamentous green alga *Cladophora sp.*, and the folios green alga, *Ulva sp*, besides also have blue-green encrusting algae. Both algae species are relatively common in Louisiana on marine coastal structures in the winter through spring, but disappear by summer until the next winter. This should not interfere with the typically dominant pulses of spring and fall oyster spat recruitment.

INTRODUCTION

The Louisiana Coastal Protection and Restoration Authority (CPRA) authorized a oysterbreak demonstration project in 2007 as part of the state's Priority Project List #17 (PPL17). The PPL17 project is titled, "Bio-Engineered Oyster Reef Demonstration (LA-08)," hereafter referred to as Project LA-08. The primary purpose of this project is "to test a new, bio-engineered product to address rapid shoreline retreat and wetland loss along the Gulf of Mexico Shoreline in areas with soils of low load bearing capacity" (from LA-08 Fact Sheet from CPRA). This bio-engineered product is an oysterbreak reef made of stackable, concrete rings. One oysterbreak is composed of rings made from OysterKrete™ and the other oysterbreak is composed of rings made from Standard-Weight concrete. OysterKrete is a patented concrete mixture "specifically formulated to attract naturally occurring oyster larvae" (from http://wayfarertech.com/).

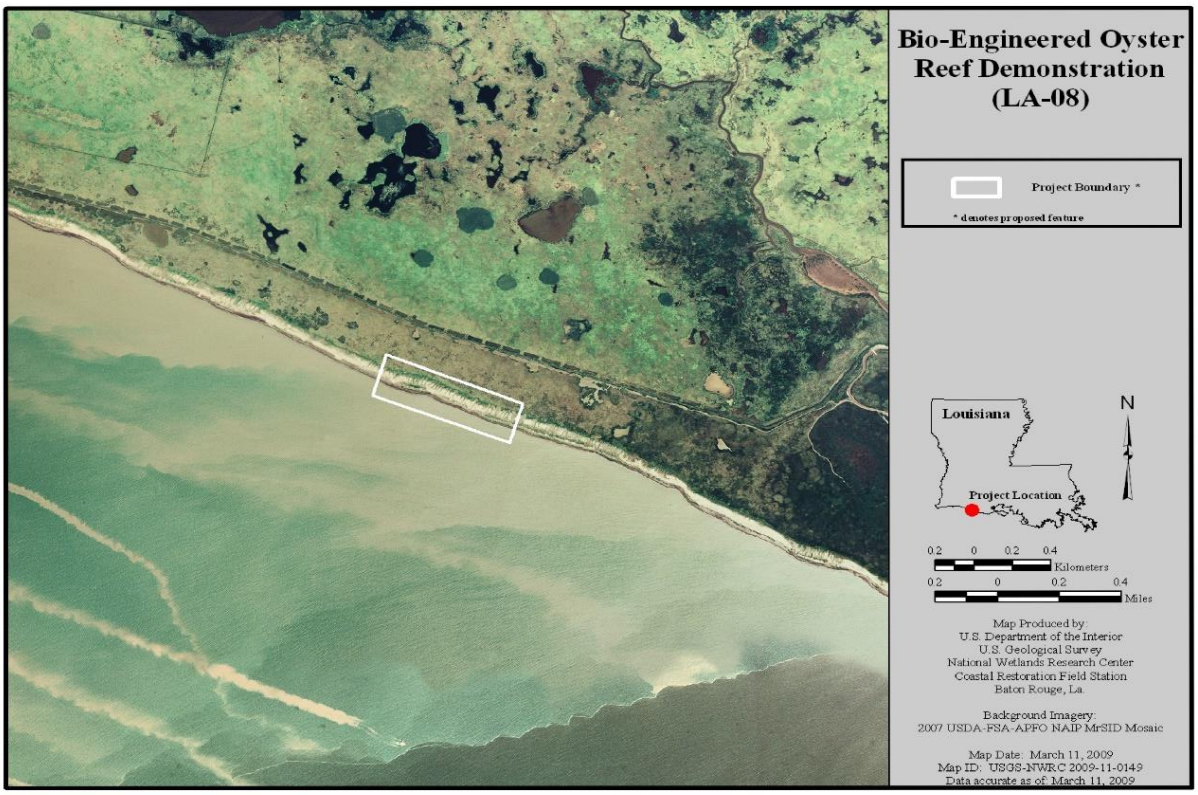

Figure 1. Location of Project LA-08 on Gulf Shoreline of Rockefeller Wildlife Refuge.

Oysterbreak construction was completed on February 18, 2012. "The reef area contains two, 215 ft. reef segments; the western oysterbreak is composed of Oysterkrete©, and the eastern Oysterbreak is composed of Standard-Weight concrete," (from McGinnis and Pontiff, 2012, Operations, Maintenance, and Monitoring Plan); hereafter, referred to as the OysterKrete (OK) and Standard-Weight Concrete (SW) oysterbreaks, respectively (Figure 2).

T-Baker Smith was awarded the biological assessment contract for the CPRA-funded project. The assessment is to document the efficiency of oysterbreaks in establishing an oyster population capable of developing a living reef. This is a mid-term year-two assessment, with another final and more robust assessment in year-four. The assessments are focused on the question if the OysterKrete oysterbreak (OK) is more efficient than the Standard-Weight concrete oysterbreak (SW) in the establishment and retention of an oyster population. The primary objective of this mid-term (second-year) biological report, approximately 21 months post-construction, is to assess the status of oyster recruitment and survival to the two oysterbreaks (Figure 2).

The biomass analyses from the mid-term data sets presented in this report should not be interpreted that one type of oysterbreak is better for oyster colonization and reef-building potential. Two, one-day sampling efforts with tidal fluctuations constrained our time on the oysterbreaks. A more complete and robust biomass assessment will be conducted in year-4, the final biological assessment year.

Figure 2. Aerial View of Completed Project LA-08 Oysterbreaks at near-High Tide along the Gulf of Mexico Shoreline; OysterKrete (OK) is to the West and Standard-Weight Concrete (SW) is to the East.

METHODS

Three one-day trips to project LA-08 were taken to develop this mid-term report. The first trip was on April 19, 2012, two months post-construction, the second on March 12, 2013, and the third on October 28, 2013. During the time between construction completion and the October 2013 biological assessment, two major storm events occurred, Hurricane Isaac in August 2012 (Appendix Figure A-1) and Tropical Storm Karen in October 2013 (Appendix Figure A-2). Because the oysterbreaks were placed in a tidal environment, and because all three trips were one-day events, effort was made to visit on a low or falling tide to allow adequate observations and assessments of the structures.

Personnel from T-Baker Smith on the April 19, 2012 and March 2, 2013 trips included Kiley Cressionie, Thomas Picou, Ronnie Duke and Earl Melancon, and Thomas McGinnis from the CPRA Operations Branch. Personnel from T-Baker Smith on the October 28, 2013 trip included Michael Trahan, Thomas Picou, Ronnie Duke and Earl Melancon, and Thomas McGinnis from the CPRA Operations Branch.

April 2012 Trip

This initial trip was to place equipment necessary to monitor oyster recruitment density, shell growth (height) of oyster spat and survival, and to place a continuous recording Onset HOBO U24-002 conductivity logger™ for water temperature and salinity recordings every hour. The logger was attached subtidally to a 5.1 cm (2 inch) pvc pipe securely driven into the muddy sand bottom between the two oysterbreaks. This technique of securing a logger to pvc pipe has worked successfully in other projects for long-term placement where storms have occurred.

Biological assessments tools to document oyster recruitment were placed in modified commercial crab traps with a coated wire mesh measuring 3.8 cm square (1.5 inch), but with no crab entrances (funnels) or escape rings. Each trap contained an unglazed quarry tile (Appendix Figure A-3) and a single experimental cylinder measuring 15x30cm (5.9x11.8in) of OysterKrete or Standard-Weight concrete. The cages were paired at each site, one with an Oysterkrete cylinder and the other with a Standard-Weight cement cylinder. Each trap was reinforced with iron rebar along the bottom horizontal axis of two sides to add weight, and each vertical corner reinforced with pvc pipe to increase rigidity (Appendix Figure A-3). Additionally, each trap was tethered to a 5.1 cm (2 inch) diameter schedule-40 pvc pipe anchored into the muddy sand bottom. A crab trap could only be accessed through a top-hinged mesh area.

The modified crab trap's mesh size, 3.8 cm (1.5 inch) square, is sufficient to allow water currents to carry oyster larvae through the cage and have them potentially set on the tiles and cylinders, while also keeping many predators out. Two sets of paired of crab traps were placed behind each oysterbreak (leeward side), two sets between the oysterbreaks, and two sets in front of each oysterbreak (windward side) for 10 sets of traps. Thus, cumulative numbers equaled 10

for experimental cylinders of each type and 20 for quarry tiles. In addition to placing the traps and data logger for monitoring purposes, the oysterbreaks were walked and observed to help develop future monitoring strategies.

March 2013 Trip

This trip to the oysterbreaks was approximately 11 months after the initial installation of monitoring cages during trip #1. During the time interval Hurricane Isaac occurred with at least tropical storm force winds experienced along the shoreline where the oysterbreaks are located (Appendix Figure A-1).

The temperature-salinity logger was either stolen or lost during a storm and no hourly data for the site exist. As stated earlier, this technique of strapping a logger to at pvc pipe has been successful for other long-term deployment, including through severe storms and hurricanes, but was unsuccessful here. The loss of the logger may be due to not accounting for the strong rip currents that probably occurred between the oysterbreaks, especially during storm activity. Additionally, all cages except four were lost. All four cages that were retrieved were located behind the oysterbreaks nearest the shore (leeward side of oysterbreaks) and therefore located in the shallowest habitat and truly intertidal. The lost cages in the front may have been lost for the same reason as the logger.

After the April 2012-depolyed cages were retrieved, a new set of cages with experimental cylinders and quarry tiles were deployed. However, this time each trap contained a pair of unglazed quarry tiles (Appendix Figure A-3) and a pair of experimental cylinders, each 15x30cm (5.9x11.8in), and made of the same material as the oysterbreaks; one of Standard-Weight concrete (SW) and the other OysterKrete (OK). In addition, this time all 10 cages were deployed behind the oysterbreaks, and therefore intertidal and leeward of potential Gulf wave and storm activity. Cages #1-5 were placed behind the Standard-Weight concrete oysterbreaks while cages #6-10 were placed behind the OysterKrete oysterbreaks. Another logger was deployed, but this time attached to a schedule-40 pvc pipe with electrical tape and then the pipe then secured to eastern-most permanent metal warning sign post with duct tape (Figure 2).

While the tide was relatively low, 0.0625 m^2 ($1/16^{th}$ m^2) oyster quadrat samples were taken from both oysterbreaks. Quadrat samples were taken from the top tier of rings on the upper rim facing windward by scraping into a plastic ziploc bag all organic material, which included not only the small oysters, but also barnacles and algae (Appendix Figure A-5). The focus of the March 2013 quadrat scrapings was to document colonization of multiple species and to determine if there was a significant difference in biomass based on location relative to tidal inundation. The oyster themselves were too small to focus exclusively on them, but is the primary focus of this project.

Each top-tier row site was labeled from Gulfward and from left to right, e.g., row 2 was more Gulfward (windward) and farther from the shoreline than row 4. Samples were taken from

specific rows of top-tier rings in a stratified random design, where a ring row was divided equally into five sections and a random sample taken from within each section. Therefore, each ring row that was sampled had five quadrats collected. Once collected, each oyster sample was bagged and labeled for transport back to the lab for analysis. Each oyster sample was dried to a constant weight in a convection oven at 80°C, then analyzed and graphed as described in the Results and Appendix sections.

October 2013 Trip

This trip was to retrieve sample materials deployed on the March 2013 trip. No new sample materials were placed at the site because the project will not be assessed again until fall 2015 when the final biological assessment occurs; at that time, assessment will be exclusively oysterbreak-based. Similar to the March 2013 trip, the Hobo temperature-conductivity probe was missing and lost. Just prior to the October assessment Tropical Storm Karen passed to the east of the site (Appendix Figure A-2).

Five stratified random quadrat biomass samples, 0.0625 m^2 ($1/16^{th}$ m^2) in area, were also taken on specific oysterbreak ring rows while the tide was relatively low. Samples were collected by prying off all oysters from within the quadrat area. Samples were taken from the top tier of rings on the upper rim facing windward. Oyster samples were transported in labeled plastic bags to the laboratory and meat removed from each shell. Oyster meat was dried in a convection oven at 80°C to a constant weight, then graphed and statistically analyzed as described in the Results and Appendix sections.

Unlike the quadrat samples collected on the March 2013 trip, where all organic material was scraped, which included barnacles and algae, the focus of the October 2013 trip was on oysters. Oysters had colonized and grown to a sufficient shell size to obtain the desired data without the interference of barnacles and algae. Therefore, the March 2013 quadrat samples cannot be compared to the October 2013 quadrat samples because of the different metrics that were used.

RESULTS AND DISCUSSION

Collecting comparable row biomass data from the two oysterbreaks is a challenge since there is a definite difference in tidal inundation between the two, as seen in Figure 2. The OysterKrete oysterbreak was placed in deeper water than the Standard-Weight oysterbreak, and therefore underwater more frequently due to tidal activity. This difference in tidal inundation could potentially skew data results and interpretation if not taken into consideration for final analyses. For example, water tidal height on top-tier ring row #2 on the normal-weight oysterbreak may be equivalent to ring row #4 on the OysterKrete oysterbreak (personal observations).

It must be noted that the pH of the cement used in all of the oysterbreaks is unknown to the authors of this report. The pH can potentially have an influence on initial oyster recruitment, but diminishes over time as the cement ages and cures in the seawater.

March 2013 Assessment

The number of replicate quadrate density samples per top-tier row of an oysterbreak, five, is a minimal number for biomass analysis and is reflected in the large standard deviation per row (Figure 3), but adequate for this mid-term report. Biomass density samples were scrapes of all tissue and shell within a quadrate, including algae, oysters and their shells, and barnacles and their shells. Individual biomass sample photos can be found in Appendix Figure A-7. In the photos, the filamentous green alga is *Cladophora sp.,* and the folios green alga is *Ulva sp.* Both algae species are relatively common on marine coastal structures in the winter through spring and disappear by summer until the next winter.

Water tidal height differences, and therefore daily differences in inundation duration can potentially have great influences on recruitment density of oysters, the density of fouling organisms such as barnacles and algae, predation rate from organisms like the oyster drill snail, as well as feeding rates, physiological stress and shell growth. Such physical differences due to tidal inundation differences could potentially cause misinterpretation of data when comparing the two oysterbreaks for oyster reef development. For example, the presence of blue-green algae (Cyanophyta) encrusted on the structures on the more Gulfward rings (Appendix Figure A-6) due to more frequent inundation and greater opportunity for colonization.

An example of tidal inundation duration influence is the biomass density samples which exhibited significant differences ($P<.05$) for top-tier rings row #2 on the Standard-Weight concrete oysterbreak compared to other row samples (Figure 3). Top-tier row #2 on the Standard-Weight oysterbreak, the more frequently inundated, was six times greater than the next highest biomass density found on the same oysterbreak, top-tier row #4; statistical analyses are found in the Appendix (Table A-1). Correspondingly, top-tier row #4 data for the Standard-Weight concrete oysterbreak was not significantly different from the OysterKrete oysterbreak (labeled as “OK” top-tier rings #6 and #7 in Figure 3). The Oysterkrete oysterbreak is in deeper water and similar in inundation frequency as row #4 on the Standard-Weight oysterbreak.

An oyster shell height (*the measured distance from shell hinge to most distal edge of shell lip*) frequency distribution can be used for generalized oyster recruitment and survival interpretations. Oysters in the northern Gulf of Mexico can spawn through most months of the year but usually have two major spawning events, one in the spring (April-May) when water temperatures are rising above 25°C and again in the fall (September-October) when water temperatures are cooling. This bimodal yearly event can usually be evident in the shell height frequency distributions for oysters a year or less in age, and during which time shell growth is relatively rapid. On average, oysters in a subtidal habitat with relatively good salinities (≥12psu)

and sufficient food can attain a shell height of 50-60mm or more within a year, while intertidal oyster growth may be somewhat slower.

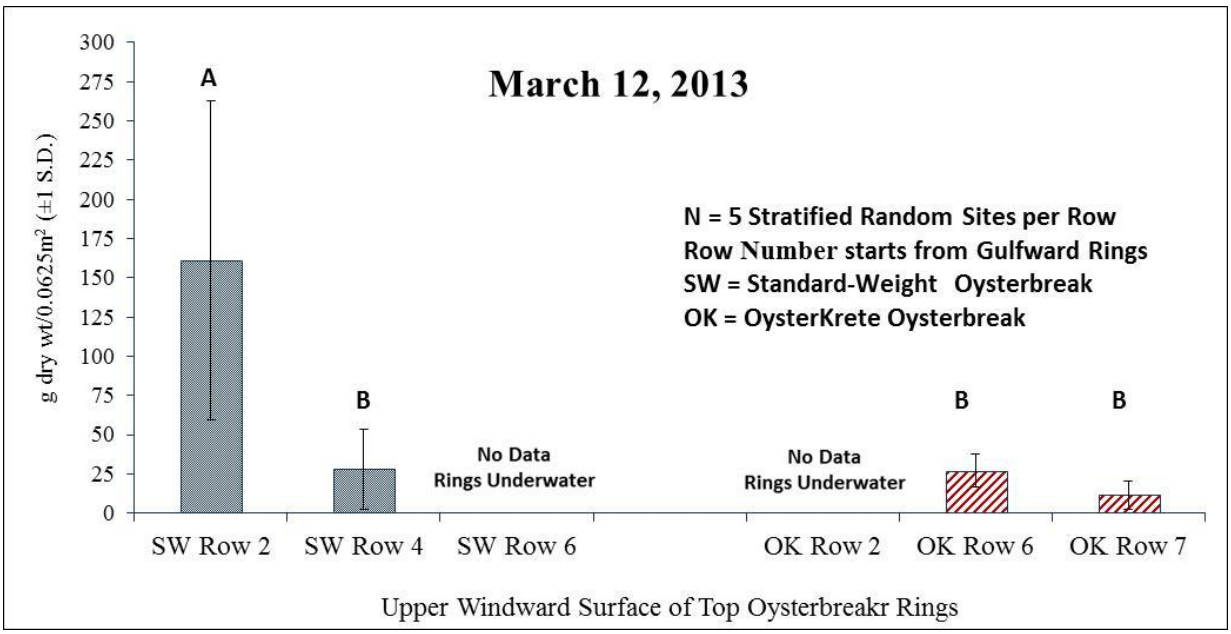

Figure 3. Mean (± 1 S.D.) Dry-Weight Biomass per Oysterbreak Ring Row based on Quadrat Samples Collected on March 13, 2013. If letters above each column are the same then no significant difference (P>.05), but if letters are different then there is significant difference (P≤.05). SW Row #6 and OK Row #2 were attempted for balanced assessment, but tidal height and wave activity prevented. (SW Row 6 was the last to be sampled, and was underwater before assessment could be adequately performed).

There were enough live oysters collected from the biomass quadrat samples in March 2013 to construct frequency distributions for oyster shell height (Figure 4). Live oysters on the two oysterbreaks had similar shell height frequency distributions, with the standard weight oysterbreak having a modal peak in the range 25-29.9mm, and the OysterKrete oysterbreak having a modal peak in the 20-24.9mm range. The majority of live oysters on both oysterbreaks were 25mm or less in shell height and therefore probably due to a fall 2012 or later recruitment. The larger sized oysters are probably due to a spring 2012 recruitment event.

Most of the experimental cages with experimental cylinders and glazed tiles were lost by March 2013, possibly due to the passage of hurricane Isaac (Appendix Figure A-1). Therefore, no density data for cylinders or tiles are presented for the 2013 assessment. However, enough oysters were present on the experimental cylinders to develop a frequency analysis of shell height to give a general interpretation of when the majority of oyster recruitment most likely occurred between April 2012 and March 2013 (Figure 5). The dominance of relative small oysters suggests a fall/winter 2012 set. The larger oysters, most probably survivors from the spring 2012 recruitment event, were all found on the OysterKrete cylinders (Figure 5). The larger oysters on the OysterKrete experimental cylinders could be coincidental or could arguably be due to better survival on the textured surface versus the smooth-surfaced Standard-Weight concrete cylinders. A textured surface with greater rugosity could potential protect oyster spat

from predators such as small Portunid and Xanthid crabs, which are known to be voracious predators on recently-set spat; recently-set oyster spat are usually no larger than 400microns (1/64 inch) in shell height. Experimental cylinders that were retrieved can be seen in the photos found in Appendices Figures A-8 and A-9.

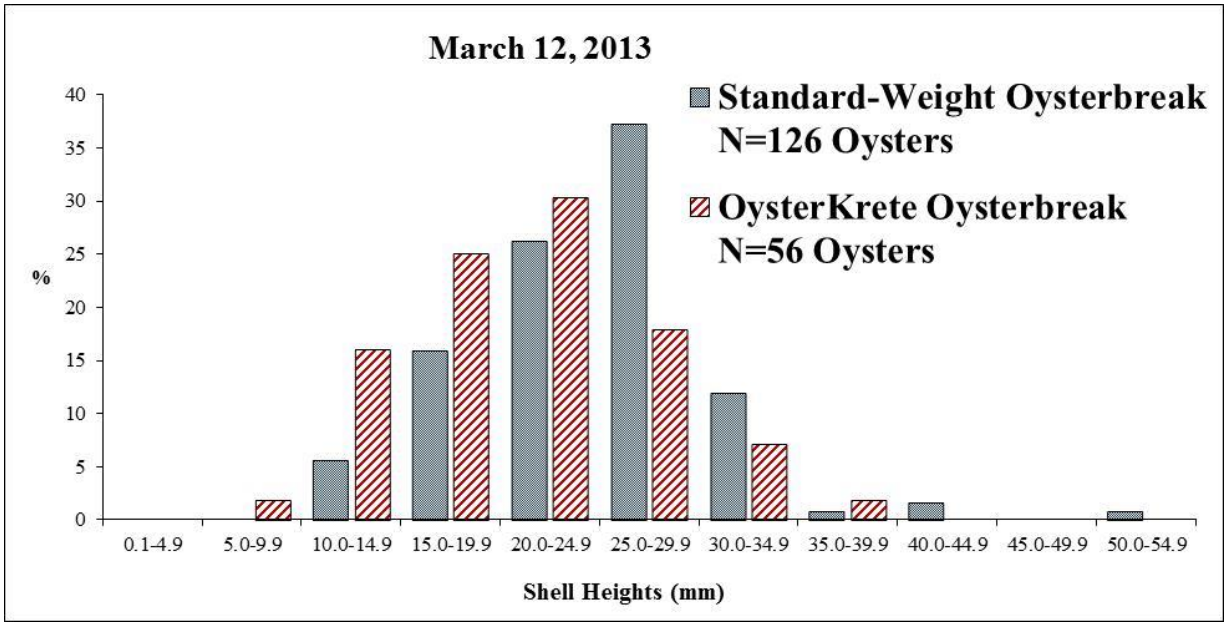

Figure 4. Oyster Shell Height Frequency Histogram for Oysterbreaks sampled March 12, 2013.

The shell height frequency distributions on experimental cylinders in March 2013 (Figure 5) are different from the oysterbreak frequency distributions (Figure 4) that were collected at the same time. The difference is due the fact that oysterbreak data is for a longer period of time for oyster recruitment and growth, and that oysterbreaks span multiple water depths. Such physical differences between experimental cylinder cage sites and oysterbreaks account for the greater shell height frequency distributions seen in Figure 4. This also supports the fact that oysters are recruiting and surviving on the oysterbreaks.

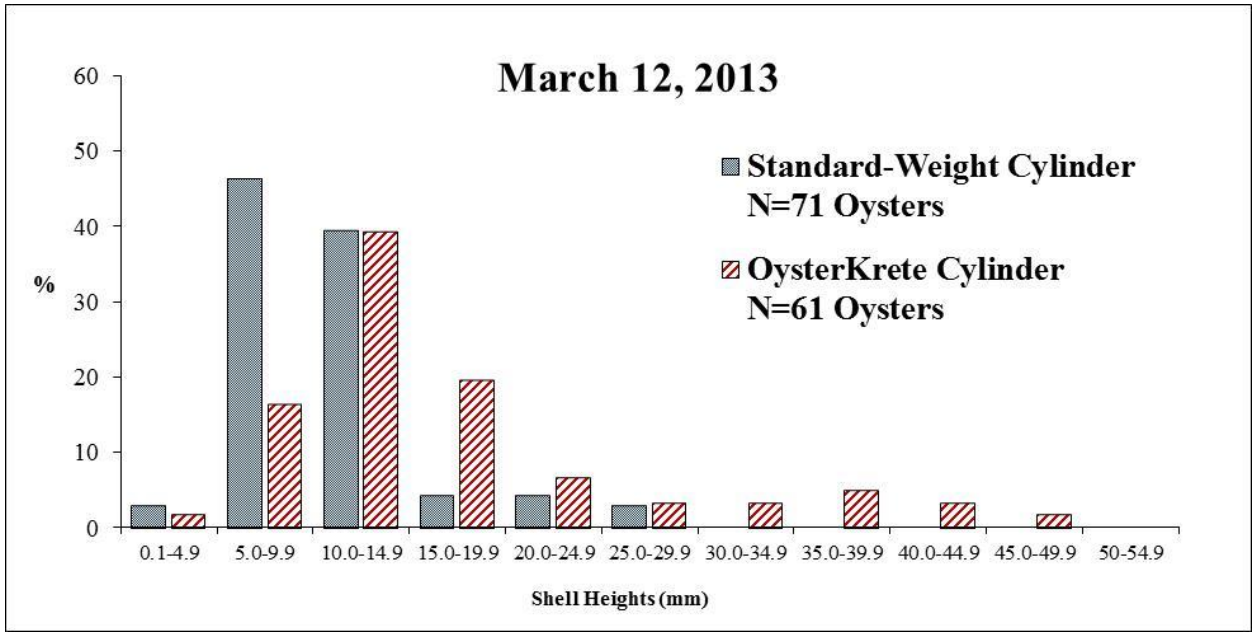

Figure 5. Shell Height Frequency Histogram of Oysters Attached to Experimental Cylinders in Cages Retrieved on March 12, 2013.

October 2013 Assessment

Although tropical storm Karen passed to the east of the LA-08 project just a few weeks prior to the October 2013 assessment (Appendix Figure A-2), there was only one experimental cage lost out of the 10 deployed. Unfortunately, the Hobo probe was lost and there is no documentation of water temperatures and salinities for the site.

Quarry tiles almost exclusively exhibited oyster spat that were less than or equal to 15mm in shell height (Figure 6). This indicates a relatively recent recruitment, probably an early fall 2013 event. Quarry tiles also have a distinction over that of many other substrates used for documenting oyster spat recruitment with the ability to document oyster spat "scars." An oyster scar is the remnant "footprint" of an oyster once it dies (for whatever reason). Recently set spat have a very thin and delicate shell that will easily separate at the hinge when death occurs, and will often leave only the remnant markings of the shell half that adhered to the tile, thus a "footprint." Spat scars were evident mostly in the 5.0-9.9mm range (Figure 6).

Further evidence of a predominantly early fall 2013 spat set, and correspondingly weak spring 2013 set can be seen in the experimental cylinders data (Figure 7). Additionally, unlike the limited data set of March 2013 (Figure 5), the October 2013 data set does not show any distinction in oyster shell height on the OysterKrete cylinders (Figure 7).

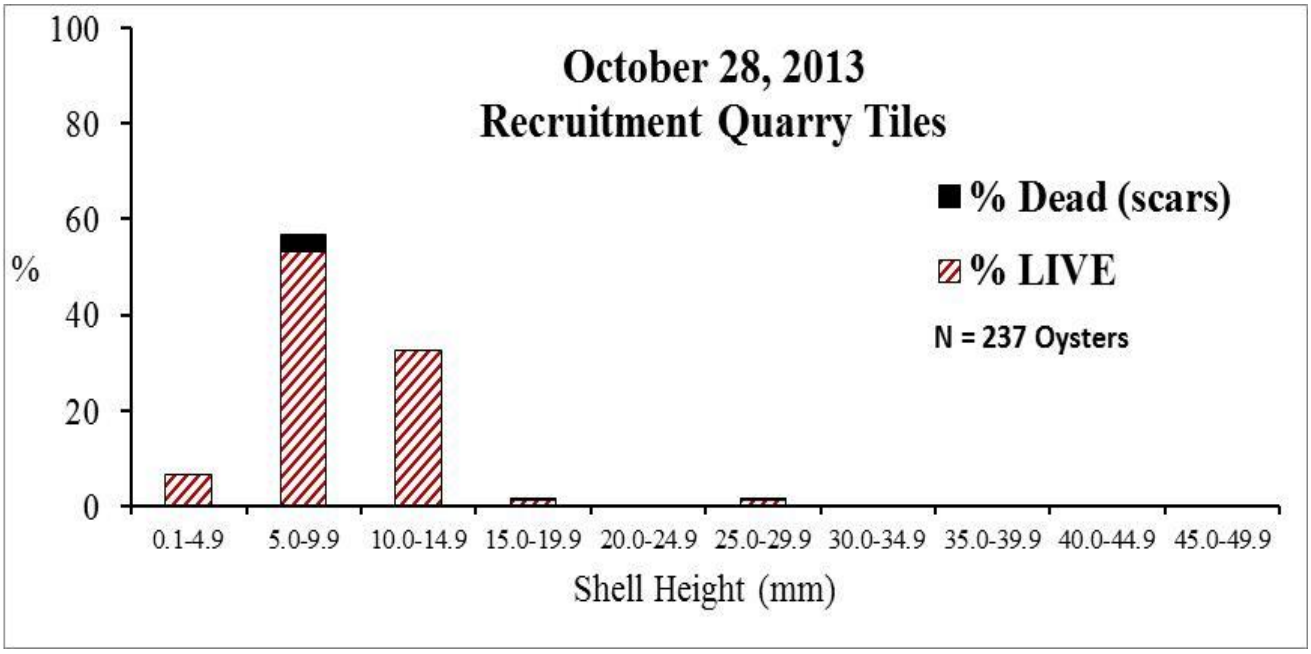

Fig 6. Oyster Shell Height Frequency Histogram of Quarry Tiles collected on October 28, 2013.

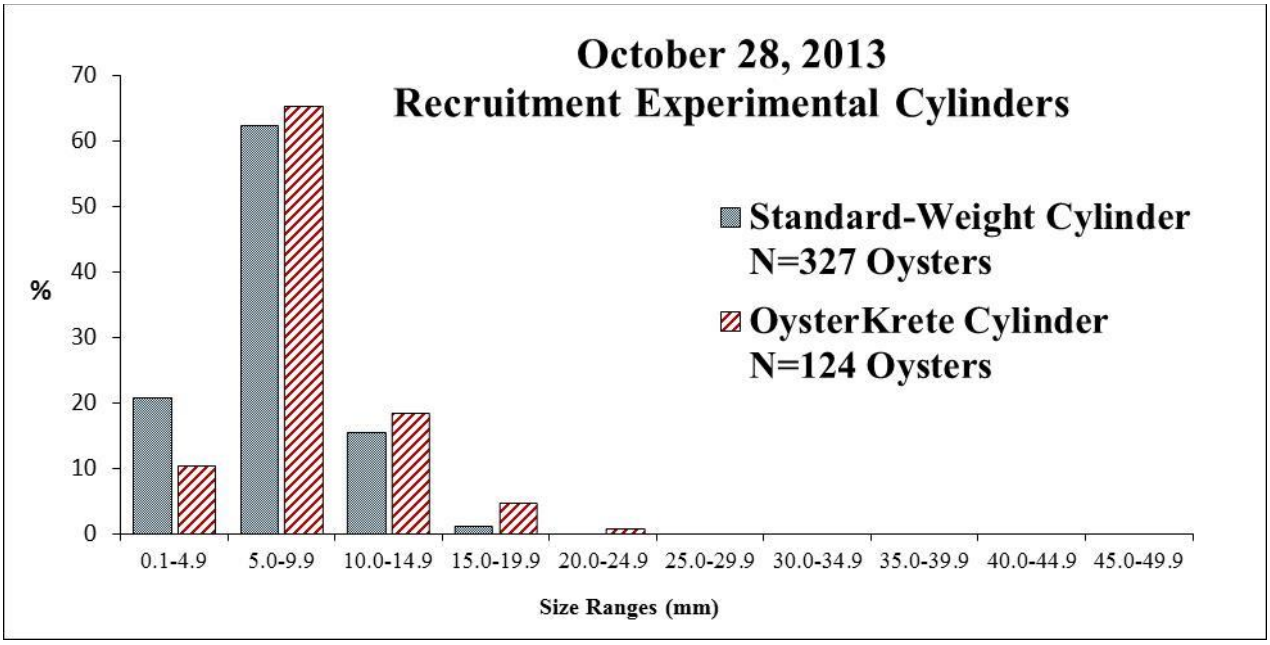

Figure 7. Shell Height Frequency Histogram of Attached Oysters to Experimental Cylinders in Cages Retrieved on October 28, 2013.

An acceptable data set, nine surviving cages out of 10 deployed, allowed for statistical analysis of the paired experimental cylinders (Appendix Table A-2). There was no statistically significant difference (Wilcoxsin-Sign Rank Test, P = 0.359) in paired oyster recruitment density between the Standard-Weight cement and the OysterKrete cylinders (Figure 8); neither one outperformed the other in oyster recruitment, survival and density.

In addition to oyster density comparisons, the experimental cylinders allowed for documentation of barnacle recruitment density, *Balanus sp*., (Appendix Table A-3). Barnacles are competitors for space and some foods, especially during early oyster colonization of a structure such as a oysterbreak. There was no statistically significant difference in paired recruitment barnacle density (t-test, P = 0.571) between the Standard-Weight cement and the OysterKrete experimental cylinders that were deployed in the cages (Figure 8); neither one outperformed the other in barnacle recruitment, survival and density. The density of barnacles on the oysterbreaks in October 2013 was 35 times greater than the density of oysters.

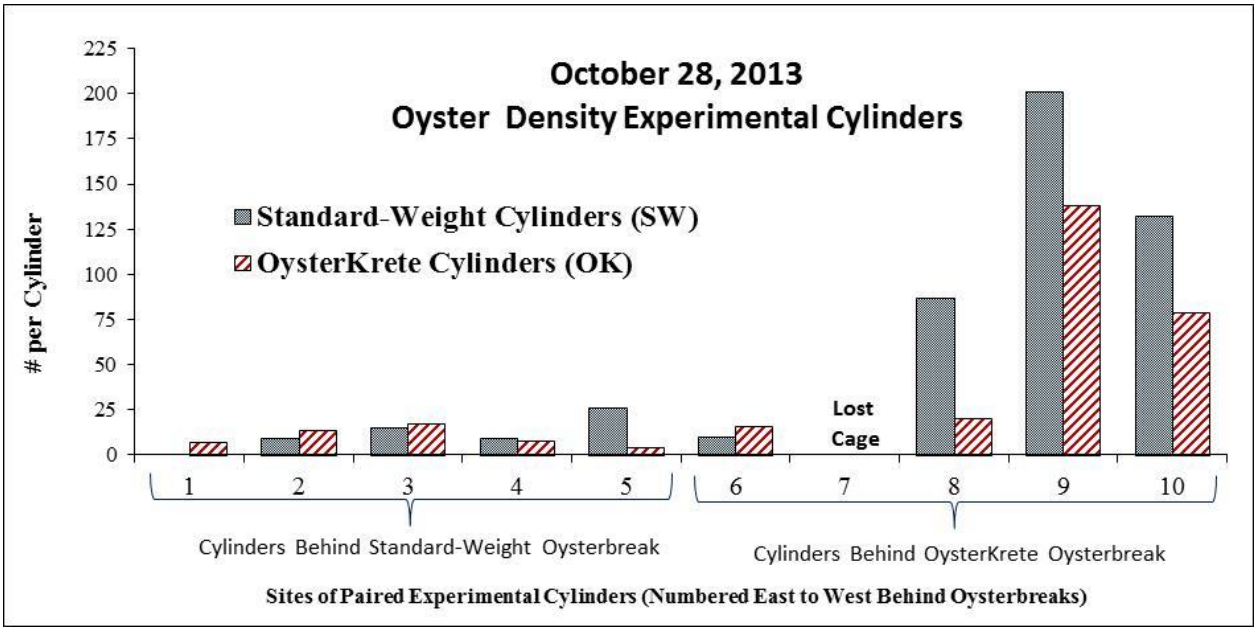

Figure 8. Density of Oysters Attached to Experimental Cylinders in Cages Retrieved on October 28, 2013.

A tombolo, a special kind of sandbar that forms in the shelter of an offshore structure and which may eventually connect to the shore, appears to be developing behind the Standard-Weight concrete oysterbreak in the aerial photo (Figure 2). The water is much shallower behind the Standard-Weight oysterbreak as compared to the OysterKrete oysterbreak. An interesting pattern in oyster and barnacle recruitment is observed on the experimental cylinders within the cages (Figures 8 and 9). The experimental cages were placed behind the oysterbreaks for protection from wave activity, with cages #1-5 behind the Standard-Weight oysterbreak and #6-10 behind the OysterKrete oysterbreak. Oysters clearly show a pattern of greater recruitment density behind the OysterKrete oysterbreak, while barnacles show just the opposite with greater density behind the Standard-Weight oysterbreak. This barnacle and oyster density pattern is probably due to the shallowness of tidal habitat behind the Standard-Weight oyster break as compared to the OysterKrete oysterbreak.

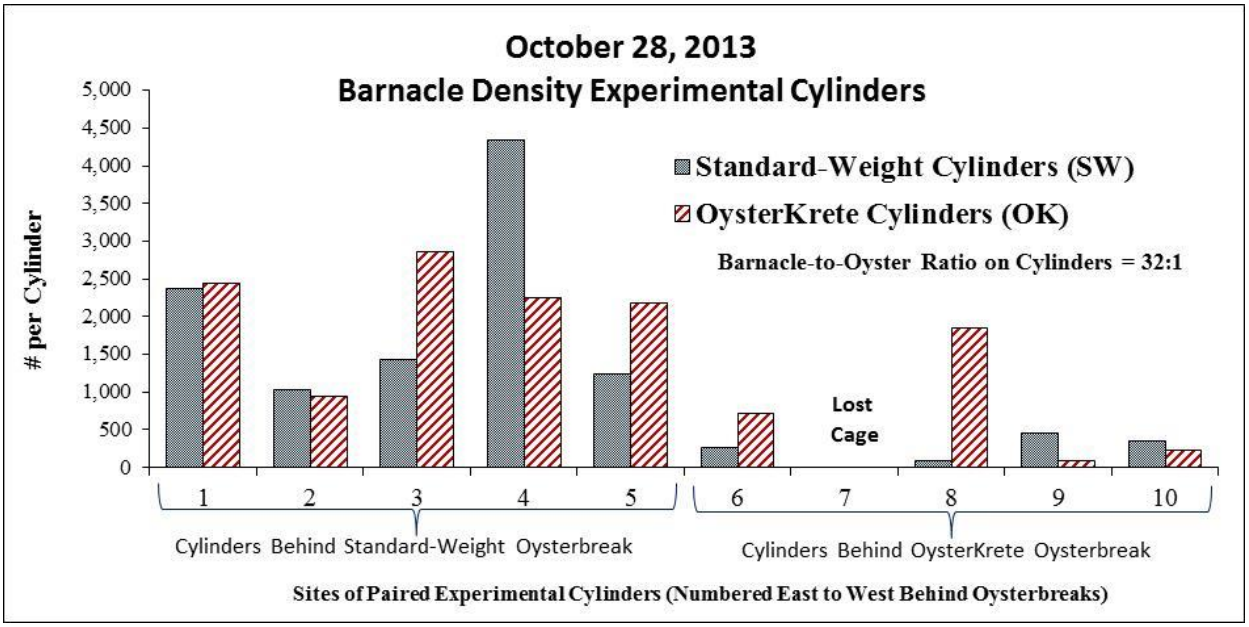

Figure 9. Density of Barnacles Attached to Experimental Cylinders in Cages Retrieved on October 28, 2013.

Oysters often recruit more abundantly in subtidal habitats, while barnacles often recruit more abundantly in intertidal habitats. This pattern of oyster and barnacle recruitment observed on the experimental cylinders in October 2013 (Figure 8 and 9) may be coincidental, but supports the assumption of difficulty that may arise during final assessments of the effectiveness of one type of oysterbreak over the other. Some of this assessment concern could possibly be addressed by not comparing each oysterbreak as a single unit, but instead comparing a ring row by location on a oysterbreak. For example, observations during assessment visits suggest that row #2 on the Standard-Weight concrete oysterbreak may be more similar to the tidal depth of row #4 on the OysterKrete oysterbreak.

Evidence of this potential matchup by row location between oysterbreaks is seen in the mean sizes of oysters on the two oysterbreaks (Figure 10). The Standard-Weight oysterbreak row #2 (SW Row 2) mean oyster shell height is statistically similar to OysterKrete row #4 (OK Row 4) with its similar tidal inundation regimen. Whereas, “SW Row 7” mean oyster shell height is statistically different from that of “OK Row 7” with its difference in tidal inundation periodicity. This pattern of oyster size differences by row location is further supported by evaluating the frequency distribution of live oysters between oysterbreaks (Figure 11). Oyster shell height distributions for “SW Row 2” is clearly similar to the height distributions for “OK Row 4”, whereas “SW Row 7” and “OK Row 7” are clearly different.

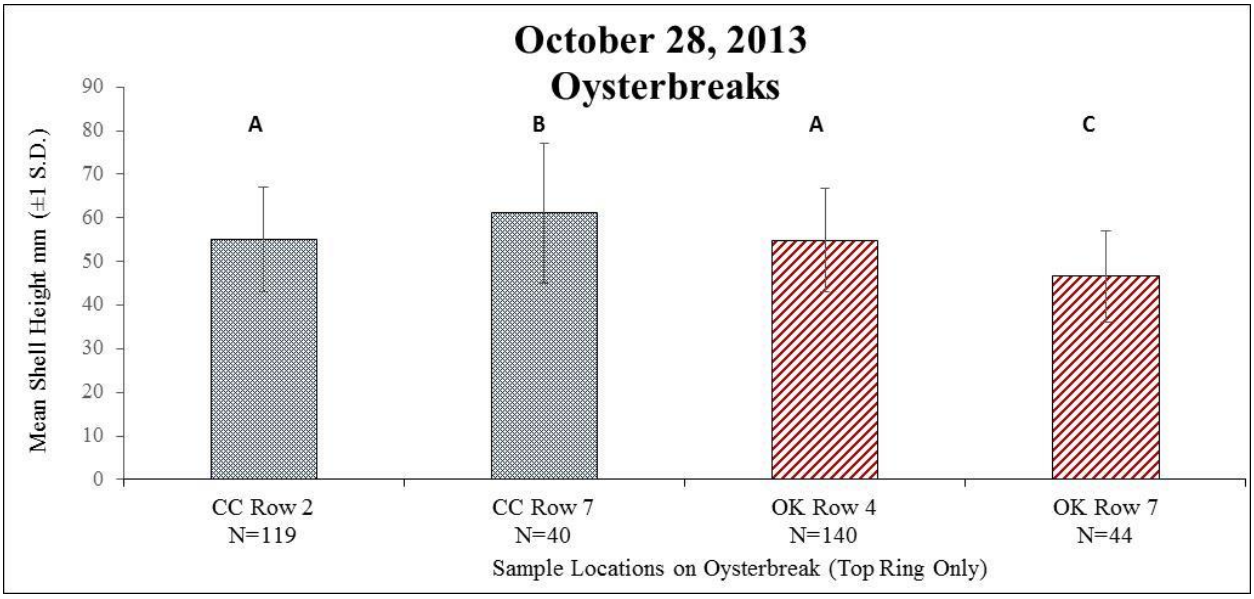

Figure 10. Mean Oyster Shell Height (±1 S.D.) by Oysterbreak Row Location, October 28, 2013. If letters above each column are the same then no significant difference (P>.05), but if letters are different then there is significant difference (P≤.05).

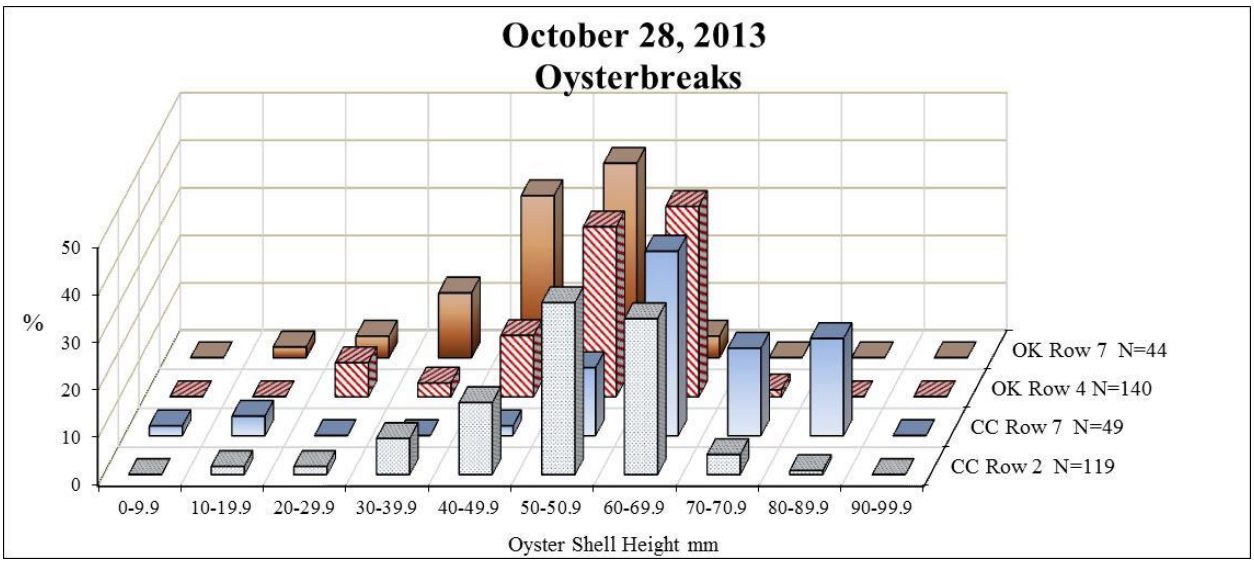

Figure 11. Frequency Distributions of Oyster Shell Heights by Oysterbreak Row Location on Standard-Weight (SW) and OysterKrete (OK), October 28, 2013.

Based on the limited number of quadrats taken (n=10 per oysterbreak) in this preliminary assessment, mean oyster density (Figure 12) per 0.0625m^2 (1/16 m^2) was similar between the Standard-Weight oysterbreak and the OysterKrete oysterbreak in October 2013(Appendix Table A-4). The mean density assessment is based on quadrat oyster data from top-tier rows #2 and #7 on the Standard-Weight oysterbreak, and rows #4 and #7 on the OysterKrete oysterbreak. This result of no significant difference in density is similar to that found on the paired experimental cylinders (Figure 8).

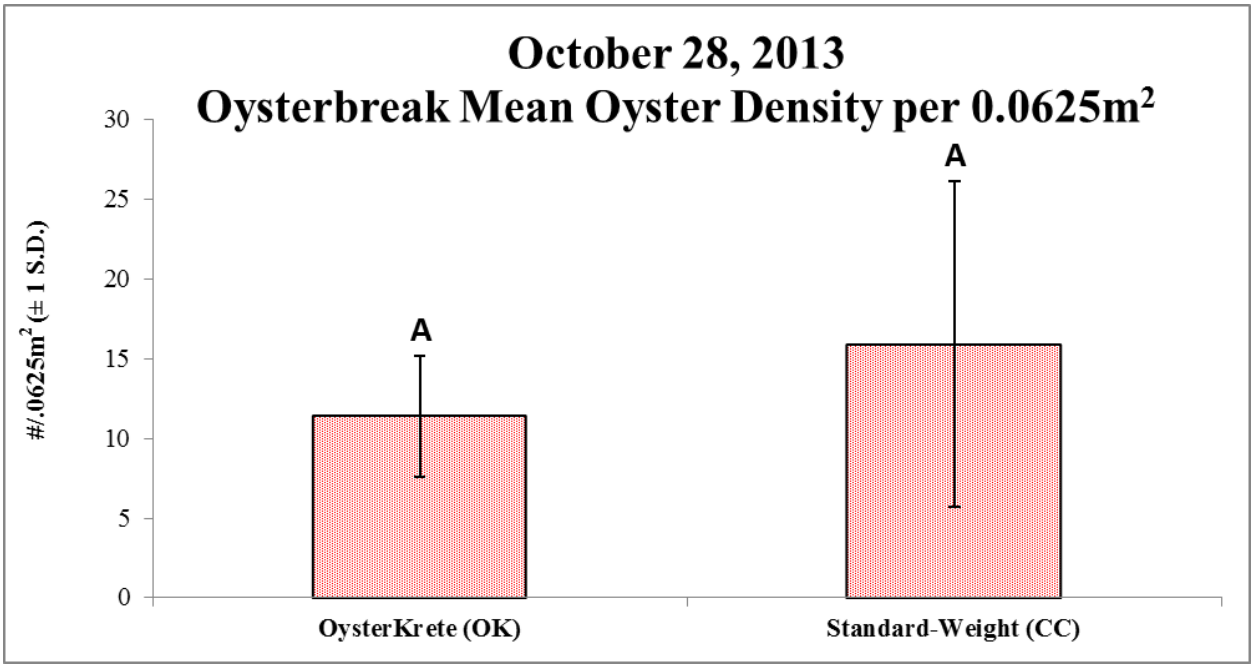

Figure 12. Mean Oyster Density (±1 S.D.) on oysterbreaks, October 2013. If letters above each column are the same then no significant difference (P>.05), but if letters are different then there is significant difference (P≤.05).

Based on the same limited number of quadrats taken (n=10 per oysterbreak) in this preliminary assessment, mean oyster biomass as grams dry weight per 0.0625m^2 (1/16 m^2) (Figure 13) was, like density, not statistically different between the Standard-Weight oysterbreak and the OysterKrete oysterbreak in October 2013(Appendix Table A-5). The mean biomass, like the density assessment, is based on quadrat oyster data from top-tier rows #2 and #7 on the Standard-Weight oysterbreak, and rows #4 and #7 on the OysterKrete oysterbreak.

Salinity and Predation

Predation on oysters is intricately tied to the synergism of water temperature and salinity. As water temperatures increase in early spring 20°C (68°F) and salinities increase above 15 psu (practical salinity units) predators become more metabolically active. Subtidal oysters are the most vulnerable when water temperature and salinity rises together. Although hourly salinity measurements are not available due to the loss of the data loggers, the coastal habitat where the oysterbreaks are located is known to have salinity averages that run through the year from the mid-teens to higher (from NOAA's National Oceanographic Data Center, http://www.nodc.noaa.gov/). For example, on October 23, 2013 during a site visit the salinity was 22.4 psu with a water temperature of 24.2°C (75.6°F).

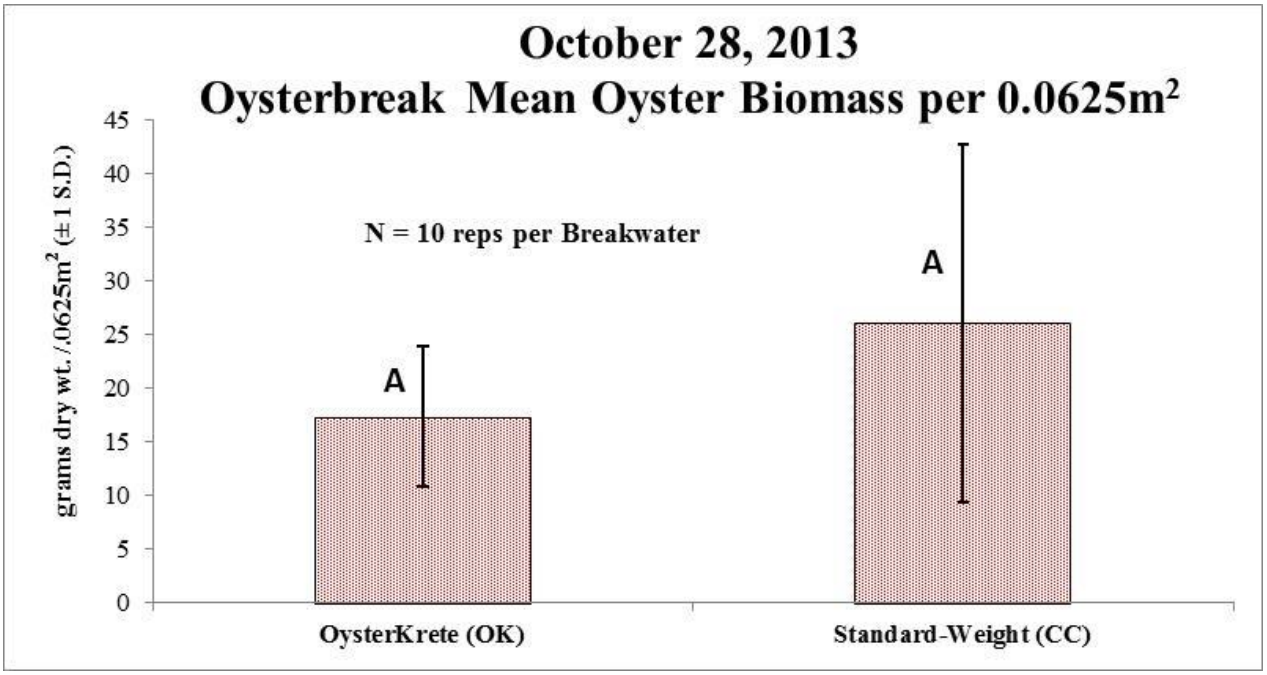

Figure 13. Mean Oyster Biomass grams dry weight (±1 S.D.) on oysterbreaks, October 2013. If letters above each column are the same then no significant difference (P>.05), but if letters are different then there is significant difference (P≤.05).

A significant oyster predator in coastal habitat that consistently has salinities greater than 15 psu is the southern oyster drill, *Stramonita haemastoma*. This snail can potentially destroy a subtidal reef by feeding on oysters. The only protection from this predator in high salinity habitat is to be located in the intertidal zone. The oyster drill was very prevalent in the October 2013 assessment of the oysterbreaks. A random collection of the oyster drills indicated that there was no difference in size of the snails (Figure 14), suggesting equal predation effects on the two oysterbreaks (Appendix Table A-6). This may negate bottom rows of oysterbreaks for oyster survival and reef development.

Potential for Reef Development

The relative growth in population size classes since construction suggest that the potential for oyster survival and reef development, at least on the top-tier of oysterbreak rings, is feasible as long as adequate recruitment occurs. Irrespective of the presence of predatory snails and the tidal inundation differences between oysterbreaks, the top rows of rings are being colonized by oysters and surviving and growing. Oysters have grown on the Standard-Weight oysterbreak from a modal height of 20-29.9mm in March 2013 to a modal height of 60-69.9mm by October 2013 (Figure 15). Oysters have grown on the OysterKrete oysterbreak from a modal height of 20-29.9mm in March 2013 to a modal height of 50-59.9mm by October 2013 (Figure 16).

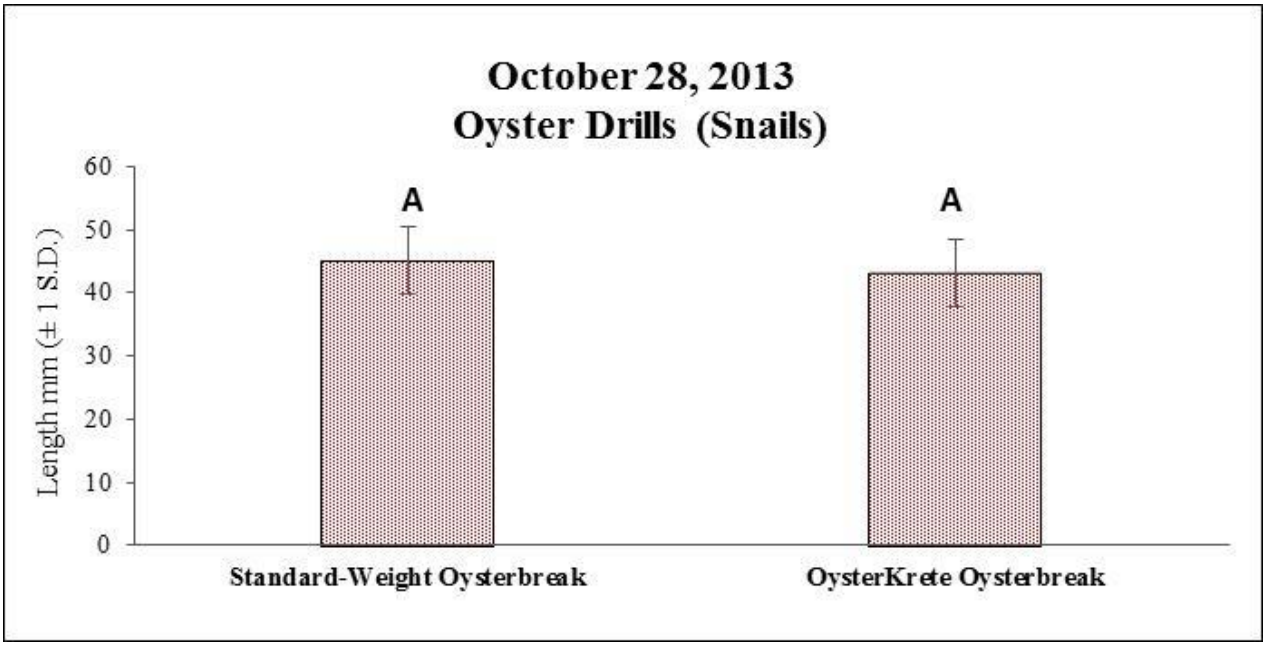

Figure 14. Mean Length (±1 S.D.) of Oyster Drill Snails by Oysterbreak, October 28, 2013. If letters above each column are the same then no significant difference (P>.05), but if letters are different then there is significant difference (P≤.05).

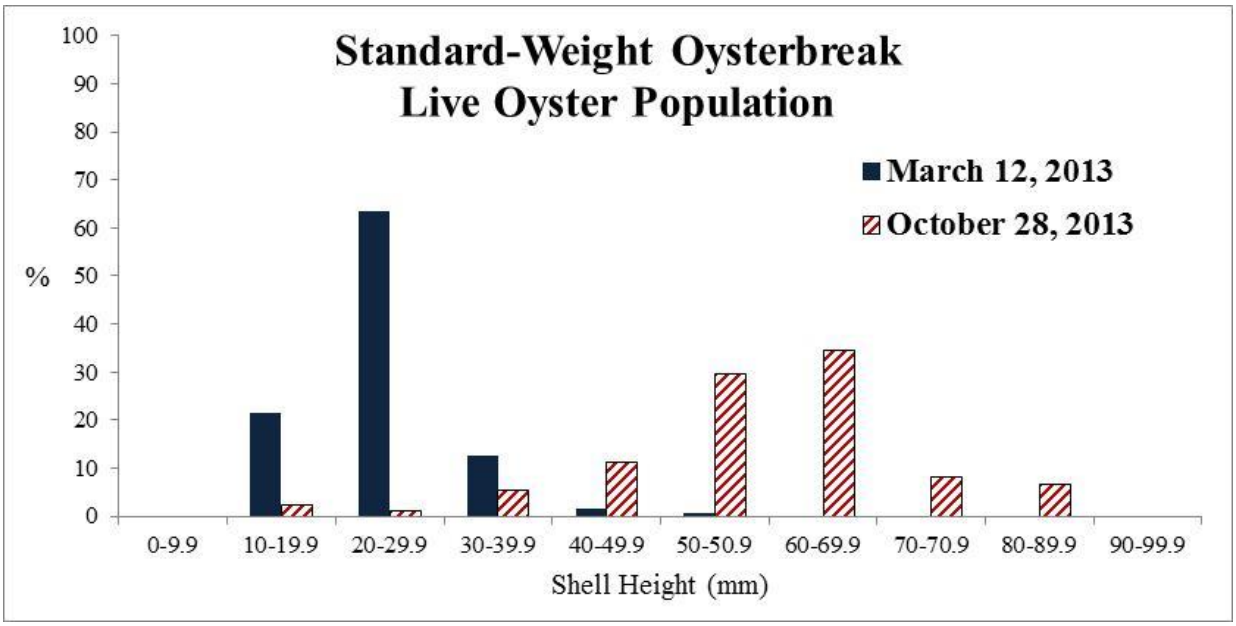

Figure 15. Comparison of Oyster Height Frequency Distributions between March 13, 2013 and October 28, 2013 on the Standard-Weight Concrete Oysterbreak.

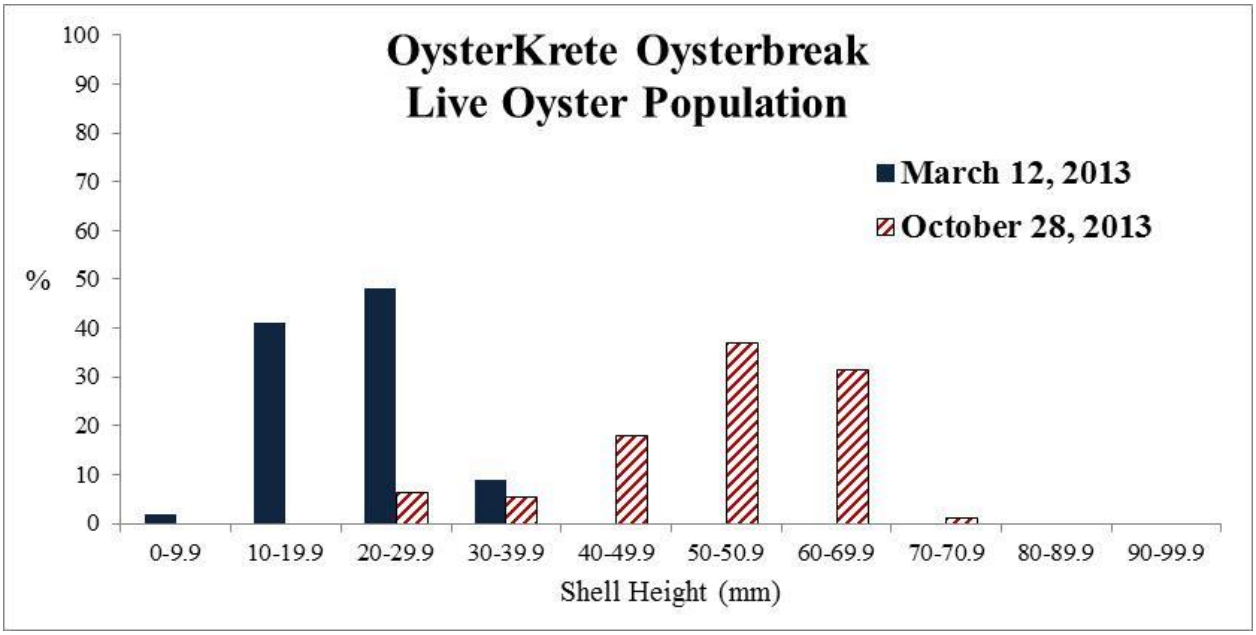

Figure 16. Comparisons of Oyster Height Frequency Distributions between March 13, 2013 and October 28, 2013 on the OysterKrete Oysterbreak.

APPENDIX

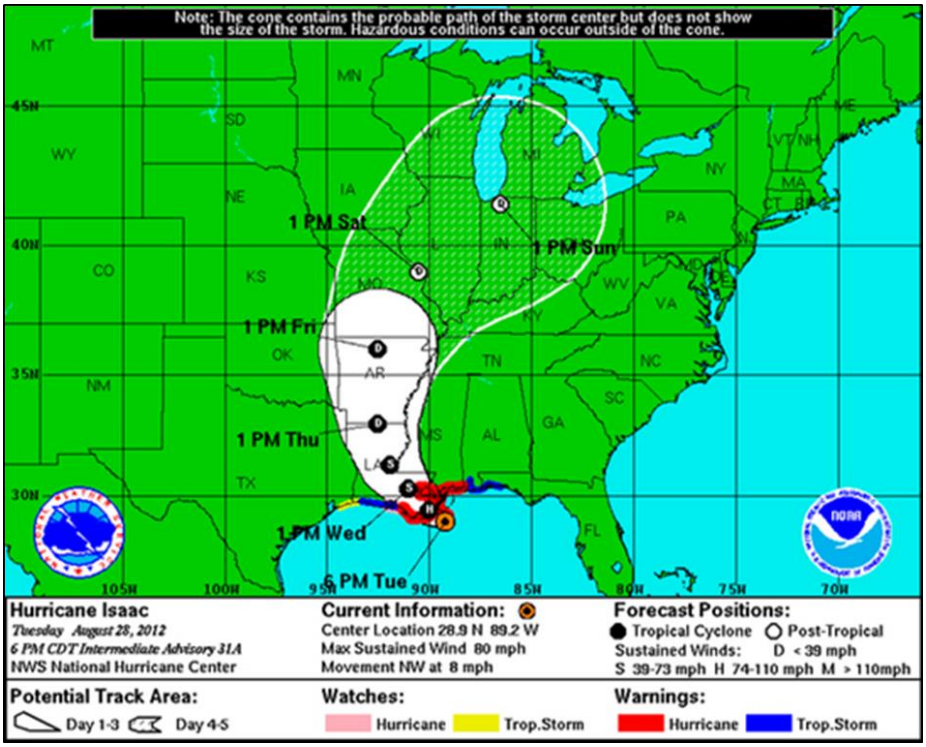

Figure A-1. Path of Hurricane Isaac.

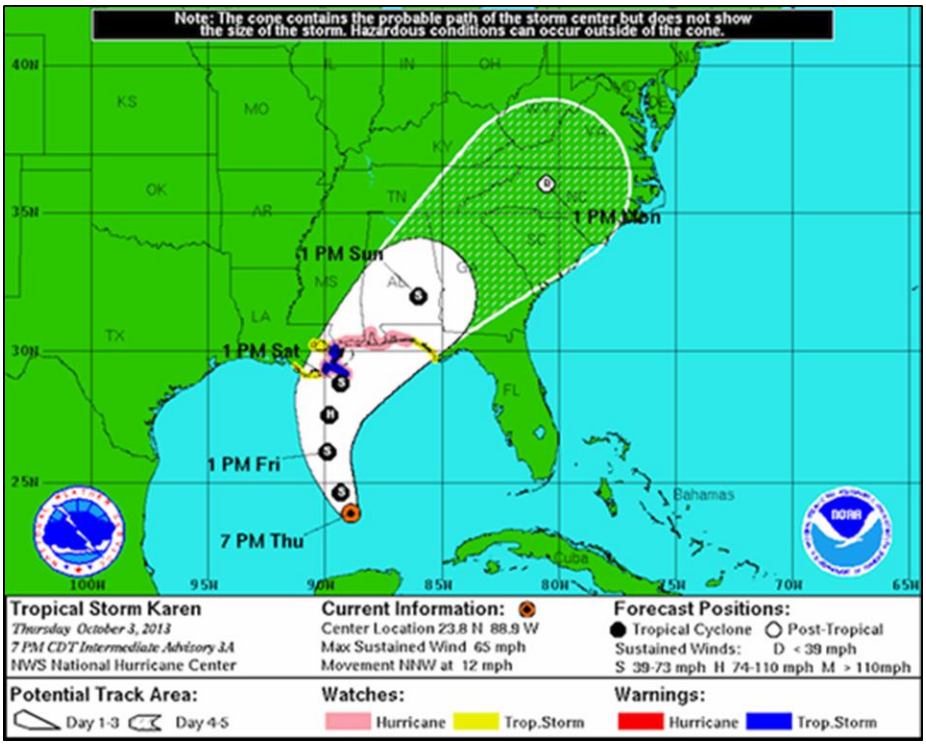

Figure A-2. Path of Tropical Storm Karen.

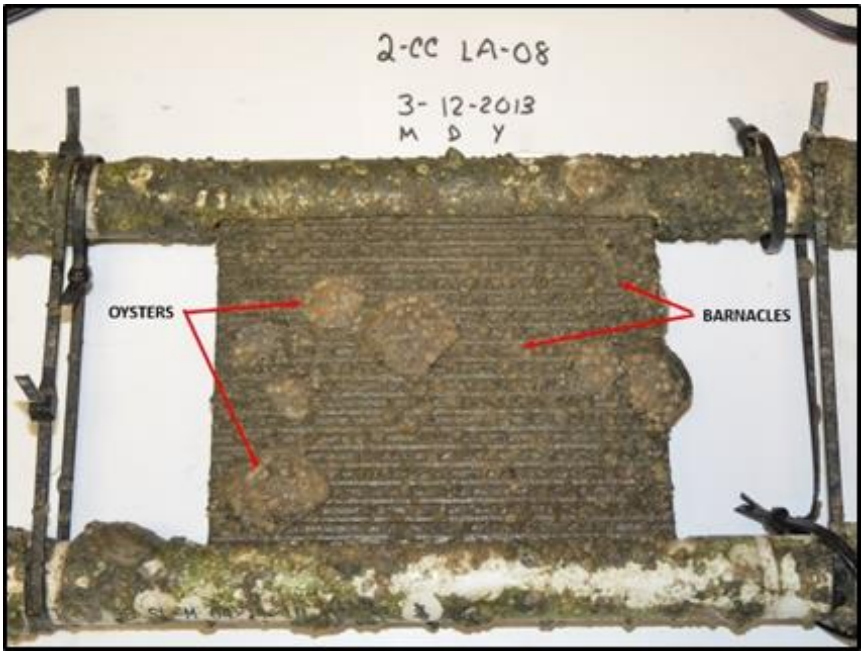

Figure A-3. Photo Example of a Quarry Tile Plate used for Oyster Spat Recruitment.

Figure A-4. Photo of Experimental Cage with two Quarry Tiles and two Experimental Cylinders, one OysterKrete (OK) and the other Standard-Weight Concrete (SW).

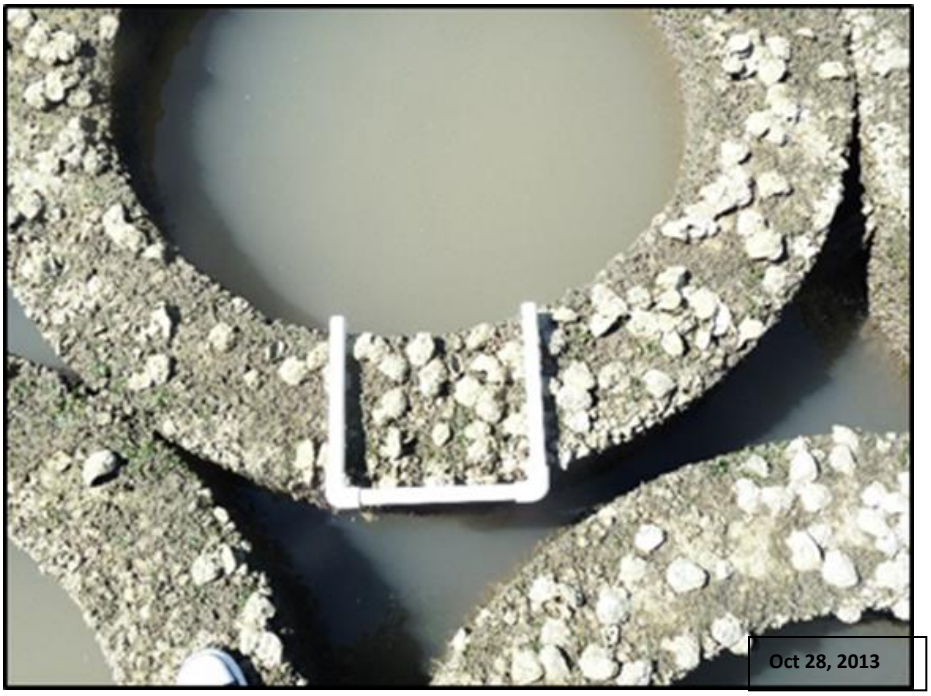

Figure A-5. Photo on Left the 0.0625 m^2 Quadrat Frame placed on Standard-Weight Concrete Ring.

Figure A-6. Standard-Weight Concrete (SW) Oysterbreak showing Algae-Encrusted Gulfward Rings.

Figure A-7. Scrapings within 0.0625 m^2 Quadrats, March 12, 2013.

Figure A-7 (continued)

Figure A-7 (continued)

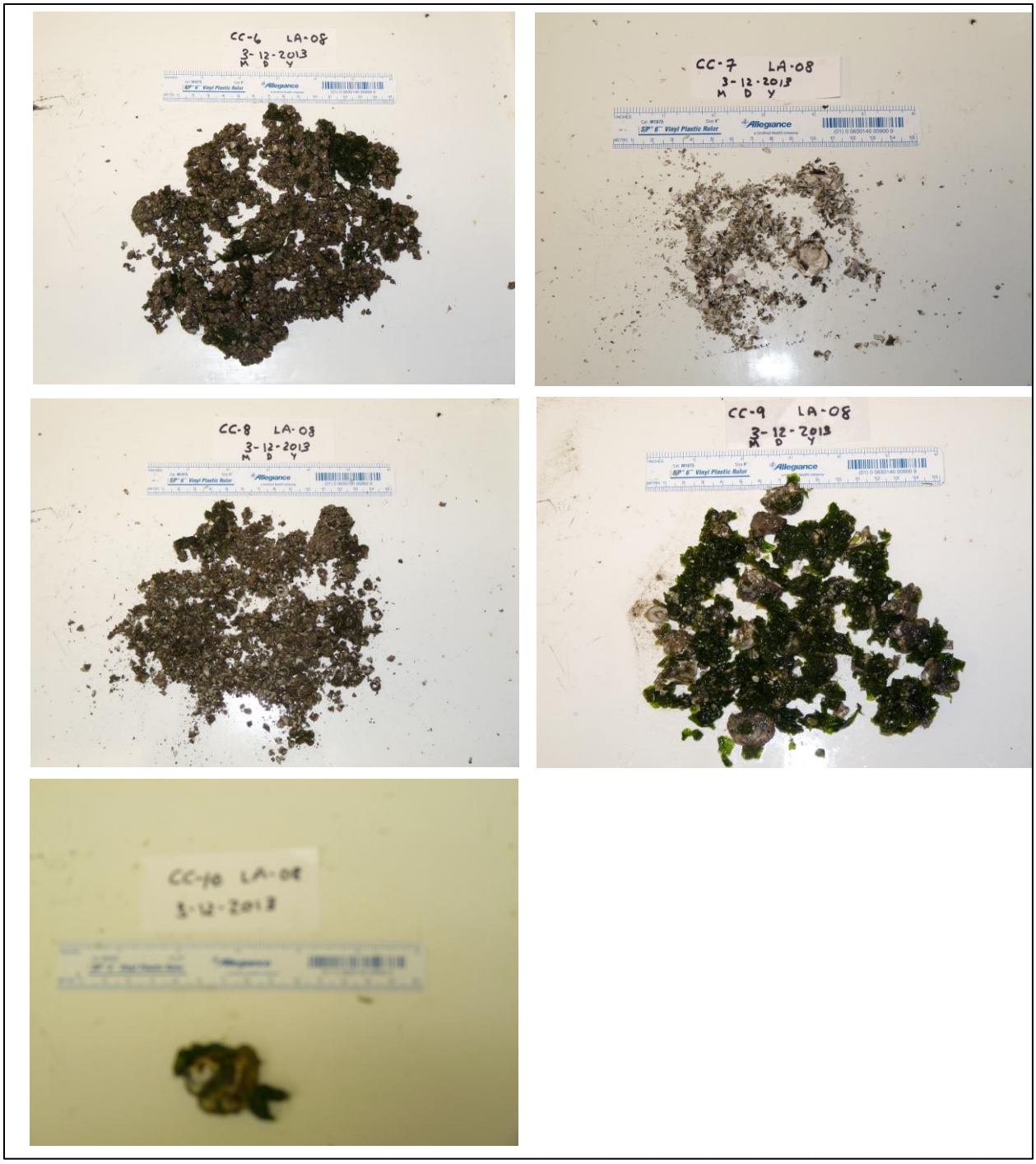

Figure A-7 (continued)

Figure A-8. Experimental Standard-Weight Concrete Cylinders in Cages Deployed on April 19, 2012 and Retrieved on March 12, 2013.

Figure A-9. Experimental OysterKrete Cylinders in Cages Deployed on April 19, 2012 and Retrieved on March 12, 2013.

Figure A-10. Paired Experimental OysterKrete and Standard-Weight Cylinders in Cages Deployed on March 12, 2013 and Retrieved on October 28, 2013.

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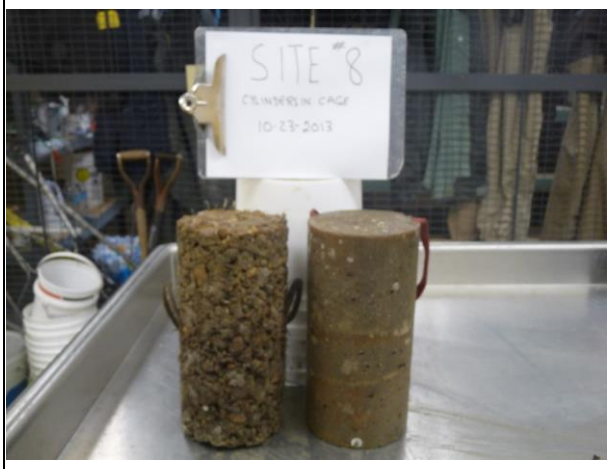

Figure A-10 (Continued)

Figure A-11. View Looking West at OysterKrete Oysterbreak at Near-Low Tide (left photo) and again at Near-High Tide (right photo) on March, 12, 2013. Photo by Tommy McGinnis.

Figure A-12. Standard-Weight Oysterbreak in Foreground and OysterKrete Oysterbreak in Background between the two poles on March 12, 2013 as Tide rises; notice that all of OysterKrete Oysterbreak is already under water. Small pvc poles behind Oysterbreaks are Locations for Experimental Cages with Cylinders and Tiles. Photo by Tommy McGinnis.

Figure A-13. Colonization of Oysters on a Top-Tier Ring of the OysterKrete Oysterbreak, October 28, 2013.

Figure A-14. Standard-Weight Oysterbreak Top-Tier Ring on West end of Structure showing Stress Fracture on October 28, 2013.

Figure A-15. Colonization of Oysters on a Top-Tier Ring of the Standard-Weight Oysterbreak on October 28, 2013.

Table A-1. Statistical Analysis of Biomass (g. dry wt.) Data from March 2013 Quadrats; CC=Standard-Weight Oysterbreak, OK=OysterKrete Oysterbreak.

One Way Analysis of Variance

Data source: Data 1 in LA-08_Fall2013Data

March 2013 Biomass Density Data (0.0625m^2)

Data Log-Transformed to attain normality

Dependent Variable: log10(col(17))

Normality Test (Shapiro-Wilk) Passed (P = 0.104)

Equal Variance Test: Passed (P = 0.476)

Group Name	N	Missing	Mean	Std Dev	SEM
CC-2	5	0	2.073	0.455	0.203
CC-4	5	0	1.23	0.544	0.243
OK-6	5	0	1.401	0.177	0.0792
OK-7	5	0	0.888	0.485	0.217

Source of Variation	DF	SS	MS	F	P
Between Groups	3	3.72	1.24	6.445	0.005
Residual	16	3.078	0.192		
Total	19	6.797			

The differences in the mean values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = 0.005).

Power of performed test with alpha = 0.050: 0.870

All Pairwise Multiple Comparison Procedures (Tukey Test):

Comparisons for factor: Breakwater Row

Comparison	Diff of Means	p	q	P	P<0.050
CC-2 vs. OK-7	1.185	4	6.041	0.003	**Yes**
CC-2 vs. CC-4	0.843	4	4.298	0.035	**Yes**
CC-2 vs. OK-6	0.672	4	3.425	0.113	**No**
OK-6 vs. OK-7	0.513	4	2.616	0.288	**No**
OK-6 vs. CC-4	0.171	4	0.874	0.925	**Do Not Test**
CC-4 vs. OK-7	0.342	4	1.742	0.617	**Do Not Test**

A result of "Do Not Test" occurs for a comparison when no significant difference is found between two means that enclose that comparison. For example, if you had four means sorted in order, and found no difference between means 4 vs. 2, then you would not test 4 vs. 3 and 3 vs. 2, but still test 4 vs. 1 and 3 vs. 1 (4 vs. 3 and 3 vs. 2 are enclosed by 4 vs. 2: 4 3 2 1). Note that not testing the enclosed means is a procedural rule, and a result of Do Not Test should be treated as if there is no significant difference between the means, even though one may appear to exist.

Table A-2. Statistical Analysis of Oyster Density Data from October 2013 Experimental Cylinders Placed in Modified Crab Cages; CC=Standard-Weight Oysterbreak, OK=OysterKrete Oysterbreak.

Paired t-test:

Data source: Data 1 in LA-08_Fall2013Data.JNB

Normality Test (Shapiro-Wilk) Failed (P < 0.050)

Test execution ended by user request, Signed Rank Test begun

Wilcoxon Signed Rank Test

Data source: Data 1 in LA-08_Fall2013Data.JNB

Group	N	Missing	Median	25%	75%
CC Oys Den/Cyl	9	0	15	9	109.5
OK Oys Den/Cyl	9	0	16	7.5	49.5

W= -17.000 T+ = 14.000 T-= -31.000
Z-Statistic (based on positive ranks) = -1.007
P(est.)= 0.343 P(exact)= 0.359

The change that occurred with the treatment is not great enough to exclude the possibility that it is due to chance (P = 0.359).

Table A-3. Statistical Analysis of Barnacle Density Data from October 2013 Experimental Cylinders Placed in Modified Crab Cages; CC=Standard-Weight Oysterbreak, OK=OysterKrete Oysterbreak.

Paired t-test:

Data source: Data 1 in LA-08_Fall2013Data.JNB

Normality Test (Shapiro-Wilk) Passed (P = 0.539)

Treatment Name	N	Missing	Mean	Std Dev	SEM
CC Barn Den/Cyl	9	0	1275.111	1352.759	450.92
OK Barn Den/Cyl	9	0	1498.111	1023.805	341.268
Difference	9	0	-223	1133.576	377.859

t = -0.590 with 8 degrees of freedom.

95 percent two-tailed confidence interval for difference of means: -1094.344 to 648.344

Two-tailed P-value = 0.571

The change that occurred with the treatment is not great enough to exclude the possibility that the difference is due to chance (P = 0.571)
One-tailed P-value = 0.286

The sample mean of treatment OK Barn Den/Cyl does not exceed the sample mean of the treatment CC Barn Den/Cyl by an amount great enough to exclude the possibility that the difference is due to random sampling variability. The hypothesis that the population mean of treatment CC Barn Den/Cyl is greater than or equal to the population mean of treatment OK Barn Den/Cyl cannot be rejected. (P = 0.571)
Power of performed two-tailed test with alpha = 0.050: 0.082

The power of the performed test (0.082) is below the desired power of 0.800.
Less than desired power indicates you are less likely to detect a difference when one actually exists. Negative results should be interpreted cautiously.
Power of performed one-tailed test with alpha = 0.050: 0.135

The power of the performed test (0.135) is below the desired power of 0.800.
Less than desired power indicates you are less likely to detect a difference when one actually exists. Negative results should be interpreted cautiously.

Table A-4. Statistical Analysis of Oyster Density per 0.0625m^2 from October 2013 Oysterbreaks.

One Way Analysis of Variance

Data source: Data 1 in Oct 2013 Oyster Density

Dependent Variable: #/.0625m^2 Oysters

Normality Test (Sha Failed (P < 0.050)

Equal Variance Test Failed (P < 0.050)

Group Name	N	Missing	Mean	Std Dev	SEM
OysterKrete	10	0	11.4	3.806	1.204
Standard-Weight	10	0	15.9	10.225	3.233

Source of Variation	DF	SS	MS	F	P
Between Groups	1	101.25	101.25	1.701	0.209
Residual	18	1071.3	59.517		
Total	19	1172.55			

The differences in the mean values among the treatment groups are not great enough to exclude the possibility that the difference is due to random sampling variability; there is not a statistically significant difference (P = 0.209).
Power of performed test with alpha = 0.050: 0.117

The power of the performed test (0.117) is below the desired power of 0.800.
Less than desired power indicates you are less likely to detect a difference when one actually exists. Negative results should be interpreted cautiously.

Dependent Variable: #/.065m^2 Oysters

Normality Test (Sha Failed (P < 0.050)

Test execution ended by user request, ANOVA on Ranks begun

Kruskal-Wallis One Way Analysis of Variance on Ranks

Data source: Data 1 in Oct 2013 Oyster Biomass.JNB

Group	N	Missing	Median	25%	75%
Standard-Weight	10	0	14.5	7.5	21.25
OysterKrete	10	0	11	8.75	13.75

H = 0.469 with 1 degrees of freedom. (P = 0.494)

The differences in the median values among the treatment groups are not great enough to exclude the possibility that the difference is due to random sampling variability; there is not a statistically significant difference (P = 0.494)

Table A-5. Statistical Analysis of Oyster Biomass (g. dry wt.) per 0.0625m^2 from October 2013 Oysterbreaks.

One Way Analysis of Variance

Data source: Data 1 in Oct 2013 Oyster Biomass.JNB

Dependent Variable: grams dry wt./.065m^2 Oysters

Normality Test (Shapiro-Wilk) Failed (P < 0.050)

Test execution ended by user request, ANOVA on Ranks begun

Kruskal-Wallis One Way Analysis of Variance on Ranks

Data source: Data 1 in Oct 2013 Oyster Biomass.JNB

Group	N	Missing	Median	25%	75%
OysterKrete	10	0	15.475	12.785	23.261
Standard-Weight	10	0	23.902	12.665	33.159

H = 1.651 with 1 degrees of freedom. (P = 0.199)

The differences in the median values among the treatment groups are not great enough to exclude the possibility that the difference is due to random sampling variability; there is not a statistically significant difference (P = 0.199)

Table A-6. Statistical Analysis of Snail Length from October 2013 Oysterbreaks; SW=Standard-Weight Oysterbreak, OK=OysterKrete Oysterbreak.

t-test

Data source: Data 1 in Notebook1

Dependent Variable: Snail Length (mm)

Normality Test (Passed (P = 0.519)

Equal Variance Passed (P = 0.852)

Group Name	N	Missing	Mean	Std Dev	SEM
OK	36	0	43.083	5.272	0.879
CC	28	0	45.036	5.337	1.009

Difference -1.952

t = -1.462 with 62 degrees of freedom.

95 percent two-tailed confidence interval for difference of means: -4.622 to 0.717

Two-tailed P-value = 0.149

The difference in the mean values of the two groups is not great enough to reject the possibility that the difference is due to random sampling variability. There is not a statistically significant difference between the input groups (P = 0.149).
One-tailed P-value = 0.0744

The sample mean of group CC does not exceed the sample mean of the group OK by an amount great enough to exclude the possibility that the difference is due to random sampling variability. The hypothesis that the population mean of group OK is greater than or equal to the population mean of group CC cannot be rejected. (P = 0.074).
Power of performed two-tailed test with alpha = 0.050: 0.302

The power of the performed test (0.302) is below the desired power of 0.800.
Less than desired power indicates you are less likely to detect a difference when one actually exists. Negative results should be interpreted cautiously.
Power of performed one-tailed test with alpha = 0.050: 0.421

The power of the performed test (0.421) is below the desired power of 0.800.
Less than desired power indicates you are less likely to detect a difference when one actually exists. Negative results should be interpreted cautiously.

APPENDIX C-ii

Final Oyster Assessment

(Data from individual observations were removed from original document)

Oyster Assessment of Project LA-08
OysterKrete Breakwater and Standard-Weight Breakwater
Rockefeller Wildlife Refuge, Louisiana

By

Earl J. Melancon, Jr., Ph. D.

Department of Biological Sciences

Nicholls State University

June 2017

Oyster Assessment of Project LA-08

Rockefeller Wildlife Refuge, Louisiana

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ACKNOWLEDGEMENTS

This project was sponsored and funded by the Coastal Protection and Restoration Authority (CPRA) of Louisiana and the National Oceanic and Atmospheric Administration's National Marine Fisheries Service (NMFS) through the fourteenth (14th) Priority Project List of the Coastal Wetlands Planning and Restoration Act (CWPPRA). The state contract number for this study was LaGov 2000152349 (LA-0008), and the University account number was Fund 212660. The construction components associated with this project were located on land owned by Louisiana's Rockefeller Wildlife Refuge and managed by the Louisiana Department of Wildlife and Fisheries (LDWF). CPRA project supervisor was Mr. Thomas E. McGinnis, Operations Division, Lafayette Regional Office, Lafayette, Louisiana. Mr. McGinnis was an invaluable contributor to the design, implementation, and success of this study and final report.

Logistical support for overnight accommodations while at the Refuge were provided by LDWF personnel. Boat and truck for field use were provided by the Biological Sciences Department, Nicholls State University (NSU). The two principal assistants, and irreplaceable for the success of this project, were graduate students Megan Nepshinsky and Samantha Humphrey Hicks. Also, assisting in the laboratory for analysis of quadrat samples were Lilly Benoit and Claire Benoit. Dr. Aaron Pierce, Associate Professor of Biological Sciences at NSU, coordinated and performed the field work documenting breakwater rings' relative elevations. Relative elevations were converted to NAVD88 elevations from data provided by the environmental engineering company, T. Baker Smith, LLC. Earlier, initial oyster survey work that led to this project was coordinated and assisted by Mr. Ronnie Duke, Environmental Project Manager/Biologist, with T. Baker Smith, LLC. University financial coordination of project funds was performed by Donna Naquin and Cindy Andrews with the Controller's Office.

Without the cooperation and assistance of all individuals mentioned above, this project could not have been successfully completed. My sincere thanks and appreciation to all of them.

INTRODUCTION

The Louisiana Coastal Protection and Restoration Authority (CPRA) authorized a OysterBreak demonstration project in 2007 as part of the state's Priority Project List #17 (PPL17). The PPL17 project is titled, "Bio-Engineered Oyster Reef Demonstration (LA-08)," hereafter referred to as Project LA-08. The primary purpose of this project is "to test a new, bio-engineered product to address rapid shoreline retreat and wetland loss along the Gulf of Mexico Shoreline in areas with soils of low load bearing capacity" (from LA-08 Fact Sheet from CPRA). Project LA-08 is located along the Gulf of Mexico in the Rockefeller Wildlife Refuge of southwestern Cameron Parish (Figure 1.) This bio-engineered product is an OysterBreak™ reef made of stackable, concrete rings. One OysterBreak is composed of rings made from OysterKrete™ and the other OysterBreak is composed of rings made from Standard-Weight concrete. OysterKrete is a patented concrete mixture "specifically formulated to attract naturally occurring oyster larvae" (from http://wayfarertech.com/). OysterBreak construction was completed on February 18, 2012. "The reef area contains two, 65.5 m (215 ft.) reef segments; the western OysterBreak is composed of OysterKrete©, and the eastern OysterBreak is composed of Standard-Weight concrete," (from McGinnis and Pontiff 2012) (Figures 2a and 2b).

The eastern oyster, *Crassostrea virginica* (Gmelin), is the dominant reef-building estuarine organism along the northern Gulf of Mexico (Cake 1983). Because of Louisiana's climate, it can spawn almost year-round, but usually exhibits bimodal peaks of mass spawning in late spring-early summer and again in early-late fall. When waters are warm in summer, planktonic larvae often require 2-3 weeks to metamorphose through several life stages before they are ready for settlement and a benthic life. Optimal setting occurs between 10 and 30 psu and maximum setting occurs between about 18 and 22 psu. Newly settled oysters often experience high mortalities in the first six months of life. At the time of setting, oyster larvae are usually no more than 0.4-0.5 mm (1/64-inch) in size, and are very vulnerable to predation and to burial due to sediment overburden. A hard substrate that provides refuge from predators and provides vertical relief from sediments is important to assure a chance for survival. Once the larva has set, it will become known as a "spat oyster" until it is 25 mm (1 inch) in shell length.

Oysters in the northern Gulf of Mexico may live for 10 years or longer (Cake 1983). Optimal survival of oyster populations requires a salinity range of approximately 5-15 psu in summer months. This narrow ecological salinity range reduces the abundance of higher-salinity oyster predators and disease, most active in summer, while still allowing for physiological functions to continue. When other environmental variables are within acceptable ranges for oyster survival, salinity generally becomes the overriding factor for sustaining an oyster population.

The oyster is a gregarious animal that can develop shallow subtidal and intertidal reef structure along a shoreline that also adds significant ecological value. An oyster reef is a 3-

dimensional structure created by successive years of larval settlement on adult oysters, while also providing multiple levels of solid surface and interstitial heterogeneity that is rare in the marine ecosystem. Oyster reef success depends on many interacting factors which include complex associations of physical, chemical, geological and biological processes (Baggett et al. 2014). Environmental and biological variables such as food quality and quantity, suitable bottom substrate, adequate tidal flushing, wave energy, water currents, water temperature, salinity, and tidal height and period of inundation provide critical intertidal-subtidal zonation and refuge from predators and disease, all interacting to produce a habitat capable of developing and sustaining an oyster population. Understanding the environmental variables that provide the necessary infrastructure for an oyster population to survive is fundamental to interpret success or failure of reef development.

There were two biological goals to specifically accomplish during this four-year project and study along the Gulf of Mexico shore on the Rockefeller Wildlife Refuge*:*

(1) To quantify the oyster colonization of the OysterBreak^{TM} structures, and ability to build a sustained reef population with complex structure composed of multiple oyster size-class distributions (multiple cohorts), and,

(2) To test OysterKrete© (Breakwater Reach-A) against Standard-Weight concrete (Breakwater Reach-B) in its ability to enhance colonization of oysters on the OysterBreak^{TM} structures.

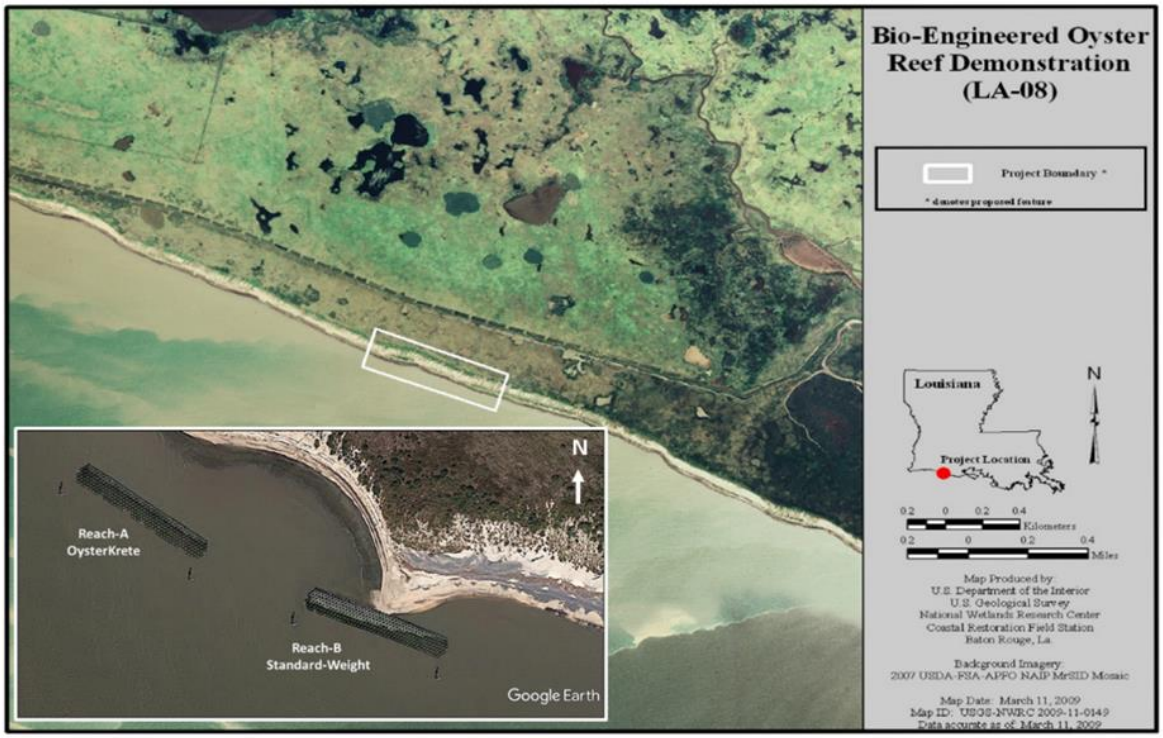

Figure 1. Location of project LA-08 on Gulf shoreline of Rockefeller wildlife refuge.

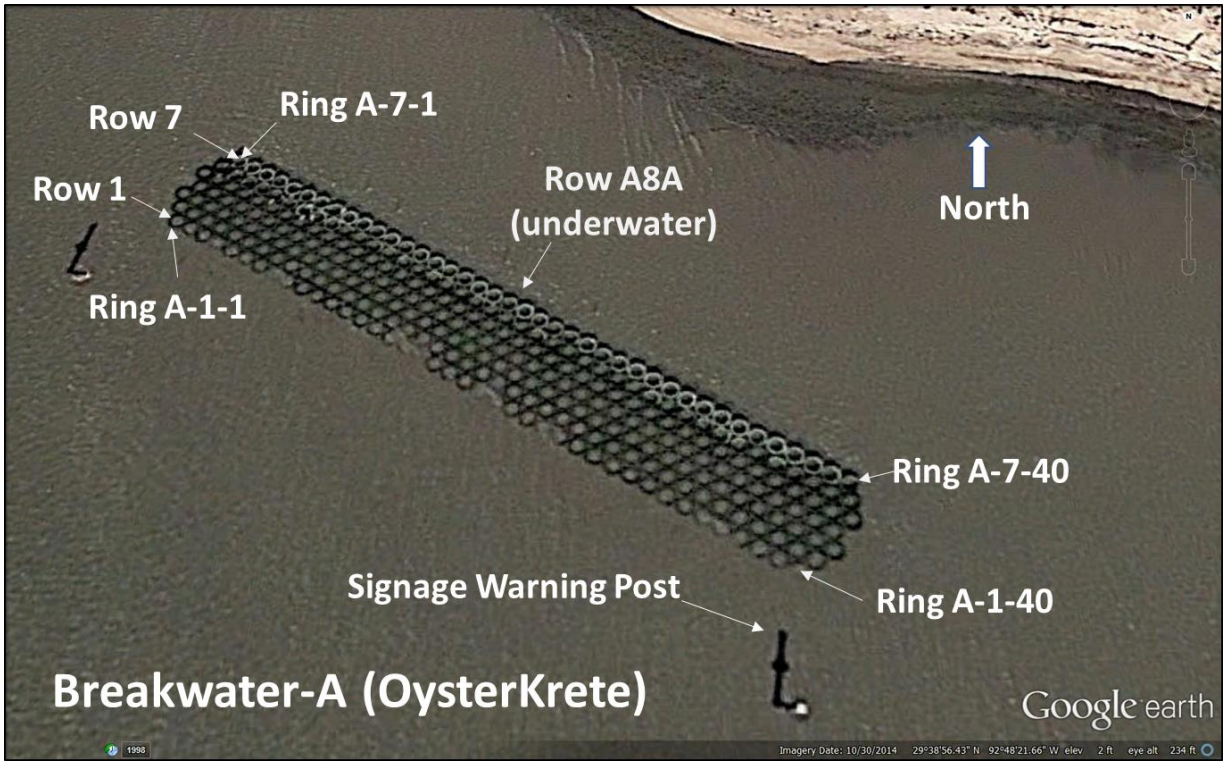

Figure 2a. Aerial view of OysterBreak Reach-A (OysterKrete) at low tide along the Gulf of Mexico shoreline on October 30, 2014. Notation for rows and ring numbers included and used throughout report.

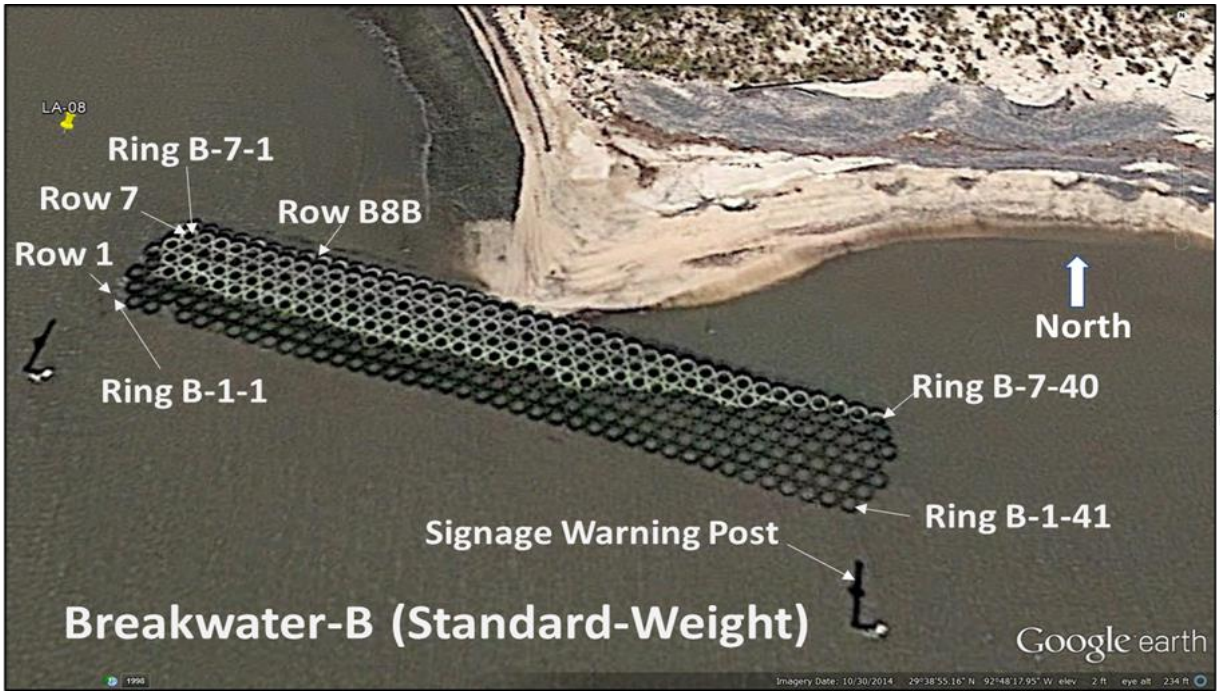

Figure 2b. Aerial view of OysterBreak Reach-B (Standard-Weight) at low tide along the Gulf of Mexico shoreline on October 30, 2014. Notation for rows and ring numbers included and used throughout report.

METHODS

Both goals were accomplished by successfully completing four objectives specifically outlined in the CPRA-Nicholls State University contractual agreement. The data for this final report were collected from spring 2015 through winter 2016. The four Objectives are as follows:

(1) Document Oyster Density,
(2) Document Oyster Size Classes (surrogate for approximate age),
(3) Document Oyster Reef development and Growth, and
(4) Document Water Quality.

Assessment of oyster reef development on the breakwaters was accomplished by an assortment of methods, some quantitative and others observational. Quantitative methods on individual rings included the density (quadrat), size frequency distribution, reef height above the surface, elevation and percent oyster coverage. Percent coverage was determined by consensus of two observers, while reef height was measured as the average of three replicates from the ring surface using a plastic ruler. Observational assessment was measured by taking a photo of each ring surface.

Oyster density (quadrat) samples were collected in the winter after a cold front passage and in conjunction with low tide to expose the top layer of rings. Density quadrat samples were collected by scraping with a chisel all oysters from the Gulf-ward facing 0.32 m^2 area on the upper surface of the top row of rings on the two breakwaters, OysterKrete and Standard-Weight (see photo in Appendix for quadrat location on a ring). All quadrat density samples were bagged, labeled, iced and transported to the Nicholls State University wet lab on campus and stored at 4 ºC (38 ºF) in a walk-in cooler until processed.

Oyster quadrats were taken on selected rings based on a stratified random design for the OysterKrete breakwater (Reach-A), but that design had to be modified for the Standard-Weight (Reach-B) breakwater. Each OysterKrete row (Reach-A in Figures 2a) was divided into four sections with three randomly selected rings sampled per section, resulting in 12 density quadrats per each row except for one row with 11. A total of 83 density quadrat samples were collected from Reach-A, the OysterKrete breakwater.

The Standard-Weight breakwater had highly variable elevation differences within each row of rings when compared to the OysterKrete breakwater, and also had a higher overall elevation height (Figure 3). Each Standard-Weight row (Reach-B in Figure 2b) could not be equally divided into four sections because of significantly lower elevation for many of the lower rows' rings on the eastern end of the breakwater. Every other ring on the western end of the lower rows were sampled for quadrate density from the first 22 to 26 rings (rows B1-B3), while

for rows four through seven (B4-B7) a more stratified random sample procedure similar to OysterKrete was used. The deeper, lower elevation rings on the eastern end of the Standard-Weight breakwater were randomly sampled and included when low-water exposure allowed. A total of 85 density quadrat samples were collected from the top row of rings facing Gulfward on Reach-B, the Standard-Weight breakwater. The Standard-Weight breakwater had also developed a significant population of oysters on the leeward-facing foundation (bottom) row, and six (6) of those rings were also sampled for quadrat densities and labeled as row B8B (Figure 2b).

The relative elevation of each breakwater ring assessed for quadrat density, along with additional rings, was measured relative to a single point at the high tide line located along the adjacent shore using a Topcon Total Station model GTS 239W® surveyor instrument. Later, the relative elevation of ring #B-7-1 was used as the benchmark site (lat. 29º 38'55.51", long. 92º 48' 19.27") and converted to an NAVD88 data point by using elevation data provided by the environmental engineering firm T. Baker Smith, LLC during the August - October 2016 survey for CPRA. The converted NAVD88 elevation for site #B-7-1 was then used to convert all other relative elevation data to NAVD88 data. Any potential errors in elevation conversions are the responsibility of this author.

Oyster size frequency data were collected by measuring all oysters from each quadrat density sample. Oysters were measured to the nearest millimeter using a plastic ruler placed from the hinge (umbo area) of the shell to the most distal linear edge. Oysters, still hinged and closed were classified as live, while those still hinged but open (gaping) were classified as dead; few hinged dead oysters were collected. A live-to-dead oyster ratio was not calculated and reported for mortality because dead shells were quickly disarticulated (became unhinged) by wave energy forces. Therefore, only live oysters are reported.

To assess water quality, a continuous recording Onset HOBO U24-002 conductivity logger® was deployed at the site for water temperature and salinity recording every hour from June 26, 2016 to October 29, 2016. This produced a relatively good representation of conditions during the most critical warm-months period of predation potential, peak spawning, spat recruitment and early-life shell growth. The deployment consisted of suspending the data logger within the internal space of a 5 cm (2-inch) diameter pvc pipe pushed into the bottom sands and located behind the Standard-Weight breakwater. The pvc pipe was perforated with many 19 mm (¾-inch) drilled holes to allow tidal water exchange. The data logger was positioned in the center of the pipe using heavy duty nylon twine and suspended 0.3 m (1 ft.) above the sediment. Efforts were made to correlate the hourly-collected water temperature and salinity data with the nearest constant recorder sondes maintained by state and federal agencies to produce hourly annual estimates, but the data did not correlate and the attempt was abandoned.

All generated oyster data, except for shell heights, were initially attempted to be normalized before statistical analysis, but normalization did not improve data resolution for use

in parametric analyses. Therefore, statistical analyses of oyster data consisted primarily by using the non-parametric Kruskal-Wallace One-Way Analysis of Variation (ANOVA) method on median values. Ring elevation data was subjected to a Cluster Analysis based on Euclidian distances after 50 iterations, resulting in the separation of values into three clusters. Cluster Analysis was performed using the program SYSTAT™ for Windows, version 11.00.01. Kruskal-Wallace ANOVA was performed using the program SigmaStat™ for SIGMAPLOT™ for Windows, version 12.5.

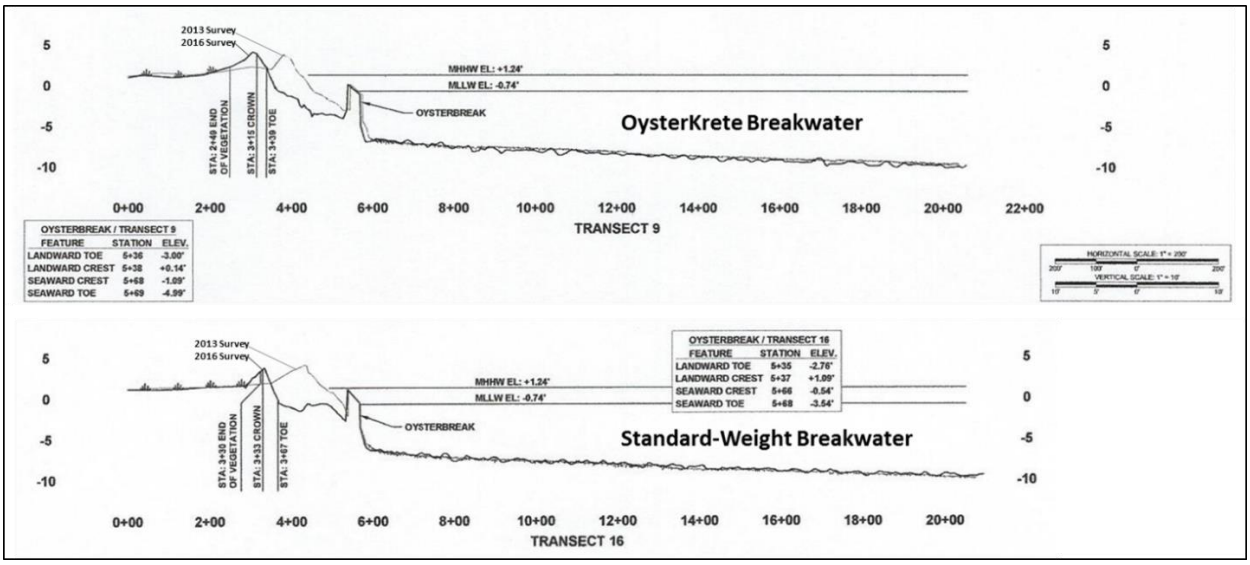

Figure 3. Elevation (ft., NAVD88, Geoid 12A) of Breakwaters Relative to Mean High High Water (MHHW) and Mean Low Low Water (MLLW) Through a Middle Transect from August – October 2016 survey. Data and Schematics Provided by T. Baker Smith, LLC.

RESULTS AND DISCUSSION

Water Quality:

Salinity along the shores of Rockefeller Refuge are influenced predominantly by ocean circulation, with salinity that can be as high as 30-34 psu, and from westward-flowing freshwater land and river discharges captured in longshore currents from the east (Murray 1976). Primary freshwater discharges from the east into the Gulf come from land runoff from the Mermentau basin and through Southwest Pass adjacent to Marsh Island. Southwest Pass drains much of the Teche/Vermilion basin and a good portion of the Atchafalaya River discharging from Wax Lake outlet and Morgan City. This pattern of east to west current flow was also locally evident by how the commercial crabbers consistently placed their traps in the Gulf to the west of Joseph Harbor Bayou pass, the closest tidal inlet located to the east of the breakwaters.

Freshwater flows from the east influenced the breakwaters during spring through fall 2016 sonde deployment. In August 2016, the Vermillion Basin had the highest monthly mean precipitation since the time of breakwater construction, 16.5 cm ± 3.7 (6.5 in. ± 1.5), 60% higher than the next highest monthly mean (data access NOAA National Centers for Environmental Information). Additional information from NOAA showed that the Teche/Vermillion Basin during this same time also had the highest mean monthly precipitation since construction, 0.3 cm ± < 0.1 (0.7 in. ± 0.1), 58% higher than next highest monthly mean. The Atchafalaya river at Morgan City was at a low stage by August 2016, 0.98 m (3.2 ft.), and did not contribute as much discharge as earlier in the year, peaking at 1.8 m (5.9 ft.) in March 2016 (data access U. S. Army Corps of Engineers). Salinity at the LA-08 site probably increased to levels above that observed during spring to fall 2016 whenever the basins' precipitation decreased and the Atchafalaya River discharge was low.

During the summer and early fall of 2016 the shallow Gulf waters adjacent to the breakwaters exceeded 34º C (93º F) on June 28th, and remained near or above 30º C (86º F) to October 1, before beginning to drop until the lowest temperature recorded, 24º C (76º F), on the last day of monitoring, October 24th (Figure 4). Salinity fluctuated considerably but always remained within the physiological tolerance range of oysters during those summer months (Figure 4). Salinity reached its highest at the onset of deployment at 25 psu on June 9th, but quickly fell for the next four weeks to a low of 9 psu on July 10th. Salinity rose and fell through the remainder of the monitoring period, with a minimum salinity of 5 psu on August 17th and a high of 23 psu on July 27th.

Salinity was within the range for successful oyster larvae physiological survival and recruitment (salinity ≥ 8 psu needed) for summer 2016 (Figure 4), and for oyster spat physiological survival and growth throughout the summer and fall of 2016 (salinity ≥ 5 psu needed). The relatively low salinity during August-September 2016 were most probably due to the influences by heavy precipitation in the Mermentau and Teche/Vermilion Basins (NOAA

Salinity depression during the summer and fall 2016 helped reduce the opportunities for predation. Salinity consistently above 15-18 psu are also ideal for oyster predators, especially on spat (Cake 1983). Salinities above 15psu occurred primarily in late July to early August 2016 (Figure 4). Oyster spat are vulnerable to predation from snails (*Stramonita haemastoma*), blue crabs (*Callinectes sapidus*), Gulf stone crabs (*Menippe adina*), and multiple species of small mud crabs (Xanthidae family). These species were observed to be present at the breakwater sites. Predator abundance will often confine long-term oyster survival and reef development to the intertidal zone out of reach by most.

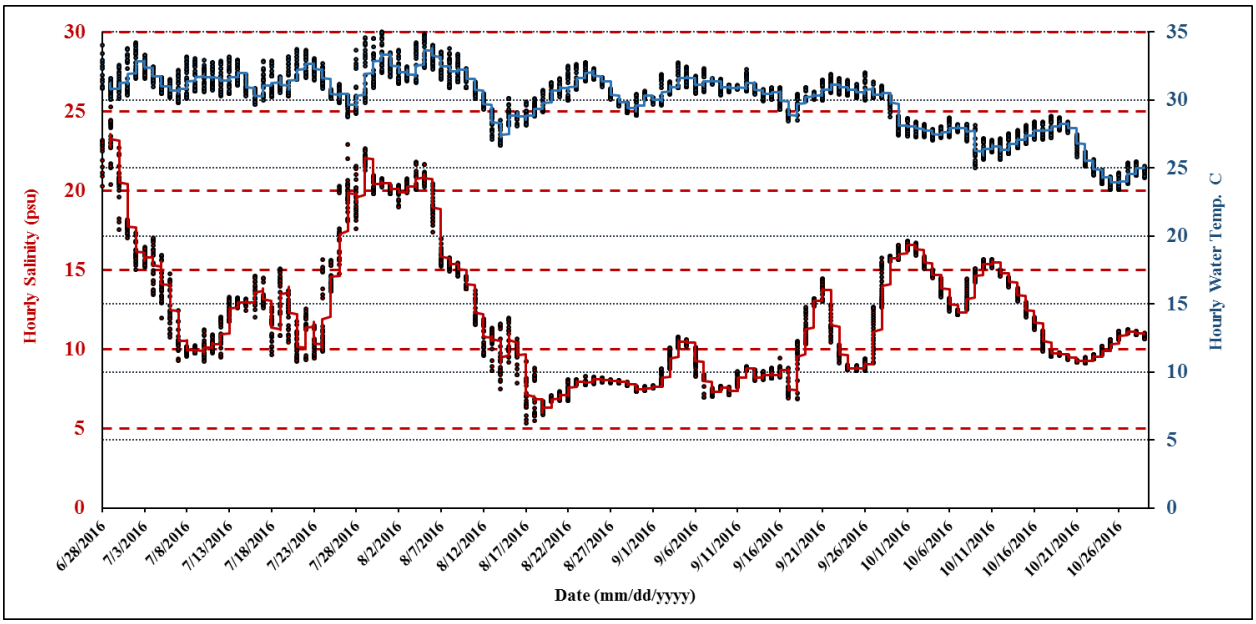

Figure 4. Hourly water temperature (blue) and salinity (red) at LA-08 through summer and fall 2016.

Oyster Population Structure and Age:

Once eggs are fertilized oyster larvae usually remain in the water column for up to 2-3 weeks during the late spring through early fall before attaching to substrate as spat. During this time, the larvae are essentially drifting with the prevailing currents. The closest known concentration of oysters spawners with a reef-type complex is in Joseph Harbor Bayou approximately 4.1 Kilometers (2.2 Nautical Miles) to the east. Recruitment of larvae may be coming from this area since longshore currents are predominantly flowing east-to-west along the Louisiana coast. However, because of the length of time during the larval phase, oysters that have recruited to the breakwaters could have originated from much farther east than Joseph Harbor Bayou. It is also possible that as oysters recruited to the structures, they too became spawners to recruit to the structures, if currents allowed. Regardless of oyster larvae origination from the east, the Standard-Weight breakwater's location was the first they encountered and could have potentially influenced recruitment density when compared to the OysterKrete

breakwater. Based on row B8B, the larval pool available to the breakwaters was sufficient to colonize and develop reef structure over time.

Analyses of shell height frequencies (Figure 5) indicate that several cohorts existed after four (4) years. However, there was a decline in older oyster after the second year of life (assuming most oysters have reached a shell height of 75 mm or greater by the age of 15-18 months, which is typical for Louisiana oysters in a relatively high salinity habitat). Most oysters, whether existing on OysterKrete concrete, Standard-Weight concrete, or on the Standard-Weight leeward side of bottom foundation row B8B, had a majority in the 30 mm (< 1 yr. old, assumed to be fall/winter 2015 recruits) to 80 mm range (1-2 yrs. old, assumed to be spring/fall 2014 recruits). A slight exception to this range exists for the Standard-Weight oyster population with a relatively good population of oysters greater than 80 mm in shell length (2+ yrs. old; red trend line Figure 5). The Standard-Weight breakwater (B) with the greatest percentage of larger oysters (Figure 5) may be due to survival on the higher-elevation rows when compared to the lower-elevation rows B1, B2 and B3 (Figure 6). For comparison, the size frequency distributions exhibited on the two LA-08 breakwaters were similar to the four-years post-construction size frequency distributions found on fabricated living shorelines in Terrebonne Bay (Melancon et al. 2013), with most also 1-2 years old.

The median size of oysters was significantly different ($p < .05$) for all three habitats (Figure7). It is interesting to note that the most protected area, the leeward back foundation row #B8B, had a comparatively low median and mean shell height than on most of the exposed rows (Figure 6). This may be due to higher percentage survival of row B8B fall 2015 of the smaller oyster spat, 11-30 mm, (Figure 5) and the comparatively small percentage of larger oysters. The reason for the comparatively smaller percentage of larger oysters on row B8B is not known, but may be due to the inherent randomness of spat settlement and variable densities.

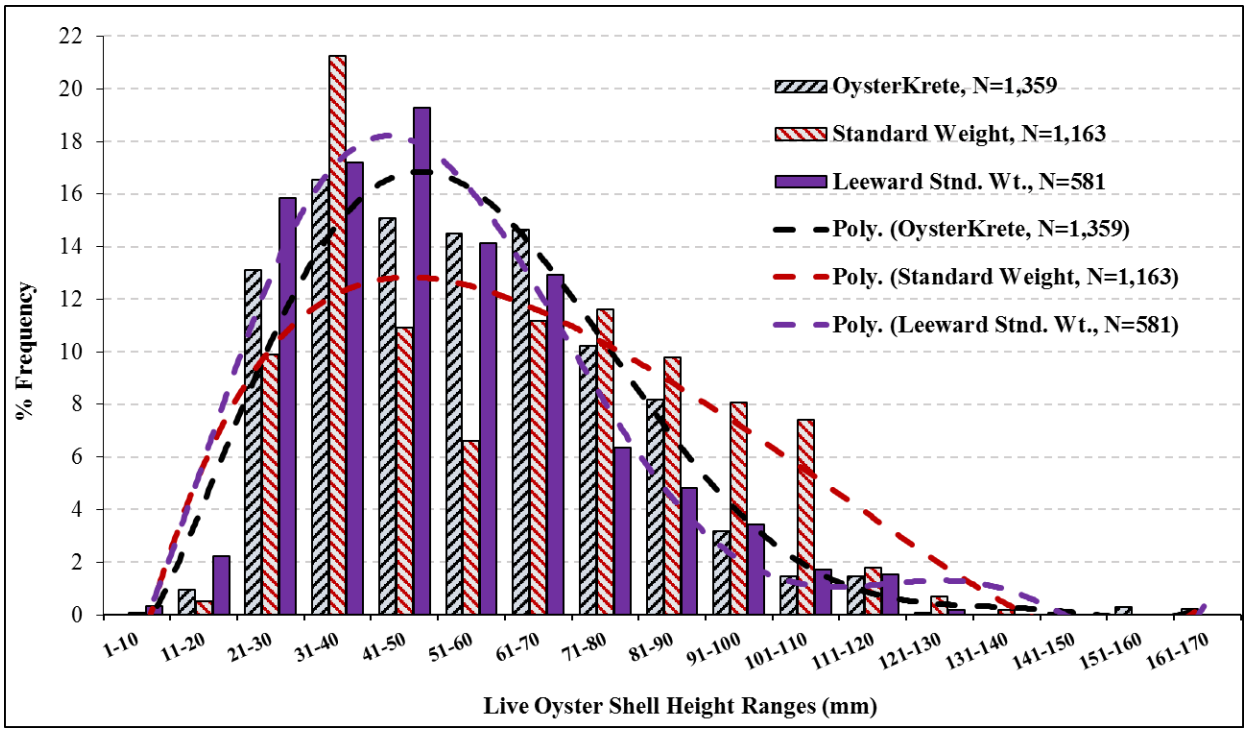

Figure 5. Live oyster shell height frequency distribution in January 2016 after 4-years post-construction (February 17, 2012 – January 2016), along with trend lines. Frequency data collected from quadrat (density) samples. OysterKrete is Reach-A, Standard-Weight is Reach-B, and Leeward is row B8B.

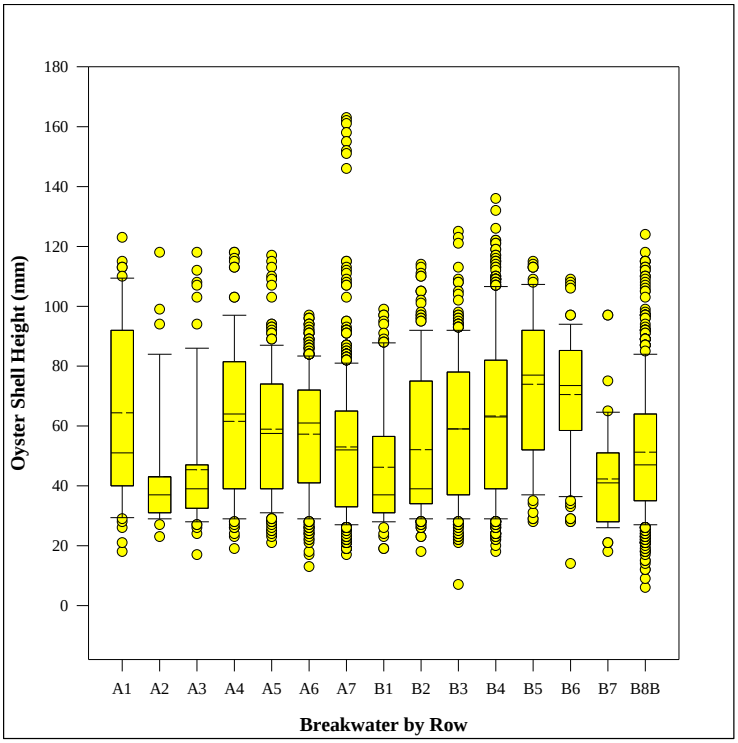

Figure 6. Median (solid line) and mean (dashed line), 25% and 75% quartiles, and range of oyster shell heights by row. Data collected January 2016, approximately 4-years post-construction.

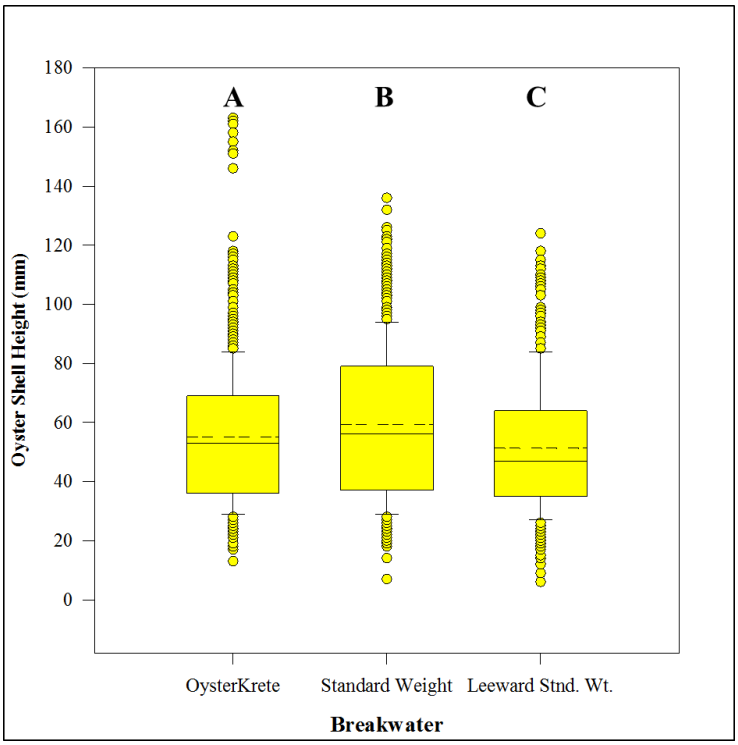

Figure 7. Median (solid line) and mean (dashed line), 25% and 75% quartiles, and range of oyster shell heights. Each breakwater median height was significantly different from the other (p< .05 and represented by the letters A-B-C and using statistical method Kruskal Wallace ANOVA on RANKS). Data collected January 2016, approximately 4-years post-construction.

Reef Development and Oyster Distributions:

At the end of construction, February 2012, the Standard-Weight breakwater had an average elevation 0.15 m (0.5 ft.) higher than the OysterKrete breakwater (McGinnis and Pontiff 2014). This elevation difference is important because the Rockefeller Refuge shoreline is a high-energy shoreline for wave development when using wind fetch distance (LaPeyre et al. 2015) and frequency of tidal inundation (Melancon et al. 2013) as critical influential parameters for oyster assessments. Both parameters potentially influence oyster recruitment and reef development on the two breakwaters. For example, during a July 2012 wave energy reduction assessment by T. Baker Smith, LLC, surveyors stated in McGinnis and Pontiff (2014 Appendix A) that they, "…. encountered higher significant wave heights compared to the East OysterBreak [Standard-Weight] Gage during high water levels. This may be attributed to the reef crest elevation of the West OysterBreak [OysterKrete] being lower than East OysterBreak, exposing higher waves heights to the West OysterBreak.". Additionally, McGinnis and Pontiff (2014) state "…. the OysterBreak – West [OysterKrete breakwater] was completely submerged 48% of the time while the east OysterBreak – East [Standard-Weight breakwater] was completely submerged 15% of the time during 2012-2013 based on water levels at CRMS0600 [site] located near LA-08."

Elevation difference and wave energy differences between breakwaters created challenges for biological comparisons from the onset of assessment. Elevation influence was visually evident on the Standard-Weight breakwater as lack of inundation greatly influenced the potential for oyster reef development by limiting oyster recruitment (Figure 8). Additionally, timing and duration of breakwater aerial exposure is not due exclusively to astronomical tidal activity, but also due to irregular exposure events during fall and winter storms and cold front passages originating from the northwest. It is during the synchronization of cold front passages and astronomical low tide events that created the best opportunities for biological assessments.

A total of 174 quadrat density samples were collected; OysterKrete breakwater = 83, Standard-Weight breakwater = 85, and leeward row B8B = 6. The quadrat size used in this study was 0.32m^2 instead of 1 m^2 to easily fit on the curvature of a ring. Standard protocol is to extrapolate less than 1m^2 quadrats and express oyster density in number per square meter (Baggett et al. 2014). In this case, such extrapolation protocol to square meter density masked the actual scattered nature of the oysters on both breakwaters, exclusive of row B8B.

The relatively good oyster population size-frequency distributions did not translate into a consistently good oyster density distribution within or between breakwaters (Figure 9), with the exception for row B8B. On the exposed windward upper surface of the rings, the oysters were often dispersed, and thus when extrapolated to number per square meter, implied a relatively good distribution that did not exist. Consequently, there was very little oyster reef development and consolidation on either of the breakwaters. This uneven density distribution appears to be greatly influenced by proximity to the forces of wave energy on the Gulfward-facing rows (Figure 9).

The greatest density occurred on the leeward side of the Standard-Weight breakwater, row B8B (Figure 10). In contrast, most A8A breakwater leeward rings had no oysters except for a few rings (Figure 10), and had elevations lower than the back rings on the B8B row (visual observation during high tides, no elevation measurements taken). Predation pressure due to greater annual inundation when compared to row B8B may be the reason row A8A had very few oysters, another factor that must be recognized when discussing parameters that influence oyster survival. Due to very limited oyster settlement on row A8A, no density samples were taken from that leeward-facing foundation row because of prioritization due to time constraints. Steadily increasing winds and rough seas during the elevation-gathering field day prevented more than six (6) samples being documented on row B8B.

A total of 282 ring elevations were collected from the breakwaters; OysterKrete = 130, Standard-Weight = 146, and Leeside row B8B = 6. But high-elevation rings above -0.097 m NAVD88 (Geoid 12A) could not be considered when comparing oyster density on the breakwaters; there is a significant trend of density with elevation on the OysterKrete breakwater (Figure 11), whereas the Standard-Weight breakwater has highly variable elevations and

corresponding variable oyster densities. Additionally, the linear increasing oyster densities on the leeward-facing row B8B corresponds significantly with elevation increase (Figure 11). Like the low elevations on row A8A with no oysters, the increasing oyster density on row B8B with increasing elevation suggests that there may be the potential for less predator pressure in the intertidal zone with increasing height.

Rings with high elevations above -0.1 m NAVD88 (Geoid 12A) in rows B4, B5, B6 and B7 did not have much if any top surface recruitment (Figure 11). Therefore, if all quadrat sites were assessed equally, the Standard-Weight Breakwater high-elevation rows would have an oyster density equal to "0" and skew statistical interpretation of results. But not all rings with an elevation < -0.1 m NAVD88 (Geoid 12A) had recruited oysters, and those rings with an oyster density value of "0" were included (Figure 11), indicating that elevation was not the sole determinant of success or failure in recruitment and reef development.

When all selected quadrat sites less than -0.1 m NAVD88 (Geoid 12A) were analyzed, irrespective of individual location and elevation, there was no statistically significant difference ($p < .05$) between breakwater types for oyster density (Figure 12), apart from the leeward-facing row B8B. After four (4) years, the OysterKrete breakwater had a median oyster population of $22/m^2$ (mean = $52/m^2 \pm 7$), the Standard-Weight breakwater had a median oyster population of $45/m^2$ (mean = $56/m^2 \pm 7$), and the leeward row B8B a median oyster population of $341/m^2$ (Mean = $307/m^2 \pm 86$). For comparative purposes, LaPeyre et al. (2017) summarized oyster densities from other Louisiana living shorelines located in mid-salinity habitat similar to the Rockefeller Refuge sites, with two sites exceeding $500/m^2$ oysters two-years post-construction and three sites with densities of $50\text{-}150/m^2$ one year post-construction.

Four-years post construction, a successful example of oyster reef development exists only on the leeward-facing row B8B with a mean top surface oyster coverage of 47 % ± 12, when compared to a mean coverage of 14 % ± 2 for Oysterkrete and 10 % ± 2 for Standard-Weight (Figure 13). For comparative purposes, four-years post-construction on living shorelines in Terrebonne Bay, Louisiana, Melancon et al. (2013) found Gabion Mats™ with 58% ± 13 oyster cover, A-Jacks™ with 60% ± 2 oyster coverage, and ReefBlks™ with 54% ± 3 oyster coverage. The Terrebonne Bay sites were all high wave energy habitats.

Reef height extending above the concrete surface is another important metric to help document reef development and profile complexity. Mean vertical reef height for row B8B was 50 mm ± 7, while Standard-Weight averaged 24mm ± 1 and Oysterkrete vertical reef height averaged only 21 mm ± 1 (Figure 14). Four-years post construction, a successful example of oyster reef development exists only on the leeward-facing row B8B, with large cohesive clusters of oysters of all angular shapes (Figure 15). In contrast, oysters exposed on the windward-facing breakwaters A and B had a mostly low and rounded shape (Figure 16), indicative of wave energy exposure.

During the winter 2016 assessment there appeared to be a correlation between row location and oyster recruitment to the interior center hole of a ring, especially on the Standard-Weight Breakwater B. As row elevation increased there was a denser internal hole population of oysters, although not quantified by quadrat methods. For example, the lower-elevation rings located more Gulfward, e.g., rows B1, B2 and B3, had fewer oysters in the central hole when compared to higher-elevation rows, B5, B6 and B7 (lower east end only on this row). This phenomenon is shown in Figure 17.

Other than potential recruitment limits, there may be another influence of increasing elevation and increasing density of oysters within the interior ring hole Figure (17). Oysters are heterotrophic and a population can consume a significant concentration of dissolved oxygen (D. O.) while submerged at high tide, especially during summer months when temperatures are high. It is possible that oysters in the higher-elevation rings are regularly exposed to the air during low tide and have ability to utilize oxygen from the atmosphere. Whereas, oysters in the lower-elevation rings are more inundated and have less availability of oxygen thereby potentially depleting D. O. to critical levels. This hypothesis should be investigated further because this can have major influence on oyster population development if sufficient water circulation and air exposure is a limiting factor in the internal spaces of rings.

Figure 8. Looking westward from middle of Breakwater-B (Standard-Weight concrete) with no surface oysters recruited to many rings in rows B4, B5, B6 and B7. Most of rows B5-B7 were too high out of water for recruitment on surface. Notice in foreground a few oysters recruited on internal surface of central holes. Photo taken at low tide. Breakwater-A (OysterKrete) is seen in distance.

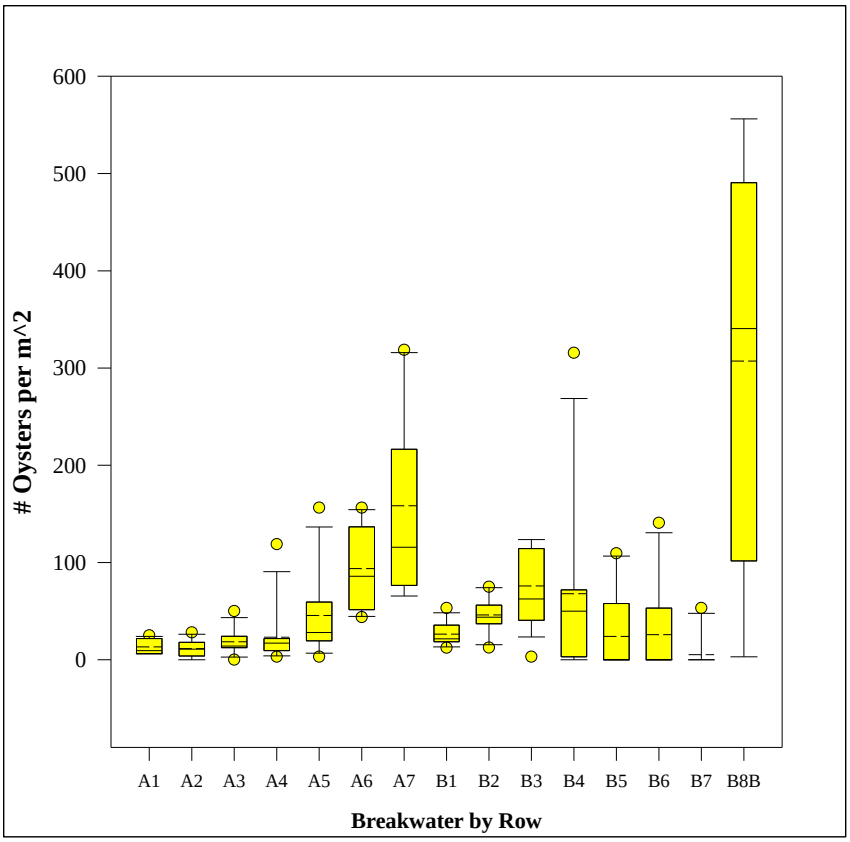

Figure 9. Median (solid line) and mean (dashed line), 25% and 75% quartiles, and range of all oyster density quadrats by row.

Figure 10. Leeward-facing foundation row B8B on the left showing oysters (Standard-Weight) as compared to the right photo showing row A8A (OysterKrete). Photos taken facing west. Arrows indicate where oysters are located.

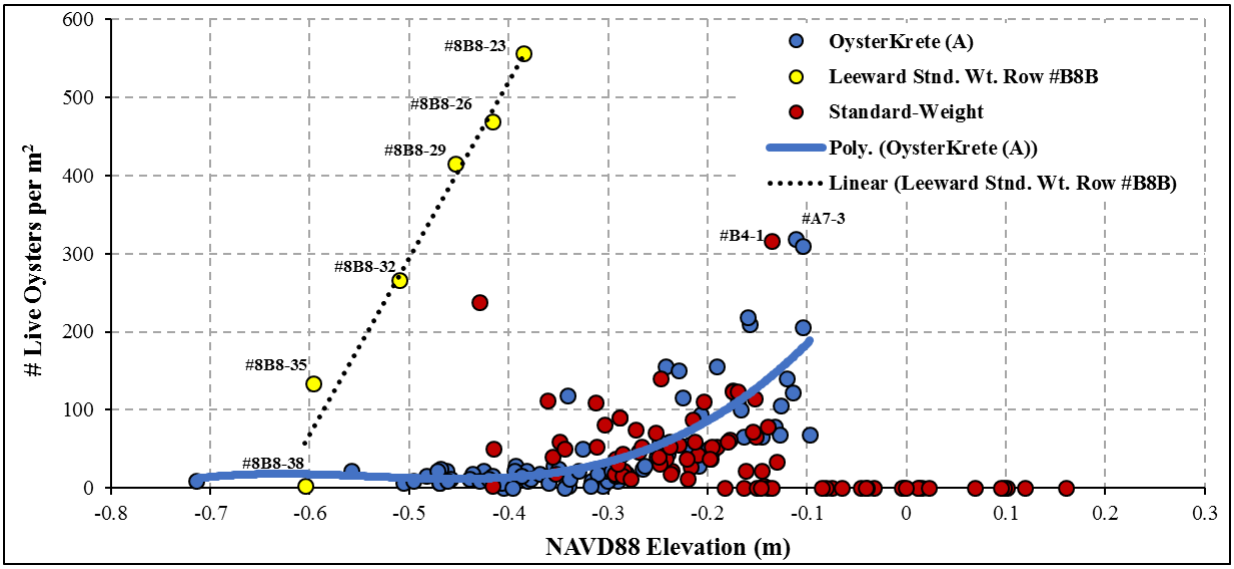

Figure 11. Individual Quadrat Oyster Density vs. Elevation for all Rings Measured at the LA-08 Site (OysterKrete (A) N=83 rings, Standard-Weight (B) N=74 rings, Leeward Standard-Weight Row (B8B) N=6). The greater the Elevation Value, the higher the Ring Top Surface was in the Water Column Resulting in less Annual Tidal Inundation. A few individual rings identified with site number for reference.

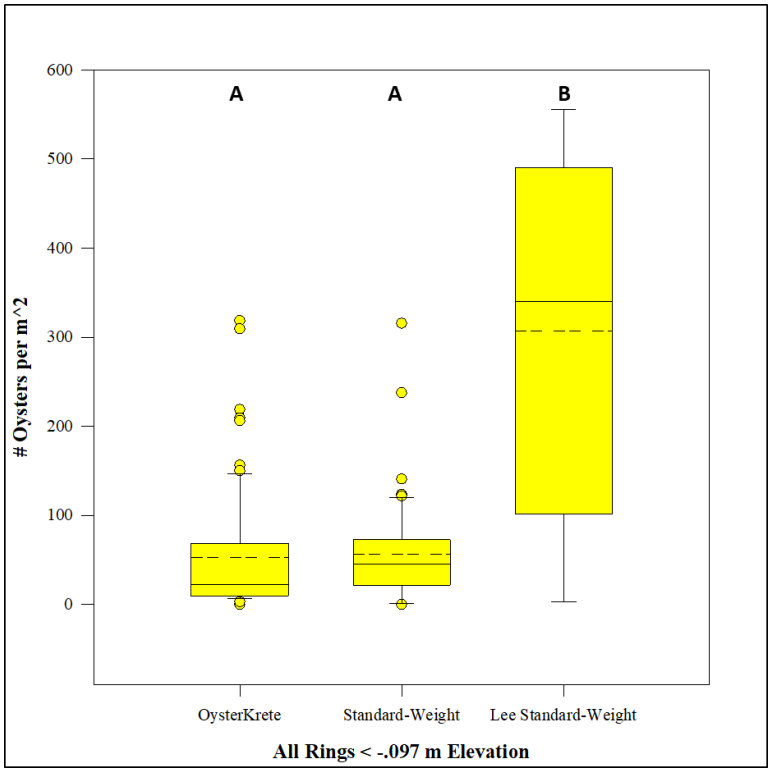

Figure 12. Analysis of all quadrat density samples <-0.1 m NAVD88 (Geoid 12A) elevation. Breakwaters with different letters indicate significant difference between median values (Kruskal Wallis one way analysis of variance on ranks, $p < .05$). Median (solid line) and mean (dashed line), 25% and 75% quartiles, and range of oyster density.

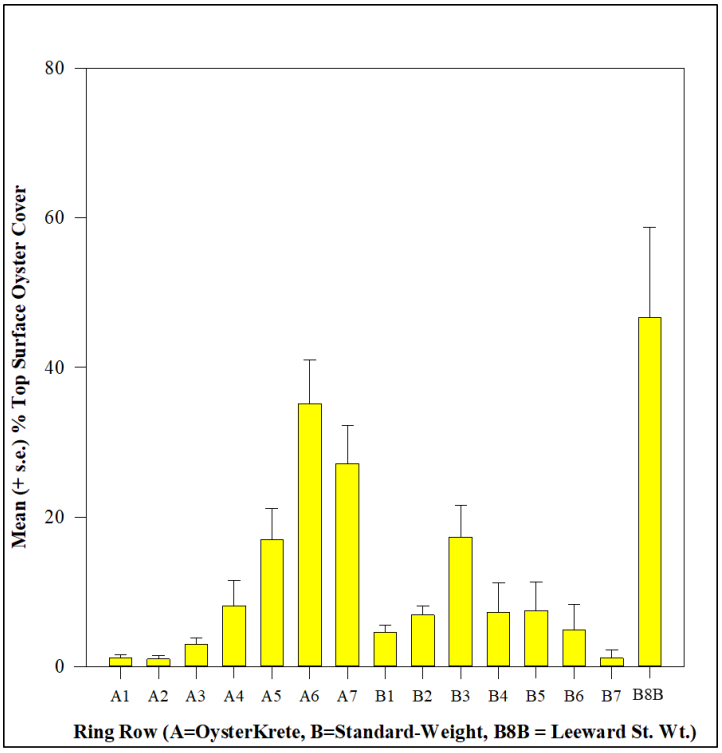

Figure 13. Percent oyster cover on top surface of OysterBreak rings within each row surveyed January 2016.

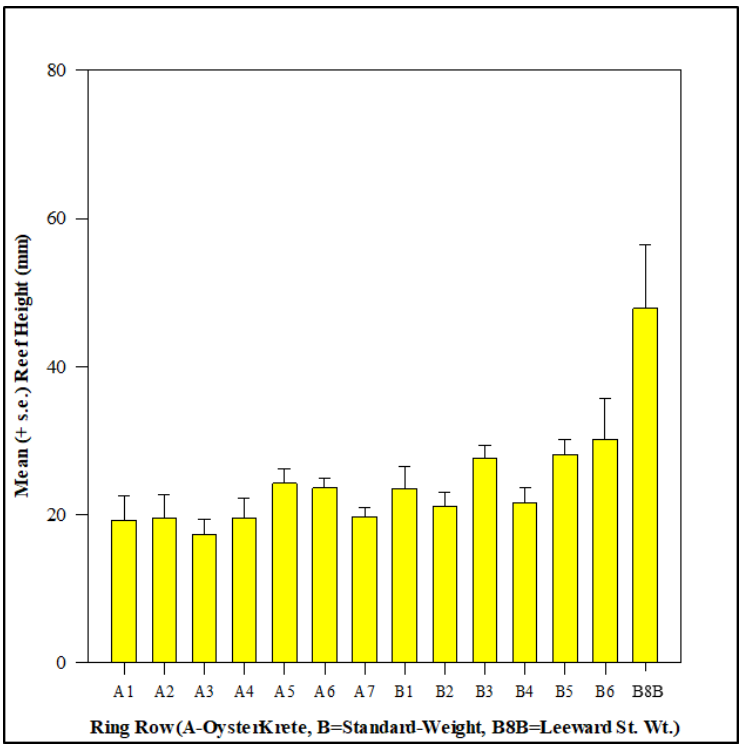

Figure 14. Mean vertical reef height of oyster populations on ring top surfaces within each breakwater row January 2016. (no data for row B7; rows B4, B5 and B6 very limited data from east-end rings with lower elevations).

Figure 15. A successful example of reef structure exists on the leeward-facing hard-surface row B8B. Observe multiple size-frequencies with fusion of oysters into dense complex shapes with relatively good elevations of high-profiles above the ring surface. Recruited to rings, 4-years post-construction.

Figure 16. A failed example of reef development of surface oyster population showing scattered, rounded low-profile-shaped oysters, characteristic of wave energy influences on the topside hard-surface Gulfward-facing rings. Recruited to rings, 4-years post-construction.

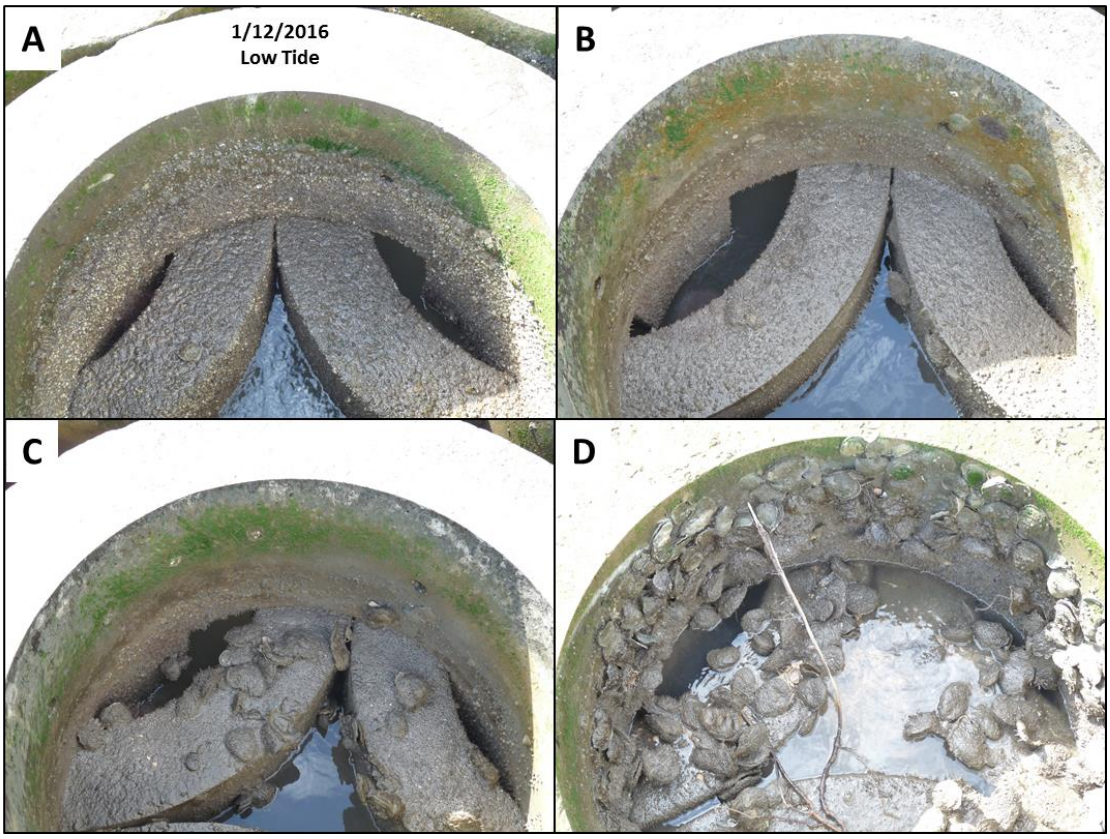

Figure 17. Interior center hole of top layer of rings on Standard-Weight breakwater. Oysters in photos A and B are typical of low-elevation rings (rows B1-B3). Oysters in photos C and D are typical of high-elevation rings (rows B4-B7). All photos January 2016.

OysterKrete Concrete vs. Standard-Weight Concrete:

The second objective of this study was to compare the two concretes for ability to attract oysters and influence initial shell growth. The large variations in ring elevations on each breakwater row < -0.1 m NAVD88 (Geoid 12A), coupled with the influence of wave energy on the lower rows, created considerable difficulty in comparing breakwater concrete types. Nevertheless, a cluster analysis was used to associate similar rings based solely on elevation to compare OysterKrete concrete to Standard-Weight concrete. Therefore, interpretation of any statistical results comparing the two concrete types must consider this inability to include wave energy as a factor.

The cluster analysis identified an elevation range between -0.3 m to -0.1 m NAVD88 (Geoid 12A) to compare quadrat density of OysterKrete (N=36) versus Standard-Weight (N=51) rings (Figure 19). Elevation differences within and between breakwaters was substantial, and the relative slope of the clustered sites used within rows was different (Figure 19). It is not known if difference in slopes of breakwater sites -0.3influenced results.

Analysis and interpretation of the results is difficult because most of the OysterKrete quadrats with a relative elevation between -0.3 m to -0.1 m were on rows A5, A6 and A7, all farthest from the influence of wave energy, and for Standard-Weight found on rows B1, B2, B3 and B4 (Figure 21). This location difference can potentially skew results in favor of Oysterkrete. OysterKrete rings within that elevation range are in the upper rows away from wave energy influences when compared to the Standard-Weight rings located in the lower rows (Figure 20). Oyster density was clearly greater on the higher ring rows of OysterKrete probably because of the potential for greater protection from wave energy and potential refuge from predators (refer to Figure 11). Percent oyster cover also increased with row elevation (refer to Figure 13).

Understanding the limitations of analyses and interpretation, oyster density was significantly different between breakwaters (Figure 21), with OysterKrete having a median oyster population density of 92/m^2 (mean = 108/m^2 ± 140) and Standard-Weight with a median population of 43/m^2 (Mean = 54/m^2 ± 8). This significant higher oyster density on OysterKrete occurred even though prevailing currents allowed larvae to encounter the Standard-Weight breakwater first. However, 4-year post construction shell heights between the two concrete types showed no statistically significant difference. (Figure 22).

The results must be compared to the 2013 LA-08 results reported by McGinnis and Pontiff (2014 Appendix B). In that study, paired experimental cylinders of OysterKrete and Standard-Weight concrete were analyzed. The cylinders were protected from wave energy and positioned within each experimental cage at the same elevation. Results showed no statistically significant difference (Wilcoxsin-Sign Rank Test, $p = 0.359$) in recruiting oysters, with a median density of 15/m^2 spat on Standard-Weight and a median density of 16 spat/m^2 on OysterKrete. However, there was a statistically significant difference in initial oyster spat shell growth (Kruskal-Wallis One Way Analysis of Variance on Ranks, $p < .05$) with a Standard-Weight median size of 7.3 mm to that of OysterKrete with a median size of 5.8 mm.

Evaluations are mixed when results from 2016 are compared to 2013; OysterKrete did not outperform Standard-Weight in recruiting oysters in 2013, but did in 2016. When results from 2016 for shell growth is compared to 2013 results, there was no significant difference in 2016, but there was significant difference in favor of Standard-Weight in 2013.

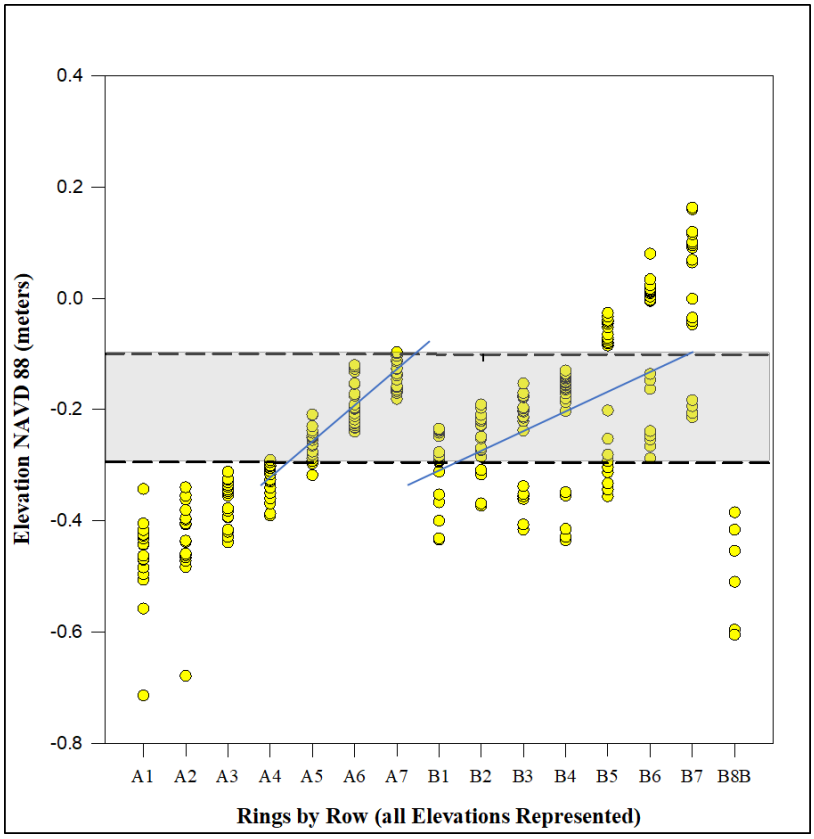

Figure 19. Plot of individual ring elevation within each breakwater row. Shaded area indicates results of Cluster Analysis used for comparing OysterKrete (Reach-A) with standard-weight rings (Reach-B) for ability to recruit oysters, -0.3 m to -0.1 m. Row B8B was not included in the Cluster Analysis. Solid blue line for each breakwater indicates relative slope for selected cluster sites within rows.

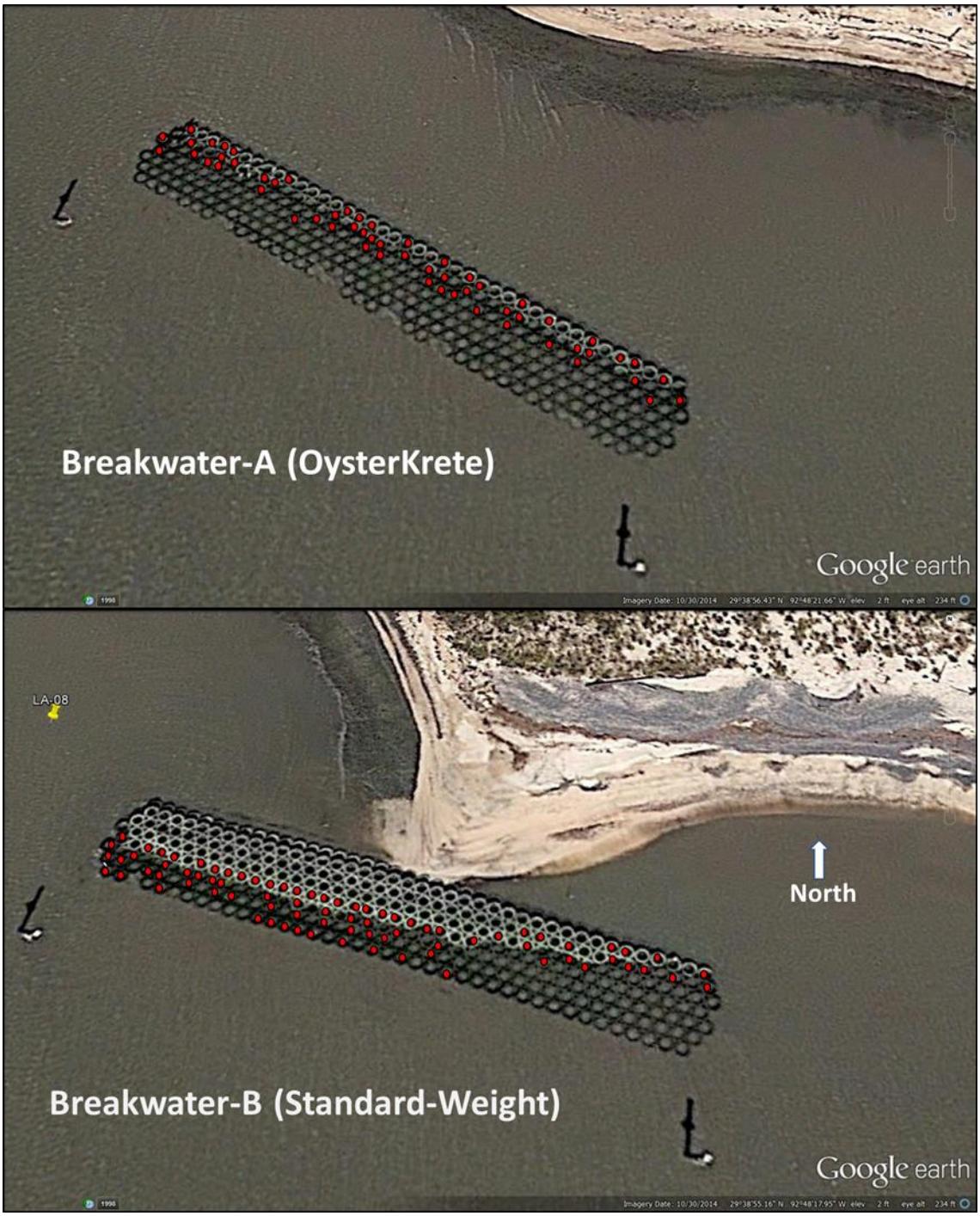

Figure 20. Location of Select Sites (red circles) identified in Cluster Analysis with elevations between -0.3m to -0.1 m NAVD88 (Geoid 12A) and used in comparisons of OysterKrete concrete to Standard-Weight concrete.

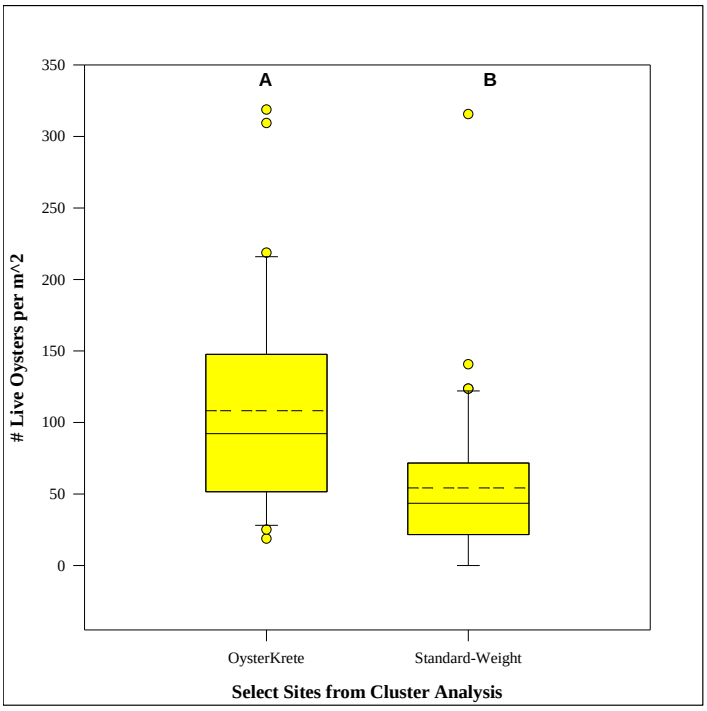

Figure 21. Analysis of density samples of select quadrats based on NAVD88 elevations between -0.3 m and -0.1 m. Breakwaters with different letters indicate significant difference between median values (Kruskal Wallis one way analysis of variance on ranks, p < .05). Median (solid line) and mean (dashed line), 25% and 75% quartiles, and range of oyster density exhibited.

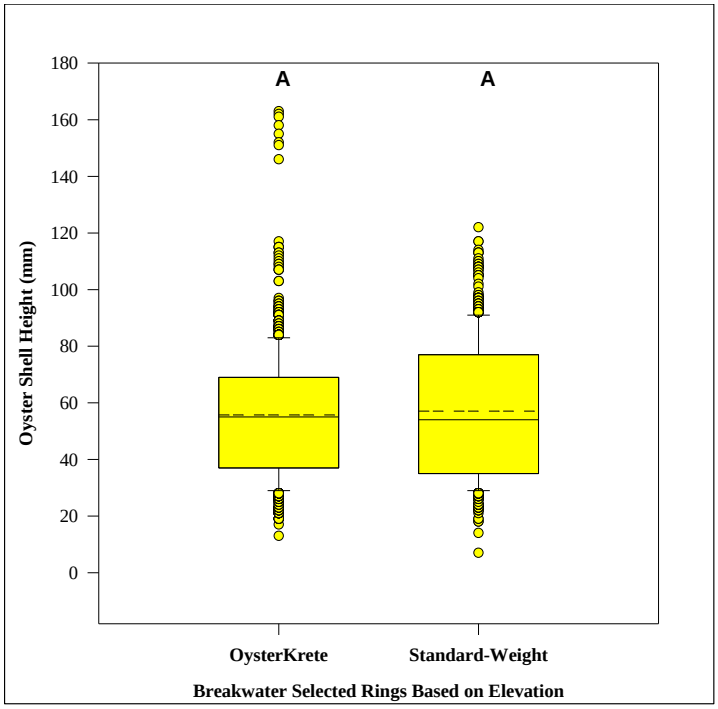

Figure 22. Analysis of shell heights for those select ring elevations between -0.288 m and -0.104 m NAVD88 (Geoid 12A). Breakwaters with different letters indicate significant difference between median values (Kruskal Wallis one way analysis of variance on ranks, p < .05). Median (solid line) and mean (dashed line), 25% and 75% quartiles, and range of oyster density

SUMMARY

There were two biological goals to specifically accomplish during this four-year project and study along the Gulf of Mexico shore on the Rockefeller Wildlife Refuge*:*

(1) To quantify the oyster colonization of the OysterBreak^{TM} structures, and ability to build a sustained reef population with complex structure composed of multiple oyster size-class distributions (multiple cohorts), and,

(2) To test OysterKrete© (Breakwater Reach-A) against Standard-Weight concrete (Breakwater Reach-B) in its ability to enhance colonization of oysters on the OysterBreak^{TM} structures.

Both goals were accomplished by successfully completing the four objectives specifically outlined in the CPRA-Nicholls State University contractual agreement:

(1) Document Oyster Density,
(2) Document Oyster Size Classes (surrogate for approximate age),
(3) Document Oyster Reef development and Growth, and
(4) Document Water Quality.

Based on observations and documentation of data pertaining to the four objectives, the following results are summarized:

- The LA-08 project site water quality, specifically water temperature and salinity, were within acceptable ranges for oyster larvae recruitment, recruited oysters' survival and shell growth, and reef development in an intertidal habitat

- Oysters recruited in sufficient numbers to potentially develop reef. Multiple oyster cohorts were found, with the dominant year classes of 1-year and 2-year old dominating on both breakwaters, including the leeward row B8B.

- Wave energy greatly influenced how oysters recruited, with only the leeward side of the last row of breakwater rings (B8B) showing reef formation. Oysters on the exposed Gulfward facing breakwaters had oysters with a low-profile and rounded shape, while those on the leeward facing row B8B had oysters with a much higher elevation profile and multiple angular shapes.

- Oyster recruitment to structures was not uniform across the breakwaters. Oysters on the exposed Gulfward facing breakwaters were sparsely populated and not sufficient for reef development. Oysters on the leeward facing, bottom row (B8B) were clustered and dense, typical of good reef structure.

- Oyster recruitment was correlated with Breakwater Rings' elevation, with some rings totally devoid of oyster on the top surface because they were too high out of water. Low elevation rings were potentially more vulnerable to predation.

- Evaluation of OysterKrete concrete versus Standard-Weight concrete to attract oyster larvae to recruit as spat is inconclusive.

- Evaluation of OysterKrete concrete versus Standard-Weight concrete to stimulate spat oysters to produce shell growth is inconclusive.

CONCLUSIONS

Project Effectiveness:

- Both structure types, OysterKrete and Standard-Weight, failed to form oyster reef after 4-years. From the perspective of developing oyster reef with erosion protection-ability, neither is effective. Only the leeward-facing row B8B, protected from wave-energy, developed a good reef complex.

- Adequate evaluation of OysterKrete concrete to Standard-Weight concrete could not be conducted for either the difference in attracting oyster larvae for recruitment or the difference in ability to stimulate oyster shell growth once larvae recruit and become spat. This inability to evaluate is primarily because of the many elevation differences between and within each breakwater.

Recommended Improvements:

- The two dominant environmental variables that influenced results and interpretation were wave-energy and elevation. Elevation and slope disparity is inherent in any project involving placement of structures in a habitat that is heterogenous and constantly changing. Since habitat in such a dynamic beach location is constantly changing, the two concrete ring types could have been mixed within each of the two breakwaters. Mixing would have created better ability to address variability from a statistical perspective and interpret results. This mixing may be difficult during construction, but should be considered as part of construction protocol and cost in future demonstration projects.

- Included in any future demonstration project should be sufficient funds to place a fortified structure at the site to house a constant water quality sonde recorder that includes water depth (water elevation) changes. The fortified structure must be vandal-proof and hurricane-force sustainable. This data could help in evaluating the annual potential for predators, oyster physiological needs, and how often individual rings are inundated by tides and storms.

Lessons Learned:

- Wave energy is a fundamental issue for any shoreline structure placed in such a dynamic location where wind is a relentless force.

- Neither concrete type is very suitable for oyster reef development on a shoreline with high wind fetch and ability to generate waves. In this structure configuration, concrete with its solid surface and resistance to wave forces was shown to be a deterrent to oyster

recruitment and reef-building success. The issue was structure location in a high wave energy habitat, as evidenced by the leeward row B8B development of oyster reef.

- It is important to have a proper slope to reduce the blunt force of wave energy, but the slope of each breakwater did not negate the influence of wave energy to the top high elevation rows. Those oysters that did recruit on the upper rows of breakwaters, intended to be away for the harshest wave energy conditions, had the same appearance of a rounded and low-profile shape as the low elevation rows. The shell shape likely due to less space competition and to a low profile to lessen resistance to wave forces. Additionally, the elevation of some breakwater rings were above tidal influences and did not allow oyster.

- Louisiana is a microtidal habitat that rarely exceeds a range of 0.3-0.5 m (1-1.5 ft.) in a diurnal cycle. There appears to be a very limited window to establish the correct structure slope-to-elevation ratio to potentially produce oyster reef in a high-energy and predator-friendly habitat.

- If results from a small-footprint study are to be interpreted and extrapolated on a large scale, the ability to find equivalent bottom depths and bottom slopes to place structures is paramount, but probably not attainable or practicable because elevation and slope will intrinsically be variable. The heterogeneous nature of the two breakwaters for elevation and slope reflected a real-world setting for potential oyster reef development. Therefore, paired replication of types within a structure would have been preferable to constructing homogeneous structure types for each concrete. Proper Sighting of Structures is imperative for successful oyster reef development and sustainment.
    - The long-shore, westerly, water currents are sustaining the reduction of ocean salinities that allow for oyster reef development, but predators are present. If ring structures on the leeward-facing back row subside to low-intertidal and subtidal, oyster predation will probably reduce ability to sustain the oyster populations that now exist. Predation will probably outpace oyster recruitment.

    - The long-shore, westerly, water currents are providing the oyster larvae to recruit to the structures. As the shoreline erodes the structures could become less entrained within the prevailing currents and reduce larvae supply.

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APPENDIX

Schematic of Density Quadrats Photo Labeling

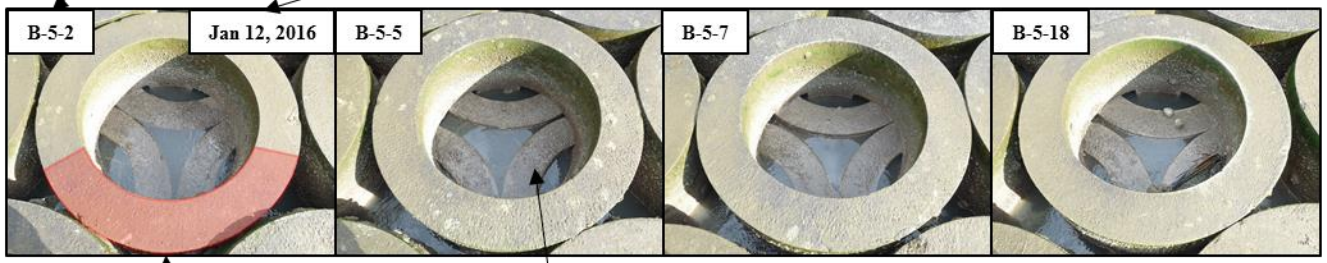
Breakwater: (A = OysterKrete, B = Standard Weight)
Row # : (#1 = most Gulfward, #7 = most Leeward)
Ring # : (facing Leeward (towards shore) and rings numbered consecutively from left to right)

Date photos taken; all consecutive photos that are not labeled are same date unless otherwise documented

The Leeward-Facing (Shoreward) Direction

Ring I.D. # and Density of Live Oysters in 0.32 m² Quadrat area measured

Leeward



Site I.D.	Live Oyster Quadrat Density (0.32 m²)
B-5-1	0
B-5-5	0
B-5-7	0
B-5-18	0
B-5-19	0
B-5-22	0
B-5-25	0
B-5-35	26
B-5-36	35
B-5-39	16

Gulfward

Shaded area is location of each 0.32 m² Oyster Density Quadrat taken; Always the Gulfward-Leading Portion of a Concrete Ring, with exception of row B7B (leeward-facing underlying foundation row of rings); note that photos of rings in Rows A-1 and B-1 are oriented opposite all other rows

Inner Ring Area showing Underlying set of Foundation Rings

The Gulfward-Facing (offshore) Direction

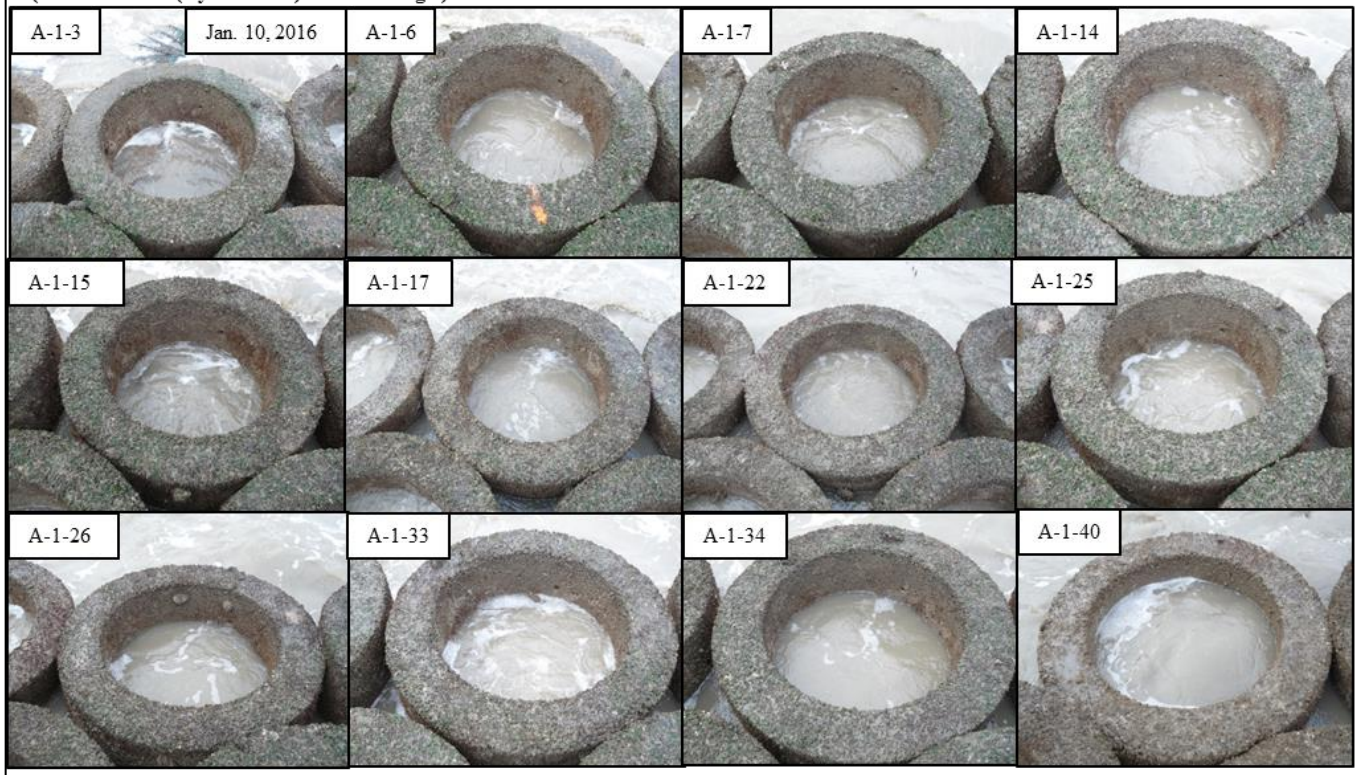
Latitude and Longitude of First and Last Breakwater Ring within a Row

Begin 29°38'55.49"N 92°48'19.35"W

End 29°38'54.85"N 92°48'17.20"W

(Breakwater-A (OysterKrete) –Row #- Ring #)

Gulfward



Leeward

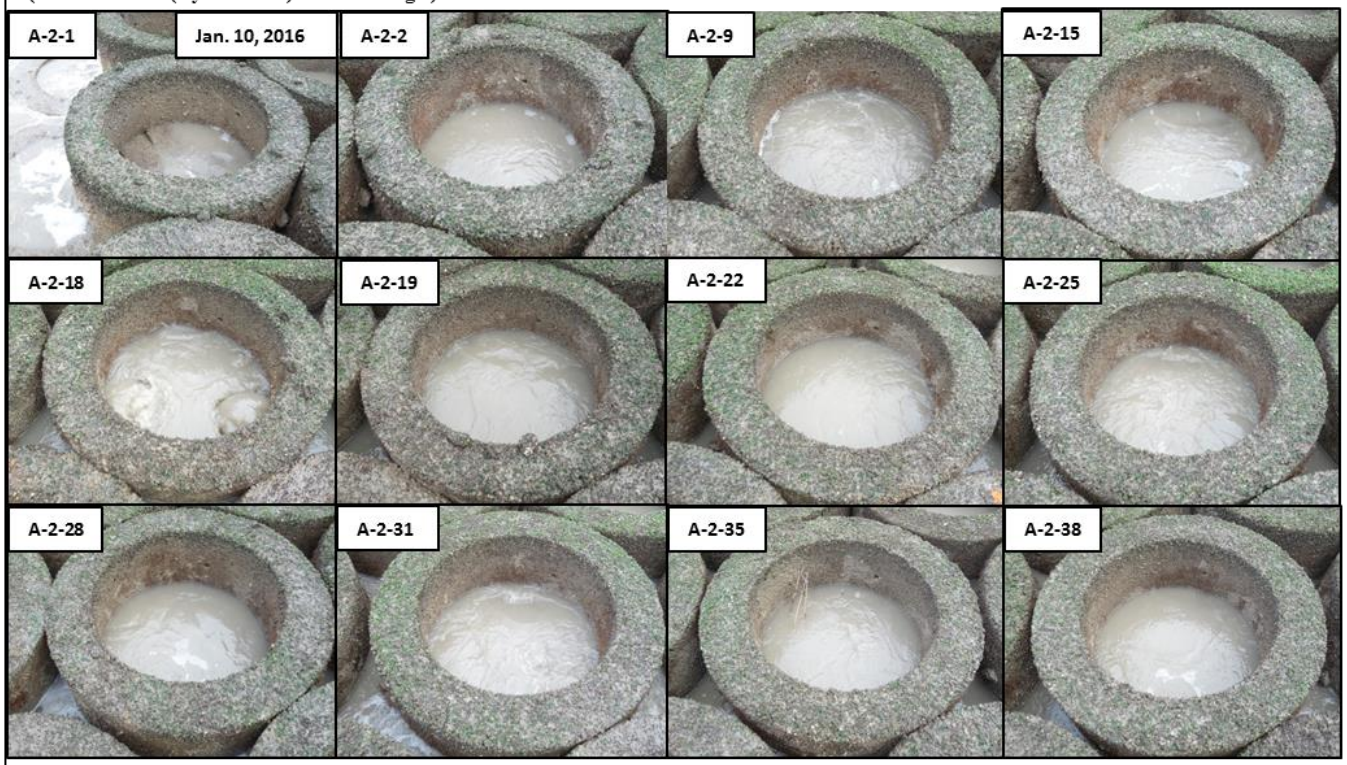
Site I.D.	Live Oyster Quadrat Density (0.32 m²)
A-1-03	2
A-1-06	5
A-1-07	7
A-1-14	2
A-1-15	3
A-1-17	2
A-1-22	2
A-1-25	8
A-1-26	7
A-1-33	3
A-1-34	7
A-1-40	3

Begin 29°38'56.93"N 92°48'23.04"W

End 29°38'55.94"N 92°48'21.18"W

(Breakwater-A (OysterKrete) –Row #- Ring #)

Leeward



Gulfward

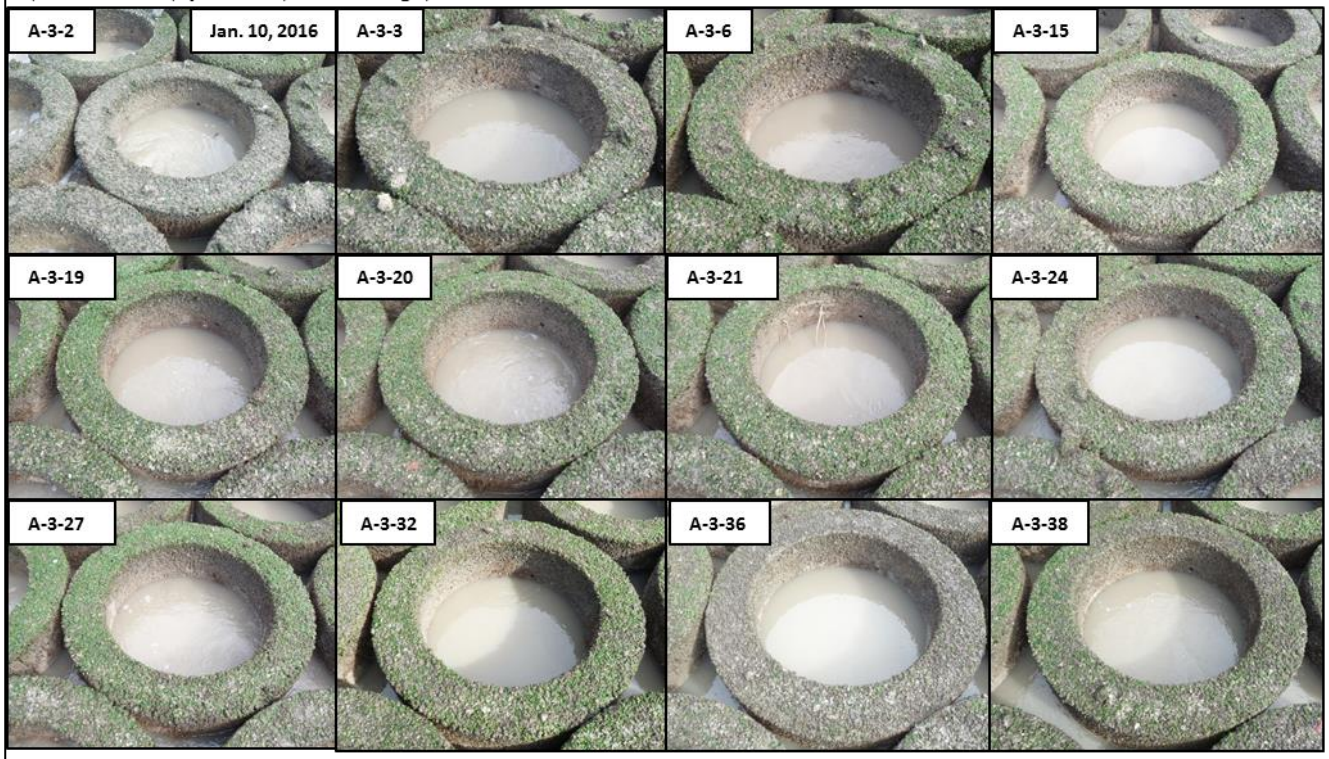
Site I.D.	Live Oyster Quadrat Density (0.32 m²)
A-2-01	1
A-2-02	9
A-2-09	4
A-2-15	0
A-2-18	5
A-2-19	7
A-2-22	4
A-2-25	2
A-2-28	3
A-2-31	0
A-2-35	3
A-2-38	6

Begin 29°38'56.98"N 92°48'23.04"W

End 29°38'55.96"N 92°48'21.13"W

(Breakwater-A (OysterKrete) –Row #- Ring #)

Leeward



Gulfward

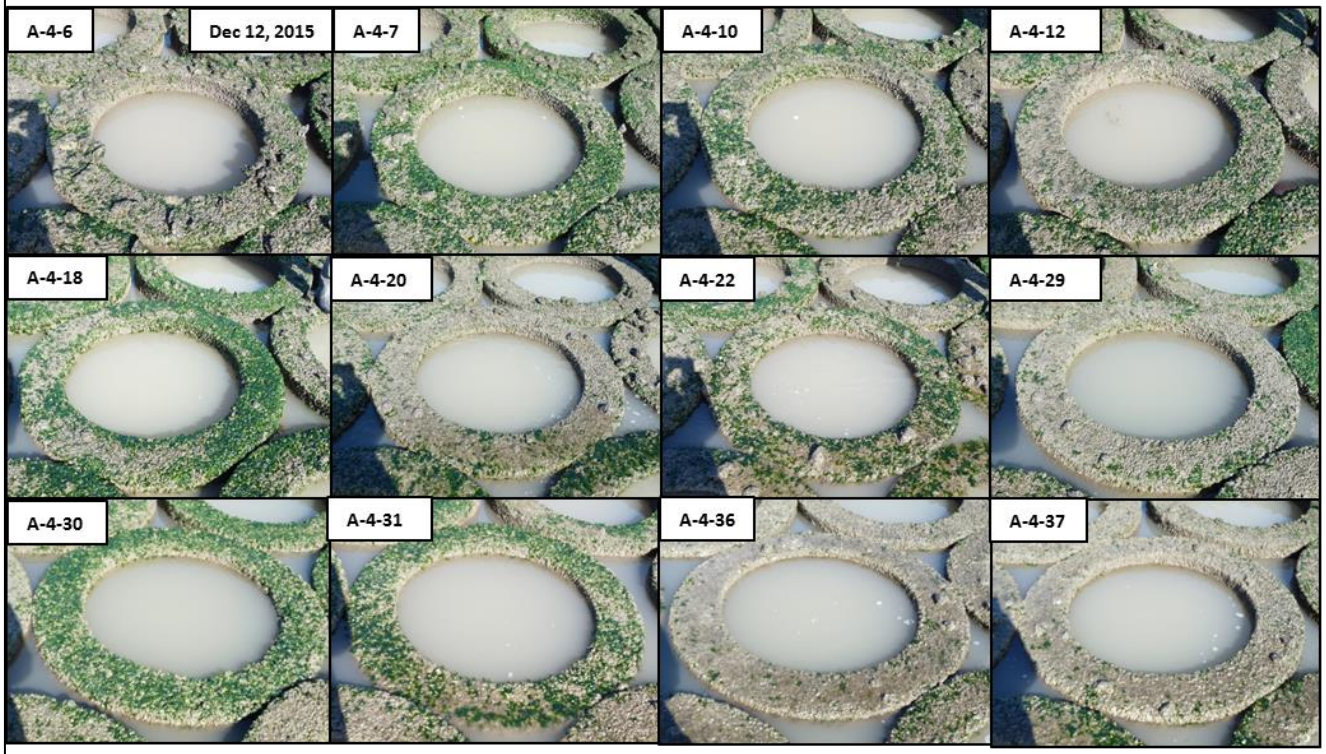
Site I.D.	Live Oyster Quadrat Density (0.32 m²)
A-3-02	9
A-3-03	7
A-3-06	16
A-3-15	0
A-3-19	4
A-3-20	3
A-3-21	5
A-3-24	4
A-3-27	4
A-3-32	8
A-3-36	7
A-3-38	4

Begin 29°38'57.03"N 92°48'23.04"W

End 29°38'55.98"N 92°48'21.08"W

(Breakwater-A (OysterKrete) –Row #- Ring #)

Leeward



Gulfward

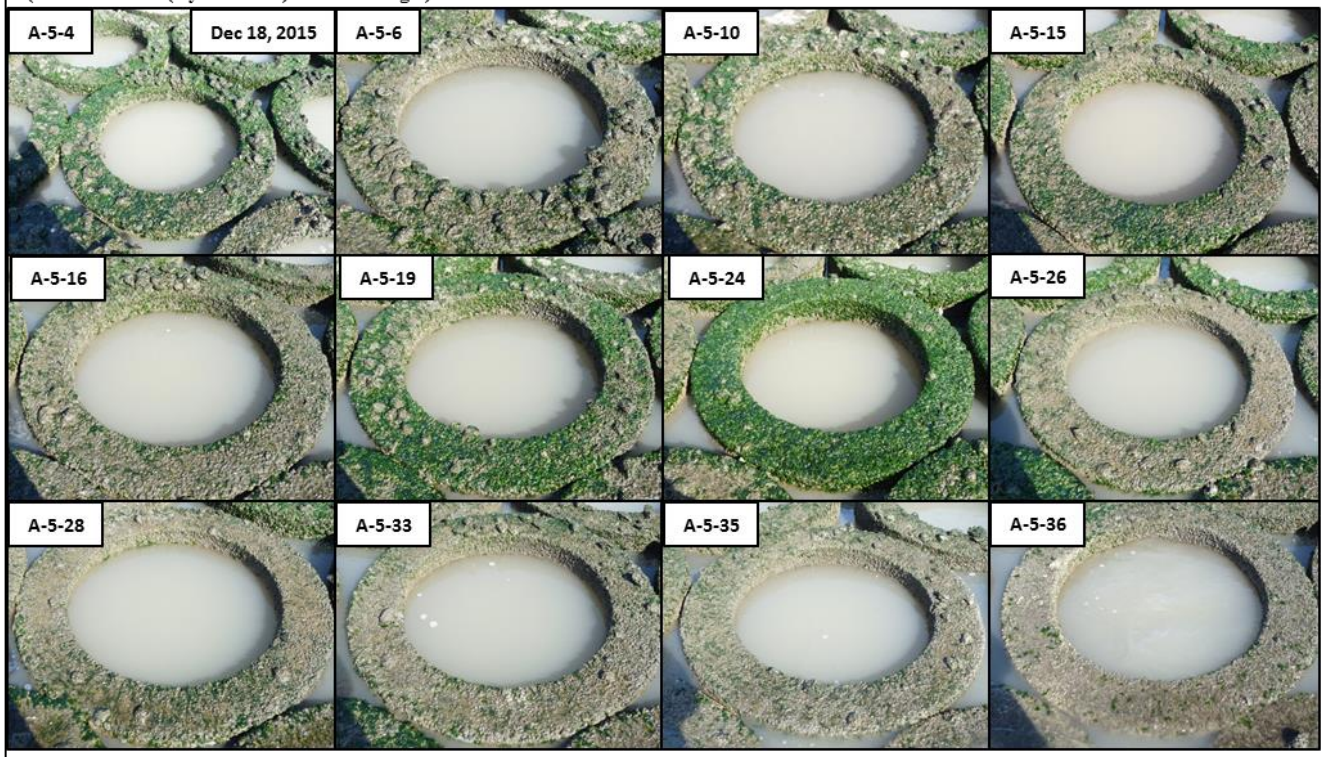
Site I.D.	Live Oyster Quadrat Density (0.32 m²)
A-4-06	38
A-4-07	7
A-4-10	1
A-4-12	3
A-4-18	3
A-4-20	5
A-4-22	6
A-4-29	8
A-4-30	7
A-4-31	2
A-4-36	3
A-4-37	6

Begin 29°38'57.05"N 92°48'22.99"W

End 29°38'56.03"N 92°48'21.07"W

(Breakwater-A (OysterKrete) –Row #- Ring #)

Leeward



Site I.D.	Live Oyster Quadrat Density (0.32 m²)
A-5-04	29
A-5-06	50
A-5-10	13
A-5-15	9
A-5-16	8
A-5-19	19
A-5-24	9
A-5-26	19
A-5-28	5
A-5-33	7
A-5-35	6
A-5-36	1

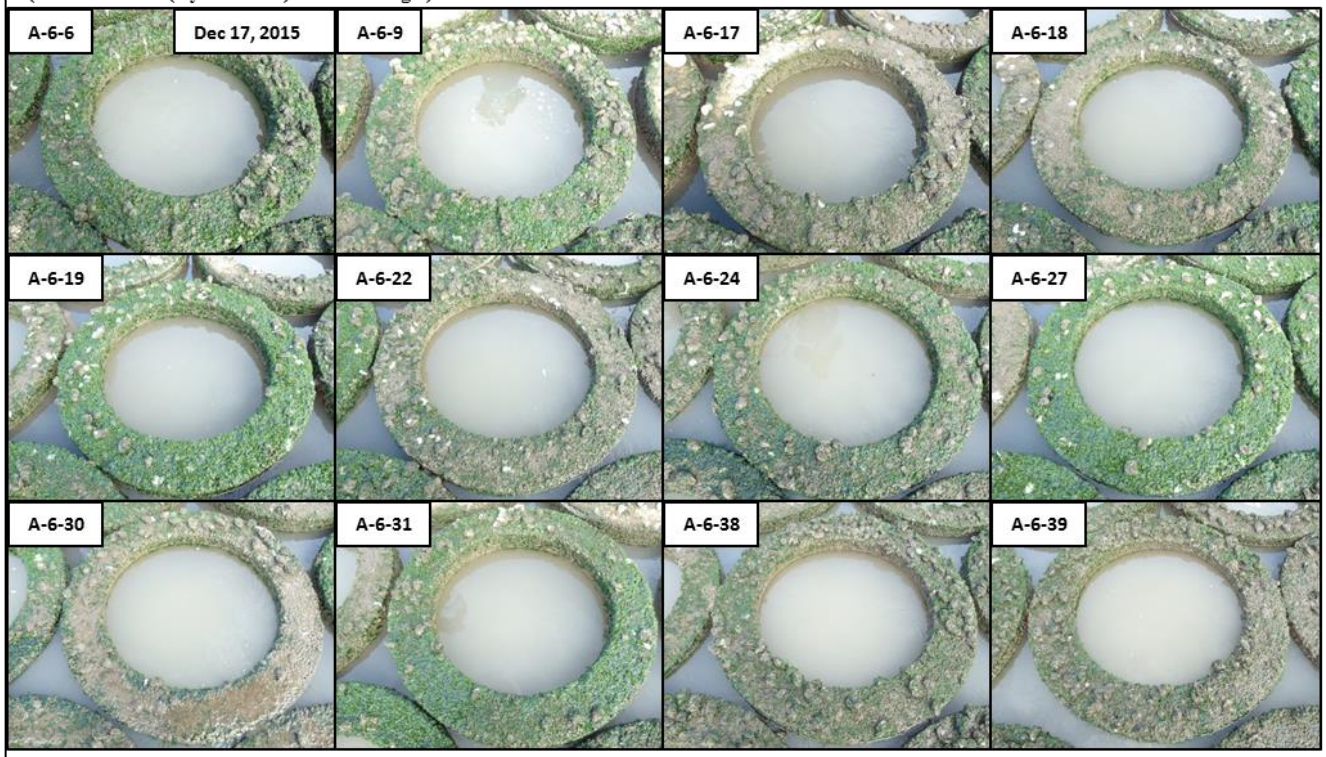
Begin 29°38'57.10"N 92°48'22.99"W

End 29°38'56.06"N 92°48'21.02"W

Gulfward

(Breakwater-A (OysterKrete) –Row #- Ring #)

Leeward



Site I.D.	Live Oyster Quadrat Density (0.32 m²)
A-6-06	37
A-6-09	45
A-6-17	14
A-6-18	25
A-6-19	30
A-6-22	22
A-6-24	18
A-6-27	15
A-6-30	48
A-6-31	16
A-6-38	40
A-6-39	50

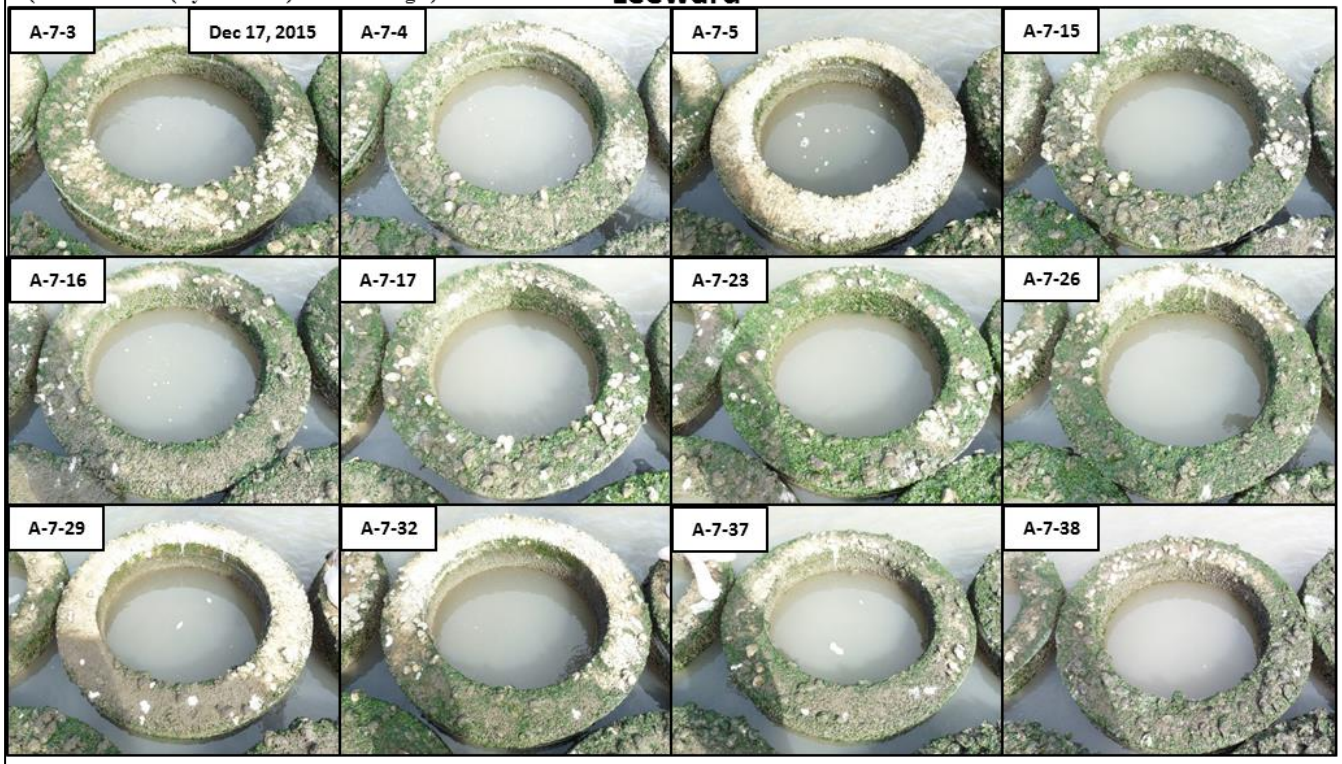
Begin 29°38'57.14"N 92°48'22.94"W

End 29°38'56.11"N 92°48'21.02"W

Gulfward

(Breakwater-A (OysterKrete) –Row #- Ring #)

Leeward



Gulfward

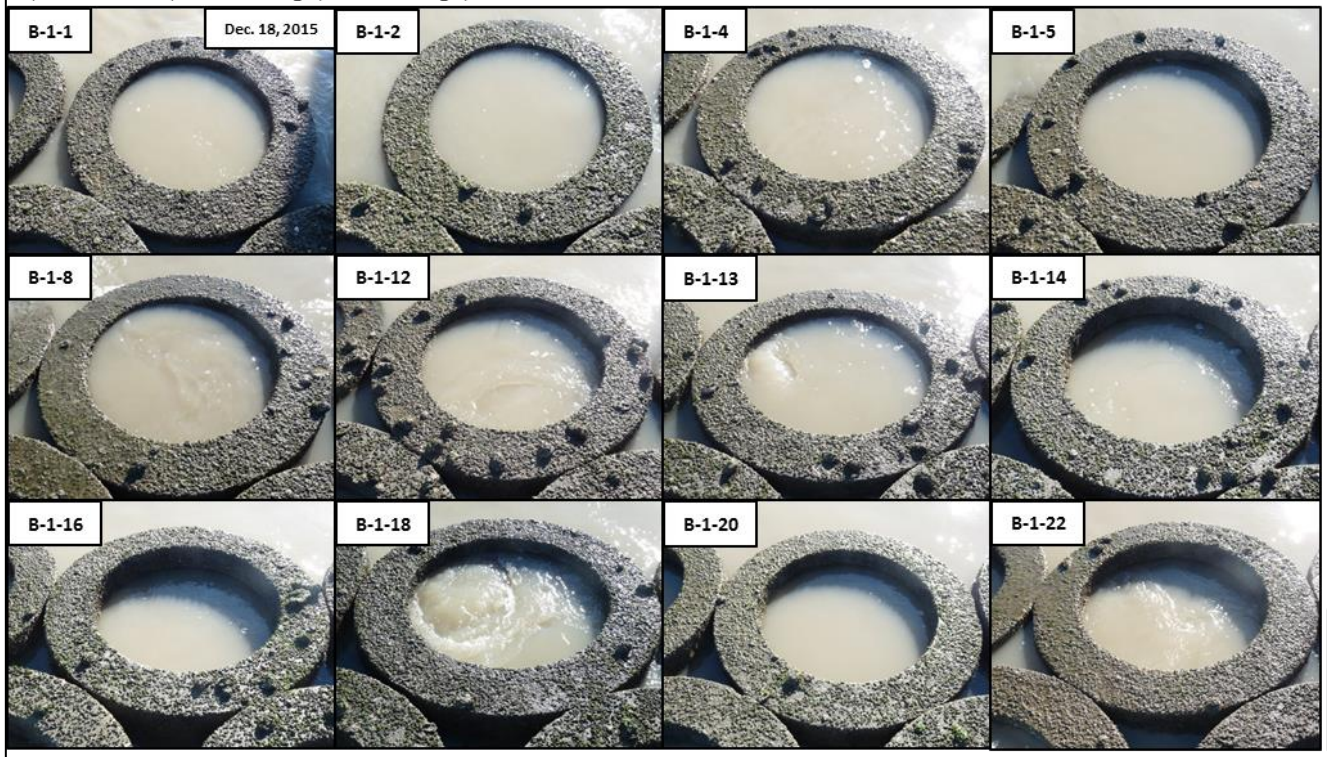
Site I.D.	Live Oyster Quadrat Density (0.32 m²)
A-7-03 *	102
A-7-04	66
A-7-05	22
A-7-15	99
A-7-16	21
A-7-17	67
A-7-23	39
A-7-26	35
A-7-29	21
A-7-32	34
A-7-37	32
A-7-38	70

* Only site taken with 0.50 m^2 area. All others 0.32m^2 area.

Begin	29°38'57.15"N 92°48'22.89"W
End	29°38'56.16"N 92°48'21.01"W

(Breakwater-B (Standard Weight) –Row #- Ring #)

Gulfward



Site I.D.	Live Oyster Quadrat Density (0.32 m2)
B-1-1	7
B-1-2	6
B-1-4	17
B-1-5	7
B-1-8	6
B-1-12	12
B-1-13	5
B-1-14	6
B-1-16	12
B-1-18	10
B-1-20	4
B-1-22	10

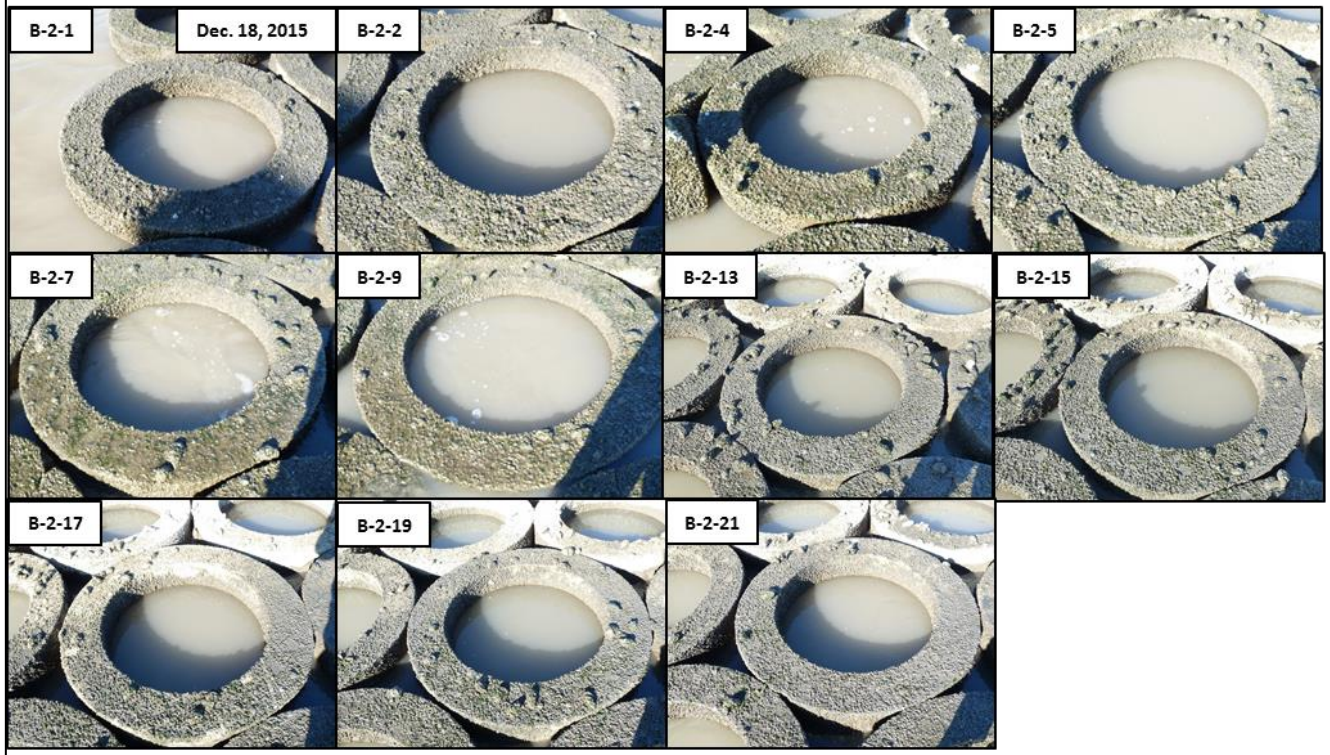
Begin	29°38'55.30"N 92°48'19.37"W
End	29°38'54.70"N 92°48'17.32"W

Note: any rough-looking texture appearance to Standard-Weight concrete surface is due to recruitment of small barnacles, *Balanus sp.*

Leeward

(Breakwater-B (Standard Weight) –Row #- Ring #)

Leeward



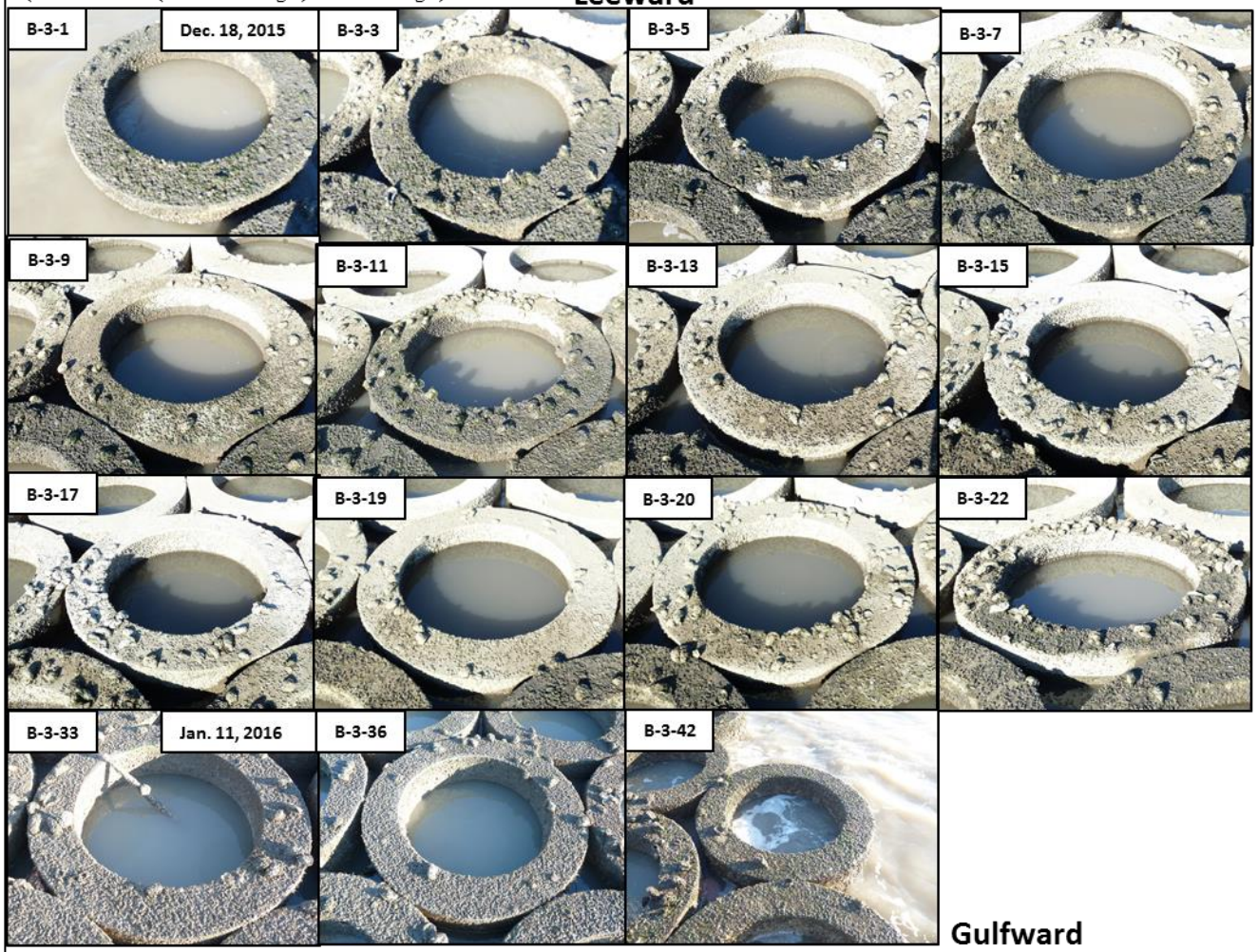
Gulfward

Site I.D.	Live Oyster Quadrat Density (0.32 m²)
B-2-1	24
B-2-2	23
B-2-4	12
B-2-5	14
B-2-7	18
B-2-9	15
B-2-13	13
B-2-15	9
B-2-17	14
B-2-19	17
B-2-21	4

Begin	29°38'55.35"N 92°48'19.38"W
End	29°38'54.74"N 92°48'17.28"W

(Breakwater-B (Standard Weight) –Row #- Ring #)

Leeward



Gulfward

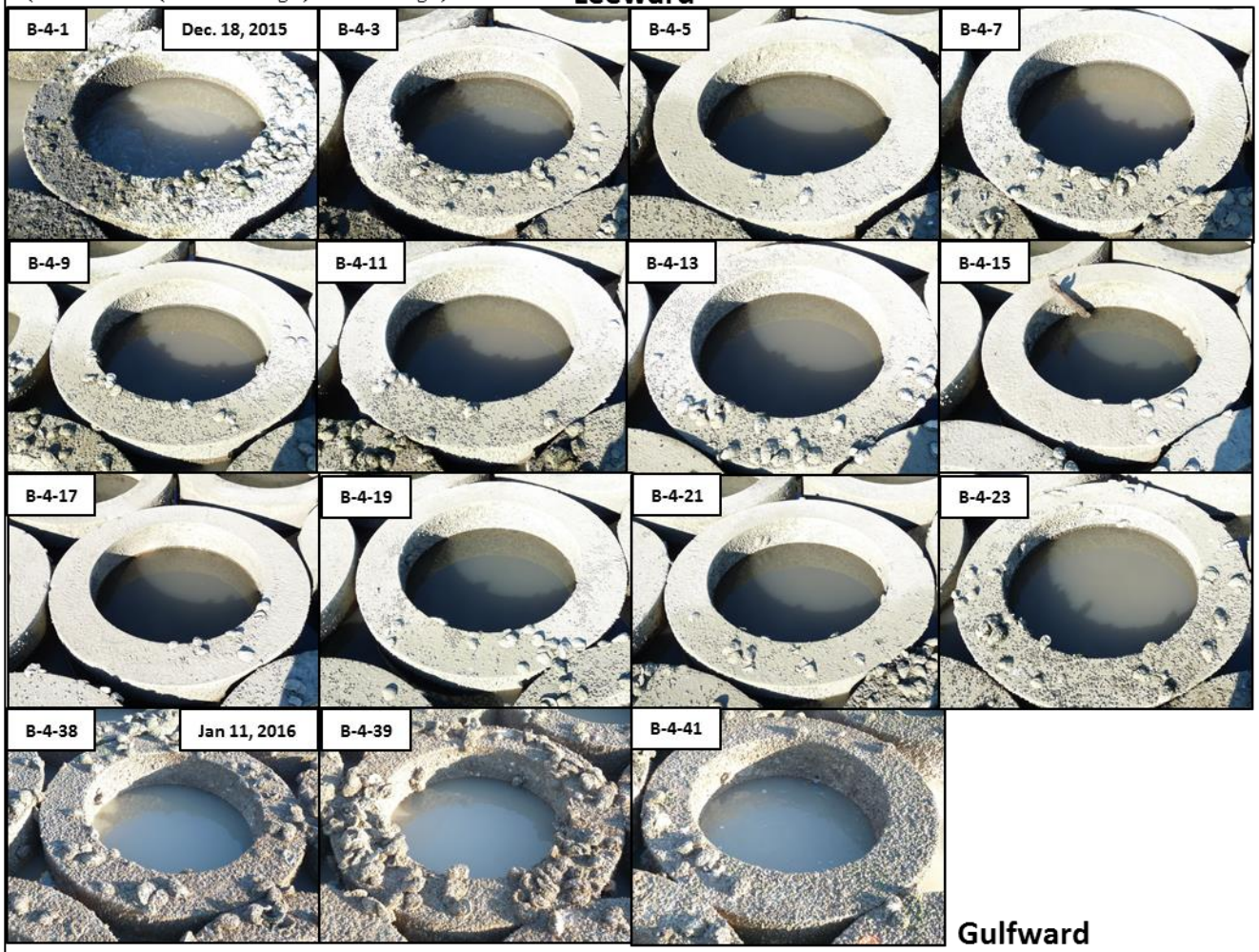
Site I.D.	Live Oyster Quadrat Density (0.32 m²)
B-3-1	39
B-3-3	17
B-3-5	20
B-3-7	19
B-3-9	12
B-3-11	36
B-3-13	17
B-3-15	40
B-3-17	40
B-3-19	12
B-3-20	37
B-3-22	28
B-3-33	13
B-3-36	36
B-3-42	1

Begin 29°38'55.41"N 92°48'19.39"W

End 29°38'54.77"N 92°48'17.23"W

(Breakwater-B (Standard Weight) –Row #- Ring #)

Leeward



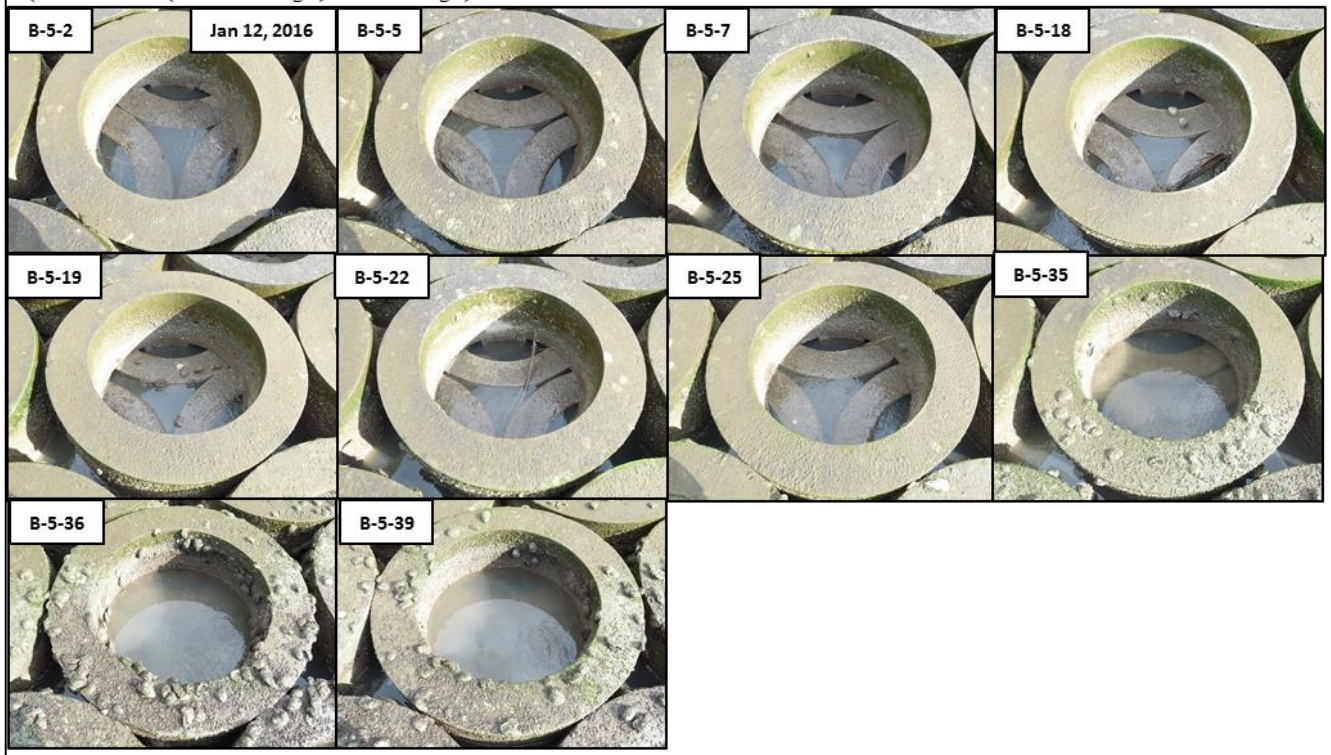
Gulfward

Site I.D.	Live Oyster Quadrat Density (0.32 m²)
B-4-1	101
B-4-3	25
B-4-5	1
B-4-7	21
B-4-9	11
B-4-11	7
B-4-13	23
B-4-15	6
B-4-17	8
B-4-19	13
B-4-21	7
B-4-23	19
B-4-38	16
B-4-39	76
B-4-41	19

Begin	29°38'55.43"N 92°48'19.35"W
End	29°38'54.82"N 92°48'17.24"W

(Breakwater-B (Standard Weight) –Row #- Ring #)

Leeward



Site I.D.	Live Oyster Quadrat Density (0.32 m²)
B-5-2	0
B-5-5	0
B-5-7	0
B-5-18	0
B-5-19	0
B-5-22	0
B-5-25	0
B-5-35	26
B-5-36	35
B-5-39	16

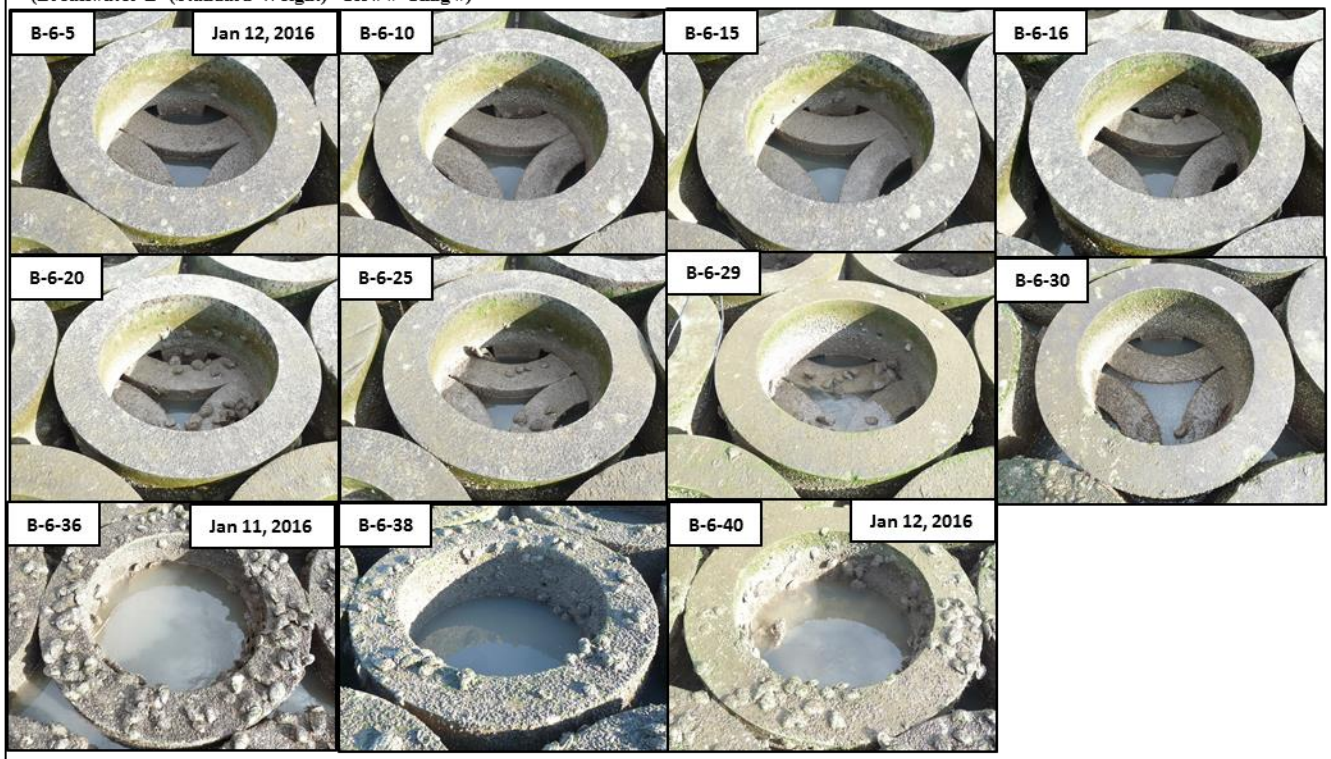
Begin 29°38'55.49"N 92°48'19.35"W

End 29°38'54.85"N 92°48'17.20"W

Gulfward

(Breakwater-B (Standard Weight) –Row #- Ring #)

Leeward



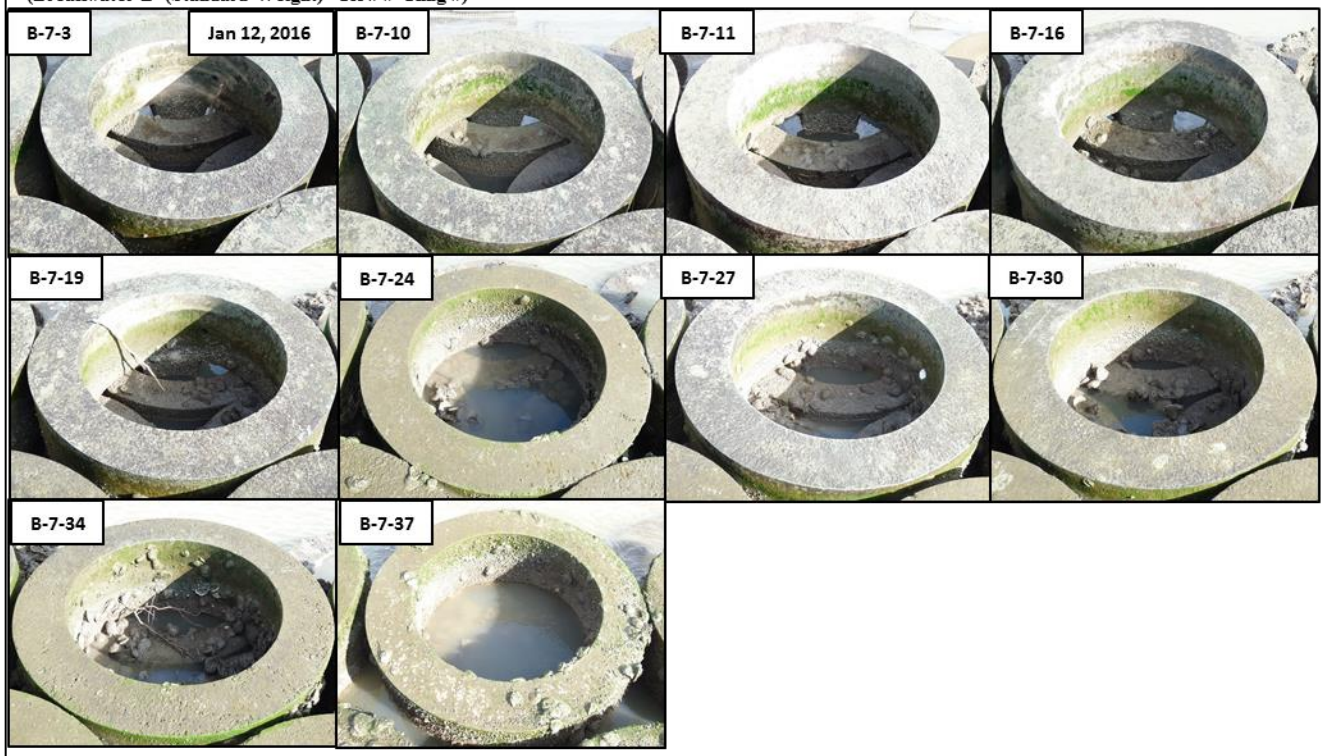
Gulfward

Site I.D.	Live Oyster Quadrat Density (0.32 m²)
B-6-5	0
B-6-10	0
B-6-15	0
B-6-16	0
B-6-20	0
B-6-25	0
B-6-29	0
B-6-30	0
B-6-36	45
B-6-38	17
B-6-40	29

Begin	29°38'55.50"N 92°48'19.31"W
End	29°38'54.90"N 92°48'17.21"W

(Breakwater-B (Standard Weight) –Row #- Ring #)

Leeward



Site I.D.	Live Oyster Quadrat Density (0.32 m²)
B-7-3	0
B-7-10	0
B-7-11	0
B-7-16	0
B-7-19	0
B-7-24	0
B-7-27	0
B-7-30	0
B-7-34	0
B-7-37	17

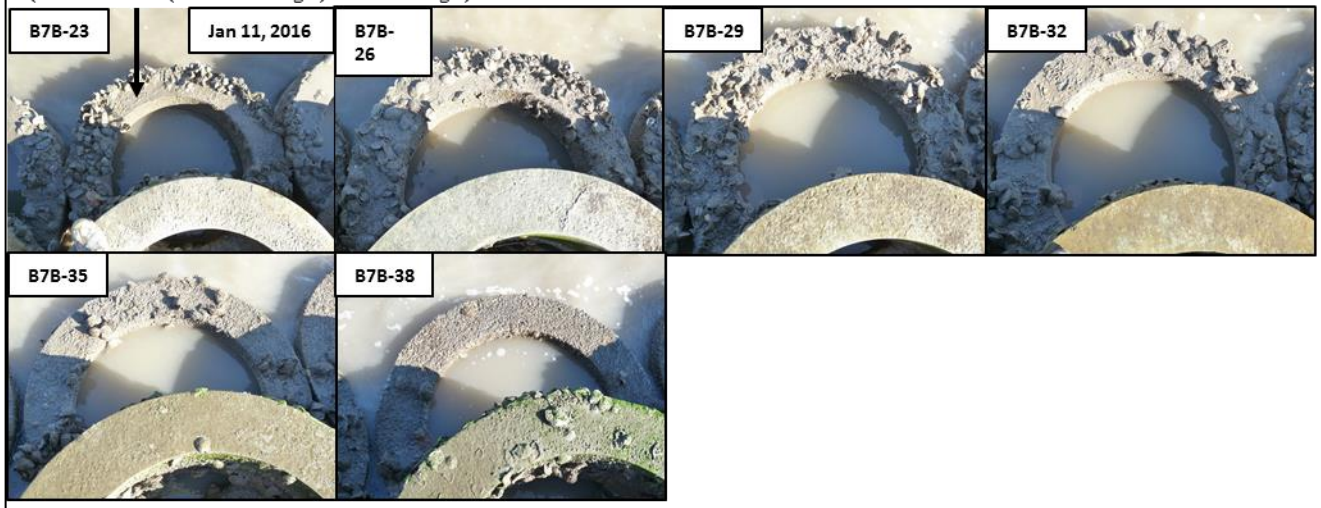
Begin 29°38'55.53"N 92°48'19.26"W

End 29°38'54.94"N 92°48'17.21"W

Gulfward

(Breakwater-B (Standard Weight) –Row #- Ring #)

Leeward



Site I.D.	Live Oyster Quadrat Density (0.32 m²)
B-7B-23	178
B-7B-26	150
B-7B-29	133
B-7-B32	85
B-7B-35	43
B-7B-38	1

Begin 29°38'55.59"N 92°48'19.23"W

End 29°38'54.99"N 92°48'17.18"W

Gulfward

Appendix Table 6. Statistical Analysis of All Quadrat Density Samples of Ring Elevations < -.097 m.

One Way Analysis of Variance

Data source: Data 1 in ULTIMATE OysDen NAVD88-LA08_Jan 2016.JNB

Dependent Variable: # Oys/m^2 for sites < -.097 m Elevation

Normality Test (Shapiro-Wilk) Failed (P < 0.050)

Test execution ended by user request, ANOVA on Ranks begun

Kruskal-Wallis One Way Analysis of Variance on Ranks

Data source: Data 1 in ULTIMATE OysDen NAVD88-LA08_Jan 2016.JNB

Dependent Variable: # Oys/m^2

Group	N	Missing	Median	25%	75%
OysterKrete	83	0	21.875	9.375	68.750
Standard-Weight	63	1	45.313	21.621	72.656
Lee Standard-Weight	6	0	340.625	101.563	490.625

H = 10.115 with 2 degrees of freedom. (P = 0.006)

The differences in the median values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = 0.006)

To isolate the group or groups that differ from the others use a multiple comparison procedure.

All Pairwise Multiple Comparison Procedures (Dunn's Method) :

Comparison	Diff of Ranks	Q	P<0.05
Lee Standard- vs OysterKrete	54.840	2.966	Yes
Lee Standard- vs Standard-Weig	42.879	2.293	Yes
Standard-Weight vs OysterKrete	11.961	1.629	No

Appendix Table 7. Statistical Analysis of Selected Quadrat Density Samples Based on Relative Elevations Between -0.3 m to -0.1 m, Excluding B8B Rings.

One Way Analysis of Variance

Dependent Variable: #Oys/M^2 Select Sites

Normality Test (Shapiro-Wilk) Failed (P < 0.050)

Test execution ended by user request, ANOVA on Ranks begun

Kruskal-Wallis One Way Analysis of Variance on Ranks

Dependent Variable: #Oys/M^2 Select Sites

Group	N	Missing	Median	25%	75%
OysterKrete	32	0	92.188	51.563	147.656
Standard-Weight	48	0	43.496	21.621	71.667

H = 14.419 with 1 degrees of freedom. (P = <0.001)

The differences in the median values among the treatment groups are greater than would be expected by chance; there is a statistically significant difference (P = <0.001)

To isolate the group or groups that differ from the others use a multiple comparison procedure.

All Pairwise Multiple Comparison Procedures (Dunn's Method) :

Comparison	Diff of Ranks	Q	P<0.05
OysterKrete vs Standard-Weight	20.130	3.796	Yes

Note: The multiple comparisons on ranks do not include an adjustment for ties.