State of Louisiana

Coastal Protection and Restoration Authority of Louisiana

Office of Coastal Protection and Restoration

2010 Operations, Maintenance, and Monitoring Report

for

Terrebonne Bay Shore Protection Demonstration (TE-45)

State Project Number TE-45
Priority Project List 10

June 2010
Terrebonne Parish

Prepared by:
Earl J. Melancon, Jr.
Mark A. Linson
Glen P. Curole
Daniel A. Dearmond
and
Quenton C. Fontenot

CPRA/Office of Coastal Protection and Restoration
Thibodaux Field Office
1440 Tiger Drive, Suite B
Thibodaux, LA 70301

Suggested Citation:

Melancon, E. J. Jr., M. A. Linson, G. P. Curole, D. A. Dearmond, and Q. C. Fontenot. 2010. *2010 Operations, Maintenance, and Monitoring Report for Terrebonne Bay Shore Protection Demonstration (TE-45), Coastal Protection and Restoration Authority of Louisiana, Office of Coastal Protection and Restoration, Thibodaux, Louisiana. 51 pp.*

Operations, Maintenance, and Monitoring Report
For
Terrebonne Bay Shore Protection Demonstration
(TE-45)

Table of Contents

I. Introduction

The Coastal Wetlands Planning, Protection and Restoration Act (CWPPRA) of 1990 (PL 101-646, Title III) authorized the Terrebonne Bay Shore Protection Demonstration Project (TE-45) as part of the 10th Priority Project List authorized on January 10, 2001. The TE-45 project is located southeast of Chauvin, Louisiana in Terrebonne Parish along the rapidly eroding northwest shore of Lake Barre , which is part of the Terrebonne Basin system (Figure 1). The project was federally sponsored by the United States Fish and Wildlife Service (USFWS) and locally sponsored by the Louisiana Office of Coastal Protection and Restoration (OCPR) under CWPPRA. The project evaluates three fabricated structures placed along the shore for their effectiveness in abating shoreline erosion, and for their ability to develop and sustain an oyster reef. The project is distributed along three (3) shoreline sites, Reach A, Reach B, and Reach E (Figures 2-4). The TE-45 demonstration project's monitoring life is eight (8) years post-construction.

The TE-45 project consists of three shoreline protection features; ReefBlk structures (foreshore), A-Jack structures (onshore), and Gabion Mat (onshore) structures. All three features and a reference area were installed at Reach A, Reach B, and Reach E in 91 m (300 ft) lengths (Figures 1-4). In addition, Reach A and Reach B were only separated by one structure length, 91 m (300 ft), (Figure 1) due to high land loss rates in the previous Reach B location. The placement of the treatments was randomly selected and the structures fronted a continuous 305 m (1000 ft) of shoreline at each Reach. Tie-in units were used to attach the foreshore treatment (reef block) to the shoreline (Figures 2, 3, and 4). The tie-in units were constructed with the A-Jack structures. The ReefBlk structures, the A-Jack structures, and the tie-in units were built on top of a geogrid and crushed stone foundation and were anchored at 3 m (10 ft) intervals while the Gabion Mat structures were laid directly on top of the existing marsh and bay bottom and were not anchored (Appendix A, Figures A-1 and A-2). The ReefBlk structures were constructed by welding triangle shaped metal frames together. The outer perimeters of the frames were fitted with mesh bags that were filled with oyster shells (Appendix A, Figure A-3). The ReefBlk treatment was installed to a minimum elevation of 0.3 m (1.0 ft) NAVD 88 (Appendix A, Figure A-1). The A-Jack structures were fabricated by forming concrete into an A-jack shape (Appendix A, Figure A-4). The A-Jacks used for the TE-45 project were 0.6 m (2 ft) tall and were lashed together with steel cables (Appendix A, Figures A-1 and A2). The Gabion Mat structures were manufactured by constructing a mattress shaped mesh frame with 6 m (20 ft) x 1.5 m (5 ft) x 0.3 m (1 ft) dimensions. The Gabion Mats were filled with crushed stone and sealed by braiding 0.3 m (1 ft) thick geogrid tabs to the mesh frame (Appendix A, Figure A-5). The Gabion Mats were laid 2 m (7 ft) into the marsh while the remaining 4 m (13 ft) of the mats rested on the bay bottom (Appendix A, Figures A-1 and A2). Construction of the TE-45 structures began on September 6, 2007 and was completed by December 19, 2007.

Louisiana's interior bay shorelines are experiencing high rates of erosion and marsh loss. There is significant dual benefit in lessening bay shoreline erosion with the use of fabricated structures that also have the ability to establish oyster populations. Oyster populations can continuously respond to changing environmental conditions such salinity, subsidence and sea

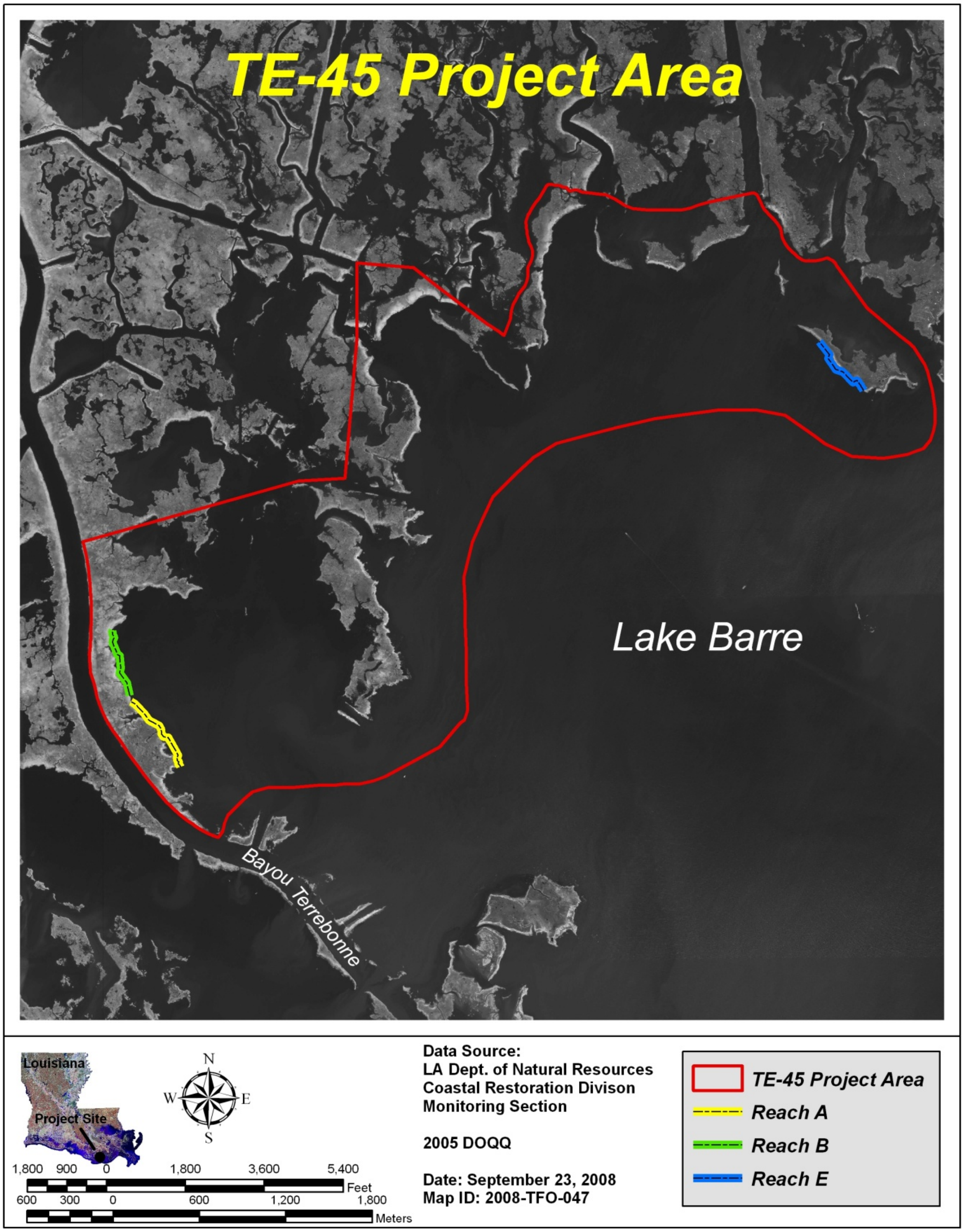


Figure 1. **Location of the Terrebonne Bay Shore Protection Demonstration (TE-45) project area with the delineated shoreline Reaches investigated and selected for protection.**

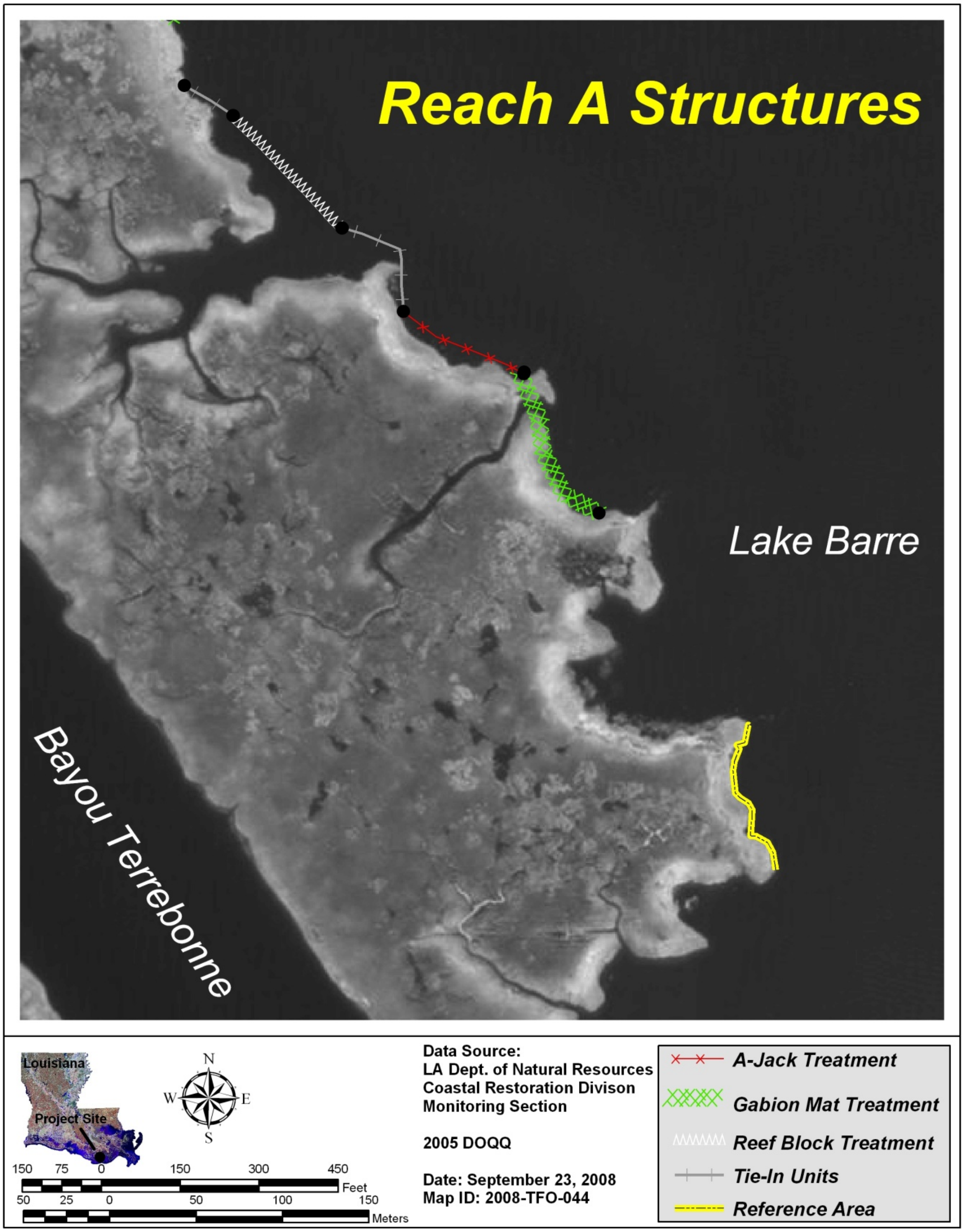


Figure 2. Location of the Reach A project features (structure treatments) at the Terrebonne Bay Shore Protection Demonstration (TE-45) project.

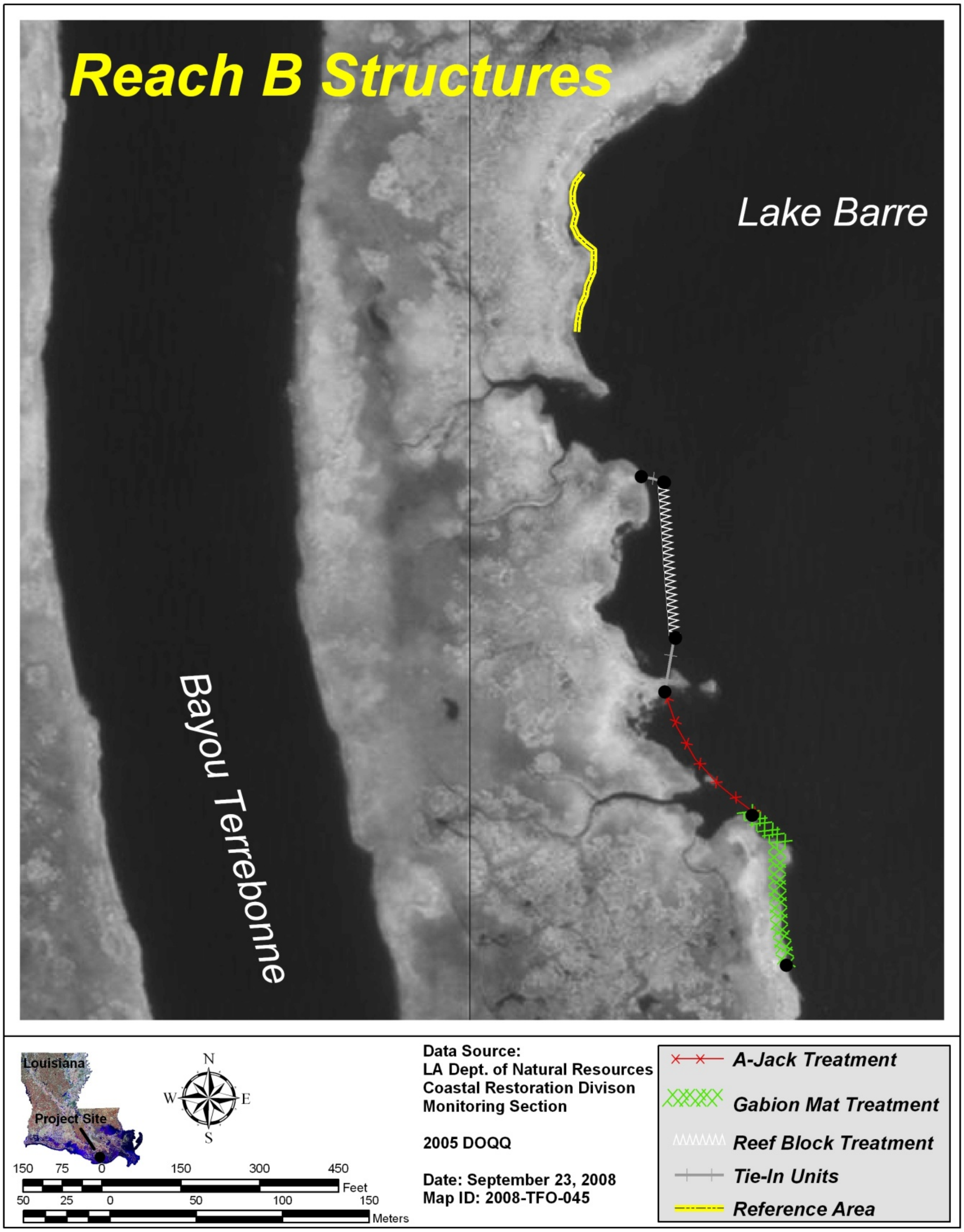


Figure 3. **Location of the Reach B project features (structure treatments) at the Terrebonne Bay Shore Protection Demonstration (TE-45) project.**

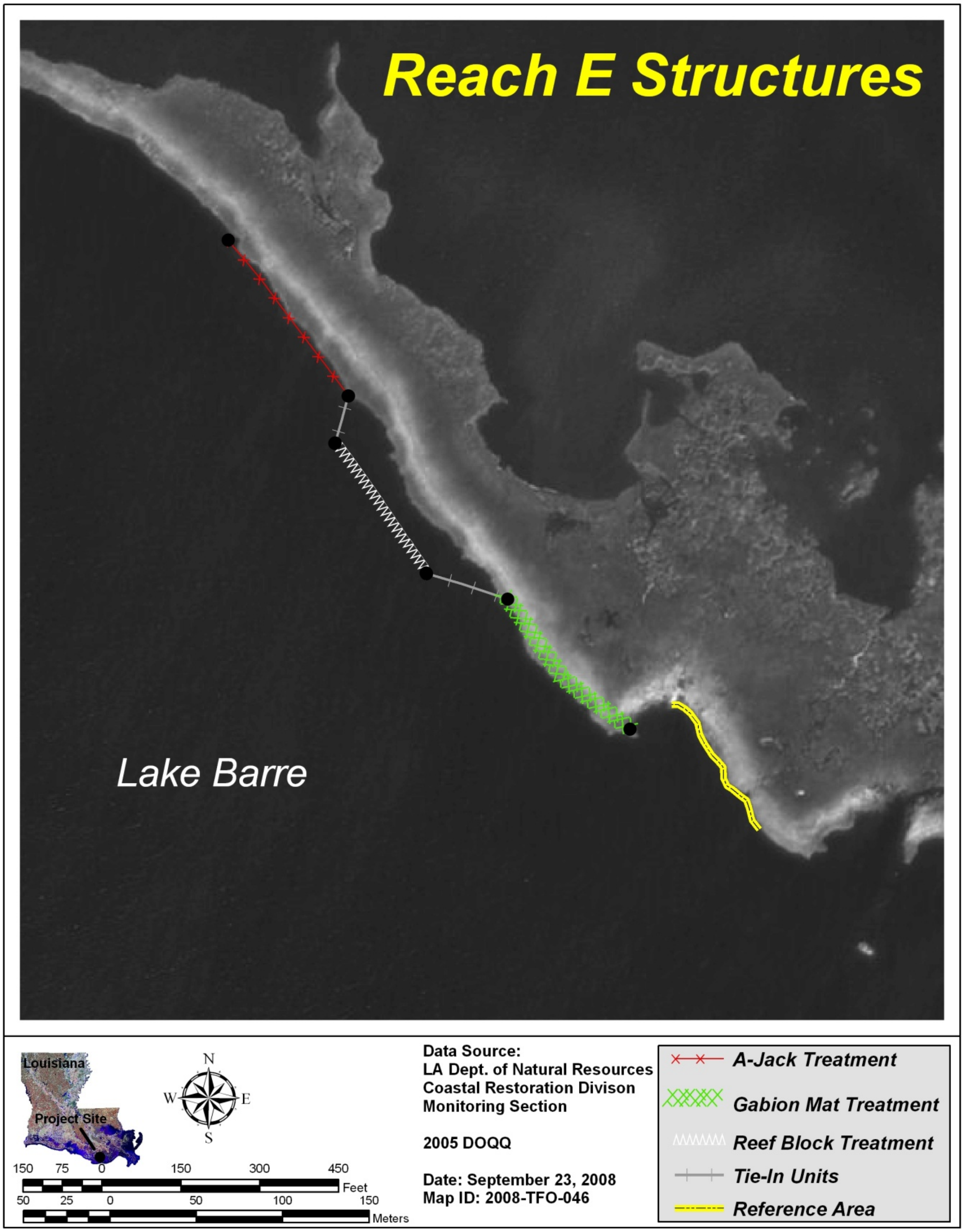


Figure 4. **Location of the Reach E project features (structure treatments) at the Terrebonne Bay Shore Protection Demonstration (TE-45) project.**

level rise with continuous reef growth. For example, Meyer et al. (1997) demonstrated the effectiveness of oyster cultch (shell) to marsh edge stabilization and sediment accumulation, while Gagliano et al. (1997) demonstrated that fabricated vertical structure placed along an eroding marsh shoreline in Louisiana may have significant erosion-control and oyster habitat-developing potential.

Historical Background Information

In Louisiana, coastal land loss has been estimated at approximately 64.7 square kilometers (25 square miles) year^{-1} (Dunbar et al. 1992) to 90.6 square kilometers (35 square miles) year^{-1} (Barras et al. 1994). More specifically, the average shoreline erosion rate for the five proposed Reaches along the north shore of Lake Barre are 1.51 meters (4.95 feet) year^{-1} for the period of 1932 to 1983 (May and Britsch 1987). Due to high rates of erosion along the north shore and salinities conducive for oysters, this project location was chosen to evaluate the effectiveness of the three (3) different structure types.

The eastern oyster, *Crassostrea virginica* (Gmelin), is the dominant reef-building estuarine organism along the northern Gulf of Mexico. Because of Louisiana's climate, it has the ability to spawn almost year round, but usually exhibits bimodal peaks of mass spawning in spring-early summer and again in early-late fall (Butler 1954). When waters are warm in summer, planktonic larvae require less than two weeks to metamorphose through several life stages before they are ready for settlement and a benthic life (Galtsoff 1964). Newly settled oysters often experience high mortalities in the first six months of life (Roegner and Mann 1995). At the time of setting, oyster larvae are usually less than 0.5 mm 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 of significant importance 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. The juvenile stage is short-lived with oysters maturing with functioning gonads within 4-12 weeks of settlement in summer water temperatures (Menzel 1951). Young oysters grow rapidly and may reach 75 mm (3 inches) in shell length within 15-18 months in Louisiana waters. After an oyster is approximately eight years old, somatic tissue growth is insignificant or ceases and the volume of the mantle/shell cavity remains relatively constant (Cake 1983). Oysters in the northern Gulf of Mexico may live for 10 years or longer.

The oyster occurs in salinities ranging from 5-40 ppt (Shumway 1996). Optimal growth and survival of commercially viable oyster populations require a salinity range of 5-15 ppt, when coupled with an appropriate temperature regime. This narrow ecological salinity range reduces the abundance of higher-salinity oyster predators and disease while still allowing for physiological functions to continue. When other environmental variables are within acceptable ranges for oyster survival, salinity becomes the overriding factor for sustaining an oyster population (Dekshenieks et al. 2000). Melancon et al. (1998) delineated resource zones where oysters can be found under persistent drought (dry) or rainy (wet) conditions within the Terrebonne estuary; four zones were established, with a mid-bay region referred to as the wet-dry zone where oysters can be found irrespective of wet or dry conditions, and thus allowing for both subtidal and intertidal oyster habitats. This mid region of the estuary is where the majority of naturally productive commercial oyster leases exist today. The location of the TE-45 project is within this wet-dry zone.

The oyster is a gregarious animal that has the ability to develop shallow subtidal and intertidal reef structure along a shoreline that also adds significant ecological value to an estuary. An oyster reef is a 3-dimensional structure created by successive years of larval settlement on adult oysters, while also providing multiple levels of hard surface and interstitial heterogeneity that is rare in the marine ecosystem (Bartol et al. 1999). The oyster becomes the keystone organisms for a multitude of invertebrate and vertebrate species in a dynamic estuarine community (Coen et al. 1999), which also includes many recreational and commercial species (Zimmerman et al. 1989).

The location, distribution and physical dimensions of an oyster population depend on many interacting factors which include complex associations of physical, chemical, geological and biological processes (Kennedy et al. 1996). Environmental and biological variables such as predation and disease, food quality and quantity, suitable bottom substrate, adequate tidal flushing, water currents, temperature, salinity, and an array of other variables interact to produce a habitat capable of developing and sustaining an oyster population. For example, Bahr and Lanier (1981), describing intertidal reefs along the South Atlantic coast, identified many important driving forces for oyster survival and reef development, including predation and competition, water current regime, particulate organic matter (food), tidal amplitude, and extreme air temperatures. Bartol et al. (1999), working with intertidal oysters in the Piankatank River of the Chesapeake Bay system, demonstrated the importance of vertical relief and depth of substrate in providing critical intertidal-subtidal zonation and refuge for oyster survival.

Powell et al. (1994) and Dekshenieks et al. (2000), both studying subtidal oysters in the Galveston Bay estuary, developed mathematical models to interpret rates of oyster mortality and population crashes using the forcing functions of salinity, water flow rate, food availability (chlorophyll-a and total suspended solids), turbidity, and water temperature. Lenihan (1999), also working with subtidal oysters, demonstrated that shape influences water flow across a reef and becomes a critical variable to settlement and reef development success. Understanding the environmental variables that provide the necessary infrastructure for an oyster population to survive is fundamental to the TE-45 project's ability to interpret success or failure of reef development.

II. Maintenance Activity

a. Inspection Purpose and Procedures

An annual inspection of the Terrebonne Bay Shore Protection Demonstration Project (TE-45) was held on August 19, 2010. In attendance were Daniel Dearmond and Glen Curole with OCPR. The damage assessment began at approximately 10:00 a.m. at Reach A and ended at approximately 10:30 a.m. at Reach E. The field trip included a visual inspection of the nine (9) shoreline protection structure installations (three (3) treatments types at each of the three (3) Reaches), the tie-in units, all warning signs, and two (2) project monitoring stations (continuous recorders and staff gauges). Due to high tides on the day of the inspection, most structures were not visible. Due to high tides, we have provided inspection photographs included in Appendix B of this report that were taken in December 2009 during data collection trips for the oyster monitoring component of the demonstration project when tides were much lower.

The purpose of the annual inspection of the Terrebonne Bay Shore Protection Demonstration Project (TE-45) is to evaluate the constructed project features in order to identify any deficiencies. The inspection results are used to prepare a report detailing the condition of the project features and recommending any corrective actions considered necessary. Should it be determined that corrective actions are needed, the OCPR shall provide, in the report, a detailed cost estimate for engineering, design, supervision, inspection, construction, and contingencies and an assessment of the urgency of such repairs (OCPR 2010). The annual inspection report also contains a summary of maintenance projects which were completed since completion of constructed project features and an estimated projected budget for the upcoming three (3) years for operation, maintenance, and rehabilitation. The three (3) year projected operation and maintenance budget is shown in Appendix C. A summary of past operation and maintenance projects completed since construction of the Terrebonne Bay Shore Protection Demonstration Project are outlined in Section II.b.

b. Summary of Past Operations and Maintenance Projects

No maintenance activities have been performed for the TE-45 project since the completion of construction. As a demonstration project, there are no funding provisions in the project O&M budget for maintenance events. Only funding associated annual inspections are provided in the project O&M budget.

c. Inspection Results

<u>Reaches A, B,and E</u>

All of the shoreline structures at the three (3) sites appeared to be in good condition. All gabion mats were intact. The A-Jacks and ReefBlks were upright with no indication of rollover. Oyster growth was noted on all structures. No tie-units (A-Jacks) appear to be damaged. The two (2) monitoring stations were also intact with no apparent damage. The only noted damage was the northern-most warning sign at Reach B and the northwest warning sign at Reach E. These signs were bent during Hurricanes Gustav and Ike.

III. Operation Activity

No operation activities are required for the TE-45 project.

IV. Monitoring Activity

a. Monitoring Goals

The specific measurable goals established to evaluate the effectiveness of the project are:

1. To reduce shoreline erosion while minimizing scouring to the bay bottom adjacent to each shoreline protection treatment.

2. To quantify and compare the ability of each of the shoreline protection treatments to reduce erosion and enhance oyster production.

3. To quantify and compare the cost-effectiveness of each shoreline protection treatment in reducing shoreline erosion and enhancing oyster production.

b. Monitoring Elements

The following monitoring elements provide the information necessary to evaluate the specific goals listed above:

Elevation

Topographic and bathymetric surveys were employed to document elevation and volume changes along the Terrebonne Bay Shore Protection Demonstration (TE-45) project Reaches (Reach A, Reach B, and Reach E). Pre-construction (August 2007) and as-built (February 2008) elevation data were collected using traditional cross sectional transects and real time kinematic (RTK) survey methods. The pre-construction survey was surveyed perpendicular to baselines at 31 m (100 ft) intervals while the as-built survey was surveyed perpendicular to the structures at 23 m (75 ft) intervals. All survey data were established using or adjusted to tie in with the Louisiana Coastal Zone (LCZ) GPS Network. The Reach A, Reach B, and Reach E reference areas were not surveyed during the pre-construction period (August 2007). During the following spatial analysis, Reaches A and B were combined into a single grid model because of their close proximity while Reach E was analyzed separately.

The August 2007 and February 2008 survey data were re-projected horizontally and vertically to the UTM NAD83 coordinate system and the NAVD 88 vertical datum in meters using Corpscon® software. The re-projected data were imported into ArcView® GIS software for surface interpolation. Triangulated irregular network models (TIN) were produced from the point data sets. Next, the TIN models were converted to grid models (2.0 m^2 cell size), and the spatial distribution of elevations were mapped. The grid models were clipped to the TE-45 shoreline polygons to estimate elevation and volume changes.

Elevation changes from August 2007-Feburary 2008 were calculated by subtracting the corresponding grid models using the LIDAR Data Handler extension of ArcView® GIS. After the elevation change grid models were generated, the spatial distribution of elevation changes along the TE-45 shorelines were mapped in half meter elevation classes. Lastly, volume changes along the shorelines were calculated in cubic meters (m^3) using the Cut/Fill Calculator function of the LIDAR Data Handler extension of ArcView® GIS. Note, these elevation and volume calculations are valid only for the extent of the survey area.

Shoreline Change

Shoreline position data were analyzed to estimate shoreline changes in the Terrebonne Bay Shore Protection Demonstration (TE-45) project and reference areas using the Digital Shoreline Analysis System (DSAS version 2.1.1) extension of ArcView® GIS (Thieler et al. 2003). Shoreline positions were determined by digitizing aerial photographs at a 1:800 scale as per the Steyer et al. (1995) method, which defines shoreline position as the edge of the live emergent vegetation. The resulting polylines established the shoreline positions in UTM NAD 83 coordinates. Pre-construction and post-construction aerial photographs were acquired over an eleven year period to discern the A-Jack, Gabion Mat, and ReefBlk structures affect on shoreline erosion rates. Pre-construction aerial photographs were collected on January 28, 1998 and November 1, 2005 while post-construction aerial photographs were captured on September 16, 2007 (as-built) and October 30, 2008 (1 year post-construction). All images were georectified using UTM NAD 83 horizontal datum.

The January 1998 and November 2005 shorelines were created in ArcView® GIS software to establish pre-construction shoreline change rates, and the September 2007 and October 2008 shorelines were created to establish post-construction shoreline change rates. Secondly, offshore baselines were drawn for Reach A, Reach B, and Reach E project and reference areas. Thirdly, the DSAS attribute editor was populated by identifying shorelines and baselines and dating shorelines. Next, 300 m (984 ft) simple transects were cast from the baseline at 10 m (33 ft) intervals producing shoreline change, intersect, and transect shapefiles. Then, these shapefiles were edited by eliminating transects that intersect the shorelines at irregular angles. Finally, shoreline change data were imported into Excel® to calculate average and annual erosion rates for each period and each treatment. Shoreline change rates were assessed and mapped for the ensuing periods January 1998-November 2005 (pre-construction) and September 2007-October 2008 (post-construction) for the area behind each Reach and each 91 m ft (300) treatment. Therefore, the October 2008 one-year post-construction shoreline erosion measurements are minimally influenced by oyster populations since reef structure was just becoming established on the treatments.

Hydrology

Hourly water temperature, specific conductance, salinity and water height were collected from two stationary YSI data sonde units attached to wooden post driven into the bay bottom and adjacent to the study sites. Sonde site TE45-H01 was near Reaches A and B, while site TE45-H02 was near Reach E (Figure 5). Calibration of the YSI data sondes followed the established protocols developed by the Louisiana Office of Coastal Protection and Restoration (OCPR) (Folse et al. 2008). Discrete water quality samples were also taken using a Hydrolab MS5. Discrete data included water temperature, salinity, turbidity, pH, D.O., and % D.O. saturation. Discrete water samples were also collected for chlorophyll-a (µg/l) and total suspended solids (µg/l).

Oyster Spat Availability in Project Area

Plastic Vexar® mesh bags, with a mesh size of 1.9 cm (¾ inch), were used for oyster spat recruitment monitoring within the project area and independent of structures. The Vexar® mesh bags had a width of 20.0 cm and a length of 30.0 cm. Ten oyster shells were placed in each bag with the nacreous layer (Mother-of-Pearl layer) facing downward.

Intertidal recruitment bags were suspended off the bottom horizontally in plastic trays using plastic zip ties. The trays were fastened to the Gabion Mats with zip ties and placed at approximately mid tide height. Three intertidal trays containing two shell bags in each were placed on the Gabion Mats at each Reach for a total of nine.

Subtidal spat recruitment bags were also suspended horizontally and facing downward within modified crab traps at a density of two bags per trap. The subtidal cages were placed on the bay bottom on the windward side of each treatment within a Reach at a distance of approximately six meters (20 ft) from the structures. Each cage was tethered to a PVC pole. Spat bags were deployed and retrieved monthly each year from May to November. Nine cages were placed at each Reach for a total of 27.

Oyster Recruitment to Experimental Structures

Each structure type (treatment) was assessed at each Reach by randomly selecting 15 sites along its 91m (300ft) length by using the uniformly-distributed-random-numbers statistical method (Sigma Stat v3.1). In the winters of 2008 (December 2008-February 2009) and 2009 (December 2009-March 2010), when tides were lowest and when eastern oyster recruitment peaks were complete, the same structures were visually and quantitatively examined. The surficial (surface) layer of attached eastern oysters and its major competitors for space, barnacles (*Balanus spp*.) and hooked mussels (*Ischadium recurvum*) were counted. Surficial counts were restricted to only what could be seen while viewing from above at low tide and without moving or destroying any oysters, rocks or shells.

Surficial quantitative density counts, eastern oyster length frequencies, and faunal percent coverage (oysters + barnacles + hooked mussels) were used as indices to measure eastern oyster recruitment success to each structure type. Surficial faunal coverage was collected from 15 subsamples (replicates) per structure type per Reach each winter. Surficial density data during both winters were collected on 5 of the 15 subsamples per structure type per Reach for a total of 15 for Gabion Mats from three tidal heights (high, mid, and low intertidal), 15 for A-Jacks and 15 for ReefBlks. GPS coordinates were recorded for each location using a Trimble GeoXT GPS hand held unit.

Each structure's shape required placing a PVC quadrat frame in a unique way, and also required measurements to be taken at low tide when exposed. The only time of year when structures were exposed long enough was during the winter months. Winter was also advantageous since all structures had been exposed to two oyster spring-through-fall spawning and recruitment cycles.

A Gabion Mat's surficial density was measured using a 0.25 m^2 pvc quadrat frame that was subdivided into four measuring 1/16 m^2 in each area and placed at three intertidal heights along its 6 m (20 ft) length; high-intertidal at 0.5 m above the mean high tide mark (from bottom of quadrat frame), mid-intertidal (from top of quadrat frame) as denoted by the high-water mark on the mat (usually 3.0-3.5m from the top of the mat), and low-intertidal at 0.5 m above the mat's low end (bottom of quadrat frame). Once placed on the mat, one 1/16 m^{-2} was randomly selected to quantify surficial densities of oysters, hooked mussels and barnacles. Surficial oyster length frequency data was also generated from each 1/16 m^{-2} quad, except for the high-intertidal sites which required counting oysters across the entire width of the mat 1.8 m (5 ft) to obtain a sufficient number.

An A-Jack's surficial density per replicate was obtained by laying a pvc quadrat frame that was 250 mm (0.8 ft) wide and 350 mm (1.1 ft) long on top of the structure. This generated an area equivalent to half the thickness of the two-deep unit allowing data to be differentiated into leeward (facing the marsh shore) and windward (facing the bay) by flipping the frame over. All concrete arms within a quadrat were counted for surficial oyster, hooked mussel and barnacle densities. There were no significant statistical differences in leeward and windward oyster densities and therefore the two areas are combined as one in the results and discussions that follow. Surficial oyster length frequency data were also generated from each quadrat.

A ReefBlk's surficial density per replicate was obtained by holding a 250 mm (.8 ft) wide quadrat PVC frame parallel to a side's top horizontal rebar. Since a ReefBlk is a triangular-shaped structure with each side measuring 1.5 m (5 ft) in width, the frame was randomly placed along its width. Surficial oysters within the frame on the vertical structure were counted down to the water level. At low tide, a minimum of 250 mm (.8 ft) of exposed vertical surface height was required for measurement. Four surficial sides for each unit were measured; all three exterior sides and the interior side positioned parallel to the shoreline. The triangular ReefBlk units pointed leeward (towards marsh shore) and windward (towards the bay), but no significant statistical differences in oyster densities were detected. Therefore a unit is not referenced as to its orientation in the results and discussions that follow. Surficial oyster length frequency data were also generated from each quadrat.

Besides taking surficial measurements, in the winter of 2009 total faunal densities (surficial + interior) were measured from some of the same replicates. Replicates per structure type per Reach were randomly selected from the same 15 replicates used for the surficial counts. The number or total density replicates had to be limited because of the difficulty of obtaining this type of information only during low tide. For Gabion Mats, five replicate mats per Reach were measured; 5 high-intertidal, 5 mid-intertidal, and 5 low-intertidal. All limestone rocks within a 1/16 m^{-2} area were removed to collect faunal densities. For the A-Jacks units, five of the 15 from Reach A and two from Reach B were measured. High tides and bad weather prevented use of any A-Jacks from Reach E and others from Reach B. The A-Jack density data were collected by scraping four concrete arms per replicate (two from top, one from windward vertical and one from leeward vertical). For the ReefBlks, the same impediments, high tides and bad weather in winter 2009, prevented sampling from Reach E. ReefBlk total density data were collected from three replicates at Reach A and one from Reach B. ReefBlks were sampled by chiseling out a quadrat core completely through each side of the structures. A quadrate core was extracted from the center of a side between the vertical iron rebars. A ReefBlk core's surface measured 138 mm (.45 ft) in horizontal width and averaged 145 mm (.48 ft) in vertical height (within a vertical height range of 110-175 mm due to tide levels). If the center had any area void of shell, then the quadrat core sample was extracted to either the left or right of center. ReefBlks are filled with aged oyster shell and the shell did exhibit some settling occasionally creating a void.

The time restriction of having to work only during low winter tides required using the total density data values as a way to extrapolate overall densities across Reaches by using to the much larger surficial density data sets. This extrapolation was accomplished by developing a total-to-surficial square meter density ratio (total#/surficial#) from each total faunal density replicate (as described in the paragraph above) for oysters, barnacles and hooked mussels. Those values were then averaged to obtain a single total-to-surficial value per structure type for each species, hereafter referred to as the "Multiplier Value." (Appendix D, Figures D-1 to D-8) The Multiplier Value was used with the winter 2009 surficial densities to extrapolate to the total square meter densities for oysters, barnacles and hooked mussels per structure type across the three Reaches; N = 15 sites for Gabion Mid, N = 15 for Gabion low, N = 15 for A-Jack, and N = 15 for ReefBlk.

In addition to developing species' square meter density estimates, total densities of oysters, barnacles and hooked mussels per linear meter of shoreline were also calculated. Gabion Mat linear densities were calculated by taking the average of mid and low intertidal oyster densities per square meter and using half of a mat's length, 3.07 m (10.1 ft) as a factor. The upper half of the mat had oysters mostly less than 25 mm (1 inch) in shell length, and therefore not capable of reef development and thus not included in the calculations. An A-Jack unit measures 0.7 m (2.3 ft) in width and therefore represents that fraction of a linear square meter. A triangular ReefBlk unit measures 1.52 m (5 ft) long on each side and averages 0.55 m (1.8 ft) in vertical height to bay bottom, thus representing a three-sided total area of 2.52 m^2 (as-built units were actually 0.6 m (2 ft) in height but sediment shoaling along sides buried the bottoms). Therefore, by factoring in all three sides of a ReefBlk within a linear meter of shoreline generates a multiplier factor of 1.66 (2.52 $m^2 \div 1.5$ m).

Oyster length frequency data was also collected while collecting surficial and interior density data during winters 2008 and 2009. A minimum of 200 eastern oysters at each site was measured, unless noted otherwise. Also, oysters were classified as live, dead (gaping articulated valves), or scar (only one oyster valve remaining cemented to the substrate). Since oysters could not be removed from the structures for examination during surficial counts, live and dead were combined for density estimates. Only oyster that could be accurately measured to nearest millimeter using a plastic ruler were recorded.

Natural Intertidal Reef Reference Area

A reference site was established on a natural intertidal oyster reef just north of Reach E. (Figure 5). The reference site was located in a shallow-water area to prevent commercial harvest that would compromise data comparisons. Oyster density and length frequency data were collected for comparisons to the oyster populations that have recruited to the structures. As typical of natural intertidal oysters in Louisiana, the reef structure is not always continuous along a shoreline, but often patchy in distribution. Therefore, to maximize comparisons to the structures, the 0.25 m^2 (2.7 ft^2) frame was randomly placed wherever reef or oyster clusters existed, and not on bare mud habitat.

Statistics

Data was log transformed if it helped achieve normality; otherwise the original data numbers were used in the analyses. Analyses consisted of paired t-tests, one-way and two-way ANOVAs using the post-hoc Student-Newman-Keuls Method of Pairwise Multiple Comparison Procedures. The statistical packages used were Sigma Stat (v3.1) and PC-SAS (v9.1.3) and analyses are in Appendix D.

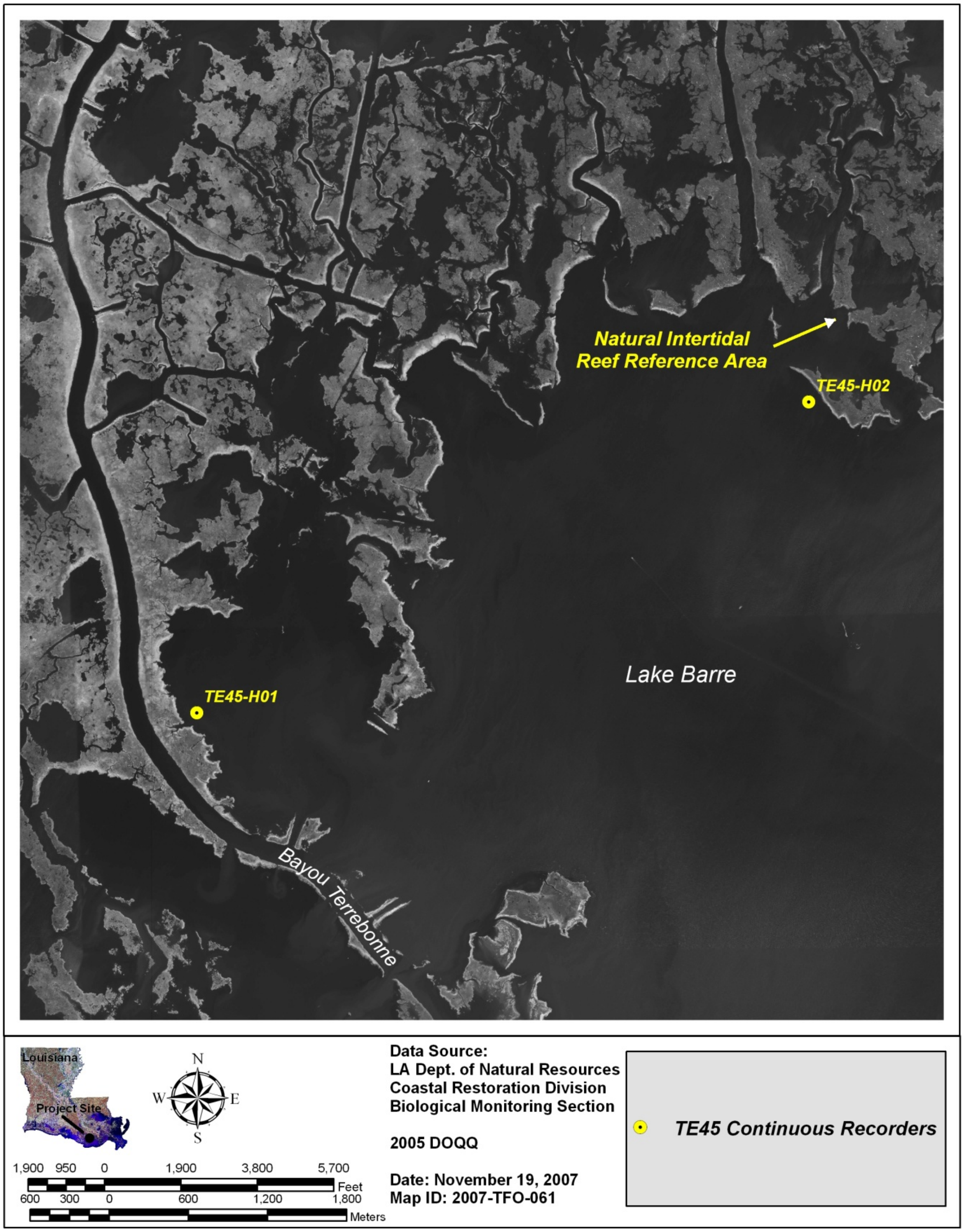


Figure 5. Location of continuous recorder stations and the natural intertidal oyster reef used as a reference to treatments.

c. Preliminary Monitoring Results and Discussion

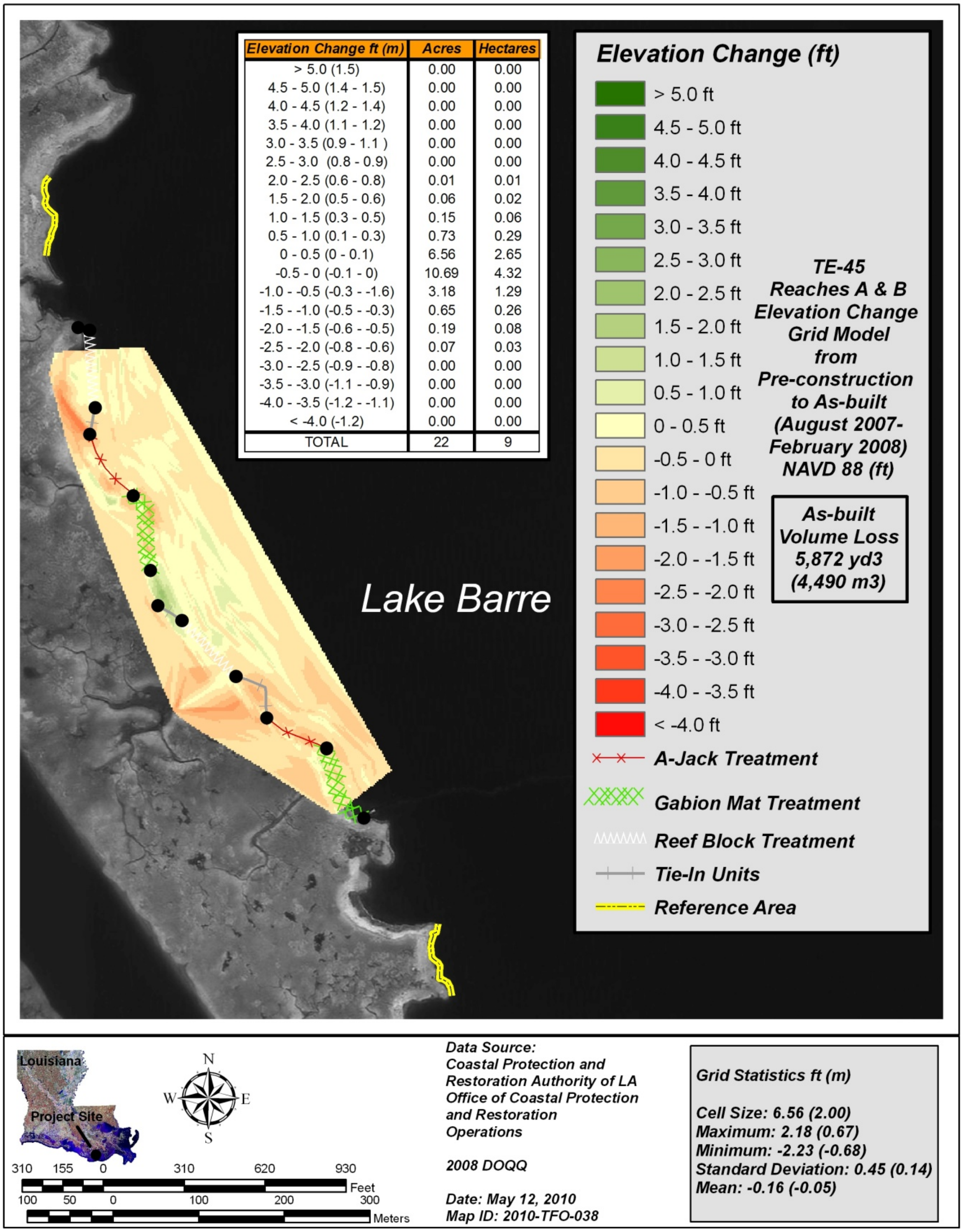
Elevation

The Terrebonne Bay Shore Protection Demonstration (TE-45) project Reaches experienced very small volume reductions during the 6-month interval between the pre-construction (August 2007) and as-built (February 2008) surveys. Elevation change and volume distributions for the TE-45 Reaches are shown in Figure 6 (Reaches A and B) and Figure 7 (Reach E). Elevation grid models for the pre-construction and as-built surveys are also provided in Appendix E (Figures E-1 to E-4). Approximately, 4,490 m^3 (5,872 yd^3) of sediment were removed from the Reach A and B shorelines and 2,708 m^3 (3,542 yd^3) of sediment were removed from the Reach E shoreline during the 6 month pre-construction period (Figures 6 and 7). Because of the different orientation and frequency of the pre-construction and as-built survey transects, the volume loss inside the TE-45 Reaches is probably exaggerated. However, it is interesting that all three Reaches recorded pre-construction volume losses denoting that sediments were removed from the shorelines during the interval between the surveys. For consistency purposes, future post-construction surveys will follow the as-built methodology.

Shoreline Change

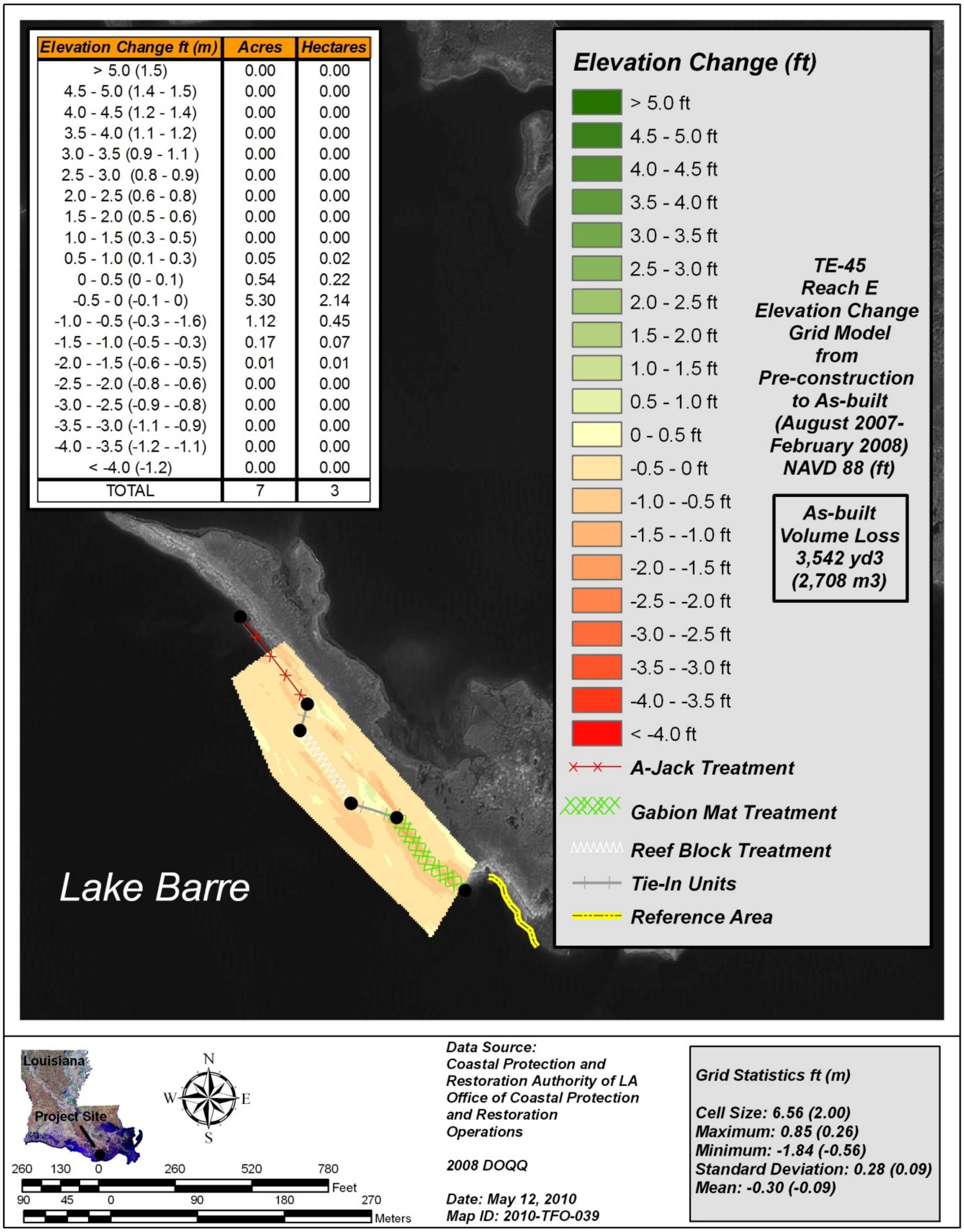
Preliminary pre and post-construction shoreline position data indicate that all structures have reduced shoreline erosion rates in the Terrebonne Bay Shore Protection Demonstration (TE-45) project area. Pre-construction shoreline erosion rates averaged -5 m/yr (-16 ft/yr) in the project area and -6 m/yr (-18 ft/yr) in the reference area from January 1998 to November 2005 (Figure 8). Post-construction results for the period from September 2007 to October 2008 (1 year post-construction) show average erosion rates of -0.6 m/yr (-2 ft/yr) in the project area and -2 m/yr (-8 ft/yr) in the reference area (Figure 9). The large decrease in erosion rates behind the TE-45 structures is notable considering that Hurricane Gustav made landfall a few miles southwest of the project area on September 1, 2008 (Figure 10).

Pre-construction data reveals that the Terrebonne Bay Shore Protection Demonstration (TE-45) project and reference area Reaches and the future structure locations were eroding at differential rates. Shoreline change graphics for the pre-construction period are provided in Appendix F (Figures F-1 to F-3). Reach A recorded the highest erosion rate, -6 m/yr (-19 ft/yr) while the Reach B and Reach E shorelines eroded at -5 m/yr (-17 ft/yr) and -3 m/yr (-11 ft/yr) during the 8-year pre-construction interval (Figure 8). Not only did the Reaches erode at differential rates but the shorelines within each Reach and the reference areas also eroded at varying rates. The impending locations of the Gabion Mat -6 m/yr (-19 ft/yr), A-Jack -6 m/yr (-18 ft/yr), and the ReefBlk -4 m/yr (-12 ft/yr) treatments transgressed at asymmetrical rates (Figure 8). Similarly, the reference areas receded at disproportionate rates of -10 m/yr



Elevation Change ft (m)	Acres	Hectares
> 5.0 (1.5)	0.00	0.00
4.5 - 5.0 (1.4 - 1.5)	0.00	0.00
4.0 - 4.5 (1.2 - 1.4)	0.00	0.00
3.5 - 4.0 (1.1 - 1.2)	0.00	0.00
3.0 - 3.5 (0.9 - 1.1)	0.00	0.00
2.5 - 3.0 (0.8 - 0.9)	0.00	0.00
2.0 - 2.5 (0.6 - 0.8)	0.01	0.01
1.5 - 2.0 (0.5 - 0.6)	0.06	0.02
1.0 - 1.5 (0.3 - 0.5)	0.15	0.06
0.5 - 1.0 (0.1 - 0.3)	0.73	0.29
0 - 0.5 (0 - 0.1)	6.56	2.65
-0.5 - 0 (-0.1 - 0)	10.69	4.32
-1.0 - -0.5 (-0.3 - -1.6)	3.18	1.29
-1.5 - -1.0 (-0.5 - -0.3)	0.65	0.26
-2.0 - -1.5 (-0.6 - -0.5)	0.19	0.08
-2.5 - -2.0 (-0.8 - -0.6)	0.07	0.03
-3.0 - -2.5 (-0.9 - -0.8)	0.00	0.00
-3.5 - -3.0 (-1.1 - -0.9)	0.00	0.00
-4.0 - -3.5 (-1.2 - -1.1)	0.00	0.00
< -4.0 (-1.2)	0.00	0.00
TOTAL	22	9

Figure 6. **Elevation and volume change grid model from pre-construction (Aug 2007) to as-built (Feb 2008) for Reaches A and B at the Little Lake Shoreline Protection/Dedicated Dredging Near Round Lake (BA-37) project.**



Elevation Change ft (m)	Acres	Hectares
> 5.0 (1.5)	0.00	0.00
4.5 - 5.0 (1.4 - 1.5)	0.00	0.00
4.0 - 4.5 (1.2 - 1.4)	0.00	0.00
3.5 - 4.0 (1.1 - 1.2)	0.00	0.00
3.0 - 3.5 (0.9 - 1.1)	0.00	0.00
2.5 - 3.0 (0.8 - 0.9)	0.00	0.00
2.0 - 2.5 (0.6 - 0.8)	0.00	0.00
1.5 - 2.0 (0.5 - 0.6)	0.00	0.00
1.0 - 1.5 (0.3 - 0.5)	0.00	0.00
0.5 - 1.0 (0.1 - 0.3)	0.05	0.02
0 - 0.5 (0 - 0.1)	0.54	0.22
-0.5 - 0 (-0.1 - 0)	5.30	2.14
-1.0 - -0.5 (-0.3 - -1.6)	1.12	0.45
-1.5 - -1.0 (-0.5 - -0.3)	0.17	0.07
-2.0 - -1.5 (-0.6 - -0.5)	0.01	0.01
-2.5 - -2.0 (-0.8 - -0.6)	0.00	0.00
-3.0 - -2.5 (-0.9 - -0.8)	0.00	0.00
-3.5 - -3.0 (-1.1 - -0.9)	0.00	0.00
-4.0 - -3.5 (-1.2 - -1.1)	0.00	0.00
< -4.0 (-1.2)	0.00	0.00
TOTAL	7	3

Figure 7. **Elevation and volume change grid model from pre-construction (Aug 2007) to as-built (Feb 2008) for Reach E at the Little Lake Shoreline Protection/Dedicated Dredging Near Round Lake (BA-37) project.**

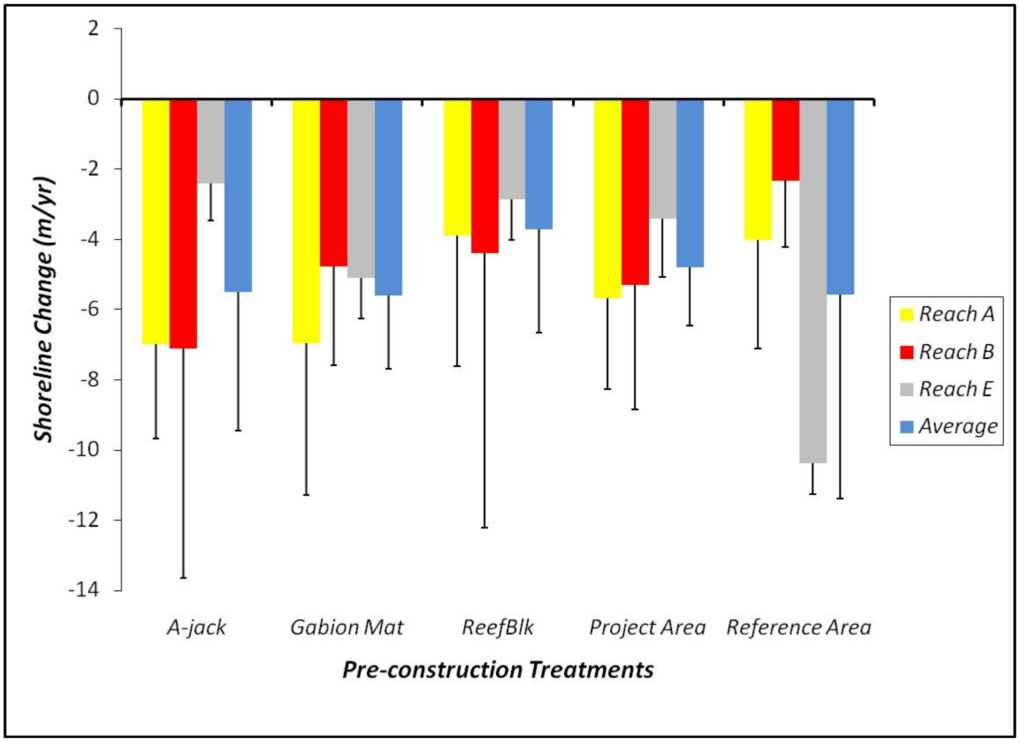


Figure 8. **Pre-construction shoreline erosion rates for each treatment and each Reach at the Terrebonne Bay Shore Protection Demonstration (TE-45) project.**

Figure 9. **Post-construction shoreline erosion rates for each treatment and each Reach at the Terrebonne Bay Shore Protection Demonstration (TE-45) project.**

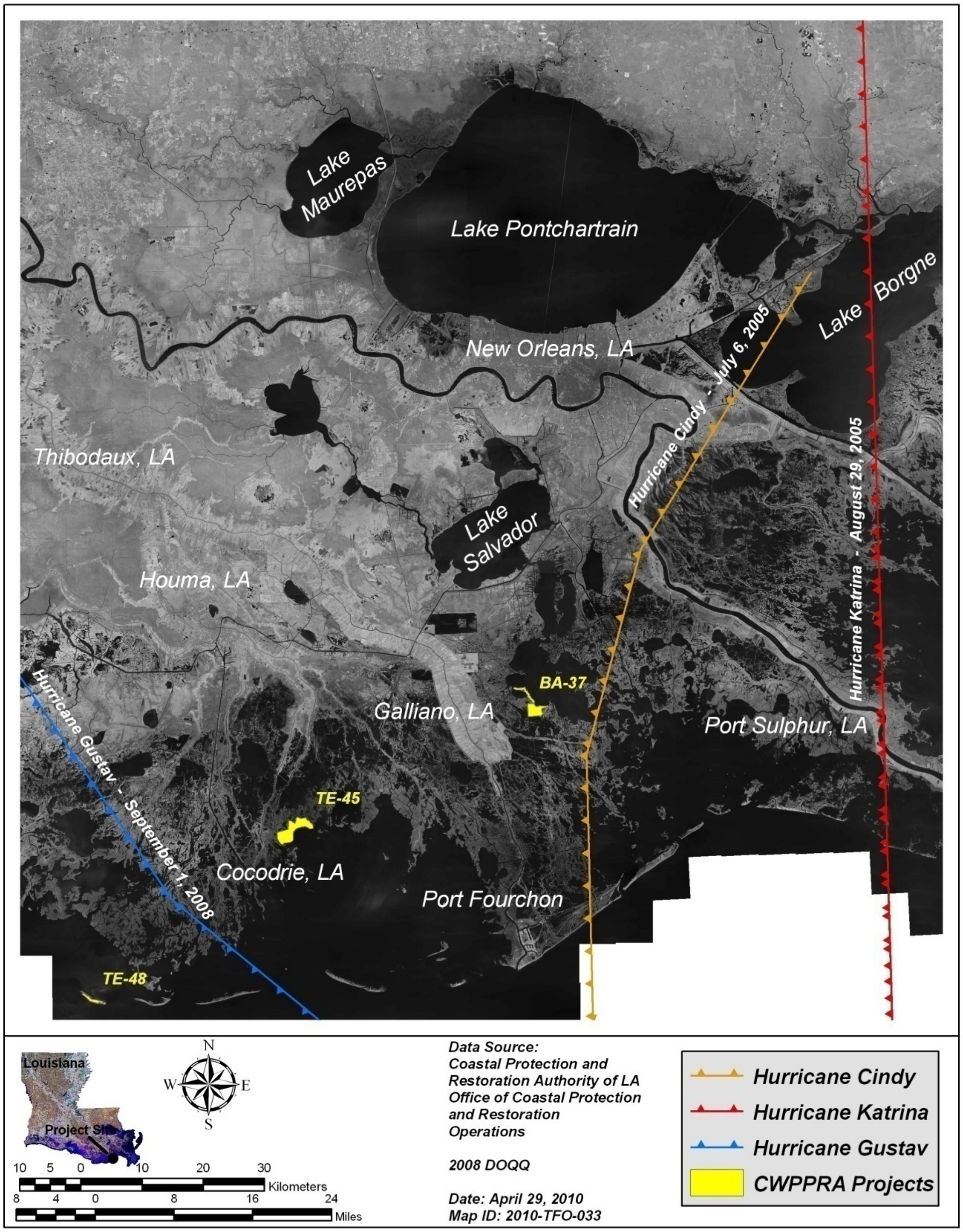


Figure 10. Pre-construction (2005) and post-construction (2008) hurricanes impacting the Terrebonne Bay Shore Protection Demonstration (TE-45) project area shoreline.

(-34 ft/yr) (Reach E), -4 m/yr (-13 ft/yr) (Reach A), and -2 m/yr (-8ft/yr) (Reach B) (Figure 8). Moreover, the Reach E reference area transgressed at a considerably faster rate than the other TE-45 shorelines in the pre-construction period. Although the pre-construction shoreline erosion rates were a little inconsistent, these differences were not significant (Figure 11). The pre-construction data also illustrates that the TE-45 Reaches were transgressing at a substantial rate before construction. The passage of Hurricane Cindy (July 2005), Hurricane Katrina, (August 2005), and Hurricane Rita (September 2005) probably exacerbated shoreline transgressions in the pre-construction project and reference areas (Figure 10).

The initial post-construction shoreline analysis suggests that the Gabion Mat, ReefBlk, and A-Jack structures are lowering shoreline erosion rates at all the Terrebonne Bay Shore Protection Demonstration (TE-45) project Reaches. The average shoreline erosion rate behind the structures was only -0.6 m/yr (-2 ft/yr) significantly less than the -5 m/yr (-16 ft/yr) in the pre-construction interval (Figure 11). Shoreline change graphics for the post-construction period are provided in Appendix F (Figures F-4 to F-6). Amid the Reaches, Reach A continued to have the highest erosion rate followed by Reach B and Reach E. These Reaches had erosion rates of -0.9 m/yr (-3 ft/yr), -0.6 m/yr (-2 ft/yr), and -0.2 m/yr (-0.8 ft/yr) (Figure 9). Interestingly, the Reaches were positioned in the same order before construction (Figures 8 and 9). The shorelines below the Gabion Mat treatment documented the lowest erosion rates, -0.1 m/yr (-0.4 ft/yr), during the 1-year interval after construction (Figure 9). However, the shoreline position below the Gabion Mat treatment was difficult to locate with aerial photography because the mats were laid on top of the marsh/water interface. Although the Gabion Mat treatments shoreline positions probably have some variability, visual inspections show little erosion. The post-construction shoreline transgressions behind the ReefBlk, -0.6 m/yr (-2 ft/yr), and A-Jack, -0.9 m/yr (-3 ft/yr), treatments were comparable (Figure 9). Therefore, all treatments have appreciably reduced shoreline erosion rates to date. Since construction, the reference area Reaches have continued to erode at differential rates. The Reach E reference area has sustained its high shoreline transgression rate, -6 m/yr (-20 ft/yr), and the Reach B reference area has eroded at a lower rate, -0.9 m/yr (-3 ft/yr) (Figure 9). A post-construction erosion rate could not be determined for the Reach A reference area because a dark spot appeared on the 2007 photography skewing shoreline positions. No significant differences were found between the reaches or treatments during the initial post-construction shoreline analysis. However, comparisons between the pre- and post-construction shoreline erosion rates were significant ($P=0.01$) (Figure 11). In addition to the low erosion rates, the structures have maintained their stability and have been successful in recruiting oyster populations during Hurricane Gustav (Figure 10) and winter storms. Both hurricanes and cold fronts have been found to erode coastal marshes (Watzke 2004; Stone et al. 1997). Other oyster reefs have reduced marsh erosion in low energy environments (Piazza et al. 2005; Meyer et al. 1997). Therefore, the Gabion Mat, ReefBlk, and A-Jack structures have potential to maintain the TE-45 shorelines. Currently, the TE-45 shoreline erosion goals are being attained. While the low erosion

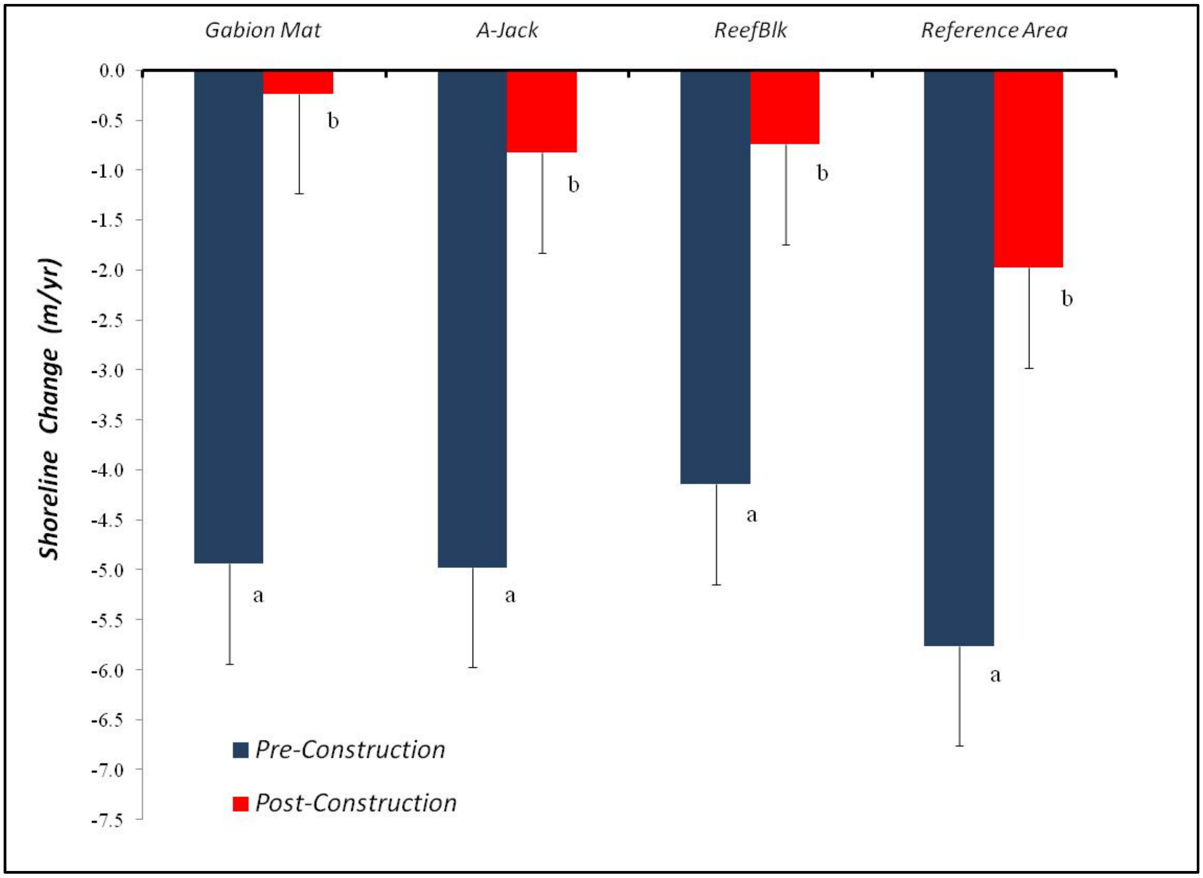


Figure 11. **Comparison of shoreline change means (-1 S.E.) for the pre-construction (mean of 8 years) and post-construction (mean of 1 year) time periods. No significant difference between sites when compared within pre or post construction periods. Highly significant differences (P = 0.01) within a site when compared between pre- and post-construction periods.**

rates experienced in the first post-construction year is impressive, only additional temporal data will determine if these low erosion rates behind these structures are sustainable.

Hydrology

To analyze and understand oyster reef development on the structures, one must document how the physical and chemical characteristics of each site influence oyster recruitment, survival and growth. Mean monthly water height relative to reference datum for each continuous recorder site is found in Figure 12. At both stations data exhibits lowest water levels during the winter months and highest during the fall months. This seasonal pattern of water height change is typical for the coast of Louisiana (Day et al. 1973). During September 2008 hurricane Gustav passed close to the TE45 project sites and water levels increased significantly during that month (Figure10).

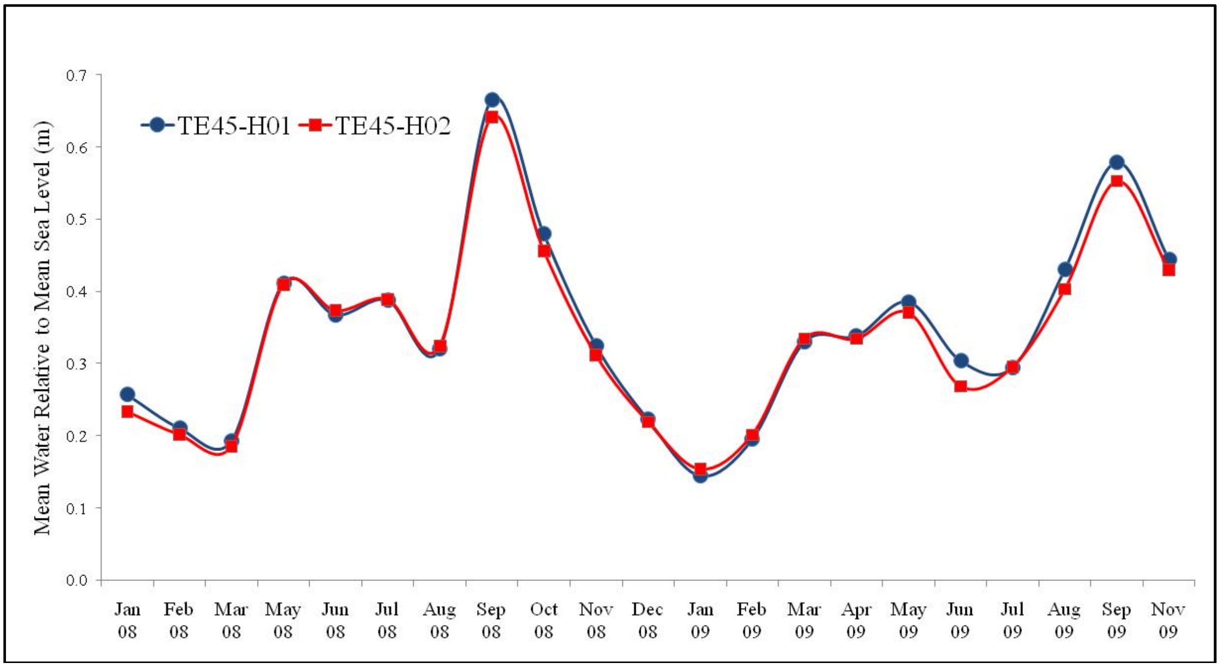


Figure 12. Mean monthly water height for each constant recorder, TE45-H01 for Reaches A and B, and TE45-H02 for Reach E.

Data from Figure 12 was used to develop an index of how often from January 2008 to November 2009 each structure was exposed to the air during a low tide or totally submerged during a high tide. Data in Figure 13 indicates that each Reach, with its own elevation characteristics, exposed the structures for different lengths of time. Reach A exhibited the greatest degree of aerial exposure to structures, followed by Reach B and then Reach E. Conversely, Reaches A and E exhibited the greatest degree of submergence of structures. Salinity and water temperature patterns from November 2007 through December 2009 exhibited characteristics conducive to oyster recruitment and survival (Figure 14).

Prolonged salinity of at least 8 ppt is needed for oyster larvae development and eventual recruitment and survival on the structures (Cake 1983). The most important times for oyster larvae are during May-June and September-October during the peak of adult spawning. Salinities at both sites exhibited good patterns for larvae recruitment and survival, with Reach E having salinities slightly higher on average. Salinities must also remain at or below about 15 ppt for a good percentage of the year to reduce or eliminate the predation snail known as the oyster drill snail, *Stramonita haemastoma.* No oyster drills have ever been seen at the study sites. Dissolved oxygen, TSS, turbidity and chlorophyll-a levels were sufficient for oyster survival and growth.

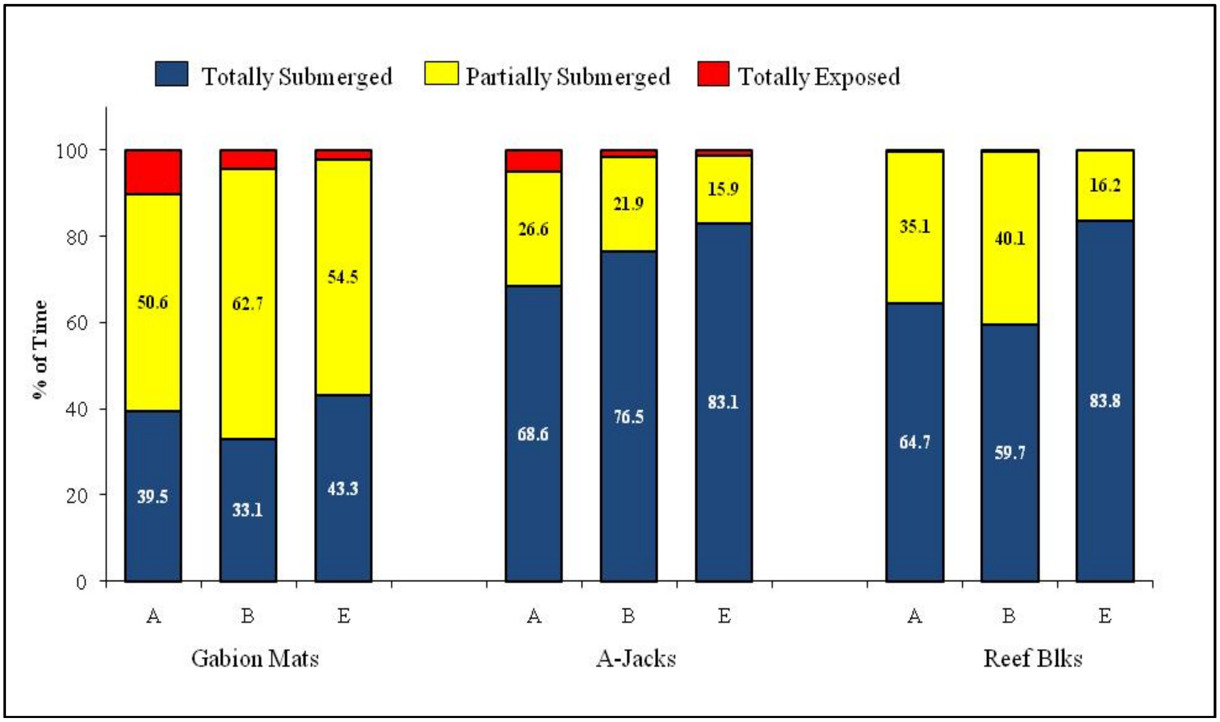


Figure 13. **Percent of time for each structure at each Reach when submerged at high tide or exposed during low tide during the period January 2008 through November 2009. Numbers in histograms represent percent of time.**

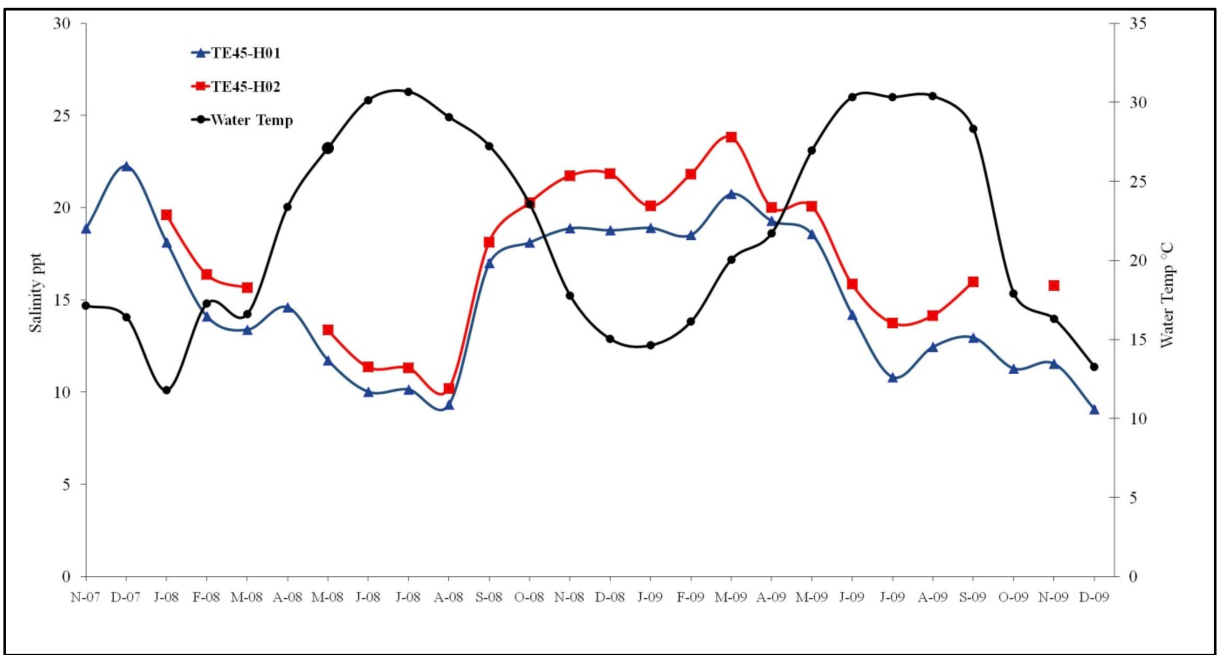


Figure 14. **Mean monthly salinity from constant recorders TE45-H01 (for Reaches A and B) and TE45-H02 (for Reach E) from November 2007 to December 2009. Mean water temperature represents both recorders since there was no significant statistical difference between sites.**

Prolonged salinity of at least 8 ppt is needed for oyster larvae development and eventual recruitment and survival on the structures (Cake 1983). The most important times for oyster larvae are during May-June and September-October during the peak of adult spawning. Salinities at both sites exhibited good patterns for larvae recruitment and survival, with Reach E having salinities slightly higher on average. Salinities must also remain at or below about 15 ppt for a good percentage of the year to reduce or eliminate the predation snail known as the oyster drill snail, *Stramonita haemastoma.* No oyster drills have ever been seen at the study sites. Dissolved oxygen, TSS, turbidity and chlorophyll-a levels were sufficient for oyster survival and growth.

Oyster Spat Availability to Structures

Oyster spat available in the water column for recruitment to the structures was documented during the time period of spring through fall in 2008 and 2009 (Figure 15). There were differences between years, with subtidal collectors showing greater recruitment. Less oyster spat recruitment to intertidal collectors was anticipated since they were exposed at low tide and thus not available to oyster larvae in the water. This variability between years and tidal heights was expected and is considered normal. The eastern oyster in the northern Gulf of Mexico can spawn in nearly every month of the year, but typically exhibits strong annual bimodal peaks in the spring and fall (Cake 1983). Gauthier and Soniat (1989) have shown an annual bimodal peak in Louisiana with the spring spawn typically generating the best oyster recruitment. The bimodal peak was evident at all three Reaches for 2008 and 2009. The greatest peak spat set occurred in May-June 2008 followed by another good recruitment in the spring-early summer of the following year.

Oyster spat recruitment success on shells at each Reach indicates that all structures had the potential to develop initial colonization and reef development. Spat recruitment density did vary from year to year and between Reaches, but overall oyster spat recruitment available to the structures Reach-wide was favorable and considered to be more than sufficient for both years, 2008 and 209.

Oyster Recruitment to Structures

To determine if a structure or reference area has developed and sustained a relatively good oyster population, a density of 25 oysters per square meter will be used as the threshold. This density follows the suggestion of Cake (1983) who stated that a density of 25 oysters per square meter is a well-established population. However, another critical criteria that must be evaluated for this project is the ability to form a cohesive mass of reef that is “fused” in such a manner to remain in place once the structures’ (treatments) infrastructure deteriorates, which is inevitable.

Each of the three structures, Gabion Mats, A-Jacks, and ReefBlks has a unique shape and size and thus pose a challenge to accurately compare each to the others for oyster

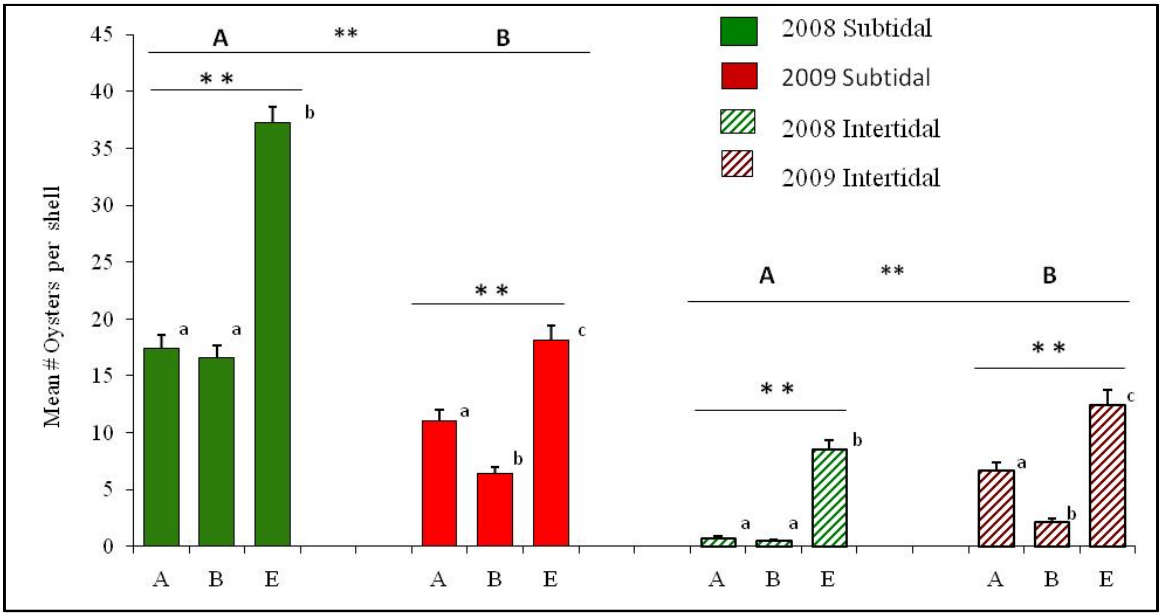


Figure 15. **Monthly mean number (+ 1 S.E.) of oyster spat set on oyster shell by Reach. A horizontal bar above a histogram indicates a statistical analysis on data below. Letters indicate whether or not a significant statistical difference is present, e.g., same letters indicate no significant difference between years while different letters do. An asterisk above the bar represents whether statistical difference is at the significant P = 0.05 (*) or highly significant P = 0.01 (**).**

recruitment and initial reef building success. In the winter of 2008 and 2009 when tides were lowest (Figure 12), and oyster spring-fall spawning and recruitment complete, the structures were visually and quantitatively examined to count the surface (surficial) layer of attached oysters and its major competitors for space, barnacles (*Balanus sps*.) and hooked mussels (*Ischadium recurvum*). Visual counts were restricted to only what could be seen while viewing from above and a mat was not disturbed in any way by moving oysters. Surficial quantitative counts (0.0625 m^2 quadrat), length frequencies, and faunal percent coverage were used as indices to measure oyster recruitment success to each structure type.

By the winter of 2009 after two successful spring-fall recruitment years, oysters along with its two major competitors for space had colonized the Gabion Mats (Figure 16). Mats were intended to be laid perpendicular (90°) along the marsh shore in the intertidal zone, but not all were placed perpendicular. Many mats were at various angles less than perpendicular and therefore not extending as far out into the water. Fifteen mats from each Reach were selected that were perpendicular or nearly so and measured approximately 6 m (20 ft) in length. This allowed for more accurate comparisons within and between Reaches. A perpendicular mat also produced the greatest diversity of habitats due to tidal activity.

Percent faunal coverage increased from the top of the mat as it extended down from the marsh shore and farther into the water (Figure 17). It is clearly evident that by 3.0-3.5 m distance, the faunal populations had reached a 90% or better surficial coverage on the limestone rocks at Reaches A and B and began to plateau. However this was not the case at Reach E where surficial faunal coverage reached a high of approximately 80% and then eventually declined as distance increased. This decrease in faunal coverage has not been determined, but one possibility is that as percentage of time underwater increased at the far end, the greater the availability of fish and invertebrate predators on the surface fauna. Another possible reason may be that the wave energy at E may be stronger than at the other two Reaches and thereby preventing hooked mussels from as readily colonizing. Reach E Gabion Mats were under water during tidal cycles more so than the other two Reaches (Figure 13).

Surficial quadrat samples were taken from five mats per Reach at high-intertidal (0.5-1.0 m distance from top of mat), mid-intertidal (3.0-3.5m distance from top) and low-intertidal (5.0-5.5m from top) to quantify oyster surficial abundance (Figure 18). High-intertidal had the lowest mean number of oysters per square meter but did show

Figure 16. **Gabion mats colonized by oysters as seen during a falling (ebb) tide in winter 2009.**

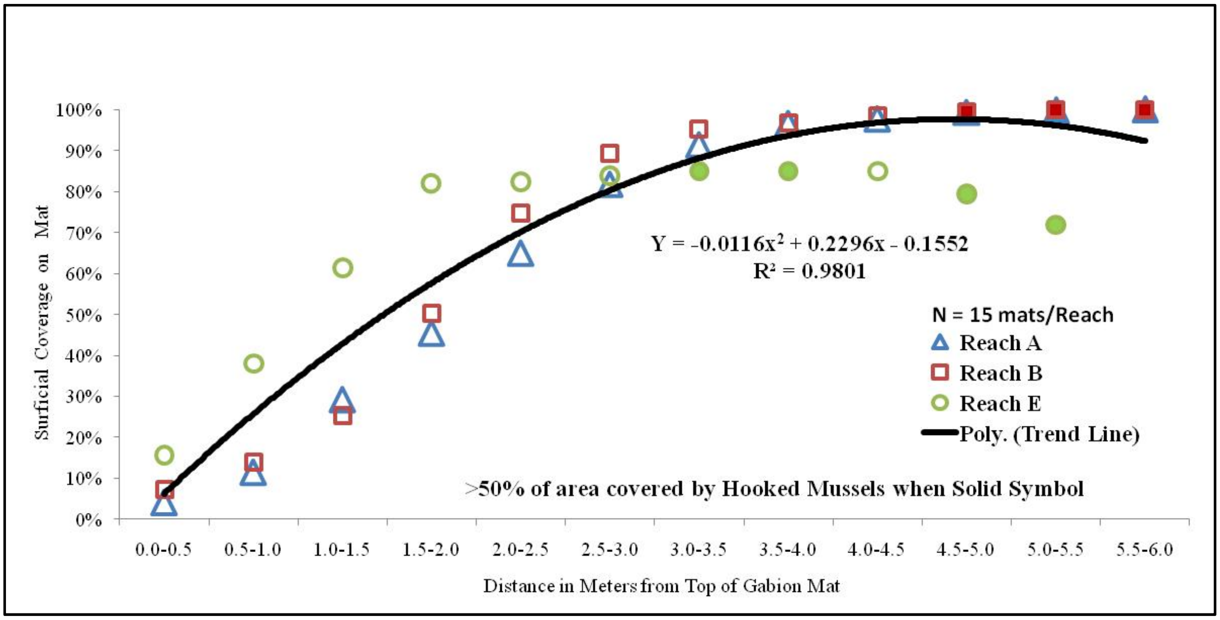


Figure 17. **Percent surficial coverage of fauna (oysters + hooked mussels + barnacles) on the Gabion Mats in winter 2009 after two spring-fall recruitment years. Approximate distance from the top of a mat to Mean High Tide mark for each Reach is as follows: A = 3.0-3.5m, B = 3.0-3.5m and E = 1.5-2.0m. The x-value in the polynomial equation is represented by the greatest distance in that distance range, e.g., 3.0-3.5m is equal to 3.5m.**

an increase in abundance in winter 2009 from winter 2008. Mid-intertidal surficial oyster abundance was nearly the same for both winter surveys, while abundance declined significantly in winter 2009 for low-intertidal. Oyster abundances not increasing and even declining in winter 2009 would seem to be counter intuitive, but further observations showed that hooked mussel populations had increased substantially from winter 2008 and was covering the oysters and thus preventing many from being counted in a visual survey.

The low-intertidal site on the Gabion Mats was used to document barnacle and hooked mussel abundance relative to oyster abundance. The low-intertidal habitat is the most inundated site during a tidal cycle as is therefore the most similar in inundation frequency to the other two structure types located in deeper waters. Hooked mussel and barnacle abundance increased significantly from winter 2008 to winter 2009 (Figure 19). A close examination by Reach shows how that increase impacted each Reach. Barnacle abundance in winter 2008 was relatively low with no statistically significant difference between Reaches. By winter 2009 barnacle abundance had increased significantly at all three Reaches, with Reach E exhibiting the greatest change. However, it is the hooked mussel population that appears to dominate the potential competition with oysters for space and possibly food. The hooked mussel population covering the mats increased dramatically by winter 2009, and in some instances nearly covered the oysters in a solid veneer (Figure 20).

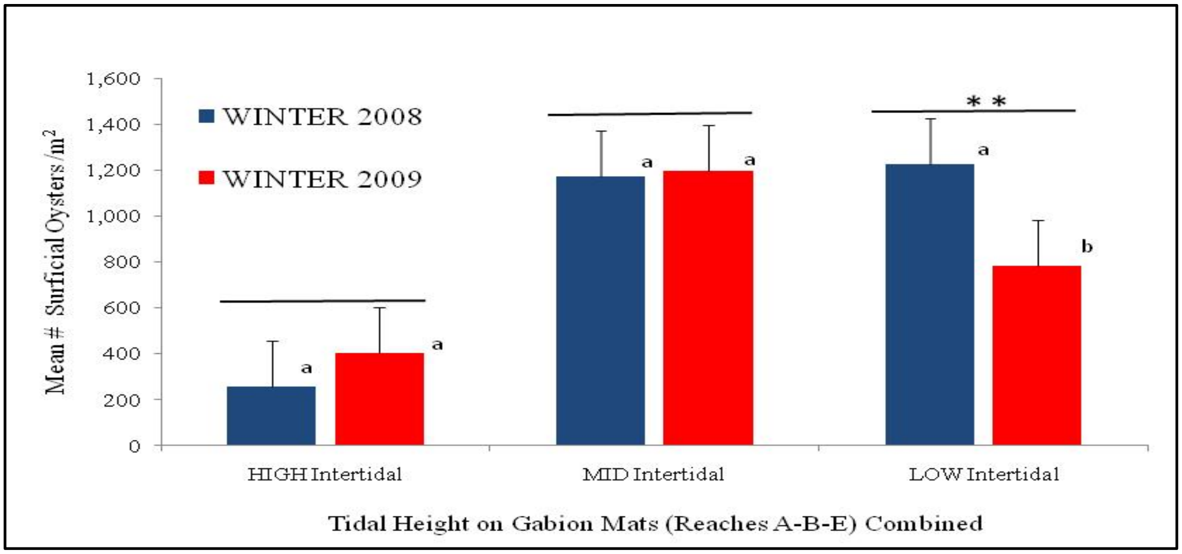


Figure 18. **Mean (+ 1 S.E.) oyster abundance on Gabion Mats by tidal habitat. A horizontal bar above a histogram indicates a statistical analysis on data below. Letters indicate whether or not a significant statistical difference is present, e.g., same letters indicate no significant difference between years while different letters do. An asterisk above a horizontal bar represents whether statistical difference is at the P = 0.05 (*) or P = 0.01 (**).**

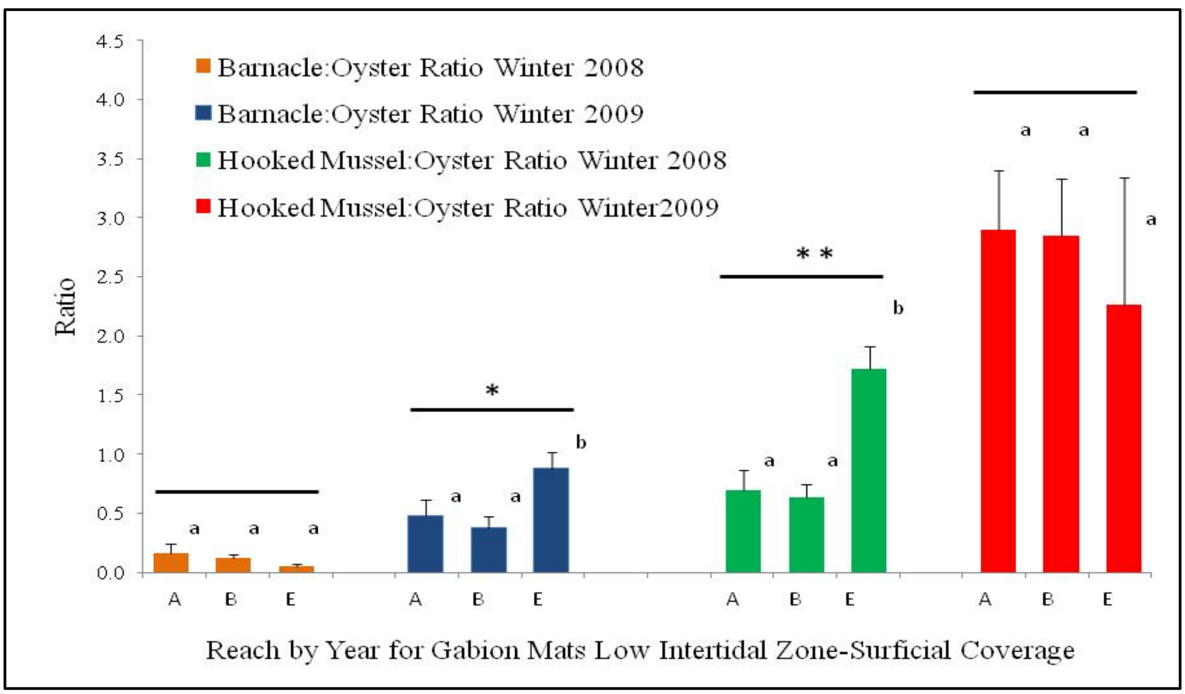


Figure 19. **Surficial ratio (+1 S.E) by year of barnacles and hooked mussels to oysters found in the low-intertidal habitat of Gabion Mats. A horizontal bar above a histogram indicates a statistical analysis on data below. Letters indicate whether or not a significant statistical difference is present, e.g., same letters indicate no significant difference between years while different letters do. An asterisk above a horizontal bar represents whether statistical difference is at the P = 0.05 (*) or P = 0.01 (**) level.**

The A-Jack structures placed at the low-water's edge of the shoreline posed a different challenge to surficial measurements when compared to the Gabion Mats. The A-Jacks had water on the windward and leeward sides of the structures most of the time during a tidal cycle (Figure 13) and were placed three deep (Figure 21). Data analyses on the A-Jacks indicated that there was no significant difference between leeward and windward surficial oyster densities. Therefore, analyses focused on the structures as a three-layer-deep unit measured on a linear (horizontal) and vertical depth basis. Each quadrate sample (rep) was 0.25 m linear width measured parallel to the shoreline with its vertical depth to the seafloor site-dependent. All oysters, barnacles and hooked mussels were visually counted without disturbance to the structures. The quadrate surficial density count included all of the structures' jutting concrete arms located within the defined area.

A-Jack percent surficial faunal coverage (oysters + barnacles + hood mussels) for winter 2009 indicates good recruitment, especially at Reaches B and E (Figure 22). The significant increase in abundance may be due to the fact that Reaches B and E were underwater a greater percentage of time than that of Reach A, and therefore more available for recruitment and the environmental harshness of aerial exposure during a low tide (Figure 13). No percent surficial coverage data is available for A-Jacks from winter 2008 for comparison to 2009.

Figure 20. **Hooked mussels recruiting to Gabion Mats and to oysters, winter 2009.**

Figure 21. **A-Jacks were placed three deep. Photo from Reach A in November 2008.**

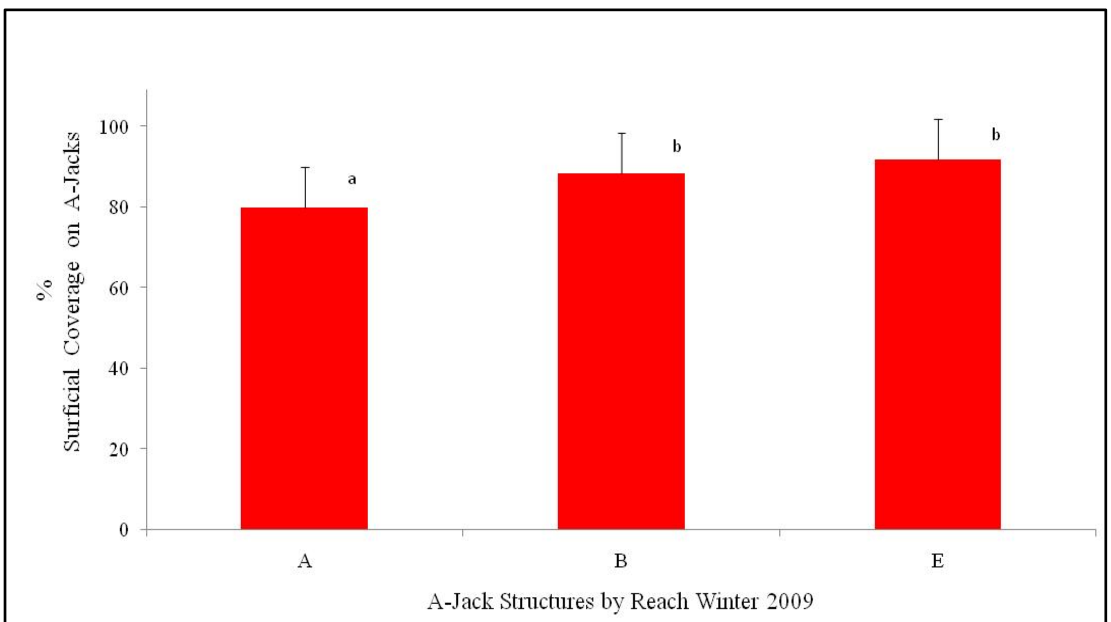


Figure 22. **Percent surficial coverage of fauna (oysters + hooked mussels + barnacles) on the A-Jacks in winter 2009 after two spring-fall recruitment years. Statistical difference is at the P = 0.05 (*) level.**

Surficial oyster density on the A-Jacks appeared to decrease from winter 2008 to winter 2009 (Figure 23 and Figure 24), but this was not what truly occurred. Surficial oyster densities on A-Jacks did increase substantially (Figure 25), but were hidden from observation because of hooked mussel populations. Hooked mussel densities had increased to such high numbers that the oysters were covered and could not be accurately counted. The ratio of surficial hooked mussel density to surficial oyster density had increased over 600%. As on Gabion Mats, the hooked mussels in many areas were so dense that they coated the oysters like a veneer (Figure 26). The barnacle ratio to oysters also increased slightly by the winter of 2009, but far below the level of increase displayed by the hooked mussel.

Further analyses of A-Jacks' oysters fouled by barnacles and hooked mussels show how each Reach was impacted. There is a clear and distinctive trend of a decreasing ratio from Reach A to Reach E for both barnacles and hooked mussels. This trend held true for both winter 2008 and winter 2009 samples. Such a trend suggests that some intrinsic influence exist that influences both species similarly for setting or survival. This influence, or combination of influences, is not known. It is possible, as similarly suggested for Gabion Mats, that one possibility is that as percentage of time underwater increased, the greater the availability of fish and invertebrate predators on the surface fauna. Another possible reason may be that the wave energy at E may be stronger than at the other two Reaches and thereby preventing hooked mussels from as readily colonizing. Reach E showed a similar trend in Gabion Mat hooked mussels ratio in winter 2009 (Figure 19).

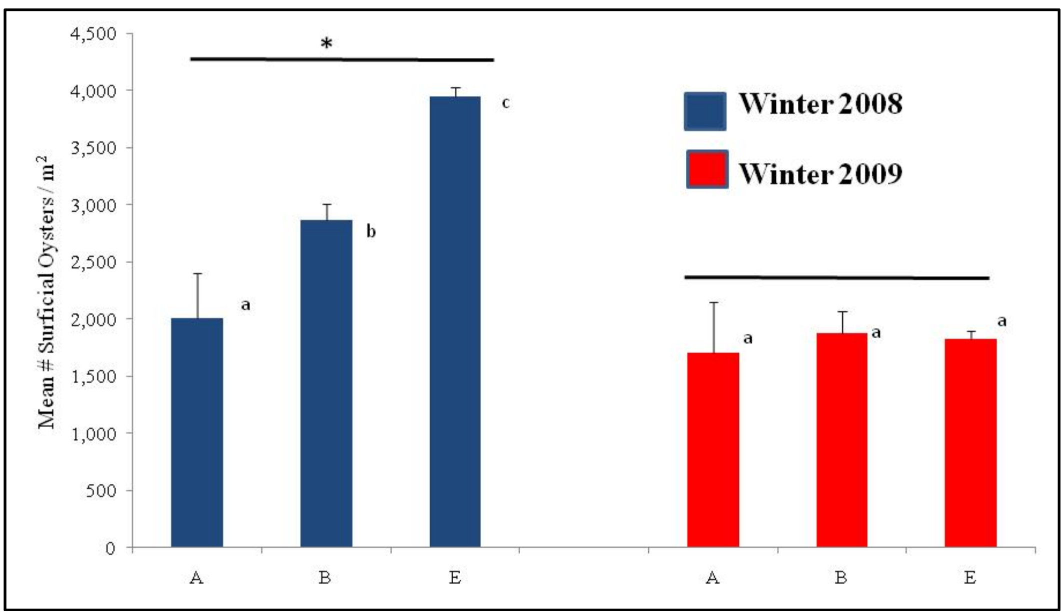


Figure 23. Mean (+1 S.E.) number of surficial oysters on A-Jack structures located at each Reach during the winters of 2008 and 2009. A horizontal bar above a histogram indicates a statistical analysis on data below. Letters indicate whether or not a significant statistical difference is present, e.g., same letters indicate no significant difference. An asterisk above a horizontal bar represents whether statistical difference is at the P = 0.05 (*) or P = 0.01 (**) level.

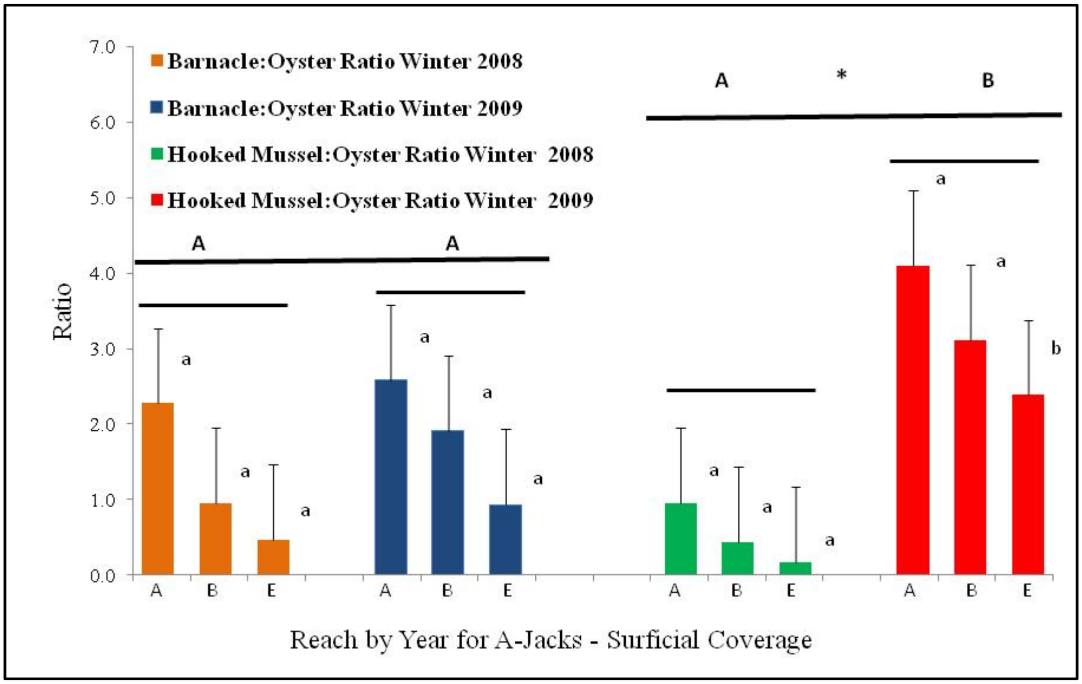


Figure 24. Mean (+1 S.E.) ratio surficial barnacles and hooked mussels to oysters on A-Jack structures located at each Reach during the winters of 2009 and 2009. A horizontal bar above a histogram indicates a statistical analysis on data below. Letters indicate whether or not a significant statistical difference is present, e.g., same letters indicate no significant difference. An asterisk above a horizontal bar represents whether statistical difference is at the P = 0.05 (*) or P = 0.01 (**) level.

Figure 25. A-Jacks colonized by oysters at Reach E as seen during a falling tide in winter 2009. Reach E had heaviest oyster set for this structure type.

Figure 26. **Hooked mussels attached to oysters on A-Jacks in winter 2009.**

Percent faunal coverage on ReefBlks in winter 2009 indicated that Reach E exhibited a significantly reduced coverage when compared to Reaches A and B (Figure 27). This less coverage is due not to less oyster density but to a phenomenon that was routinely observed on all ReefBlks, but especially prevalent at Reach E. ReefBlks had oyster shell settling in the plastic bags and leaving air gaps. Reach E's larger number, and thus less structure coverage, may be due to the very high wave and current energy shoreline that exist here. This observation of less percent coverage due to a high energy environment is supported by the significant higher surficial density of oysters on the ReefBlks at Reach E during the winter of 2008 (Figure 28). High energy areas have the potential to bring more food and better recruitment to an area to counteract the physical harshness of the environment (Figure 29). The highly significant reduction in surficial oyster density observed in winter 2009 is due to the large increase in hooked mussel populations that covered the oysters and obscuring them from a visual density count (Figure 30).

Surficial barnacle and hooked mussels populations increased in very significant numbers from 2008 to 2009 as seen in Figure 31. There was a 539% increase in the barnacle populations and a 454% increase in the hooked mussel populations from winter 2008 to winter 2009. Although barnacles pose as competition with oysters for space and potentially food, it is the dramatic increase in hooked mussel populations with their ability to create essentially a veneer covering over the oysters that probably posed a greater threat to reef development. The Reefblks had the greatest density of surficial hooked mussels of the three structure types.

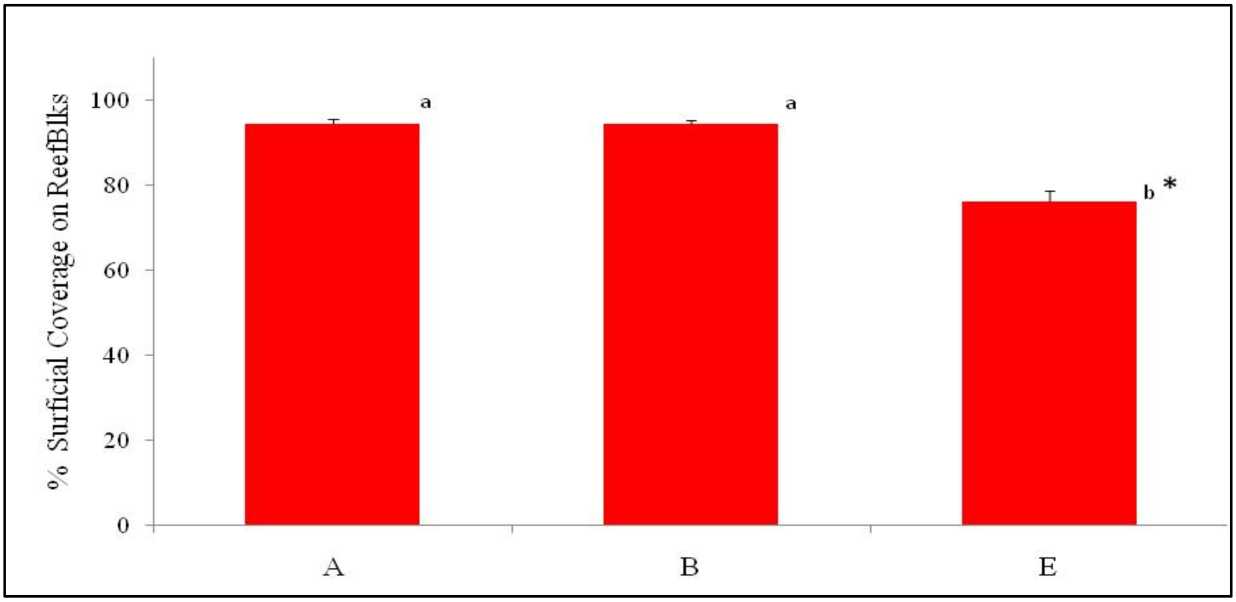


Figure 27. **Percent surficial coverage (+1 S.E.) of fauna (oysters + hooked mussels + barnacles) on the ReefBlks in winter 2009 after two spring-fall recruitment years. Letters indicate whether or not a significant statistical difference is present, e.g., same letters indicate no significant difference. Statistical difference is at the P = 0.05 (*) level.**

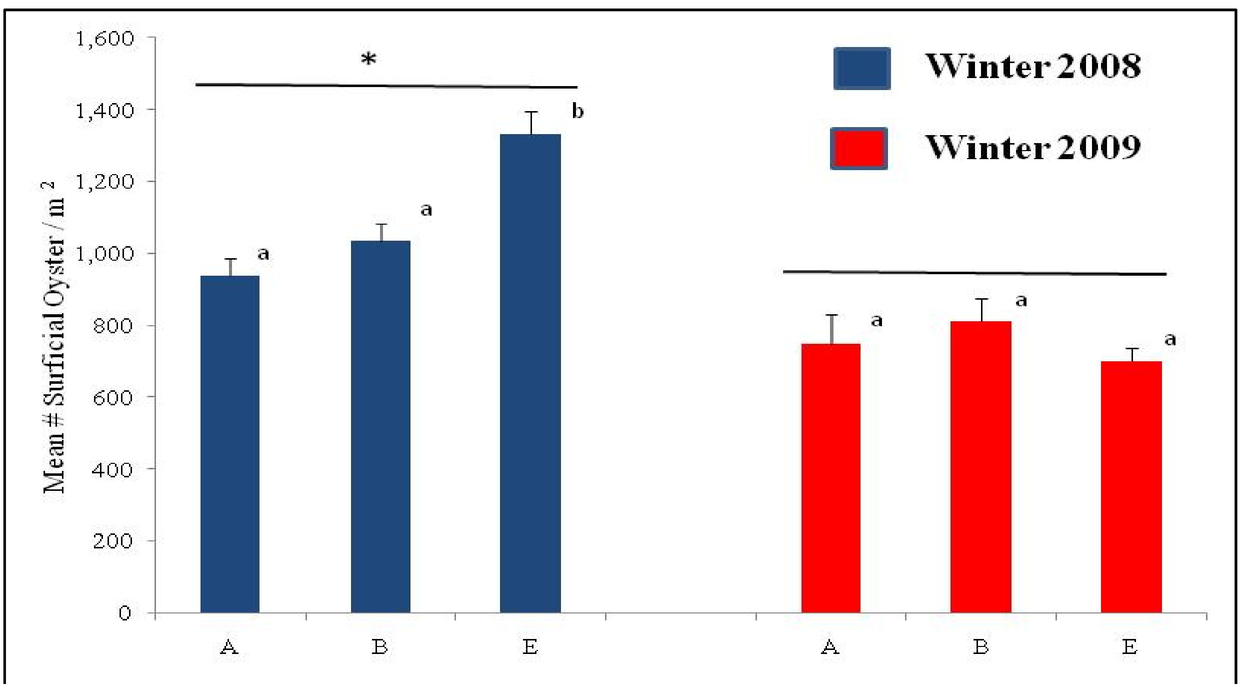


Figure 28. **Mean number (+1 S.E.) of surficial oysters on ReefBlks located at each Reach during the winters of 2008 and 2009. A horizontal bar above a histogram indicates a statistical analysis on data below. Letters indicate whether or not a significant statistical difference is present, e.g., same letters indicate no significant difference. An asterisk above a horizontal bar represents a statistical difference at the P = 0.05 (*) level.**

Figure 29. Oyster reef development on ReefBlks at Reach E, winter 2009. Reach E ReefBlks exhibited highest vertical oyster shell relief.

Figure 30. Hooked mussels attached to oysters on a ReefBlk, winter 2009.

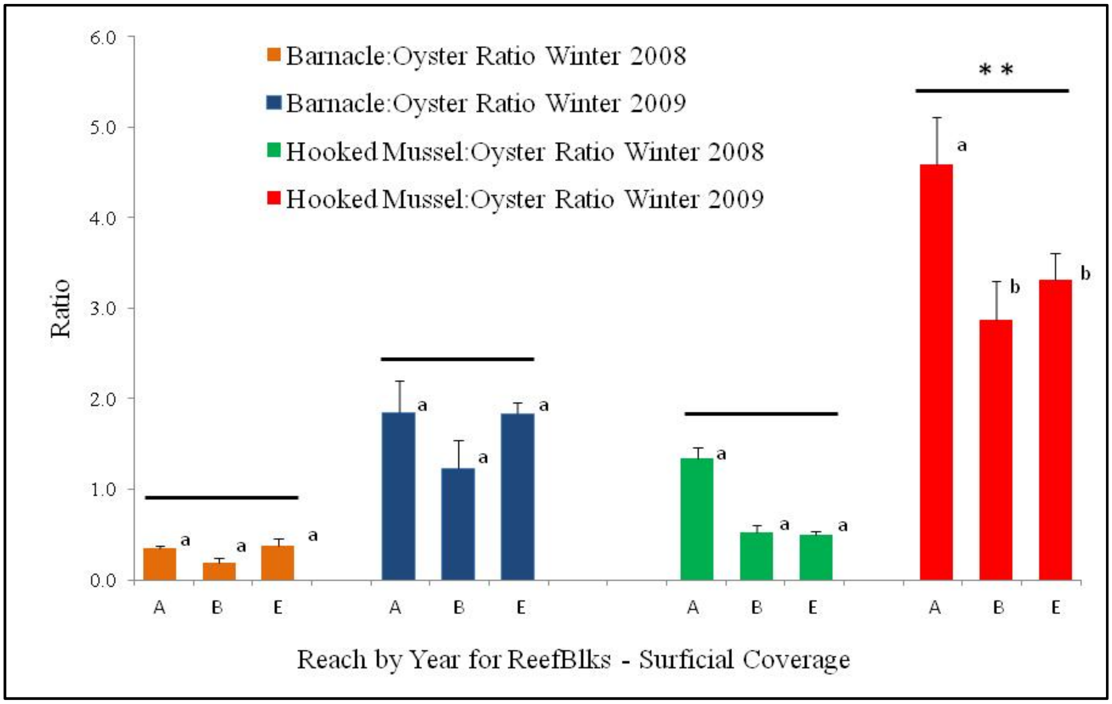


Figure 31. **Mean ratio (+1 S.E.) surficial barnacles and hooked mussels to oysters on ReefBlk located at each Reach during the winters of 2009 and 2009. A horizontal bar above a histogram indicates a statistical analysis on data below. Letters indicate whether or not a significant statistical difference is present, e.g., same letters indicate no significant difference. A double asterisks above a horizontal bar represents a statistical difference at the P = 0.01 (**) level.**

Oyster Populations Length Frequencies

An integral parameter to measure to determine if an oyster reef is becoming established is shell length frequency data. An increase in an oyster population's mean length, especially during the first few years of recruitment and survival, is an index of potential reef development (Figure 32). Multiple size class distributions also serve as an index of cohort strengths indicating multiple years of recruitment and survival, in this case two summer-fall periods (Figure 33). Surficial Oyster population means and size distributions after two years of recruitment, survival and growth compare favorable between structure types and with the natural intertidal oyster population used as a reference.

There is also a need to document how oysters are surviving and growing within the structures as compared to the surficial population. Internal oyster populations have the potential advantage of refuge from predators, but also the disadvantages of greater competition for interstitial space and water currents to bring food and flush waste. Gabion Mats exhibited a smaller sized median class of oyster when compared to the surficial populations for both mid-intertidal (Figure 34) and low-intertidal (Figure 35) areas.

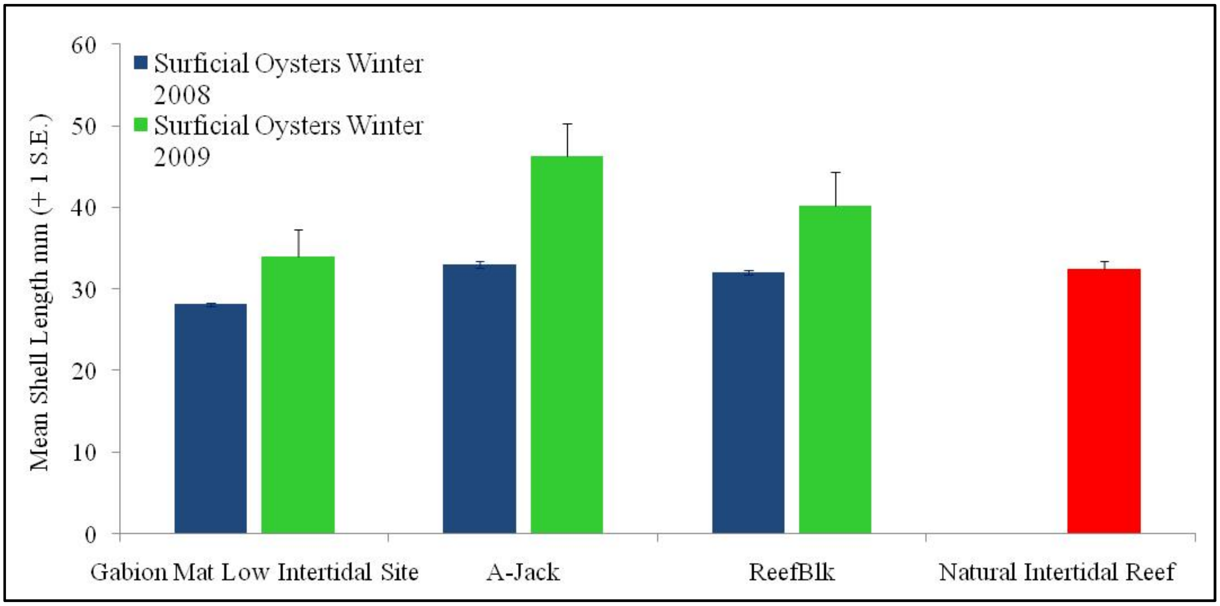


Figure 32. **Mean length (+1 S.E.) of the surficial populations of oysters on structures and natural intertidal reef after two spring-fall recruitment periods.**

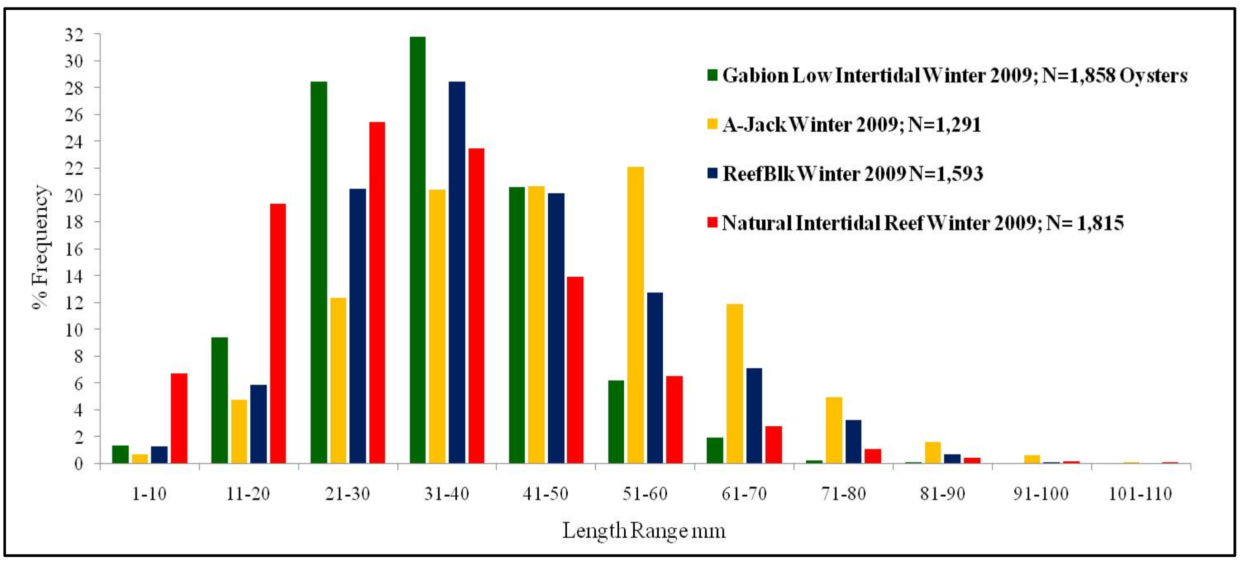


Figure 33. **Length frequencies of surficial oyster populations on structures and natural intertidal reef after two spring-fall recruitment periods.**

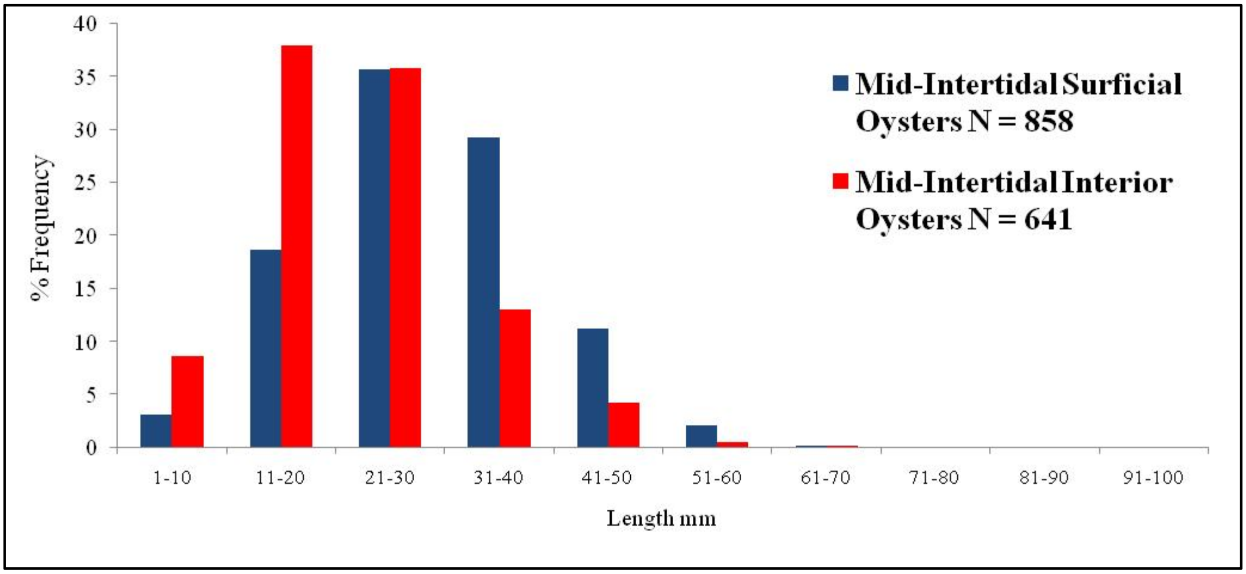


Figure 34. **Length frequencies of surficial-to-interior oyster populations on mid-intertidal Gabion Mat structures after two spring-fall recruitment periods.**

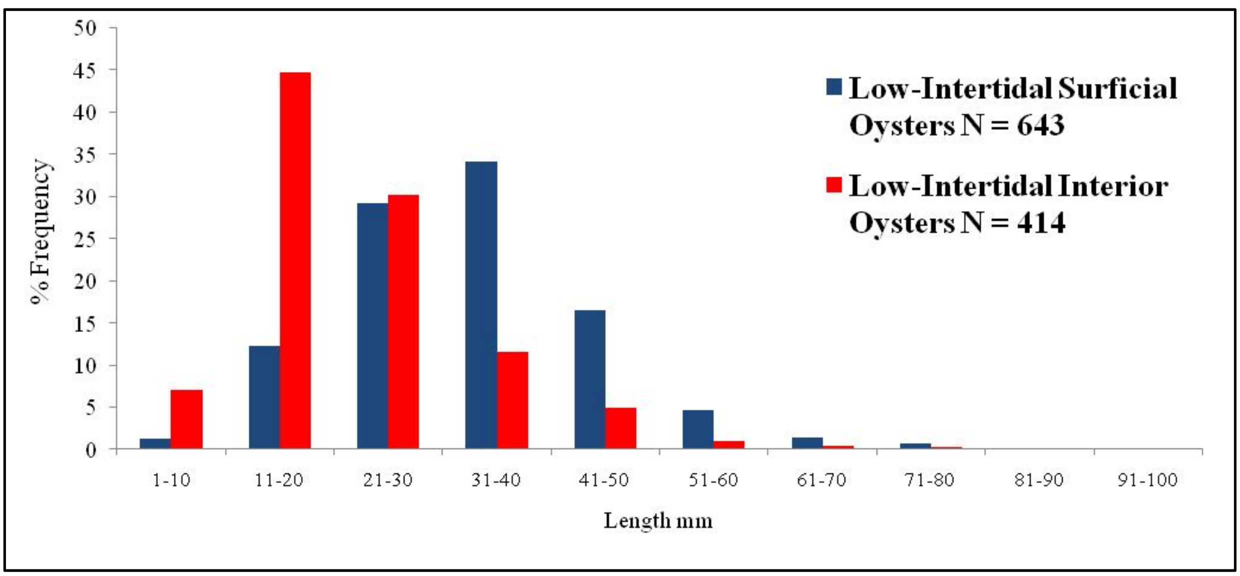


Figure 35. **Length frequencies of surficial-to-interior oyster populations on low-intertidal Gabion Mat structures after two spring-fall recruitment periods.**

Interior oyster populations for A-Jacks also exhibited a slightly smaller sized median class of oyster when compared to the surficial populations (Figure 36), but less difference than for Gabion Mats. This difference in median class size between A-Jacks and Gabion Mats, including a larger oyster class size distribution is an artifact of having to combine surficial with interior populations since it was impossible to separate the two when scraping the arms. However, one can not overlook the possibility that the difference between Gabion Mats and A-Jacks is due to interior oysters having greater access to water currents. The potential greater access to water currents is because the only significant interstitial space is self-generated by oysters as they grow on the flat concrete arm surfaces.

Internal ReefBlk oyster populations also exhibited a smaller median class size than the surficial populations (Figure 37). This too is due to the artifact of having to combine surficial with interior populations in cores.

Oyster Density

Fauna density per square meter was calculated based on density values, i.e. multiplier factors (Appendix D, Figures D-1 to D-8), developed from the core samples taken on the Gabion Mats, A-Jacks and ReefBlks. The Gabion Mats' mid and low-intertidal oyster densities were not significantly different (Paired t-test, P = 0.05) and were therefore combined to obtain a mean for comparison to A-Jacks and ReefBlks. After two-years post construction, oyster densities for the ReefBlks and Gabion Mats have exceeded densities found at the natural intertidal reef site, while A-Jacks are near equal (Figure 38). However, this should not be interpreted that true reef structure has yet adequately developed on the structures.

Besides oysters, densities of barnacles and hooked mussels were also highest on the ReefBlks (Figure 38). However, on a Reach by Reach basis, Gabion Mats and ReefBlks exhibited significantly higher densities at Reach E than the other two Reaches (Table 1 and Appendix D, Table D-1). Oyster densities for A-Jacks were not significantly different between Reaches. A-Jacks' concrete ph is not known and this may have inhibited some oyster spat setting until the concrete was sufficiently aged.

Since each of the three structure types has a unique shape, to further facilitate quantification of how oysters are establishing themselves on the stuctures, an estimate of number of oysters per linear meter was calculated (Figure 39). The number of oysters per linear meter is exceptionally high for Gabion Mats and ReefBlks when compared to A-Jacks. This high difference is due to the Gabion Mats placed perpendicular to the shore and extended out for 6 m (20 ft), and to triangular-shaped ReefBlks having three sides represented within a linear meter. The reduced number of oysters per linear meter per A-Jacks, when compared to the number per square meter, is due to the two-tiered units (Figure 21) having a perpendicular-to-the-shoreline thickness of only 0.7 m (2.3 ft).

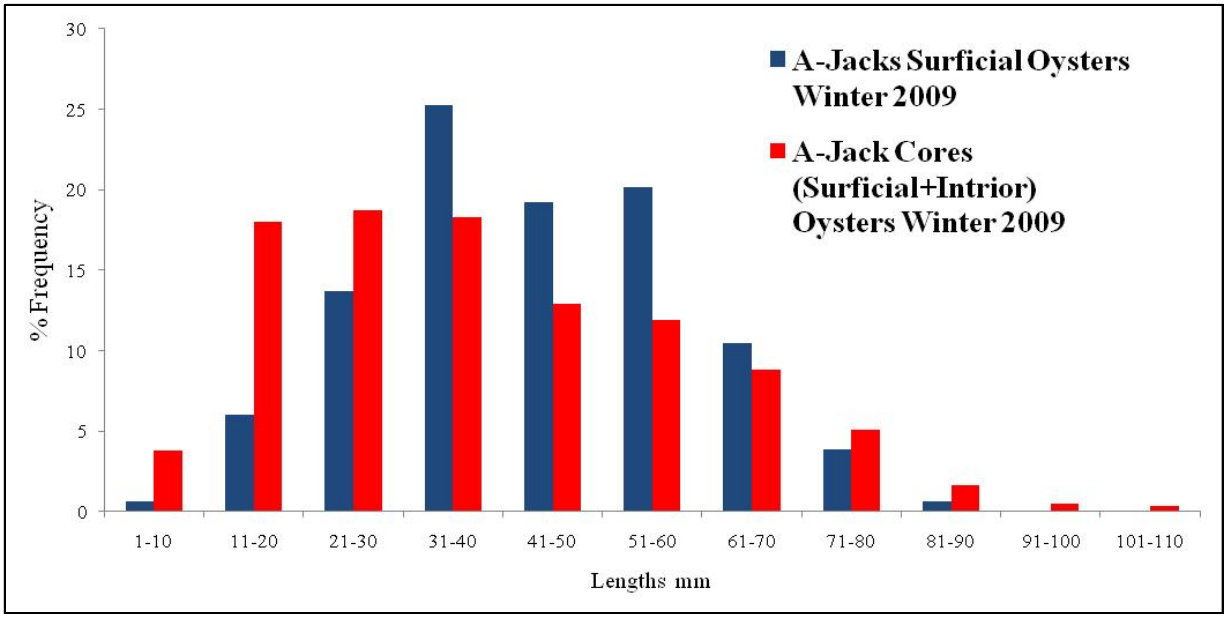


Figure 36. **Length frequencies of surficial-to-interior oyster populations on A-Jack structures after two spring-fall recruitment periods. Note: A-Jack cores, because scraped from concrete, by default included the surficial lengths as well.**

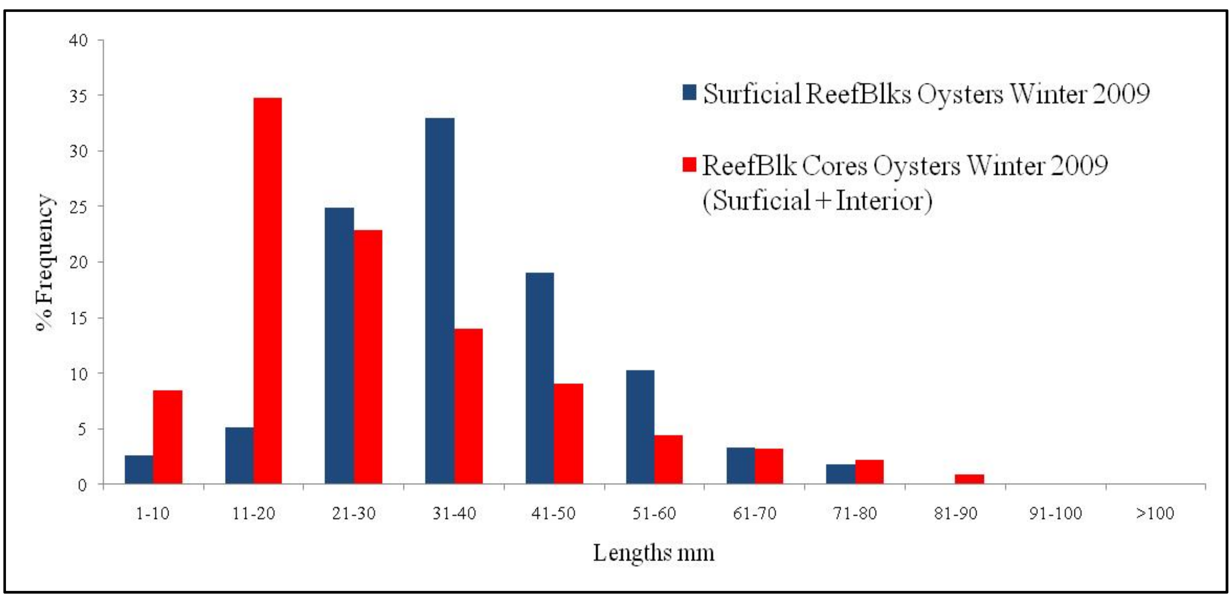


Figure 37. **Length frequencies of surficial-to-interior oyster populations on ReefBlk structures after two spring-fall recruitment periods. Note: ReefBlk cores, because surficial oysters cemented to interior shells, by default included the surficial lengths as well.**

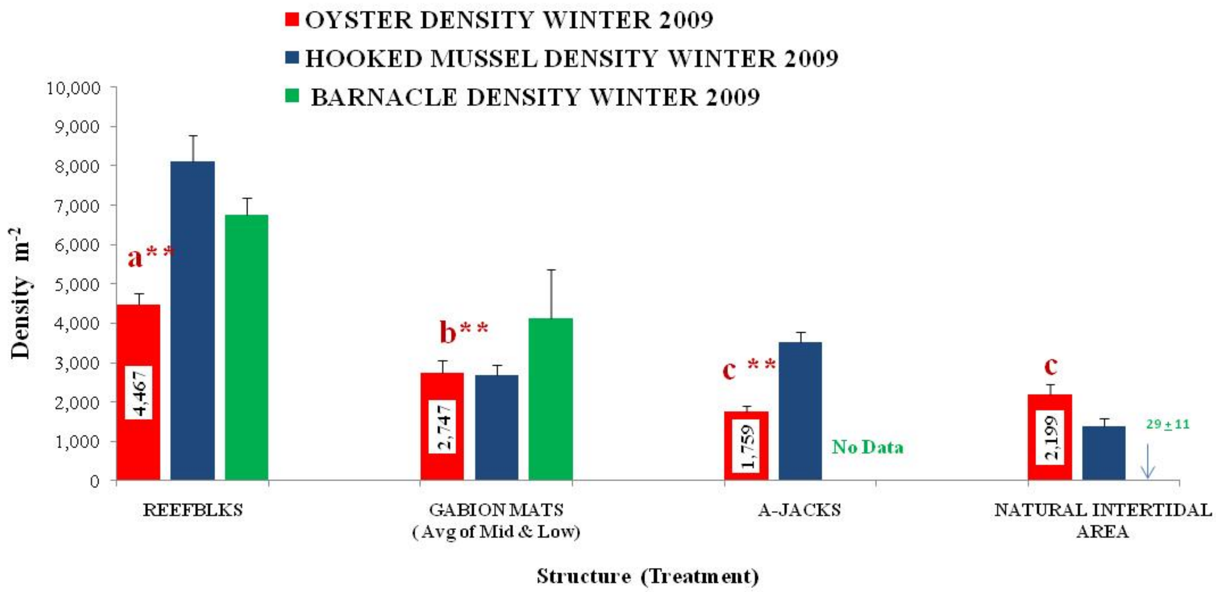


Figure 38. Density (±1 S.E.) on treatments for oysters, hooked mussels and barnacles in winter 2009, two-years post construction. Different letters by each bar represents highly significant difference (P = .01) for oyster densities. Same letters represents no significant difference for oyster density. Low and mid intertidal densities are averaged for Gabion Mats since no significantly difference was observed (Paired t-Test, P = .05).

Table 1. Comparison of Oyster and Mussel Densities (Surficial + Interior) by Reach for each Structure. Yes = Sig. Diff. at P = .05; No = No Sig. Diff. *

Oysters m^{-2}			Hooked Mussels m^{-2}		
ReefBlks	Reach-B	Reach-E	**ReefBlks**	Reach-B	Reach-E
Reach-A	**NO**	**YES**	Reach-A	**YES**	**YES**
Reach-B	---	**YES**	Reach-B	---	**NO**
A-Jacks			**A-Jacks**		
Reach-A	**NO**	**NO**	Reach-A	**NO**	**NO**
Reach-B	---	**NO**	Reach-B	---	**NO**
Gabion Mats			**Gabion Mats**		
Reach-A	**NO**	**YES**	Reach-A	**NO**	**NO**
Reach-B	---	**YES**	Reach-B	---	**NO**

* All Pairwise Multiple Comparison Procedures using Student-Newman-Keuls Statistical Method. See Appendix D.

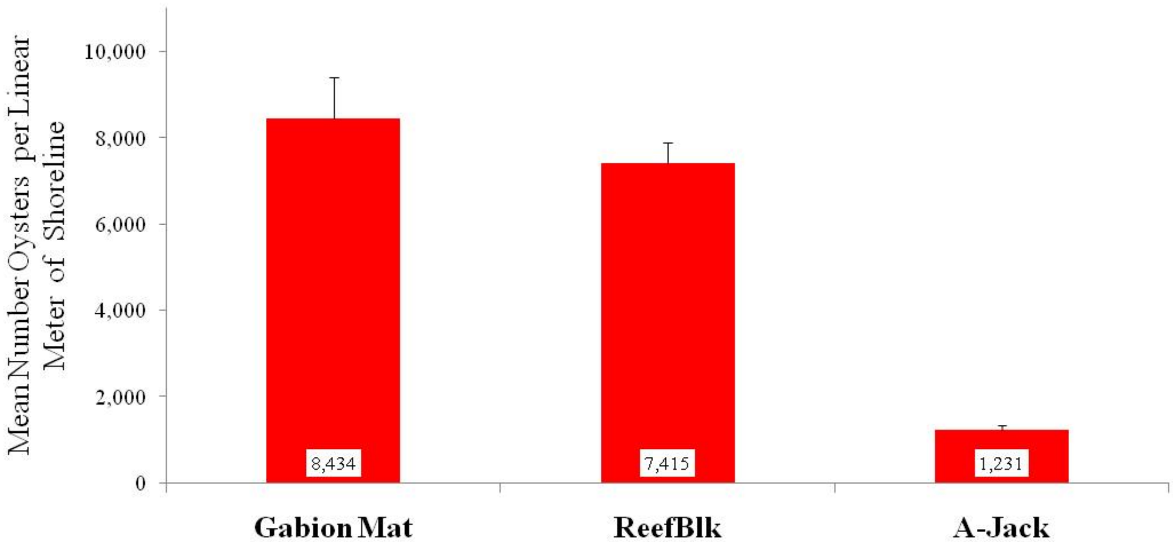


Figure 39. **Number (+1 S.E.) of oysters per linear meter of shoreline for each treatment type in winter 2009.** ***Note: Gabion Mat data represents only area from mid-intertidal to lower end of mat where reef-building potential exist, approximately half of mat length, 3.07 meters.***

V. Conclusions

a. Project Effectiveness

The following initial hypotheses were developed to monitor project TE-45: (*the term "treatment" is synonymous with structure type, namely Gabion Mats, A-Jacks and ReefBlks)*

- H_1: Mean shoreline erosion rate at treatment *x* at time *I* will be significantly lower than the mean shoreline erosion rate at the reference shoreline at time *I*.

  Preliminary results after one year indicate that erosion rates of shorelines appear to have been reduced significantly behind all three treatment (structure) types although much variability exists. More years of observation are needed.

- H_2: There is significant difference between Reaches (shoreline sites) in water quality and oyster spat availability.

  Results indicate that there are no significant differences in water quality and spat availability between Reaches and linear distance across structure types. The variability that exists in salinity, and other physicochemical parameters, are within acceptable levels for the potential establishment of oyster reef.

- H_3: Tidal height and percentage of time a structure (treatment) is aerially exposed will influence oyster recruitment density and shell growth and the ability to potentially establish an oyster reef.

  Preliminary results after two years indicate that subtidal oyster recruitment is generally greater than intertidal oyster recruitment. The top of the Gabion Mat, about half its length, was the most annually exposed during low-tide events and exhibited no capability of reef development although many small oysters were present. However, the mid-to-lower intertidal areas on a Gabion appear to be developing reef very well. The ReefBlks annually exhibited the least total exposure time at low tide and exhibited very good oyster recruitment from top to bottom on all sides. The A-Jack units also exhibited good oyster recruitment from top to bottom and were also aerially exposed much less than the Gabions.

- H_4: There is a significant difference between erosion-control structures (treatments) in ability to establish an oyster reef.

  Preliminary results after two years indicate that oysters have established themselves well on all three structure types. There is the potential for oyster reef development on all structures. However, after two years ReefBlks and Gabion Mats exhibit much denser oyster numbers than the A-Jacks. The A-Jacks' concrete ph is not known and this may have inhibited some oyster spat setting until the concrete has sufficiently aged.

b. Recommended Improvements

Structurally, there was no apparent damage to the shore protection features other than minor damage to the northern-most warning sign at Reach B and the northwest warning sign at Reach E. Although slightly damaged, the signs remain visible and pose no immediate hazard. OCPR plans to utilize in-house resources to repair the signs during the next scheduled site visit. There are no other recommended improvements at this time. Scientifically, the remaining five years of monitoring life for this project will develop a set of data that should adequately address the four hypotheses stated above.

c. Lessons Learned

The shoreline erosion rate behind each treatment type has been significantly reduced. Erosion reduction potential over the next five years should give a much greater resolution as to which, if any, treatment is significantly better than another. It now becomes essential to determine if oyster reef can develop is such a manner as to take over the role of erosion control as the treatments deteriorate. One significant need that has developed is the influence and impact hooked mussels may have on reef development. Another significant need is to establish environmental criteria needed to sustain an oyster reef as it grows in dimension and faunal complexity. For example, some environmental criteria questions to address over the next five years include: (1) How oysters in the central area of a ReefBlk triangle influenced by the potential for reduced water current, and thus food and water quality? (2) What is the nature of the benthic-pelagic coupling between the developing oyster reef and its overlying waters in terms of nutrients, water currents and dissolved oxygen? (3) How quickly will oysters grow and develop into a mature reef? (4) How does one define a mature reef for erosion control? (is it population and community structure?), (5) How does a high energy wave environment influence reef development? And, (6) As reefs develop and the structures deteriorate will there remain enough “reef cohesion” to maintain an effective erosion barrier? These and many other questions still remain.

Estuaries are highly variable and therefore require an adequate sampling regime that addresses the scale of the research question that is asked (Livingston 1987). Coupling an estuary’s inherent nature for heterogeneity with the inherent clustering nature of oysters generates a significant challenge to adequately develop a sampling regime. The sampling regime must accurately portray how each structure type is performing in reef development. Therefore, the methods of assessment must be multi-layered, where each layer of sampling strategy adds further insight for final interpretation. The sampling elements and protocols developed to date will initially satisfy that need, but must remain flexible enough to change, as long as analytical integrity is retained.

Elevation Summary

- All shoreline Reaches recorded small volume losses during the six month interval between the pre-construction (Aug 2007) and as-built (Feb 2008) surveys.

Shoreline Change Summary

- The pre-construction TE-45 shorelines transgressed at high and variable rates.
- All the structures and all the Reaches experienced substantial reductions in shoreline erosion rates during the first post-construction assessment.
- Reach A recorded the highest shoreline erosion rates for both the pre- and post-construction periods followed by Reach B and Reach E.
- The Gabion Mat treatment documented the lowest post-construction erosion rate followed by the ReefBlk and then A-Jack treatments, although much variability in the data does not yet show a clear favorite.
- Additional temporal data is needed to determine if the low erosion rates behind these structures are sustainable.

Hydrology Summary

- Seasonal tidal amplitudes were within normal limits observed in coastal Louisiana.
- Based on daily tidal amplitudes during the study period, the on-shore Gabion Mats exhibit the greatest percentage of time totally exposed at low tide, followed by the on-shore/off-shore A-Jacks that were placed at the marsh edge, and then the off-shore ReefBlks with the greatest amount time submerged.
- All three structure types at Reach E exhibited more time submerged than at Reach A and Reach B, which were comparable to one another. This suggests that daily tidal amplitudes at E were greater than at A and B, or that the structures at E were placed at a lower elevation when referenced to mean high tide water depth.
- Quantitative levels of salinity, water temperature, chlorophyll-a, total suspended solids, dissolved oxygen and turbidity were at levels that will support the life stages of the eastern oyster, and thus the potential success for reef building.

Oyster Spat Availability Summary

- During the spring through fall periods of 2008 and 2009 oyster spawning, and subsequently oyster spat recruitment to shells and tiles, exhibited a typical spring-fall bimodal peak which is characteristic of Louisiana and the northern Gulf of Mexico in general.
- Variability in oyster recruitment density by tidal height, year, month and Reach was evident, but is intrinsic in this type of data and did not vary more than expected.
- Oyster spat recruitment available to the structures Reach-wide was favorable and considered to be more than sufficient for both years, 2008 and 209, to potentially begin the development of reef onto the structures.

Oyster Recruitment to Structures Summary

- All three Reaches, A, B and E, have developed significant oyster population densities.
- ReefBlks and Gabion Mats are exhibiting very good oyster recruitment with A-Jacks lagging far behind.
- The apparently higher wave and current energy environment at Reach E may be influencing oyster population densities; shell settlement is leaving air gaps within some of the plastic mesh bags.
- Surficial barnacle and hooked mussels populations increased significantly from 2008 to 2009.
- The large increase in hooked mussel populations may pose a threat to oyster reef development because of the veneer-type covering over oysters that appears to be occurring.

Oyster Populations Length Frequencies Summary

- All three structure (treatment) types exhibit a good oyster population size distribution indicating good recruitment, survival and growth necessary to establish a reef.
- Internal oysters within the structures exhibited a smaller size than surficial oysters. This is probably due to greater competition for interstitial space and reduced water flow bring less food and a greater challenge to flush waste.

Oyster Density Summary

- The winter 2009 densities of fauna on the structures, i.e., treatments, are as follows: (mean density ± 1 S.E.)

Treatment	Oysters/m^2	Hooked Mussels/m^2	Barnacles/m^2
Gabion Mat Mid-Intertidal	3,300 ± 408	2,558 ± 567	4,173 ± 1,231
Gabion Mat Low-Intertidal	2,194± 295	2,801 ± 426	2,109 ± 278
A-Jack	1,759 ± 148	3,517 ± 259	No data
ReefBlk	4,467 ± 287	8,108 ± 655	6,751 ± 438
Natural Intertidal Reef	2,199 ± 244	1,386 ± 196	29 ± 11

- The winter 2009 number of oysters per linear meter of shore line is as follows: (mean density ± 1 S.E.)

Treatment	Number of Oysters per Linear Meter of Marsh Shoreline
Gabion Mat	8,434 ± 973
A-Jack	1,231 ± 103
ReefBlk	7,415 ± 476

VI. References

Bahr, L. M. and W. P. Lanier. 1981. The ecology of intertidal oyster reefs of the SouthAtlantic coast: a community profile. U.S. Fish and Wildlife Service, Office of Biological Services, Washington D.C. FWS/OBS-81/15, 105pp.

Barras, J.A., P.E. Bourgeois, and L.R. Handley. 1994. Land loss in coastal Louisiana 156-90. National Biological Survey, National Wetlands Research Center Open File Report 94-01. 4 pp. 10 color plates.

Bartol, I.K., R. Mann and M. Luckenbach. 1999. Growth and mortality of oysters (Crassostrea virginica) on constructed intertidal reefs: effects of tidal height and substrate level. Journal of Experimental Marine Biology and Ecology 237:157-184.

Butler, P.A. 1954. Summary of our knowledge of the oyster in the Gulf of Mexico. U.S. Fish and Wildlife Service Bulletin No. 89.

Cake, E. W., Jr. 1983. Habitat suitability index models: Gulf of Mexico American oyster. U.S. Department of the Interior Fish and Wildlife Service, FWS/OBS-82/10.57, 37pp.

Coen, L.D., M.W. Luckenback, D.L. Breitburg. 1999. The role of oyster reefs as essential fish habitat: a review of current knowledge and some new perspectives. American Fisheries Society. Symposium 22:438-454.

Day, J.W., W. G. Smith, P.R. Wagner and W.C. Stowe. 1973. Community structure and carbon budget of a salt marsh and shallow bay estuarine system in Louisiana. Center for Wetland Resources, LSU, Publication No. LSU-SG-72-04, 80pp.

Dekshenieks, M. M., E. E. Hofmann and E. N. Powell. 2000. Quantifying the effects of environmental changes on an oyster population: A model study. Estuaries 23(5):593-610.

Dunbar, J.B., L.D. Britsch, and E.B. Kemp III. 1992. Land loss rates report 3: Louisiana Coastal Plain. Technical Report GL-90-2. U.S. Army Engineer District, New Orleans. New Orleans, Louisiana

Folse, T. M., J. L. West, M. K. Hymel, J. P. Troutman, L. A. Sharp, D. Weifenbach, T. McGinnis, and L. B. Rodrigue. 2008. A Standard Operating Procedures Manual for the Coast-wide Reference Monitoring System-*Wetlands*: Methods for Site Establishment, Data Collection, and Quality Assurance/Quality Control. Louisiana Coastal Protection and Restoration Authority, Office of Coastal Protection and Restoration. Baton Rouge, LA. 191 pp.

Gagliano, M.H., S.M. Gagliano and P.J. Moses. 1997. Bay Rambo Oyster Reef: An artificial oyster reef in the deltaic estuarine area of Louisiana. Coastal Environments, Inc. Baton Rouge, LA., 30pp.

Galtsoff, P.S. 1964. The American oyster *Crassostrea virginica* Gmelin. U.S. Fish and Wildlife Service Bulletin. No. 64.

Gauthier, J.D and T.M. Soniat. 1989. Changes in the gonadal state of Louisiana oysters during their autumn spawning season. Journal of Shellfish Research 8(1):83-86.

Kennedy, V. S., R. I. E. Newell and A. F. Eble (eds.), 1996. The eastern oyster *Crassostrea virginica*. University of Maryland Press 1,089 pp.

Lenihan, H.S. 1999. Physical-biological coupling on oyster reefs: how habitat structure influences individual performance. Ecological Monographs 69:251-275.

Livingston, R. J. 1987. Field sampling in estuaries: the relationship of scale to variability. Estuaries 10(3): 194-207.

May, J.R. and L.D. Britsch. 1987. Geological investigation of the Mississippi River Deltaic Plain: Land Loss and Land Accretion. Techical Report GL-87-13. U.S. Army Engineer District, New Orleans. New Orleans, Louisiana.

Melancon, E. J, T. M. Soniat, V. Cheramie, R. J. Dugas, J. Barras and M. LaGarde. 1998. Oyster resource zones of the Barataria and Terrebonne estuaries of Louisiana. Journal of Shellfish Research 17(4):1143-1148.

Meyer,D.L., E.C. Townsend, G.W. Thayer. 1997. Stabilization and erosion control value of oyster cultch for intertidal marsh. Restoration Ecology 5: 93-99.

Menzel, R.W. 1951. Early sexual development and growth of the American oyster in Louisiana waters. Science. 113:719-720.

Office of Coastal Restoration and Protection (OCPR). 2010. Operation, Maintenance, and Rehabilitation Plan: Terrebonne Bay Shore Protection and Demonstration (TE-45) project. Baton Rouge, LA 6 pp.

Piazza, B. P., P. D. Banks, M. K. LaPeyre. 2005. The potential for Created Oyster Shell Reefs as a Sustainable Shoreline Protection Strategy in Louisiana. Restoration Ecology 13: 499-506.

Powell, E. N., E. E. Hofmann, J. M. Klinck and S. M. Ray. 1994. Modeling oyster populations IV: Rates of mortality, population crashes and management. Fisheries Bulletin 92:347-373.

Roegner, G.C. and R. Mann. 1995. Early recuitment and growth of the American oysters with respect to tidal Zonation and season. Marine Ecology Progress Series. 117:91-101.

Shumway, S. E. 1996. Natural environmental factors. *In* V. S. Kennedy, R. I. E. Newell and A. F. Eble (eds.), The eastern oyster *Crassostrea virginica*, p.467-513.

Steyer, G. D., R. C. Raynie, D. L. Stellar, D. Fuller, and E. Swenson. 1995. Quality Management Plan for Coastal Wetlands Planning, Protection, and Restoration Act Monitoring Program. Open-file series no. 95-01 (Revised June 2000). Baton Rouge: Louisiana Department of Natural Resources, Coastal Restoration Division. 97 pp.

Stone, G. W., J. M. Grymes III, J. R. Dingler, and D. A. Pepper. 1997. Overview and Significance of Hurricanes on the Louisiana Coast, U.S.A. Journal of Coastal Research. 13: 656-669.

Thieler, E. R., and D. Martin, and A. Ergul 2003. The Digital Shoreline Analysis System, Version 2.0: Shoreline Change Measurement Software Extension for ArcView: USGS U.S. Geological Survey Open-File Report 03-076.

Watzke, D. A. 2004. Short-term Evolution of a Marsh Island System and the Importance of Cold Front Forcing, Terrebonne Bay, Louisiana. MS Thesis, Louisiana State University 42 pp.

Zimmerman, R., Minello, T.J., Baumer T. and M. Castiglione. 1989. Oyster reef as habitat for estuarine macrofauna. NOAA Technical Memorandum NMFS-SEFC-249.

Addition Information

Additional information on methods, results and discussion about the first two years of this project can be found in a Master of Science thesis prepared by Mr. Mark Linson, graduate student at Nicholls State University. To obtain a copy of this document contact Dr. Earl Melancon, Jr. of Nicholls State University at earl.melancon@nicholls.edu.

Appendix A

TE-45 Structure Designs

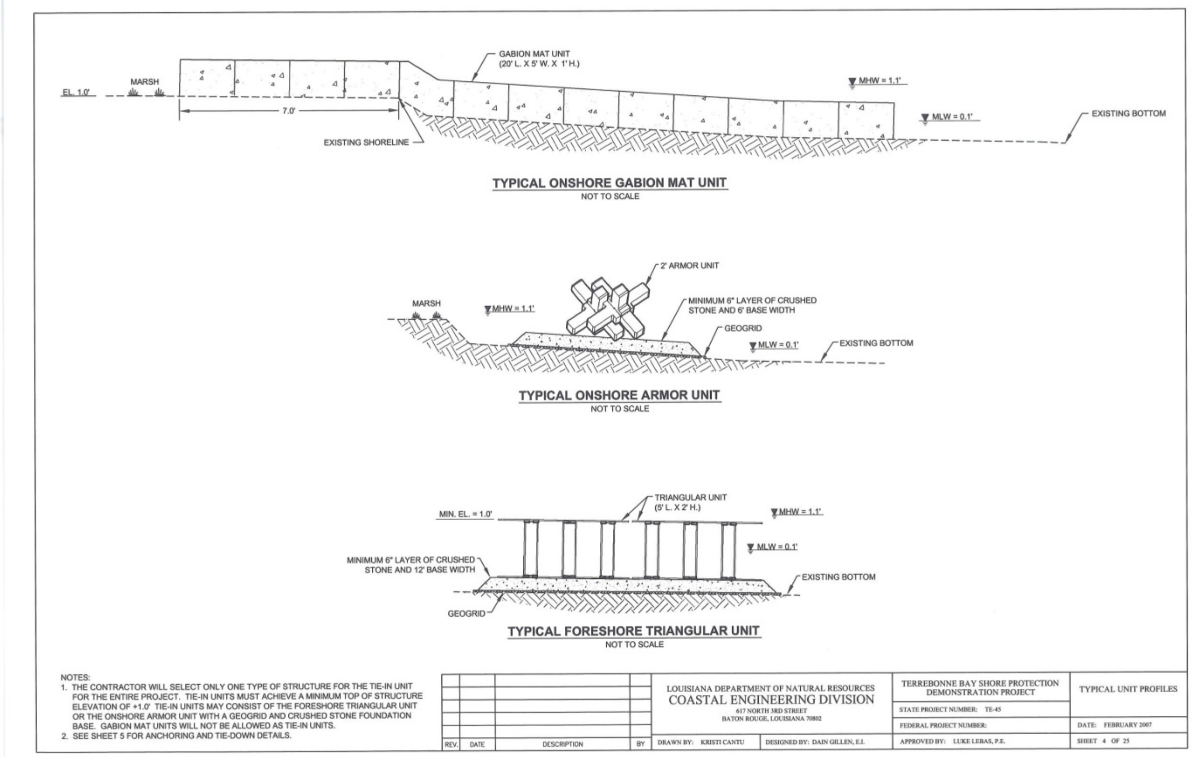


Figure A-1. **Typical cross sections showing the Terrebonne Bay Shore Protection Demonstration (TE-45) project's shoreline protection structures.**

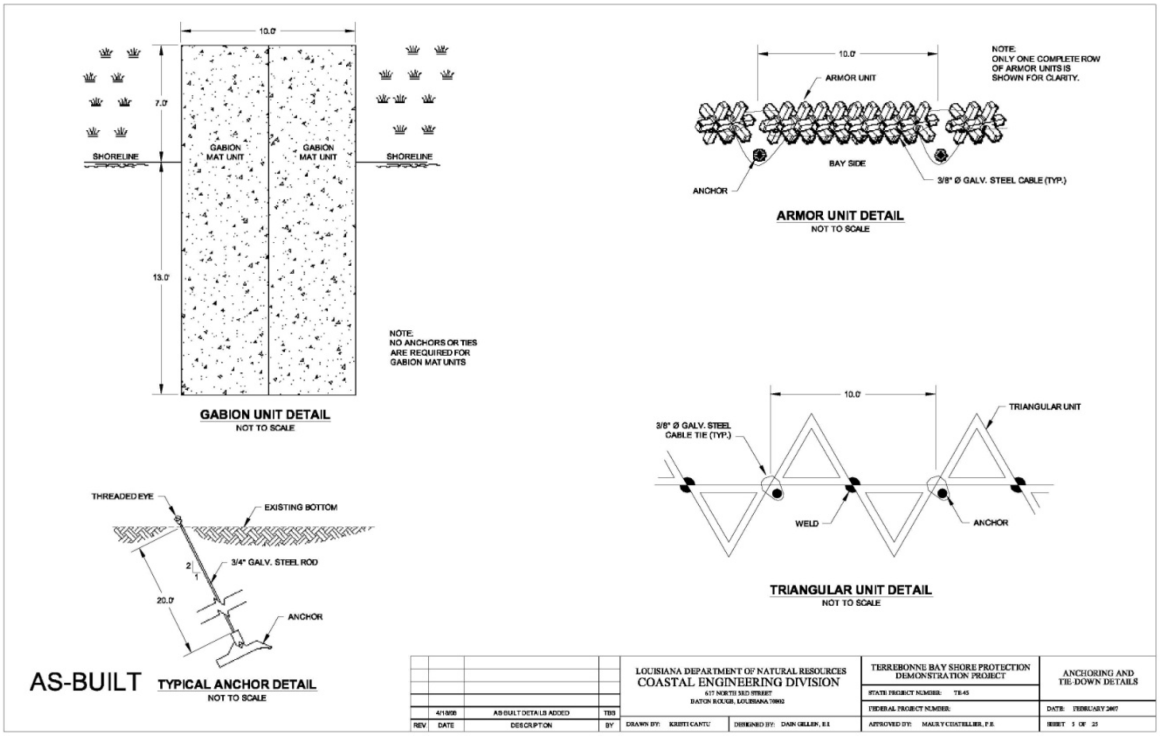


Figure A-2. **Aerial view depicting the typical layout and anchoring details for the Terrebonne Bay Shore Protection Demonstration (TE-45) project's Gabion Mat, A-Jack, and ReefBlk structures.**

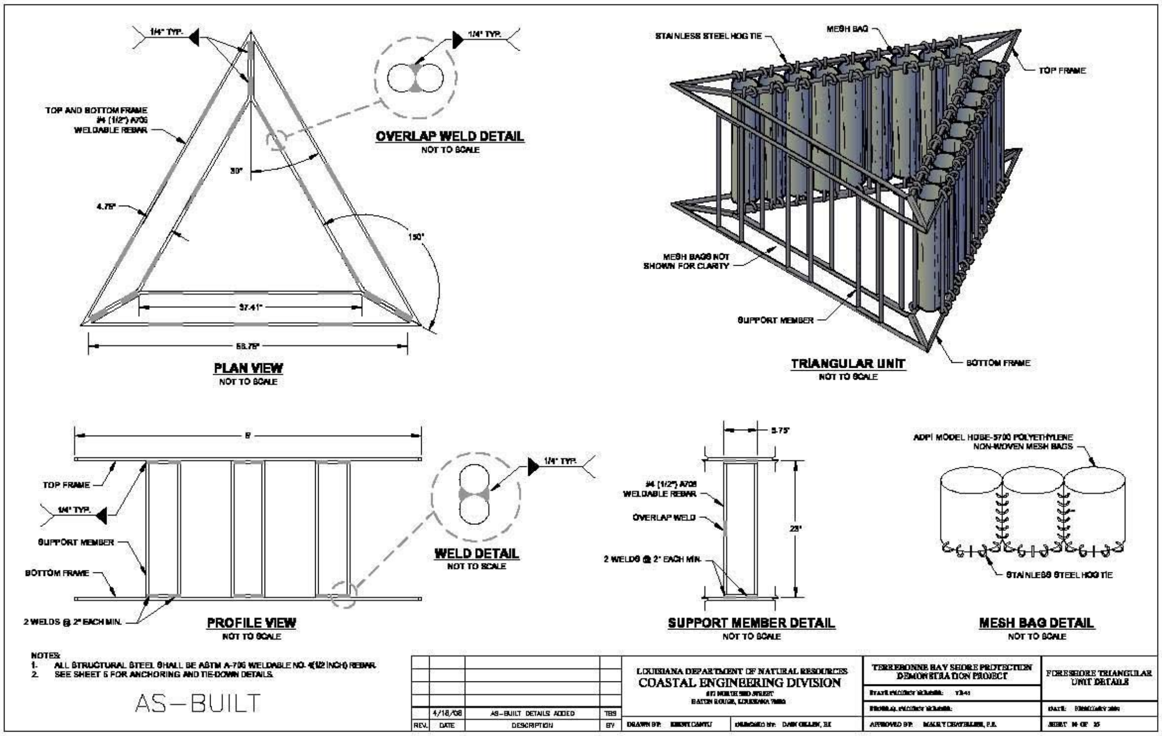


Figure A-3. **Design drawings showing the Terrebonne Bay Shore Protection Demonstration (TE-45) project's ReefBlk structure.**

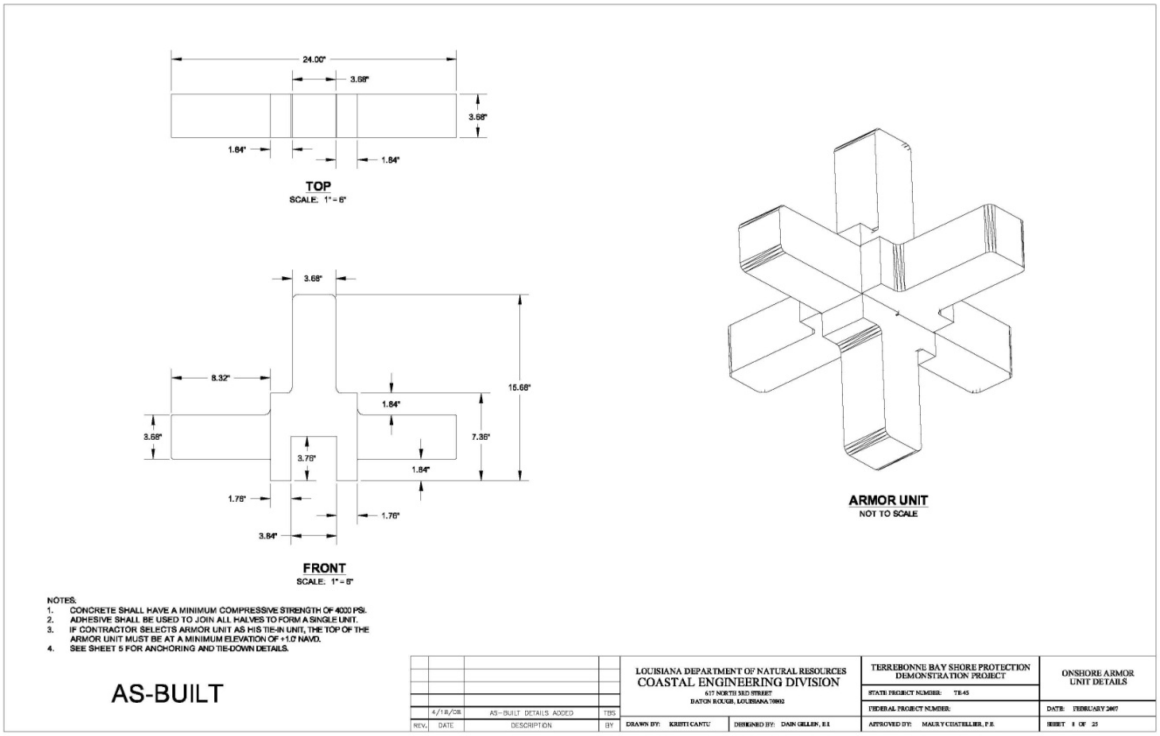


Figure A-4. **Design drawings showing the Terrebonne Bay Shore Protection Demonstration (TE-45) project's A-Jack structure.**

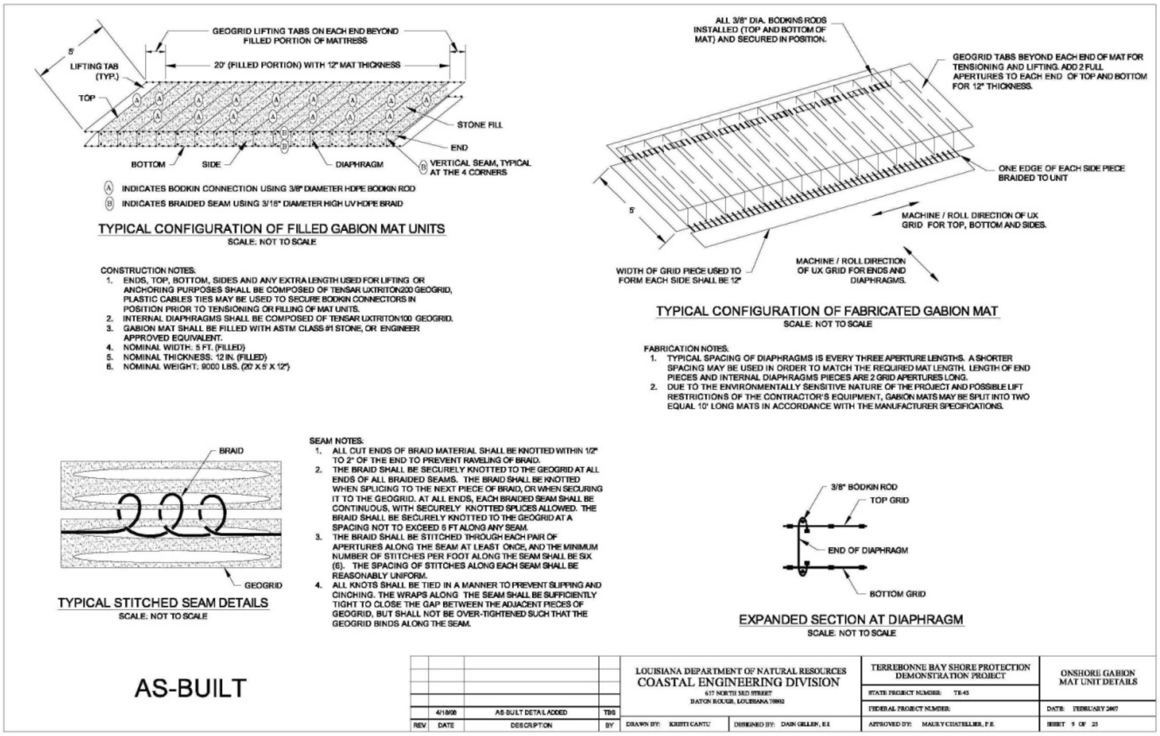


Figure A-5. **Design drawings showing the Terrebonne Bay Shore Protection Demonstration (TE-45) project's Gabion Mat structure.**

Appendix B

TE-45 Inspection Photos

Photo B-1. ***Reach A – Gabion Mats, December 2009.***

Photo B-2. ***Reach A – Gabion Mats, December 2009.***

Photo B-3. ***Reach A – Gabion Mats, December 2009.***

Photo B-4. ***Reach A – Gabion Mats, December 2009.***

Photo B-5. ***Reach A – Gabion Mats, December 2009.***

Photo B-6. ***Reach A – Concrete Armor Units (A-Jacks), December 2009.***

Photo B-7. ***Reach A – Concrete Armor Units (A-Jacks), December 2009.***

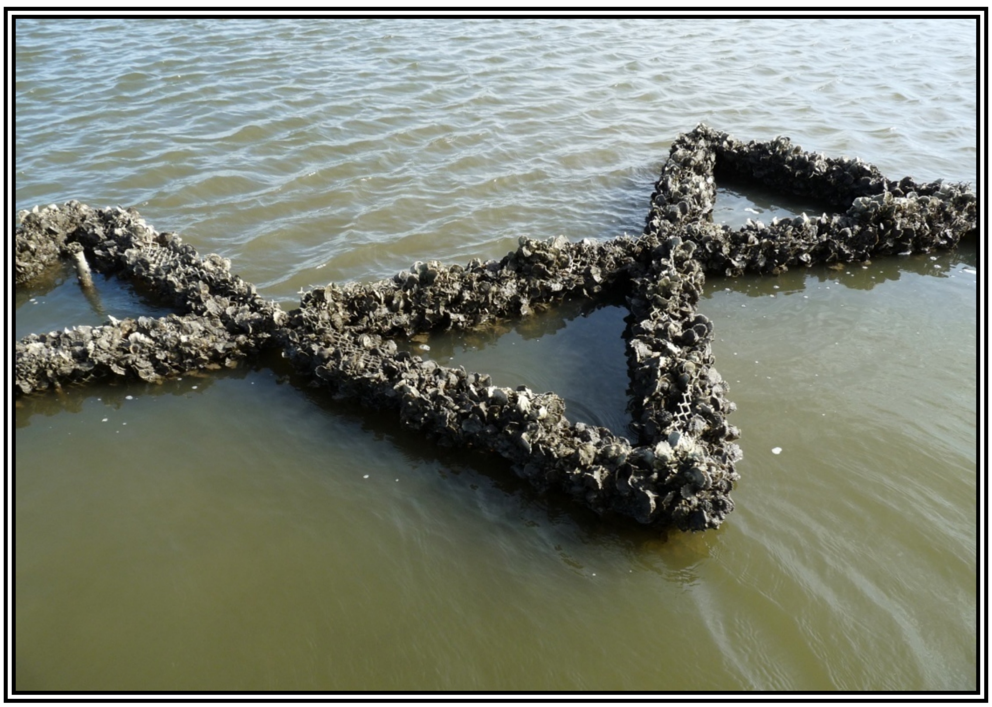


Photo B-8. ***Reach A – Steel Rebar Triangular Units (ReefBlks), December 2009.***

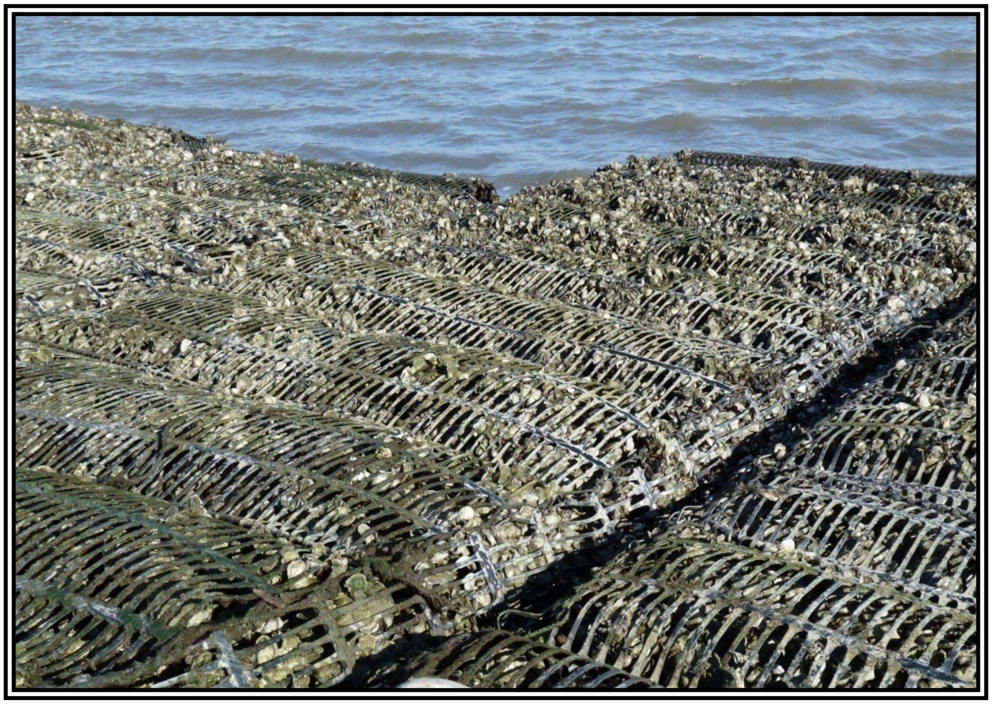


Photo B-9. ***Reach B – Gabion Mats, December 2009.***

Photo B-10. ***Reach B – Gabion Mats, December 2009.***

Photo B-11. ***Reach B – Gabion Mats, December 2009.***

Photo B-12. ***Reach B – Steel Rebar Triangular Units (ReefBlks), December 2009.***

Photo B-13. ***Reach E – Concrete Armor Units (A-Jacks), December 2009.***

Photo B-14. ***Reach E – Steel Rebar Triangular Units (ReefBlks), December 2009.***

Photo B-15. ***Reach E – Steel Rebar Triangular Units (ReefBlks), December 2009.***

Photo B-16. ***Reach E – Steel Rebar Triangular Units (ReefBlks), December 2009.***

Photo B-17. ***Reach E – Steel Rebar Triangular Units (ReefBlks), December 2009.***

Photo B-18. ***Reach E – Warning Sign (south.)***

Photo B-19. ***Reach E – Warning Sign (north).***

Appendix C

TE-45 Three Year Budget and Worksheet

Terrebonne Bay Shore Protection Demonstration / TE45 / PPL10

Three-Year Operations & Maintenance Budgets 07/01/2010 - 06/30/2013

Project Manager	O & M Manager	Federal Sponsor	Prepared By
	Dearmond	*USFWS*	*Dearmond*

	2010/2011	2011/2012	2012/2013
Maintenance Inspection	$ 5,791.00	$ 5,977.00	$ 6,168.00
Structure Operation	$ -	$ -	$ -
Administration	$ -		$ -
USACE Administration	$ -	$ -	$ -
Maintenance/Rehabilitation			

10/11 Description:

	2010/2011	2011/2012	2012/2013
E&D	$ -		
Construction	$ -		
Construction Oversight	$ -		
Sub Total - Maint. And Rehab.	$ -		

11/12 Description

	2010/2011	2011/2012	2012/2013
E&D			
Construction			
Construction Oversight			
	Sub Total - Maint. And Rehab.	$ -	

12/13 Description:

	2010/2011	2011/2012	2012/2013
E&D			$ -
Construction			$ -
Construction Oversight			$ -
		Sub Total - Maint. And Rehab.	$ -

	2010/2011	2011/2012	2012/2013
Total O&M Budgets	**$ 5,791.00**	**$ 5,977.00**	**$ 6,168.00**

Total O&M Budget FY 10/11 through FY 12/13	**$ 17,936.00**
Unexpended O&M Funds	**$ 52,713.00**
Remaining O&M Budget (Projected)	**$ 34,777.00**

Note: Unexpended o&m funds = $55,243 unexpended funds from LANA Report - $2,530 o&m expenditures to date

OPERATIONS & MAINTENANCE BUDGET WORKSHEET

Project: **<u>TE-45 Terrebonne Bay Shore Protection Demonstration</u>**

FY 10/11 –

Administration (USFWS)	$ 0
O&M Inspection & Report	$ 5,791
Operation:	$ 0
Maintenance:	$ 0

Operation and Maintenance Assumptions:
Year 3 O&M Inspection and Report – from TE-45 O&M Plan, June 2010.

FY 11/12 –

Administration (USFWS)	$ 0
O&M Inspection & Report	$ 5,977
Operation:	$ 0
Maintenance:	$ 0

Operation and Maintenance Assumptions:
Year 4 O&M Inspection and Report – from TE-45 O&M Plan, June 2010.

FY 12/13 –

Administration (USFWS)	$ 0
O&M Inspection & Report	$ 6,168
Operation:	$ 0
Maintenance:	$ 0

Operation and Maintenance Assumptions:
Year 5 O&M Inspection and Report – from TE-45 O&M Plan, June 2010.

Appendix D

TE-45 Statistics

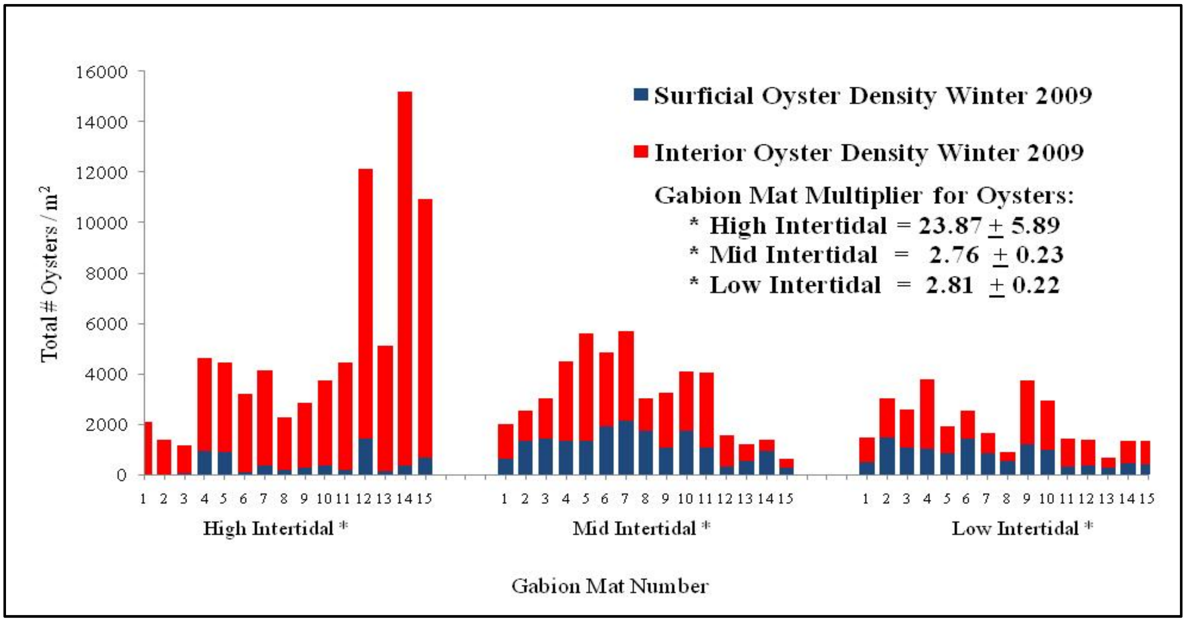


Figure D-1. **Gabion Mat multiplier factors to calculate oyster densities.**

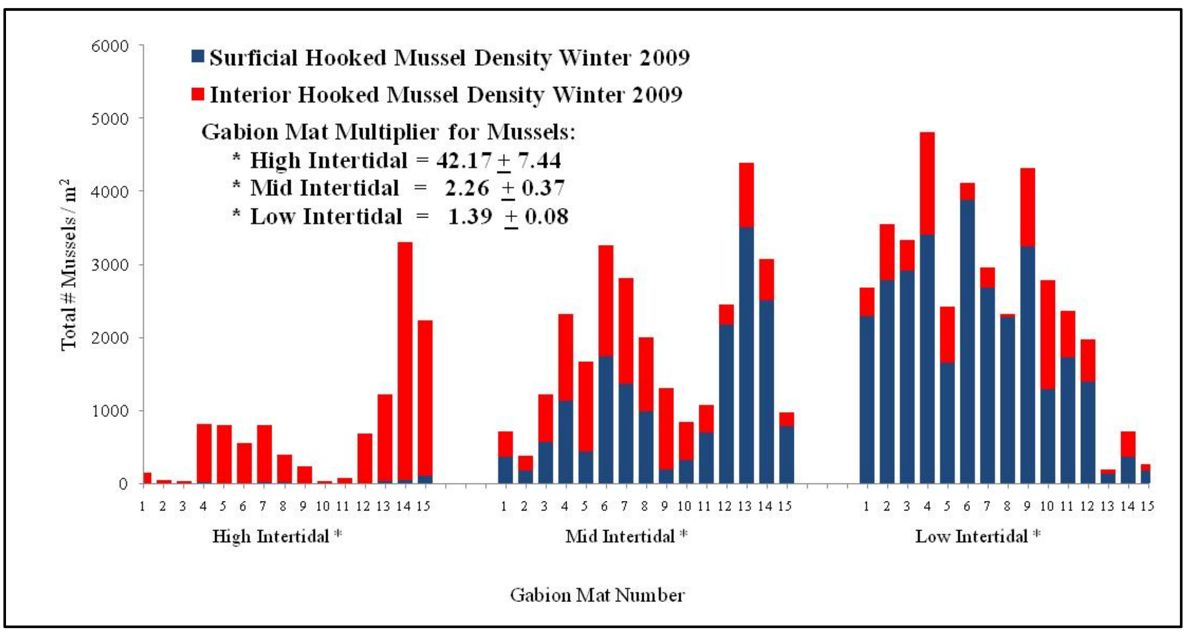


Figure D-2. **Gabion Mat multiplier factors to calculate hooked mussel densities.**

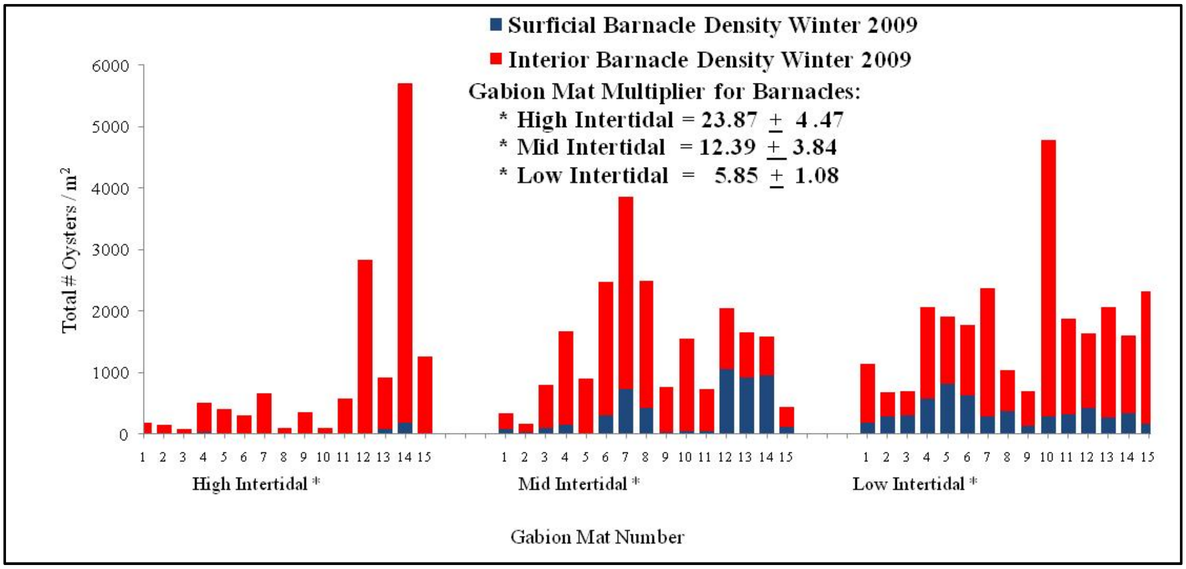


Figure D-3. **Gabion Mat multiplier factors to calculate barnacle densities.**

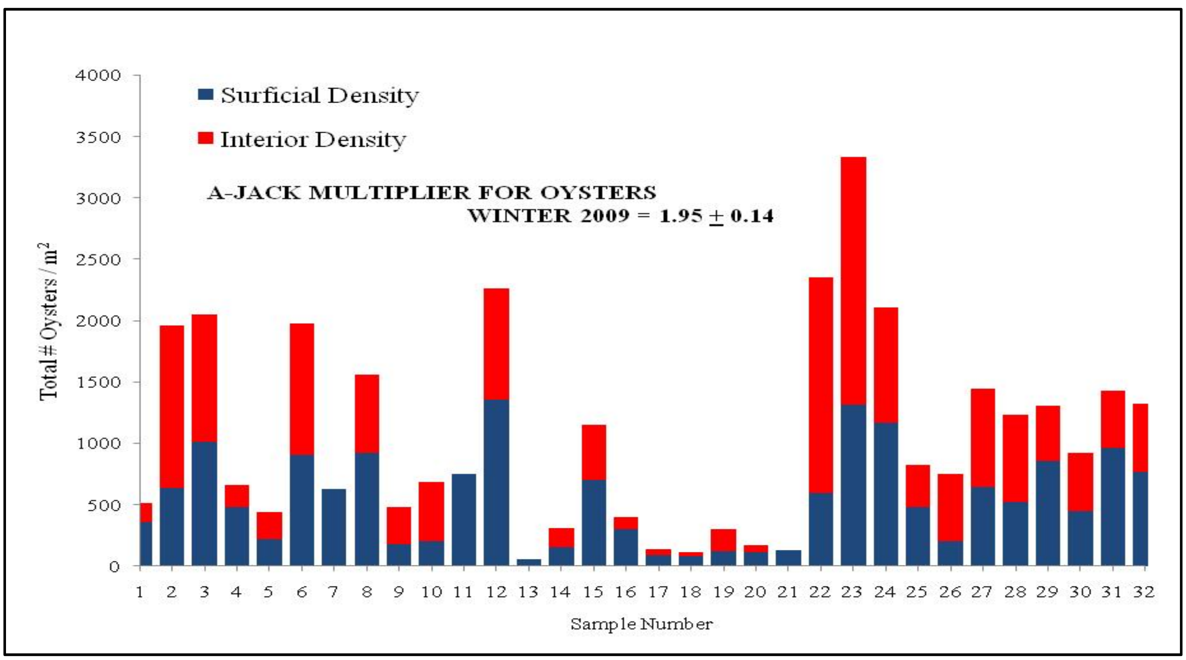


Figure D-4. **A-Jack multiplier factor to calculate oyster densities.**

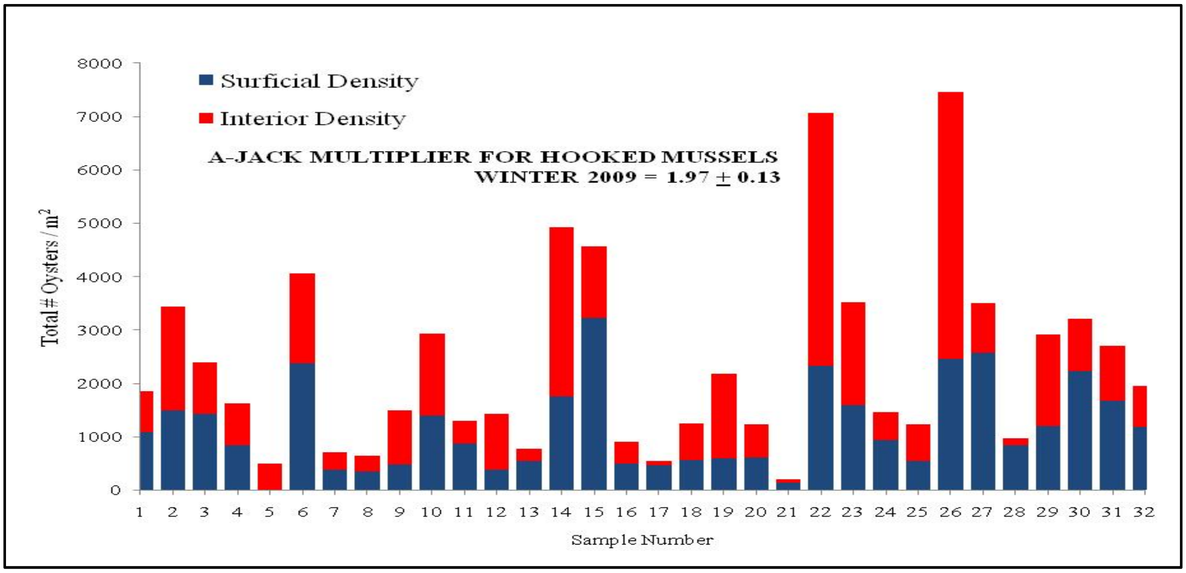


Figure D-5. A-Jack multiplier factor to calculate hooked mussel densities.

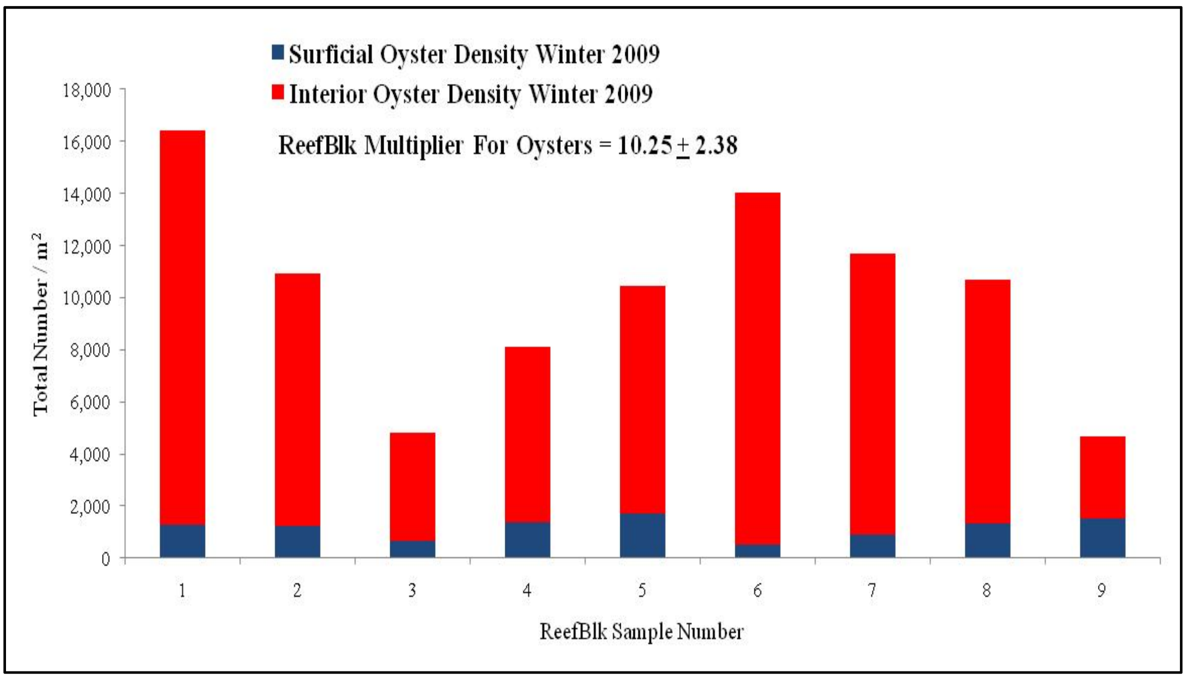


Figure D-6. ReefBlk multiplier factor to calculate oyster densities.

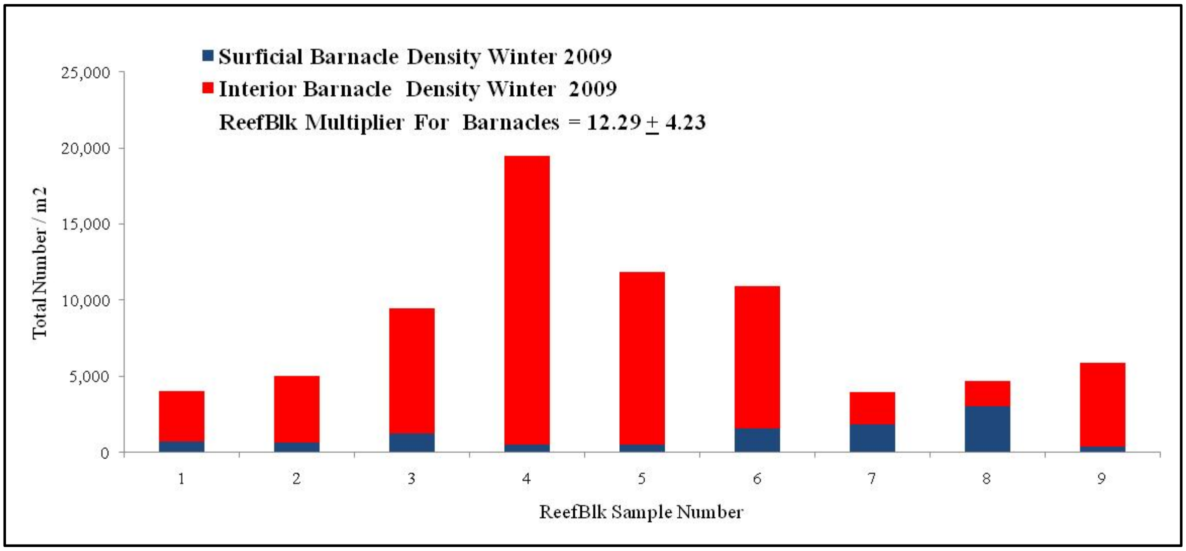


Figure D-7. ReefBlk multiplier factor to calculate barnacle densities.

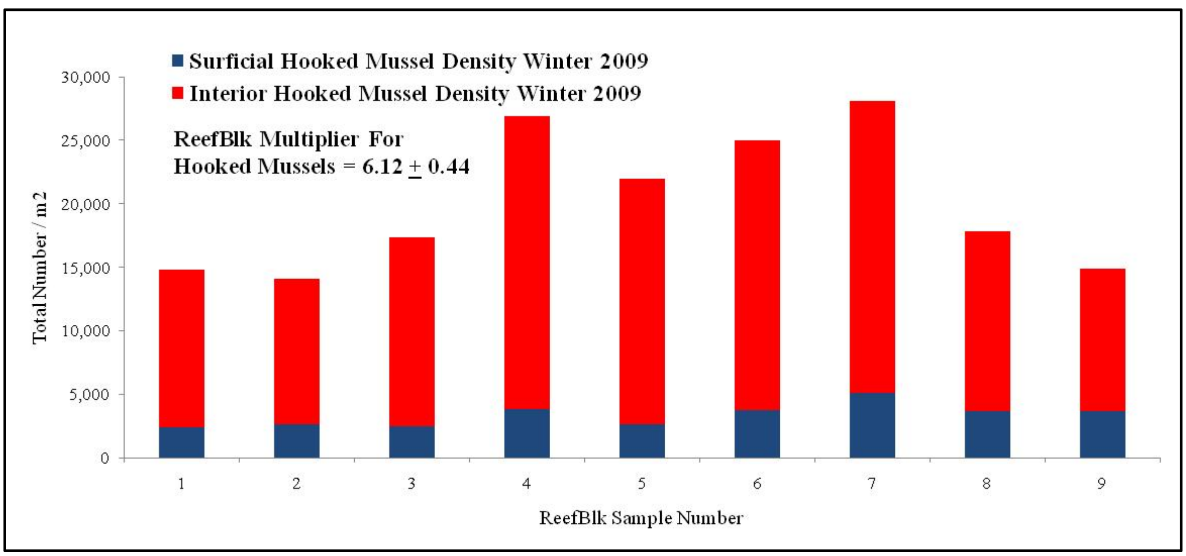


Figure D-8. ReefBlk multiplier factor to calculate hooked mussel densities.

Table D.1
One Way Analysis of Variance

Data source: Data 1 in Density Oysters Winter 2009_Surf + Interior

Dependent Variable: Oyster Density m^2

Normality Test:	Passed	(P = 0.481)
Equal Variance Test:	Failed	(P < 0.050)

Group Name	N	Missing	Mean	Std Dev	SEM
GABION MATS (Mid+Low)	15	0	2747.136	1226.993	316.808
REEFBLKS (A+B+C +D)	15	0	4466.598	1112.953	287.363
A-JACKS (W+L)	15	0	1759.086	572.203	147.742

Source of Variation	DF	SS	MS	F	P
Between Groups	2	56317082	28158541	27.502	<0.001
Residual	42	43002319	1023865		
Total	44	99319401			

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 = <0.001).

Power of performed test with alpha = 0.050: 1.000

All Pairwise Multiple Comparison Procedures (Student-Newman-Keuls Method) :

Comparisons for factor: Treatment

Comparison	Diff of Means	p	q	P	P<0.050
REEFBLKS vs. A-JACKS	2707.512	3	10.363	<0.001	Yes
REEFBLKS vs. GABION MATS	1719.462	2	6.581	<0.001	Yes
GABION MATS vs. A-JACKS	988.05	2	3.782	0.011	Yes

Table D.2
One Way Analysis of Variance
Data source: Data 1 in Desntiy Oysters Winter 2009_Surf + Interior
<u>Dependent Variable: Hooked Mussel Density m^2</u>

Normality Test:	Passed	(P = 0.390)
Equal Variance Test:	Failed	(P < 0.050)

Group Name	N	Missing	Mean	Std Dev	SEM
GABION MATS (Mid+Low)	15	0	2679.24	1042.18	269.091
REEFBLKS (A+B+C +D)	15	0	8108.14	2537.16	655.092
A-JACKS (W+L)	15	0	3516.73	1002.78	258.916

Source of Variation	DF	SS	MS	F	P
Between Groups	2	2.6E+08	1.3E+08	45.072	<0.001
Residual	42	1.2E+08	2842968		
Total	44	3.8E+08			

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 = <0.001).
Power of performed test with alpha = 0.050: 1.000

All Pairwise Multiple Comparison Procedures (Student-Newman-Keuls Method) :

Comparisons for factor:
Treatment

Comparison	Diff of Means	p	q	P	P<0.050
REEFBLKS vs. GABION MATS	5428.903	3	12.47	<0.001	Yes
REEFBLKS vs. A-JACKS	4591.409	2	10.546	<0.001	Yes
A-JACKS vs. GABION MATS	837.494	2	1.924	0.181	No

Table D.3
Two Way Analysis of Variance
Data source: Data 1 in Density Oysters Winter 2009_Surf + Interior
Balanced Design

Dependent Variable: Oyster Density m^2

Normality Test: Passed (P = 0.265)

Equal Variance Test: Passed (P = 0.427)

Source of Variation	DF	SS	MS	F	P
Reach	2	1.4E+07	6779152	11.448	<0.001
Treatment	2	5.6E+07	2.8E+07	47.553	<0.001
Reach x Treatment	4	8126429	2031607	3.431	0.018
Residual	36	2.1E+07	592155		
Total	44	9.9E+07	2257259		

The difference in the mean values among the different levels of Reach is greater than would be expected by chance after allowing for effects of differences in Treatment. There is a statistically significant difference (P = <0.001). To isolate which group(s) differ from the others use a multiple comparison procedure.

The difference in the mean values among the different levels of Treatment is greater than would be expected by chance after allowing for effects of differences in Reach. There is a statistically significant difference (P = <0.001). To isolate which group(s) differ from the others use a multiple comparison procedure.

The effect of different levels of Reach depends on what level of Treatment is present. There is a statistically significant interaction between Reach and Treatment. (P = 0.018)

Power of performed test with alpha = 0.0500: for Reach : 0.988
Power of performed test with alpha = 0.0500: for Treatment: 1.00
Power of performed test with alpha = 0.0500: for Reach x Treatment : 0.635

Least square means for Reach :

Group	Mean
A	3225.263
B	3514.686
E	2232.87

Std Err of LS Mean = 198.688

Least square means for Treatment :

Group	Mean
GABION MATS (Mid+Low)	2747.136
REEFBLKS (A+B+C +D)	4466.598
A-JACKS (W+L)	1759.086

Std Err of LS Mean = 198.688

Least square means for Reach x Treatment :

Group	Mean
A x GABION MATS (Mid+Low)	3076.016
A x REEFBLKS (A+B+C +D)	4932.803
A x A-JACKS (W+L)	1666.971
B x GABION MATS (Mid+Low)	3778.56
B x REEFBLKS (A+B+C +D)	4931.384
B x A-JACKS (W+L)	1834.114
E x GABION MATS (Mid+Low)	1386.832
E x REEFBLKS (A+B+C +D)	3535.608
E x A-JACKS (W+L)	1776.171

Std Err of LS Mean = 344.138

Note: For A-Jacks, W=Windward side of structure and L=Leeward side of structure. For ReefBlks, Letters A, B, C, and D represent sides measured. For Gabion Mats, M=Mid Intertidal Site and L= Low Intertidal Site.

All Pairwise Multiple Comparison Procedures (Student-Newman-Keuls Method) :

Comparisons for factor: Reach

Comparison	Diff of Means	p	q	P	P<0.050
B vs. E	1281.816	3	6.451	<0.001	Yes
B vs. A	289.423	2	1.457	0.31	No
A vs. E	992.393	2	4.995	0.001	Yes

Comparisons for factor: Treatment

Comparison	Diff of Means	p	q	P	P<0.050
REEFBLKS vs. A-JACKS	2707.512	3	13.627	<0.001	Yes
REEFBLKS vs. GABION MATS	1719.462	2	8.654	<0.001	Yes
GABION MATS vs. A-JACKS	988.05	2	4.973	0.001	Yes

Comparisons for factor: Treatment within A

Comparison	Diff of Means	p	q	P	P<0.05
REEFBLKS vs. A-JACKS	3265.831	3	9.49	<0.001	**Yes**
REEFBLKS vs. GABION MATS	1856.787	2	5.395	<0.001	**Yes**
GABION MATS vs. A-JACKS	1409.045	2	4.094	0.007	**Yes**

Comparisons for factor: Treatment within B

Comparison	Diff of Means	p	q	P	P<0.05
REEFBLKS vs. A-JACKS	3097.269	3	9	<0.001	**Yes**
REEFBLKS vs. GABION MATS	1152.824	2	3.35	0.023	**Yes**
GABION MATS vs. A-JACKS	1944.446	2	5.65	<0.001	**Yes**

Comparisons for factor: Treatment within E

Comparison	Diff of Means	p	q	P	P<0.05
REEFBLKS vs. GABION MATS	2148.776	3	6.244	<0.001	**Yes**
REEFBLKS vs. A-JACKS	1759.436	2	5.113	0.001	**Yes**
A-JACKS vs. GABION MATS	389.339	2	1.131	0.429	**No**

Comparisons for factor: Reach within GABION MATS

Comparison	Diff of Means	p	q	P	P<0.05
B vs. E	2391.728	3	6.95	<0.001	Yes
B vs. A	702.544	2	2.041	0.158	No
A vs. E	1689.184	2	4.908	0.001	Yes

Comparisons for factor: Reach within REEFBLKS

Comparison	Diff of Means	p	q	P	P<0.05
A vs. E	1397.195	3	4.06	0.018	Yes
A vs. B	1.419	2	0.00412	0.998	No
B vs. E	1395.776	2	4.056	0.007	Yes

Comparisons for factor: Reach within A-JACKS

Comparison	Diff of Means	p	q	P	P<0.05
B vs. A	167.143	3	0.486	0.937	No
B vs. E	57.943	2	0.168	0.906	Do Not Test
E vs. A	109.2	2	0.317	0.824	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 D.4
Two Way Analysis of Variance
Data source: Data 1 in Desntiy Oysters Winter 2009_Surf + Interior
Balanced Design

Dependent Variable: Hooked Mussel Density m^2

Normality Test: Passed (P = 0.154)

Equal Variance Test: Passed (P = 0.660)

Source of Variation	DF	SS	MS	F	P
Reach	2	1.9E+07	9611050	5.754	0.007
Treatment	2	2.6E+08	1.3E+08	76.721	<0.001
Reach x Treatment	4	4E+07	1E+07	5.996	<0.001
Residual	36	6E+07	1670193		
Total	44	3.8E+08	8538222		

The difference in the mean values among the different levels of Reach is greater than would be expected by chance after allowing for effects of differences in Treatment. There is a statistically significant difference (P = 0.007). To isolate which group(s) differ from the others use a multiple comparison procedure.

The difference in the mean values among the different levels of Treatment is greater than would be expected by chance after allowing for effects of differences in Reach. There is a statistically significant difference (P = <0.001). To isolate which group(s) differ from the others use a multiple comparison procedure.

The effect of different levels of Reach depends on what level of Treatment is present. There is a statistically significant interaction between Reach and Treatment. (P = <0.001)

Power of performed test with alpha = 0.0500: for Reach : 0.763
Power of performed test with alpha = 0.0500: for Treatment : 1.00
Power of performed test with alpha = 0.0500: for Reach x Treatment : 0.944

Least square means for Reach :

Group	Mean
A	5660.909
B	4528.529
E	4114.67

Std Err of LS Mean = 333.686

Least square means for Treatment :

Group	Mean
GABION MATS	2679.237
REEFBLKS	8108.14
A-JACKS	3516.731

Std Err of LS Mean = 333.686

Least square means for Reach x Treatment :

Group	Mean
A x GABION MATS (Mid+Low)	2420.048
A x REEFBLKS (A+B+C +D)	10856.829
A x A-JACKS (W+L)	3705.851
B x GABION MATS (Mid+Low)	2902.896
B x REEFBLKS (A+B+C +D)	6862.018
B x A-JACKS (W+L)	3820.674
E x GABION MATS (Mid+Low)	2714.768
E x REEFBLKS (A+B+C +D)	6605.574
E x A-JACKS (W+L)	3023.669

Std Err of LS Mean = 577.961

All Pairwise Multiple Comparison Procedures (Student-Newman-Keuls Method) :

Comparisons for factor: Reach

Comparison	Diff of Means	p	q	P	P<0.050
A vs. E	1546.239	3	4.634	0.007	Yes
A vs. B	1132.38	2	3.394	0.022	Yes
B vs. E	413.859	2	1.24	0.386	No

Comparisons for factor: Treatment

Comparison	Diff of Means	p	q	P	P<0.050
REEFBLKS (A+ vs. GABION MATS	5428.903	3	16.27	<0.001	Yes
REEFBLKS (A+ vs. A-JACKS (W+L	4591.409	2	13.76	<0.001	Yes
A-JACKS (W+L vs. GABION MATS	837.494	2	2.51	0.085	No

Comparisons for factor: Treatment within A

Comparison	Diff of Means	p	q	P	P<0.05
REEFBLKS (A+ vs. GABION MATS	8436.781	3	14.597	<0.001	Yes
REEFBLKS (A+ vs. A-JACKS (W+L	7150.978	2	12.373	<0.001	Yes
A-JACKS (W+L vs. GABION MATS	1285.803	2	2.225	0.125	No

Comparisons for factor: Treatment within B

Comparison	Diff of Means	p	q	P	P<0.05
REEFBLKS (A+ vs. GABION MATS	3959.122	3	6.85	<0.001	Yes
REEFBLKS (A+ vs. A-JACKS (W+L	3041.344	2	5.262	<0.001	Yes
A-JACKS (W+L vs. GABION MATS	917.778	2	1.588	0.269	No

Comparisons for factor: Treatment within E

Comparison	Diff of Means	p	q	P	P<0.05
REEFBLKS (A+ vs. GABION MATS	3890.806	3	6.732	<0.001	Yes
REEFBLKS (A+ vs. A-JACKS (W+L	3581.905	2	6.197	<0.001	Yes
A-JACKS (W+L vs. GABION MATS	308.901	2	0.534	0.708	No

Comparisons for factor: Reach within GABION MATS

Comparison	Diff of Means	p	q	P	P<0.05
B vs. A	482.848	3	0.835	0.826	No
B vs. E	188.128	2	0.326	0.819	Do Not Test
E vs. A	294.72	2	0.51	0.721	Do Not Test

Comparisons for factor: Reach within REEFBLKS

Comparison	Diff of Means	p	q	P	P<0.05
A vs. E	4251.255	3	7.356	<0.001	Yes
A vs. B	3994.811	2	6.912	<0.001	Yes
B vs. E	256.444	2	0.444	0.756	No

Comparisons for factor: Reach within A-JACKS

Comparison	Diff of Means	p	q	P	P<0.05
B vs. E	797.006	3	1.379	0.597	No
B vs. A	114.823	2	0.199	0.889	Do Not Test
A vs. E	682.183	2	1.18	0.41	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 D.5
Two Way Analysis of Variance
Data source: Data 1 in Stats_Erosion Rate by Reach by Structure
General Linear Model

<u>Dependent Variable: Erosion Rate (m/yr)</u>

Normality Test:	Failed	(P < 0.050)			
Equal Variance Test:	Failed	(P < 0.050)			
Source of Variation	DF	SS	MS	F	P
Status	1	807.819	807.819	68.589	<0.001
Structure	3	63.405	21.135	1.794	0.149
Status x Structure	3	12.184	4.061	0.345	0.793
Residual	205	2414.418	11.778		
Total	212	3393.782	16.008		

The difference in the mean values among the different levels of Status is greater than would be expected by chance after allowing for effects of differences in Structure. There is a statistically significant difference (P = <0.001). To isolate which group(s) differ from the others use a multiple comparison procedure.

The difference in the mean values among the different levels of Structure is not great enough to exclude the possibility that the difference is just due to random sampling variability after allowing for the effects of differences in Status. There is not a statistically significant difference (P = 0.149).

The effect of different levels of Status does not depend on what level of Structure is present. There is not a statistically significant interaction between Status and Structure. (P = 0.793)

Power of performed test with alpha = 0.0500: for Status : 1.000	
Power of performed test with alpha = 0.0500: for Structure : 0.213	
Power of performed test with alpha = 0.0500: for Status x Structure : 0.0500	

Least square means for Status :		
Group	Mean	SEM
Pre-Construction	-4.956	0.34
Post-Construction	-0.946	0.344

Least square means for Structure :		
Group	Mean	SEM
Gabion Mat	-2.588	0.407
A-Jack	-2.904	0.471
ReefBlk	-2.443	0.572
Reference	-3.869	0.471

Least square means for Status x Structure :		
Group	Mean	SEM
Pre-Construction x Gabion Mat	-4.941	0.572
Pre-Construction x A-Jack	-4.978	0.66
Pre-Construction x ReefBlk	-4.145	0.809
Pre-Construction x Reference	-5.761	0.66
Post-Construction x Gabion Mat	-0.236	0.58
Post-Construction x A-Jack	-0.83	0.673
Post-Construction x ReefBlk	-0.741	0.809
Post-Construction x Reference	-1.978	0.673

Comparisons for factor: Status					
Comparison	Diff of Means	p	q	P	P<0.050
Post-Constru vs. Pre-Construc	4.01	2	11.712	<0.001	Yes

Comparisons for factor: Structure						
Comparison	Diff of Means	p	q	P	P<0.050	
ReefBlk vs. Reference	1.427	4	2.722	0.218	No	
ReefBlk vs. A-Jack	0.462	3	0.881	0.808	Do Not Test	
ReefBlk vs. Gabion Mat	0.146	2	0.293	0.836	Do Not Test	
Gabion Mat vs. Reference	1.281	3	2.907	0.099	Do Not Test	
Gabion Mat vs. A-Jack	0.316	2	0.717	0.612	Do Not Test	

A-Jack vs. Reference	0.965	2	2.047	0.148	Do Not Test

Comparisons for factor: Structure within Pre-Construction						
Comparison	Diff of Means	p	q	P	P<0.05	
ReefBlk vs. Reference	1.616	4	2.189	0.409	No	
ReefBlk vs. A-Jack	0.834	3	1.129	0.704	Do Not Test	
ReefBlk vs. Gabion Mat	0.796	2	1.136	0.422	Do Not Test	
Gabion Mat vs. Reference	0.82	3	1.328	0.616	Do Not Test	
Gabion Mat vs. A-Jack	0.038	2	0.0615	0.965	Do Not Test	
A-Jack vs. Reference	0.782	2	1.185	0.402	Do Not Test	

Comparisons for factor: Structure within Post-Construction						
Comparison	Diff of Means	p	q	P	P<0.05	
Gabion Mat vs. Reference	1.741	4	2.772	0.203	No	
Gabion Mat vs. A-Jack	0.594	3	0.945	0.782	Do Not Test	
Gabion Mat vs. ReefBlk	0.504	2	0.717	0.612	Do Not Test	
ReefBlk vs. Reference	1.237	3	1.662	0.468	Do Not Test	
ReefBlk vs. A-Jack	0.0893	2	0.12	0.932	Do Not Test	
A-Jack vs. Reference	1.148	2	1.705	0.228	Do Not Test	

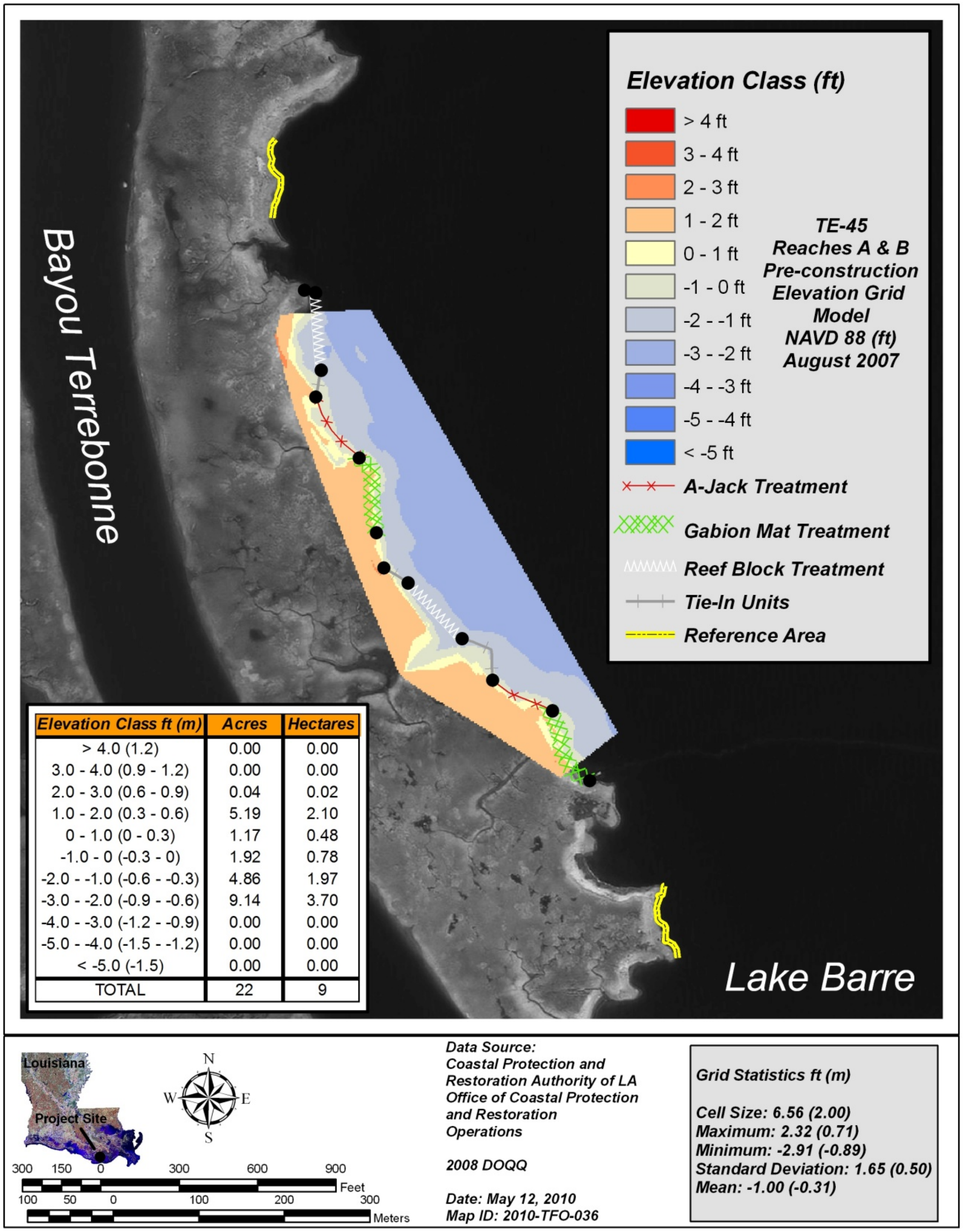
Comparisons for factor: Status within Gabion Mat					
Comparison	Diff of Means	p	q	P	P<0.05
Post-Constru vs. Pre-Construc	4.704	2	8.166	<0.001	Yes
Comparisons for factor: Status within A-Jack					
Comparison	Diff of Means	p	q	P	P<0.05
Post-Constru vs. Pre-Construc	4.148	2	6.221	<0.001	Yes
Comparisons for factor: Status within ReefBlk					

Comparison	Diff of Means	p	q	P	P<0.05
Post-Constru vs. Pre-Construc	3.404	2	4.208	0.003	Yes
Comparisons for factor: Status within Reference					
Comparison	Diff of Means	p	q	P	P<0.05
Post-Constru vs. Pre-Construc	3.783	2	5.674	<0.001	Yes

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.

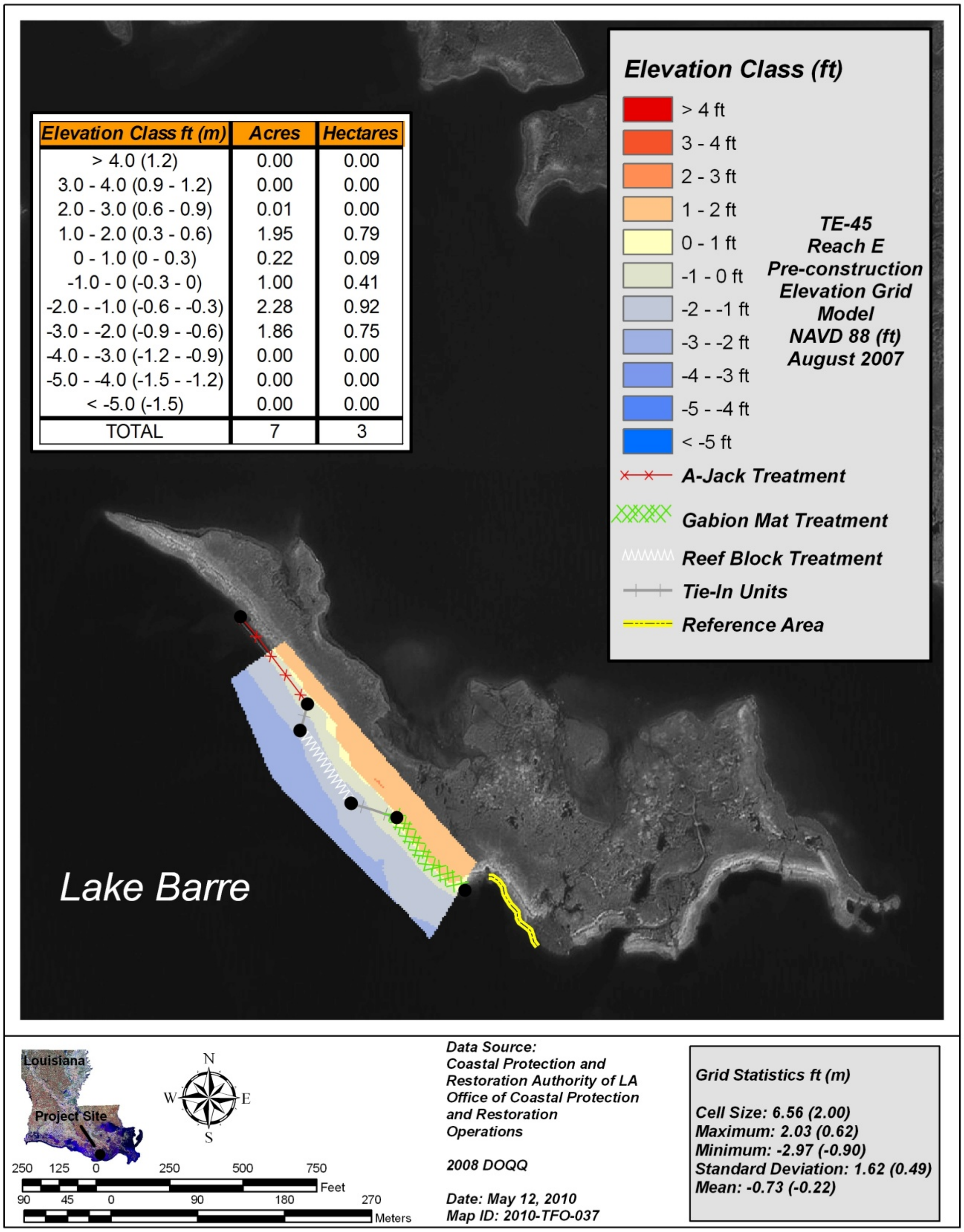
Appendix E

TE-45 Elevation Grid Models



Elevation Class ft (m)	Acres	Hectares
> 4.0 (1.2)	0.00	0.00
3.0 - 4.0 (0.9 - 1.2)	0.00	0.00
2.0 - 3.0 (0.6 - 0.9)	0.04	0.02
1.0 - 2.0 (0.3 - 0.6)	5.19	2.10
0 - 1.0 (0 - 0.3)	1.17	0.48
-1.0 - 0 (-0.3 - 0)	1.92	0.78
-2.0 - -1.0 (-0.6 - -0.3)	4.86	1.97
-3.0 - -2.0 (-0.9 - -0.6)	9.14	3.70
-4.0 - -3.0 (-1.2 - -0.9)	0.00	0.00
-5.0 - -4.0 (-1.5 - -1.2)	0.00	0.00
< -5.0 (-1.5)	0.00	0.00
TOTAL	22	9

Figure E-1. **Pre-construction (Aug 2007) elevation grid model for Reaches A and B at the Terrebonne Bay Shore Protection Demonstration (TE-45) project.**



Elevation Class ft (m)	Acres	Hectares
> 4.0 (1.2)	0.00	0.00
3.0 - 4.0 (0.9 - 1.2)	0.00	0.00
2.0 - 3.0 (0.6 - 0.9)	0.01	0.00
1.0 - 2.0 (0.3 - 0.6)	1.95	0.79
0 - 1.0 (0 - 0.3)	0.22	0.09
-1.0 - 0 (-0.3 - 0)	1.00	0.41
-2.0 - -1.0 (-0.6 - -0.3)	2.28	0.92
-3.0 - -2.0 (-0.9 - -0.6)	1.86	0.75
-4.0 - -3.0 (-1.2 - -0.9)	0.00	0.00
-5.0 - -4.0 (-1.5 - -1.2)	0.00	0.00
< -5.0 (-1.5)	0.00	0.00
TOTAL	7	3

Figure E-2. Pre-construction (Aug 2007) elevation grid model for Reach E at the Terrebonne Bay Shore Protection Demonstration (TE-45) project.

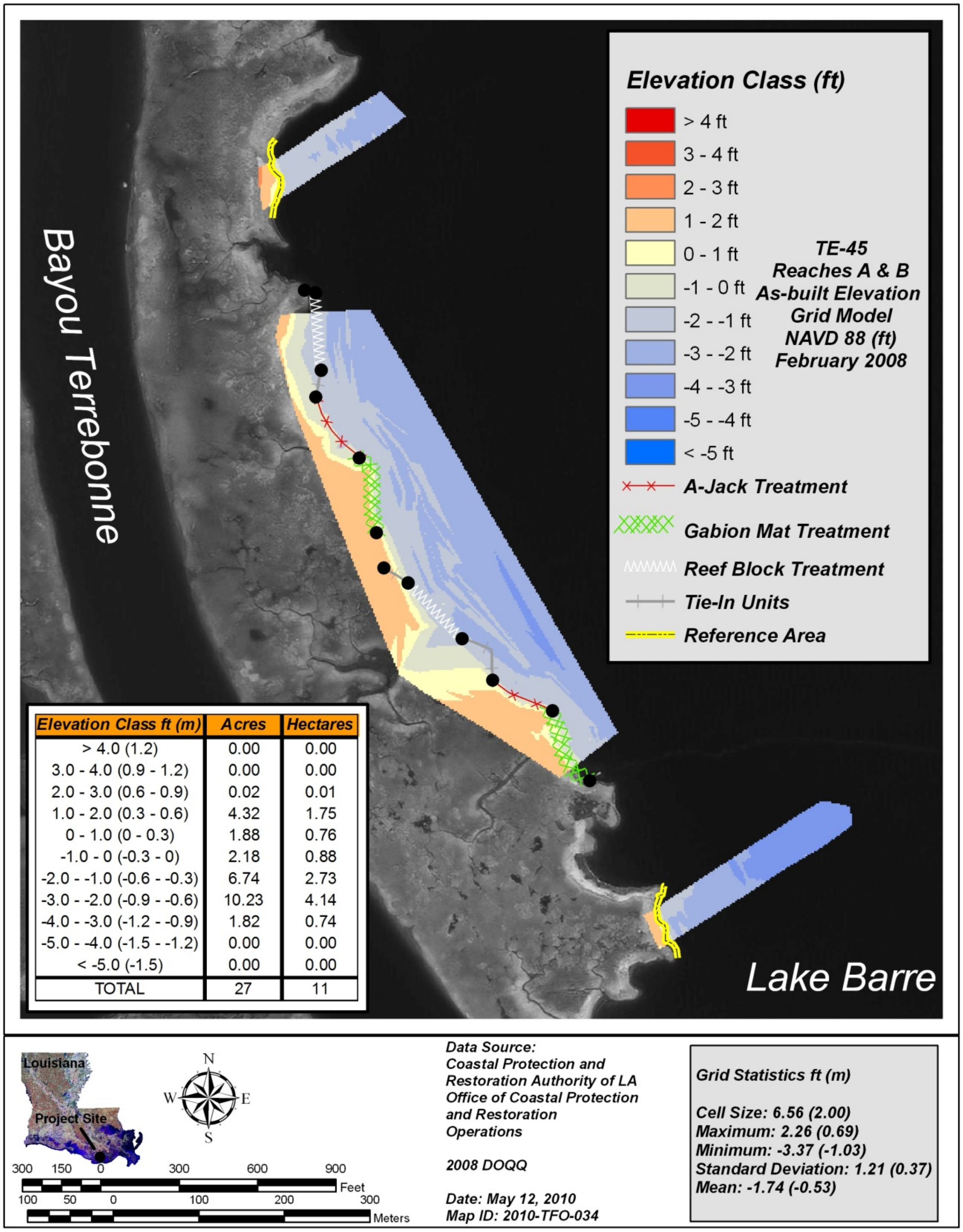
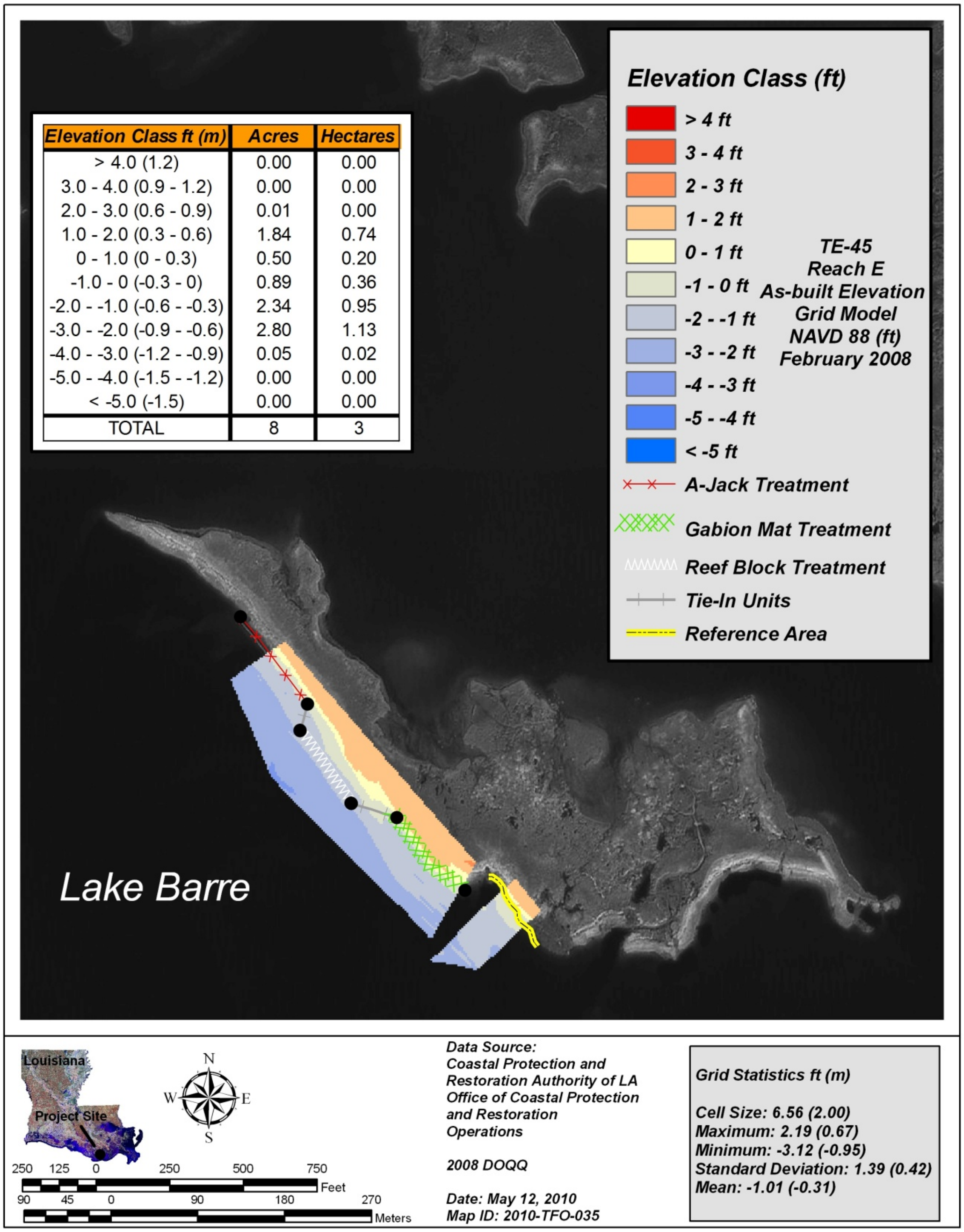


Figure E-3. **As-built (Feb 2008) elevation grid model for Reaches A and B at the Terrebonne Bay Shore Protection Demonstration (TE-45) project.**



Elevation Class ft (m)	Acres	Hectares
> 4.0 (1.2)	0.00	0.00
3.0 - 4.0 (0.9 - 1.2)	0.00	0.00
2.0 - 3.0 (0.6 - 0.9)	0.01	0.00
1.0 - 2.0 (0.3 - 0.6)	1.84	0.74
0 - 1.0 (0 - 0.3)	0.50	0.20
-1.0 - 0 (-0.3 - 0)	0.89	0.36
-2.0 - -1.0 (-0.6 - -0.3)	2.34	0.95
-3.0 - -2.0 (-0.9 - -0.6)	2.80	1.13
-4.0 - -3.0 (-1.2 - -0.9)	0.05	0.02
-5.0 - -4.0 (-1.5 - -1.2)	0.00	0.00
< -5.0 (-1.5)	0.00	0.00
TOTAL	8	3

Figure E-4. As-built (Feb 2008) elevation grid model for Reach E at the Terrebonne Bay Shore Protection Demonstration (TE-45) project.

Appendix F

TE-45 Shoreline Change Graphics

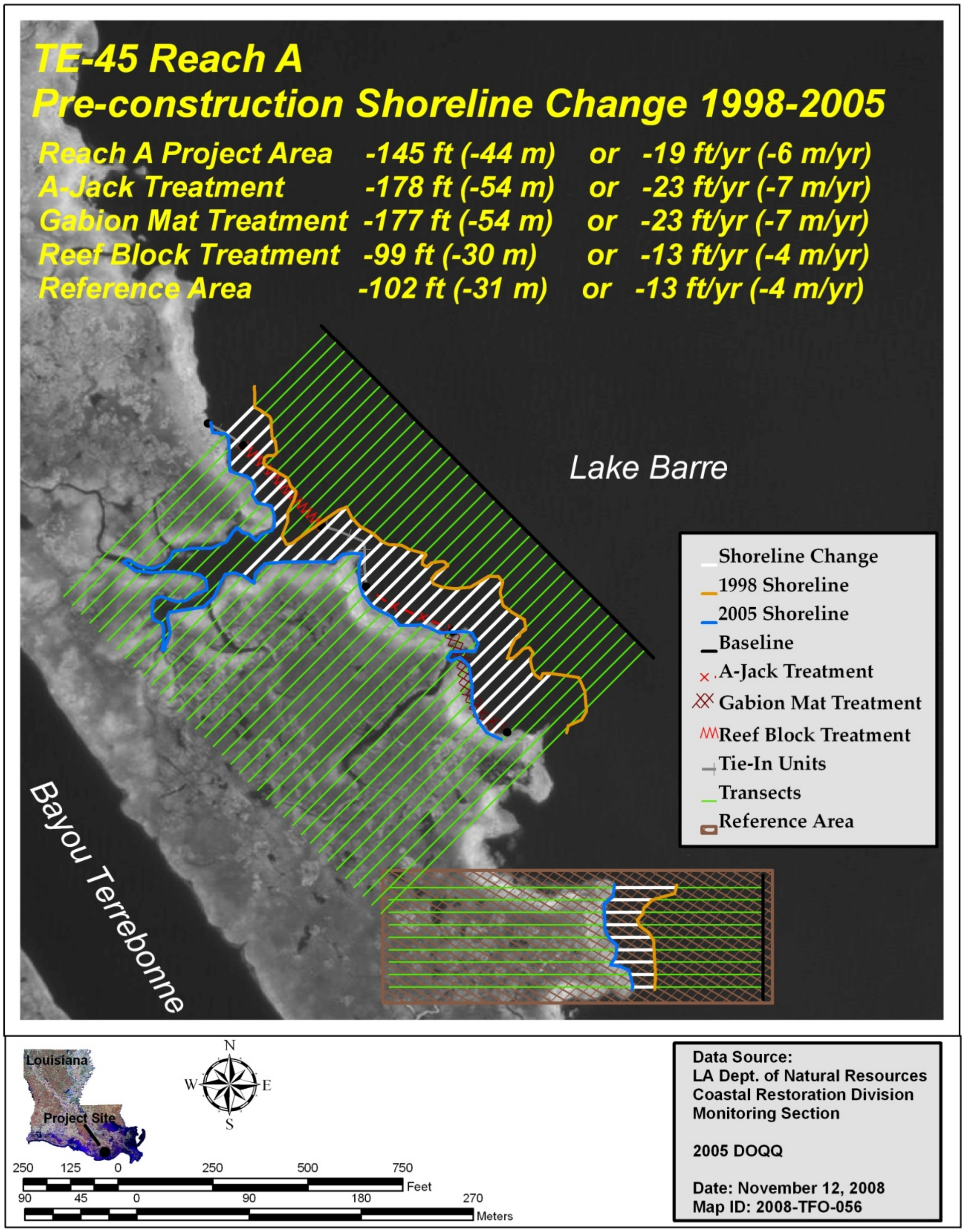


Figure F-1. **Pre-construction (1998-2005) shoreline change for Reach A at the Terrebonne Bay Shore Protection Demonstration (TE-45) project.**

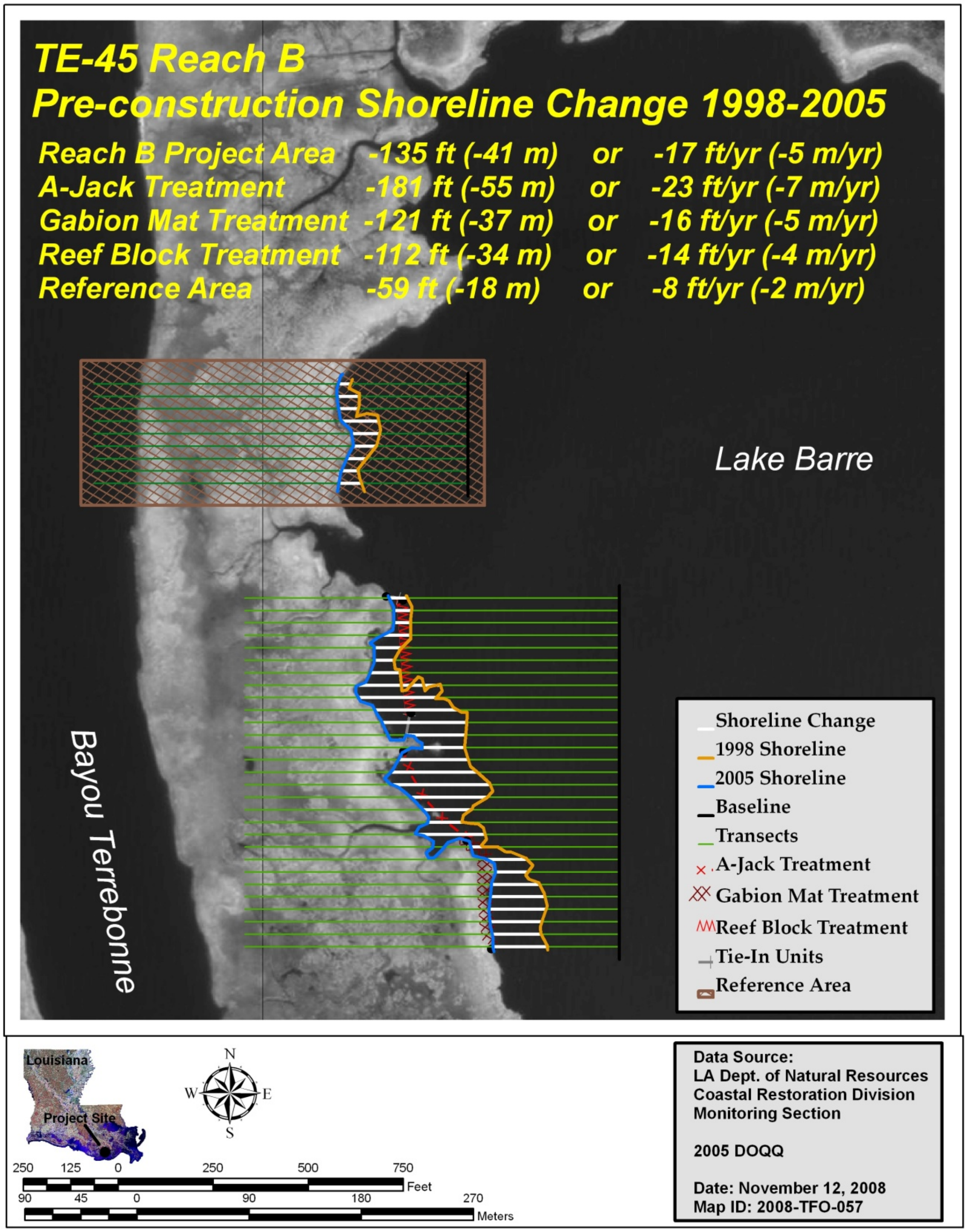


Figure F-2. **Pre-construction (1998-2005) shoreline change for Reach B at the Terrebonne Bay Shore Protection Demonstration (TE-45) project.**

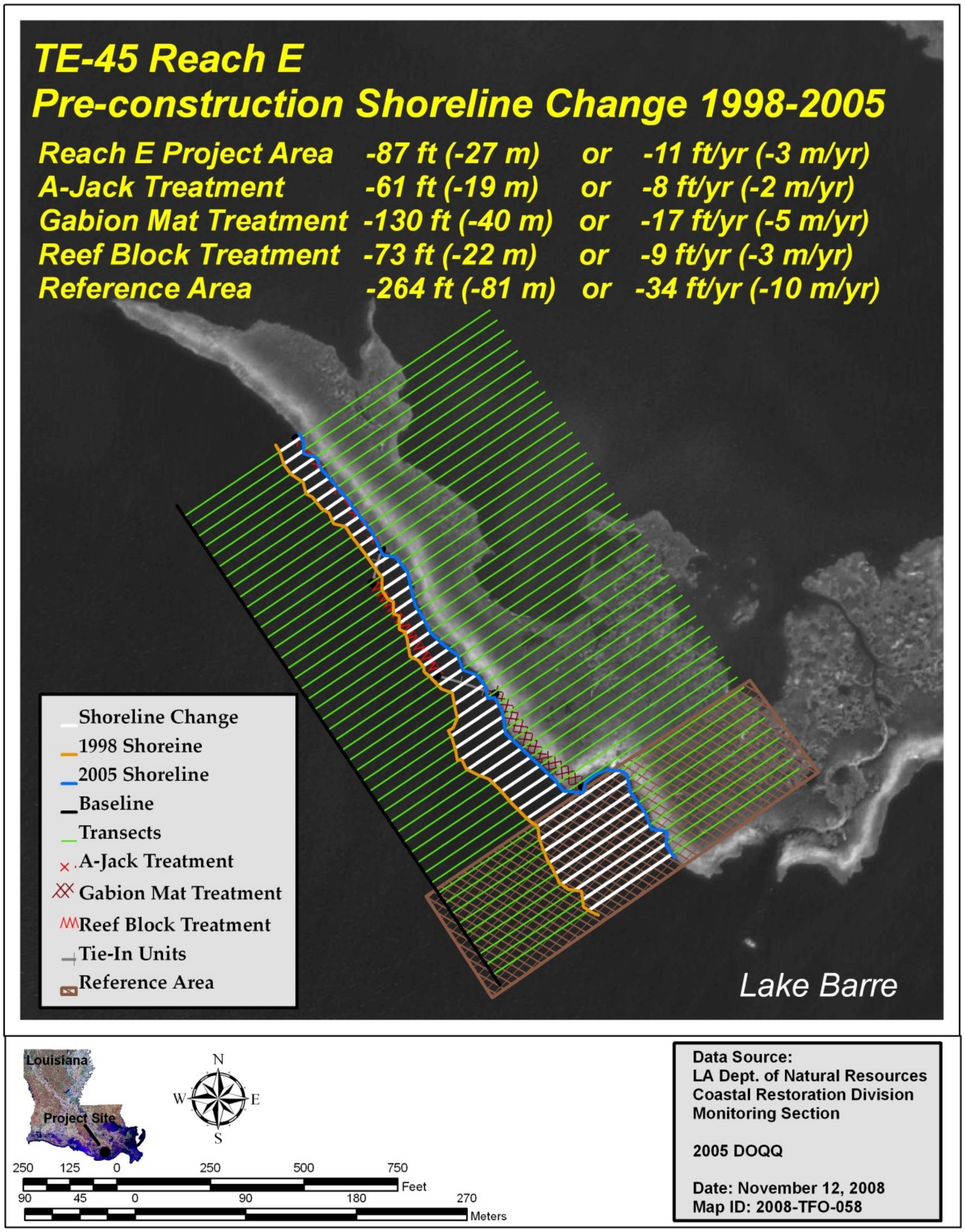


Figure F-3. **Pre-construction (1998-2005) shoreline change for Reach E at the Terrebonne Bay Shore Protection Demonstration (TE-45) project.**

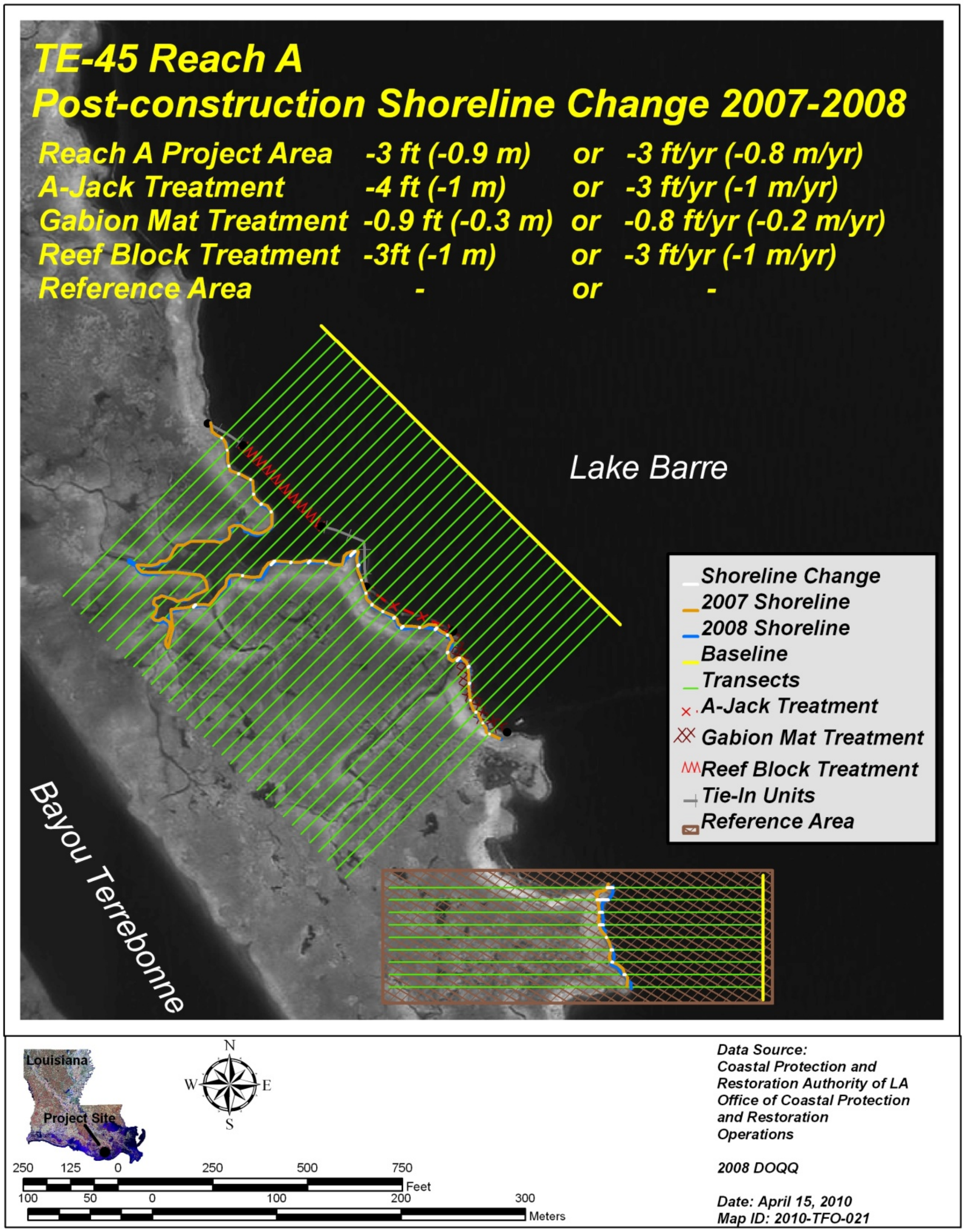


Figure F-4. **Post-construction (2007-2008) shoreline change for Reach A at the Terrebonne Bay Shore Protection Demonstration (TE-45) project.**

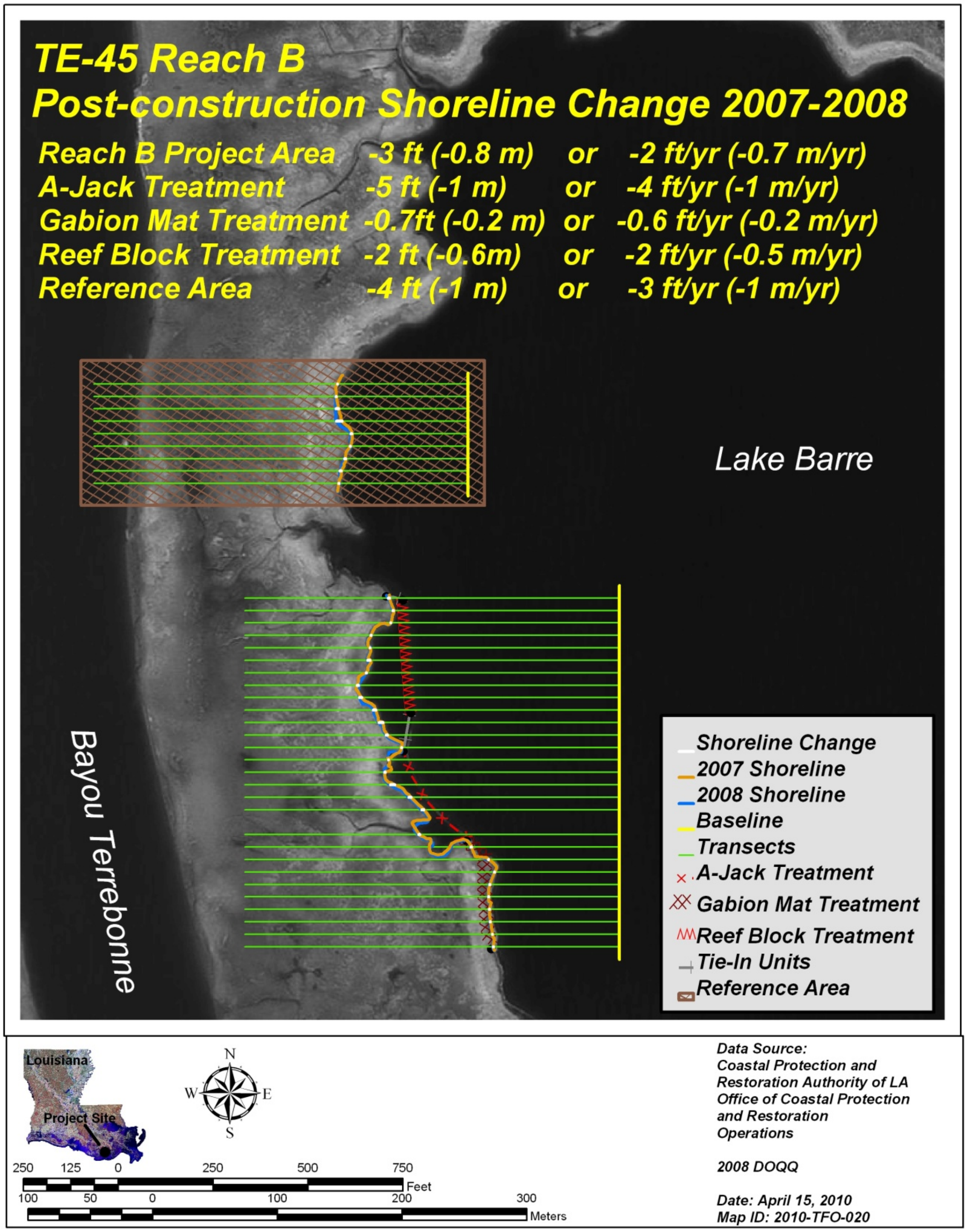


Figure F-5. Post-construction (2007-2008) shoreline change for Reach B at the Terrebonne Bay Shore Protection Demonstration (TE-45) project.

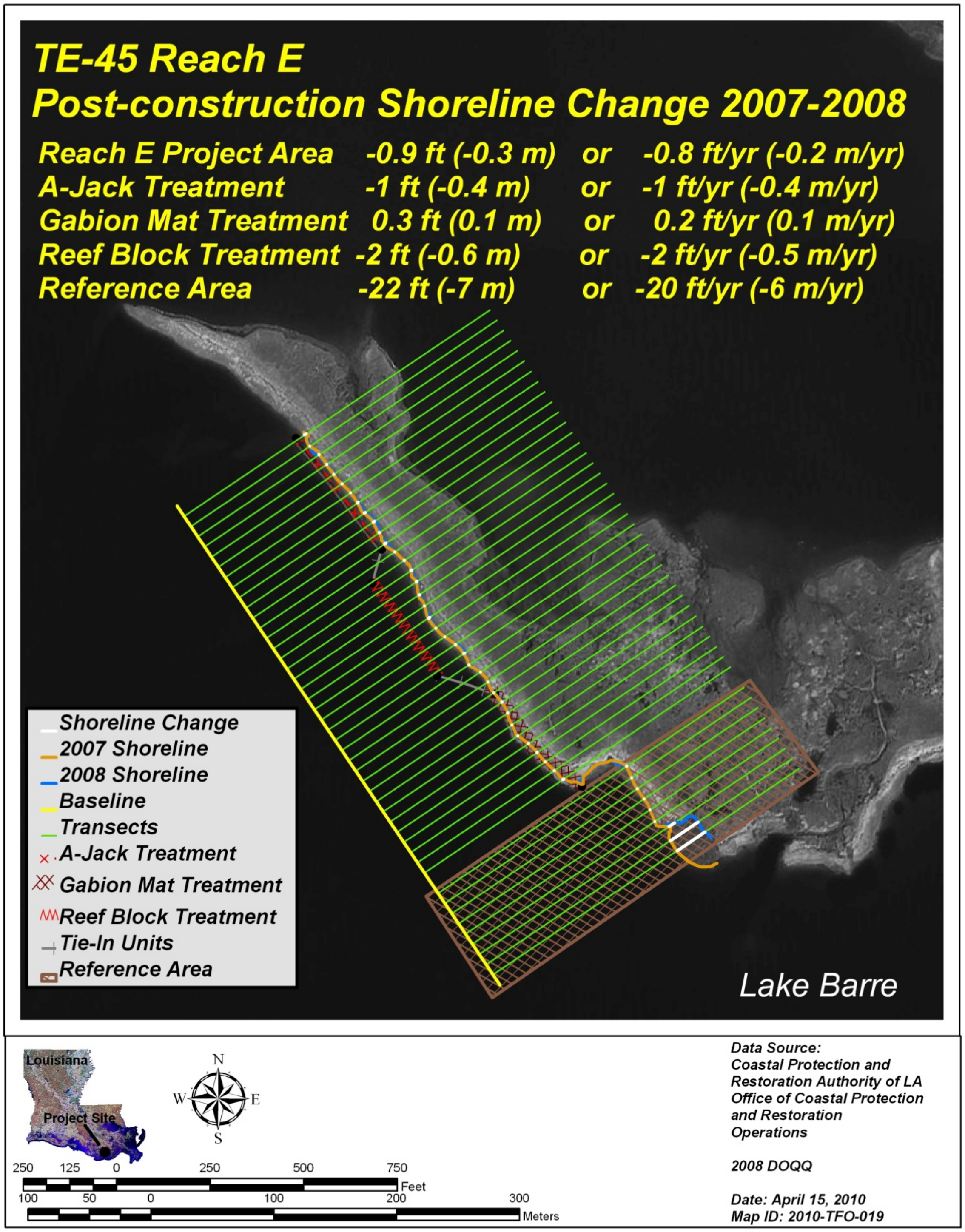


Figure F-6. Post-construction (2007-2008) shoreline change for Reach E at the Terrebonne Bay Shore Protection Demonstration (TE-45) project.