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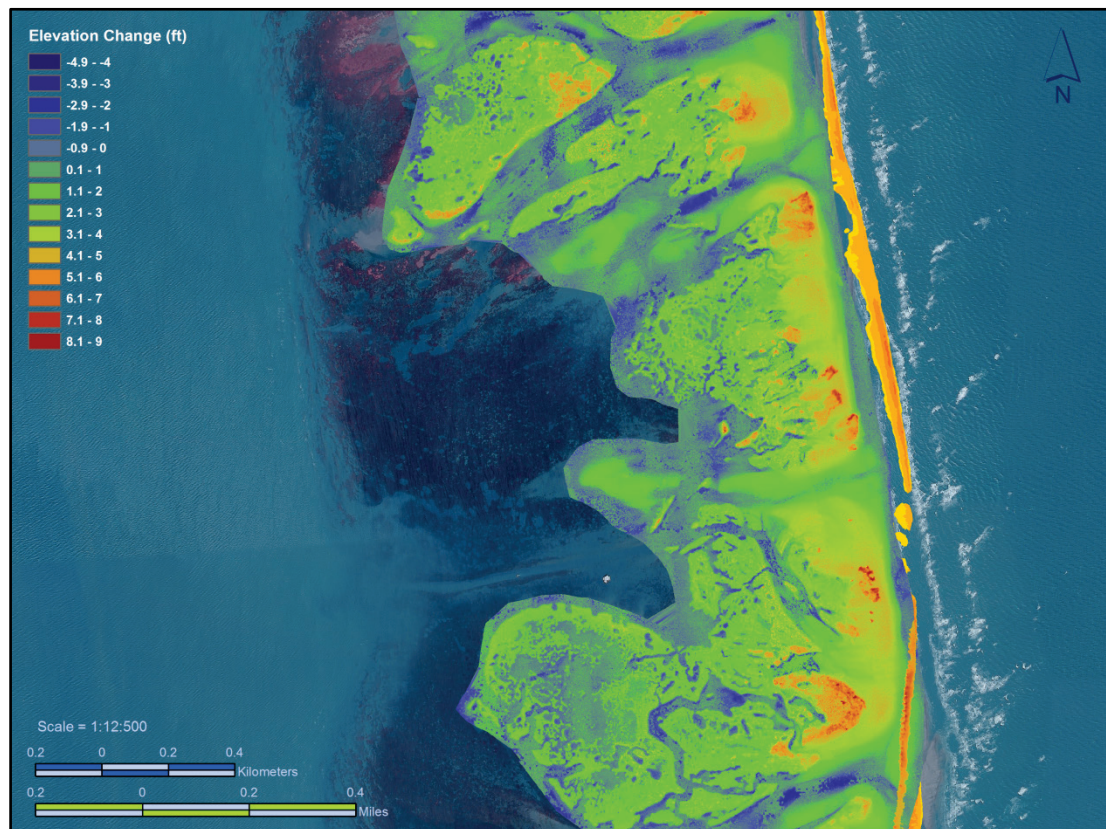
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Landscape Evolution of the Oil Spill Mitigation Sand Berm in the Chandeleur Islands, Louisiana

Glenn M. Suir, William R. Jones, Adrienne L. Garber,
and Joseph Z. Gailani

September 2016



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Landscape Evolution of the Oil Spill Mitigation Sand Berm in the Chandeleur Islands, Louisiana

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Final report

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Abstract

The failure of the Macondo-252 well and explosion of the Deepwater Horizon oil rig resulted in the release of approximately 185 million gallons of crude oil into the Gulf of Mexico. As part of the emergency response plan, the Louisiana Office of Coastal Protection and Restoration proposed (and subsequently constructed) sand barriers to reduce the amount of oil from reaching the Chandeleur Islands and inland wetlands; thereby protecting these sensitive ecosystem resources. This study was conducted to provide general measures of the sand berms resilience, performance, and potential impacts to the Chandeleur Islands. To satisfy these objectives, Geographic Information System (GIS) and remote sensing techniques were used to quantify changes in sand berm areal extent over time; provide shoreline, habitat, and landscape assessments of the Chandeleur Islands; and assess elevation changes and potential reworking of berm sediment into the island system. The sand berm provided short-term benefits and short-term advancement of the island's shoreline position, but the majority of those benefits were ephemeral since the berm experienced rapid degradation. The speed and degree of degradation were primarily the results of Tropical Storm Lee and Hurricane Isaac, and the construction of the berm in high-energy open water environments. Ultimately, the berm was not successful in providing a barrier to retard oil from reaching the island or oil migrating into Chandeleur Sound and beyond.

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Preface

The work reported herein was conducted as part of the Engineering With Nature (EWN) initiative and the Dredging Operations Technical Support (DOTS) program. EWN and DOTS programs are sponsored by Headquarters, U.S. Army Corps of Engineers (HQUSACE), and are assigned to the U.S. Army Engineer Research and Development Center (ERDC) under Project Number 454750.

The work was performed by the U.S. Army Engineer Research and Development Center, Environmental Laboratory (ERDC-EL). At the time of publication, Jeffrey A. McKee was the HQUSACE Navigation Business Line Manager overseeing the DOTS Program. W. Jeff Lillycrop (ERDC-CHL) was the Technical Director for Civil Works and Navigation Research, Development and Technology Transfer (RD&T) Portfolio. The Director of ERDC-EL was Dr. Beth Fleming. Dr. Todd Bridges and Ms. Cynthia Banks were the Program Managers of the EWN and DOTS programs, respectively.

Support and cooperation for this work were provided by the following:

- Chicago Bridge and Iron Company (CB&I)
- Louisiana Coastal Protection and Restoration Authority
- U.S. Army Corps of Engineers, New Orleans District
- U.S. Geological Survey

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COL Bryan S. Green was the Commander of ERDC, and Dr. Jeffery P. Holland was the Director.

Unit Conversion Factors

Multiply	By	To Obtain
acres	4,046.873	square meters
cubic feet	0.02831685	cubic meters
cubic yards	0.7645549	cubic meters
feet	0.3048	meters
gallons (U.S. liquid)	3.785412 E-03	cubic meters
knots	0.5144444	meters per second
miles (U.S. statute)	1,609.347	meters
miles per hour	0.44704	meters per second
square feet	0.09290304	square meters

1 Introduction

1.1 Background

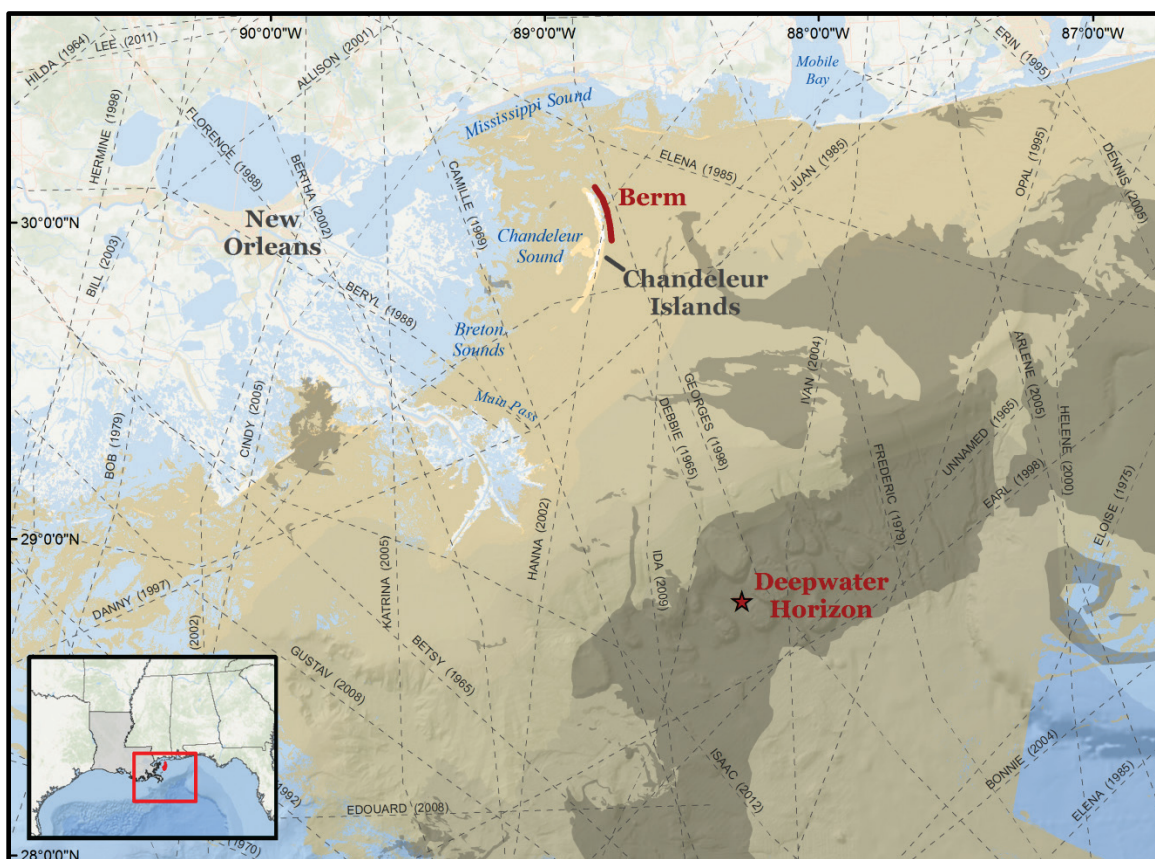
Macondo-252 well and explosion of the Deepwater Horizon oil rig, resulted in the estimated release of 185 million gallons (gal) of crude oil into the Gulf of Mexico and surrounding ecosystems (Wilde and Skrobialowski 2011) (Figure 1). As part of the emergency response plan, the Louisiana Office of Coastal Protection and Restoration (LOCPR) proposed sand barriers to reduce the amount of oil reaching barrier islands and inland wetlands, thereby protecting these sensitive ecosystem resources. The initial LOCPR plan consisted of approximately eighty miles of sand berms, seaward of two locations (the “western barrier berm” at Shell, Pelican, and Scofield Islands; and the “eastern barrier berm” at Chandeleur Islands), at an estimated construction cost of \$300 million (LOCPR 2011). It was estimated that more than 229 million cubic feet (ft³) of sand would be necessary to construct the approximately thirty mile stretch of the eastern barrier berm, making this one of the most ambitious coastal construction efforts in the history of the United States (Flocks et al. 2012).

From conception to construction, the life span and impacts of the oil-spill-mitigation sand berms have been widely debated. The berms have drawn opposition and criticism from coastal scientists, resource agencies, and members of a presidential commission. Concerns over sand berm construction have focused primarily on the use of scarce sand resources within the highly dynamic and sensitive habitats of the Chandeleur Islands. Consequently, the berms have become of significant interest to many stakeholders, serving both as a proxy for barrier island response to storm impacts (i.e., Hurricane Isaac, 28 August 2012) and useful for observing and modeling the potential contributions of manmade structures to fragile barrier island systems (Flocks and Clark 2011).

Louisiana’s Chandeleur barrier island chain, located approximately sixty miles east of New Orleans, is critical to endangered species breeding, shorebird rookeries, and fisheries and wildlife food chain support (Figure 1). The barrier islands have experienced accelerated change during the last half-century, undergoing a westward migration and significant loss of habitats. These changes are primarily caused by erosive severe storm events such as; Hurricane Camille (165 miles per hour [mph]; 17 August 1969),

Hurricane Georges (95 mph; 28 September 1998), Hurricane Earl (85 mph; 2 September 1998), and Hurricane Katrina (140 mph; 29 August 2005). These conditions can be exacerbated by sea level rise associated with climate change, and scarcity of sediment that is required to nourish the island chain. Previous studies have shown that even low-intensity storms can cause large coastal changes in the Chandeleur Islands system (Lavoie et al. 2010). Figure 1 shows the tracts of all tropical storms and hurricanes that have impacted the Chandeleur Islands since the 1960s. These storm events accelerated shoreline erosion, reduced elevations, and narrowed many island features.

Figure 1. Location map depicting the Deepwater Horizon explosion site, the extent of oil spill (dark brown regions represent oil extent on 19 June 2010 – one day before berm construction began and the light brown regions represent the cumulative extent based on daily Synthetic Aperture Radar analysis; NOAA 2014), and the Chandeleur Islands and sand berm location. Tracts of tropical storms and hurricanes that have impacted the Chandeleur Islands since the 1960s are shown as dashed lines.

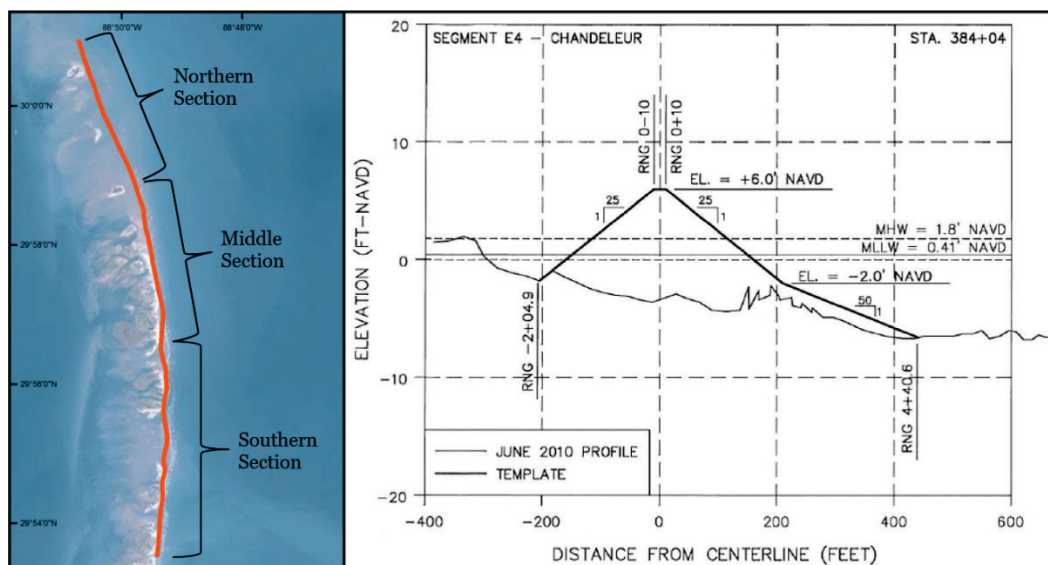


1.2 Berm

In an effort to retard Deepwater Horizon disaster oil from reaching and impacting the barrier islands and inland wetlands, the “eastern barrier

berm” (hereinafter referred to as the “Chandeleur Islands berm” or “sand berm”) was constructed (construction began 20 June 2010 and ended 21 March 2011). Figure 2 illustrates the location of the sand berm’s three distinct sections: (1) the northern section which was built in open water; (2) the middle section which was built immediately adjacent and approximately 230–295 ft seaward of existing and emergent barrier islands (entirely on water-bottoms); and (3) the southern section, which was placed directly on island beaches to minimize the volume of sediment required (LOCPR 2011, Plant and Guy 2013a). Figure 2 also contains the sand berm design template, which shows the sand berm was constructed with a +6 ft North American Vertical Datum (NAVD88) crest elevation, 20 ft crest width, and 1V:25H above -2 ft (NAVD) and 1V:50H below -2 ft (NAVD) slopes. The base of the sand berm measured approximately 400 ft at the -2 ft (NAVD) elevation.

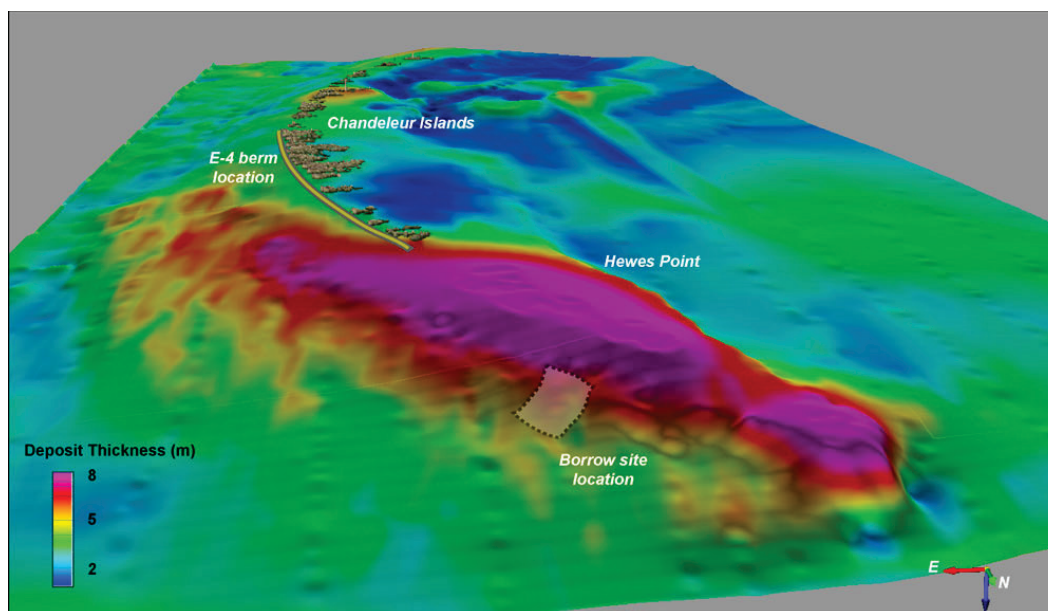
Figure 2. General location of the constructed Chandeleur Islands berm, the three distinct placement locations, and berm design template (Chicago Bridge and Iron Company Coastal Planning & Engineering, Inc. 2012a).



As stated previously, sand resources along coastal Louisiana (specifically outside of the active deltas) are exceedingly scarce (Lavoie et al. 2010). However, Hewes Point, which lies at the northern terminus of the Chandeleur Islands chain, consists of high quality quartz sand in a setting that modern oceanographic processes can no longer rework beyond the littoral system (Twichell et al. 2009). Figure 3 illustrates the general location of the berm with respect to the northern Chandeleur Islands reach and the Hewes Point borrow site. Figure A1 (Appendix A) illustrates the borrow

areas from which approximately 158 million ft³ of sediment were removed for the construction of the Chandeleur Islands sand berm (LOCPR 2011; 2015). Dredged sands were either placed directly within the berm footprint (northern reaches) or were transported to re-handling areas prior to placement within the berm's southern sections (Figure A1) (LOCPR 2015). It is estimated that approximately 86 million ft³ of dredged sediments were utilized to construct the Chandeleur Island sand berm (LOCPR 2015). The total cost of construction, \$251,080,339, is only available for the combined western barrier and eastern barrier berms (Louisiana Legislative Auditor 2011). This is due to the fluid nature of equipment and personnel during construction, and since the construction contract was not issued on a cost per island basis (Robert Routon, pers. comm. 17 April 2015).

Figure 3. Location of the Chandeleur Islands sand berm and the Hewes Point borrow site along the terminal spit (figure courtesy of Flocks et al. 2012).



1.3 Scope

Few areas in coastal Louisiana have suffered more drastic changes to shoreline position, geometry, and configuration than the Chandeleur Islands (Martinez et al. 2005a). This sensitive system is on the verge of collapse and is highly susceptible to additional pressures, including anthropogenic activities. Therefore, the purpose of this study is to quantify the evolution of the oil-spill-mitigation sand berm, monitor the sand berm's resilience and performance, and assess potential impacts and benefits to the Chandeleur Islands. Assessing the resiliency and evolution of the

sand berm and subsequent conditions of island features requires the analyses of historical and recent elevation, habitat, and shoreline change. Therefore, the objectives of this study were to (1) quantify changes in sand berm areal extent over time; (2) provide historical shoreline, habitat, and landscape assessments of the Chandeleur Islands; (3) assess elevation changes and potential reworking of berm sediment into the island system; and (4) develop descriptive and summary statistics and products.

2 Methods

The assessments performed within this study consist of near-term sand berm length, land change, elevation analyses, and historical habitat and shoreline change. Given limited field access to the Chandeleur Islands chain, Geographic Information Systems (GIS) and remote sensing techniques were ideally suited for this project. Remote sensing provided a means to classify landscape features to assess the distribution and change of those features over time. The spatial analyses performed as part of this study fell into two general categories, near-term berm-specific assessments and historical or long-term island-specific assessments. The berm-specific analyses consisted of processing and/or classifying of recently acquired aerial photography, high resolution airborne imagery, light detection and ranging (LiDAR) data sets, and elevation survey data. For historical assessments, data consisted primarily of Barrier Island Comprehensive Monitoring (BICM) program shoreline data (Fearnley et al. 2009; Martinez et al. 2005a), National Wetlands Inventory (NWI) data (U.S. Geological Survey [USGS] 1980a; 1980b; 2004), and newly derived habitat and shoreline data. In addition to these data sets, other existing geospatial data (i.e., Submerged Aquatic Vegetation [SAV]), historical maps, and reports were used as ancillary interpretive information.

2.1 Elevation

Two forms of elevation data were utilized in this study. The first were LiDAR data and the second were field survey elevation data. The LiDAR (2010, 2011, and 2012) and field surveys (2010–2012) consist of bare earth elevations in various multipoint formats. These formats, LASer (.LAS) and .XYZ, were converted to raster surface layers via Kriging interpolation.

2.1.1 LiDAR

The 2010 Experimental Advanced Airborne Research LiDAR (EAARL) data (USGS 2010), which were flown on 3 March 2010, provides an accurate and highly detailed bare-earth digital elevation model (DEM) of the Chandeleur Islands. The DEMs were produced from remotely sensed and geographically referenced elevation measurements cooperatively processed and disseminated by USGS and the National Aeronautics and Space Administration (NASA). With vertical resolution of ± 0.49 ft and a sampling

rate of 3 kilohertz or higher, EAARL data provide an extremely dense spatial ground elevation dataset. As with the 2011 and 2012 LiDAR data, the 2010 EAARL data were converted to the North American Datum (NAD) 1983 Universal Transverse Mercator (UTM) Zone 16 and the North American Vertical Datum (NAVD) of 1988 (using the GEOID09 model) coordinate systems.

The 2011 LiDAR data were collected on 31 May by the Compact Hydrographic Airborne Rapid Total Survey (CHARTS) system (U.S. Army Corps of Engineers 2013). As part of CHARTS, data coverage generally extends along the coastline from the waterline inland 1640 ft (topography) and offshore approximately 3281 ft (bathymetry). CHARTS data were classified into the following classes: unclassified valid topographic data, valid topographic data classified as ground, invalid topographic data classified as low-points, valid topographic data acquired with the bathymetric sensor, and invalid topographic and bathymetric data.

The 2012 LiDAR data were acquired on 6 February by Digital Aerial Solutions, LLC (contracted by the USGS) to document the short- and long-term changes along the Chandeleur barrier island system (USGS 2013). The data were collected at a nominal pulse spacing of 1.64 ft. The point cloud data were processed to extract bare earth data and were classified into the following classes: unclassified, ground, water, and break-line proximity.

2.1.2 Survey elevation

Survey elevation data along the berm-specific reaches of the Chandeleur Islands were collected by Chicago Bridge and Iron (CB&I) Coastal Planning & Engineering, Inc. (CB&I 2012b). Elevation surveys were performed along transects perpendicular to the island on six separate occasions (Table 1). The surveys primarily focused on the area surrounding the berm, from approximately 8202 ft seaward to 1640 ft inland. Transect line and survey point spacing averaged approximately 492 ft and 1.64 ft, respectively. Elevation data were collected prior to construction of the berm, upon completion of the berm (as-built), and at 30-, 90-, 180-, and 360-days post-construction. Survey names and dates are provided in Table 1. Survey elevation data consisted of transect information and elevation measurements (in feet) recorded in the NAD 1983 State Plane Louisiana South coordinates system and saved in the XYZ format. All XYZ point data were rasterized using a Kriging interpolation method and transformed to the NAD 1983 UTM Zone 16N coordinate system.

Table 1. Names and dates of field elevation surveys along the Chandeleur Islands sand berm.

Survey	Date
Pre-Construction	July 2010
As-Built	May 2011
30-day	July 2011
90-day	September 2011
180-day	January 2012
360-day	July 2012

To compute elevation differences between paired LiDAR and paired survey elevation data, respectively, the Spatial Analyst Minus tool was used in ArcGIS. This function subtracts the value of the end-date raster from the value of the begin-date raster on a cell-by-cell basis, producing an output raster containing difference or change values (ESRI 2014).

2.2 Berm length

The ability of the sand berm to maintain its form, in both elevation and length, were critical components for satisfying the primary project goal of retarding oil from reaching the Chandeleur Islands and inland wetlands. The berm length assessments performed as a part of this study relied heavily on work published by Plant and Guy (2013a; 2013b; 2013c). The high reflectivity of the sand used to construct the berm and the large linear nature of the berm provide opportunities to utilize high temporal, and moderate spatial resolution space, and air-borne data to identify and measure the length of berm segments over time (Plant and Guy 2013a). Plant and Guy (2013a; 2013b; 2013c) utilized moderate resolution SPOT4, SPOT5, and Landsat satellite images; and higher resolution LiDAR data sets to locate and measure the length of berm segments. Berm segments are defined as any portion of the berm that remained sub-aerial within its as-built footprint and were visible through photo-interpretation. For all assessments, the berm footprint will be defined as the 400 ft wide portion of the berm at -2 ft elevation (NAVD88). As part of this study, newly acquired high resolution airborne imagery were used to augment and extend the assessments performed by Plant and Guy (2013a; 2013b; 2013c). Since Plant and Guy (2013a; 2013b; 2013c) concluded that the full length of the berm had eroded by August of 2012, two end-point and one intermediate images were chosen to corroborate their findings. The 2011 (collected April–May, 2011; Natural Resource Damage Assessment [NRDA]), 2012 (collected April, 2012; NRDA) and 2013 (collected August, 2013; National

Agricultural Imagery Program [NAIP]) composite Digital Mapping Camera (DMC) imagery provides post-construction and recent data used to identify berm breaches and visually interpret and measure the length of sand berm segments (from northern-to southern-most terminus).

2.3 Landscape

2.3.1 Habitat

Data classification can aid in the identification and location of land loss and land gain due to landscape changes and land management activities, particularly when dealing with habitat and shoreline erosion. Habitat data generation using aerial photo-interpretation and GIS technology have been an efficient and accurate means to document and inventory landscapes and to assess and monitor trends, especially for sensitive and high priority areas that are subject to rapid change.

Landscape assessments performed as part of this study consisted of historical and recent habitat analyses based on standardized systems and other methodologies developed by the authors for prior coastal trend studies (Suir et al. 2011; Saltus et al. 2012; Suir et al. 2013a; 2013b; Suir et al. 2014). One classification system, the U.S. Fish and Wildlife Service's (USFWS) NWI Classification of Wetlands and Deepwater Habitats (Cowardin et al. 1979), is a nationally standardized and hierarchal system of habitat categorization developed from photo-interpretation. While providing a national standard, this system can be modified to better interpret site- or condition-specific habitats.

Currents, tides, waves, and wind energies are forces consistently eroding and redistributing barrier island sediments. To monitor the Chandeleur Islands and the newly created sand berm, a modified NWI classification scheme was developed to map the existing island features, while separately classifying the sand berm, its sediment, and its tidal characteristics. Within this classification scheme "Land" represents pre-existing uplands, dunes, vegetated dunes, emergent vegetation, and scrub-shrub. For classification of the newly constructed sand berm, differentiations of substrate (unconsolidated shore) were based on three tidal water regime modifiers: (1) "Irregularly Flooded" (2) "Regularly Flooded," and (3) "Irregularly Exposed." These classes, which are based on time and duration of flooding, are modified from the NWI system. Irregularly Flooded areas are defined as tidal water that floods land surfaces less often than daily. Irregularly

Exposed areas are defined as land surfaces exposed by tides less often than daily. Regularly Flooded areas are defined as tidal water that alternately floods and exposes the land surface at least once daily. Because of tidal fluctuation, water classes are based on water levels at the time of image acquisition. Using this classification approach, the degradation process and subsequent distribution of sediment can be quantified. Final classified habitat categories consisted of: (1) Land (pre-existing island features), (2) Irregularly Flooded, (3) Regularly Flooded, and (4) Irregularly Exposed.

The landscape assessments consisted of historical and recent time periods. The historical assessments consisted of decadal or greater time-periods and the recent (berm-specific) analyses generally consisted of shorter time-steps. However, the periods of analysis were ultimately based on data availability (classified or unclassified) and time requirements for performing additional habitat classifications. The historical data consisted of multiple dates of NWI sets (1956, 1978, and 1988) and multiple sets of BICM habitat data (1996, 2004, and 2005). Modifications were made to these “historical” data sets so they better coincided with the unconsolidated shore classes established for use with “recent” habitat data. The recent data analyses consisted of multiple sets of modified habitat data derived specifically for this study using high resolution 2008 USGS (3.28 ft) 4-band color infrared orthoimagery, 2011 USGS (1 ft) 4-band color infrared DMC imagery (NRDA), and 2013 USDA (3.28 ft) RGB true color DMC imagery (NAIP). The 2008, 2011, and 2013 data provide documentation of the most recent changes in Chandeleur Islands habitats in detail not available from other mapping efforts.

Data source and data development can have huge impacts on results, especially if those results are compared to data sets generated using different methods, standards, and formats. There are a number of concerns when employing data across a long time period and in highly dynamic ecosystems. Some primary concerns are variations in data format, projection, and registration. A significant horizontal misalignment in the 2013 imagery was observed. Misalignments in barrier island systems are common given the combination of constant movement of sediment in the system with the island’s slender, elongated, and ever changing features. These conditions make control point identification for image rectification difficult. Projection standardization (Universal Transverse Mercator, North American Datum Zone 16) and image-to-image co-registrations (geo-

rectification using the 2011 imagery as the control) were performed for all existing data (NWI and BICM) and imagery (2008, 2011, 2013).

Habitat classifications were derived from the high-resolution natural color and color infrared digital imagery. Habitat features were delineated based on photo radiance, contrast, texture, and pattern recognition; then digitized through manual on-screen interactive "heads-up" techniques. These individual features were then classified as land or one of the three unconsolidated shores. Ancillary data sets from 2005 through 2012 were used to help classify problematic features. Duplicate Quality Assurance and Quality Control (QA/QC) assessments were performed on all preliminary classified data to assure accuracy and integrity. Secondary photo-interpretations were performed on all vector data to further categorize the unconsolidated shores into the three tidally influenced subclasses. Following the secondary photo-interpretation, an additional QA/QC assessment was performed prior to finalization of the data.

2.3.2 Submerged Aquatic Vegetation (SAV)

The only significant communities of SAV in coastal Louisiana exist in sandy sediments of the Chandeleur's shallow back-barrier lagoon (LaRoe et al. 1995). These SAVs, which have remained virtually unaffected by human impacts, are controlled primarily by geological processes related to storms and barrier island dynamics (Friend 1995; Poirrier and Handley 2007).

Since Louisiana's SAVs are largely dependent on the fate of the highly fragile Chandeleur Island chain, the SAV habitat and wetlands in this area have been intensively mapped (Poirrier and Handley 2007). Two SAV data sets, 1992 and 2010, were acquired and utilized within this study. These data were developed by the USGS and intended as a comprehensive assessment of the distribution and extent of SAV communities along the northeast Gulf of Mexico (1992) and off-shore of the Chandeleur Islands after the Deep Water Horizon oil spill (2010).

USGS personnel derived the 1992 data set from seven 7.5' quadrangles, which were digitized at the Mid-Continent Ecological Science Center from 1:24,000 scale hard copy maps. The seagrass beds were classified according to a classification scheme developed at the U.S. Environmental Protection Agency "Seagrass Mapping Meeting" in 1990 (Handley et al. 2007). This hierarchical classification system assesses the presence of SAV then

subdivides SAV classes based on continuity of beds and the percentage of patchiness.

The SAV Technical Working Group (under a cooperative workplan with BP) derived the 2010 SAV data from 1 ft resolution visible and near-infrared imagery collected by Aerometric in October 2010 (NOAA 2012). The imagery was segmented into homogeneous image objects following an object-based image analysis (OBIA) approach. The image objects were subsequently classified using Classification and Regression Tree (CART) statistical analysis. Manual edits based on photo-interpretation were performed to refine the data and adhere to a minimum mapping unit of 43 ft².

2.4 Shoreline

As with landscape assessments, shoreline assessments consisted of historical and recent data. Shoreline assessments utilized historical BICM program data, which consisted of shoreline vectors digitized using historical maps, satellite imagery, and aerial photography from 1855, 1922, 1996, and 2004. Recent shorelines were identified and digitized using the location of the wet and dry-beach contact line (high-water line) from the same image sources as used for the landscape assessments (2008, 2011, and 2013).

The historical and recent shoreline vectors were then appended into a geodatabase. The Digital Shoreline Analysis System (Himmelstoss 2009) was used to generate transects (for measurement locations) and the shoreline geodatabase to calculate change rates for each period of analysis. The change rates were calculated by dividing the distance of shoreline movement by the time elapsed between the start and end dates (for each time period).

The combination of historical BICM and recent data provide a comprehensive shoreline-change analysis of the Chandeleur Islands (corresponding to berm location) that defines the character and patterns of shoreline change and quantifies the rates of linear shoreline retreat (Kindinger et al. 2013) before and after the construction of the sand berm.

3 Results

3.1 Elevation

3.1.1 LiDAR

LiDAR data provide a general overview of elevation and elevation changes that occurred along the northern Chandeleur Islands. panels A, C, and E in Figure 4 represent topographic elevations pre-, post-, and approximately 1-year after construction of the sand berm, respectively. Panel A (Figure 4) shows landscape features highly fragmented (separated by numerous breaches and passes) with varying ranges of elevation typical for barrier island profiles (highest elevation at the island dune that decrease towards the back island marsh platform). This 2010 landscape consisted of island features with a maximum elevation of 7.99 ft (NAVD) and an overall average height of 1.29 ft. Panel C (Figure 4) represents elevations along the newly constructed berm and existing island features. These new berm features, which are visible in open water (northern section), nearshore (middle section), and along the island's beach (southern section) closed many of the island's existing breaches and passes (Figure 2). The 2011 landscape consisted of berm features with a maximum elevation of 12.03 ft and an overall island/berm average height of 2.01 ft. Panel E (Figure 4) represents the island/berm complex at approximately one year post construction of the sand berm. In February 2012, the maximum elevation along the berm was 9.98 ft and the overall island/berm average height was 1.54 ft.

Panels B and D represent elevation change assessments performed for each period of LiDAR analysis. To identify areas of significant change, all nominal elevation changes (± 1 ft) were omitted from these assessments. Panel B (Figure 4) represents the elevation changes that occurred between March 2010 and May 2011. Significant increases in elevation (dark green) were observed along the constructed berm feature, averaging 2.61 ft above the 2010 elevations within the berm footprint (based on subaerial elevations). The increase in berm elevation between 2010 and 2011 was coupled primarily with slight increases in elevation (green in Panel B [Figure 4]) within many of the existing island features. Panel D (Figure 4) represents the change in elevation between 2011 and 2012. Red features along the sand berm represent areas that experienced decreased elevations. It is likely that much of that decrease was the result of overtopping and the re-

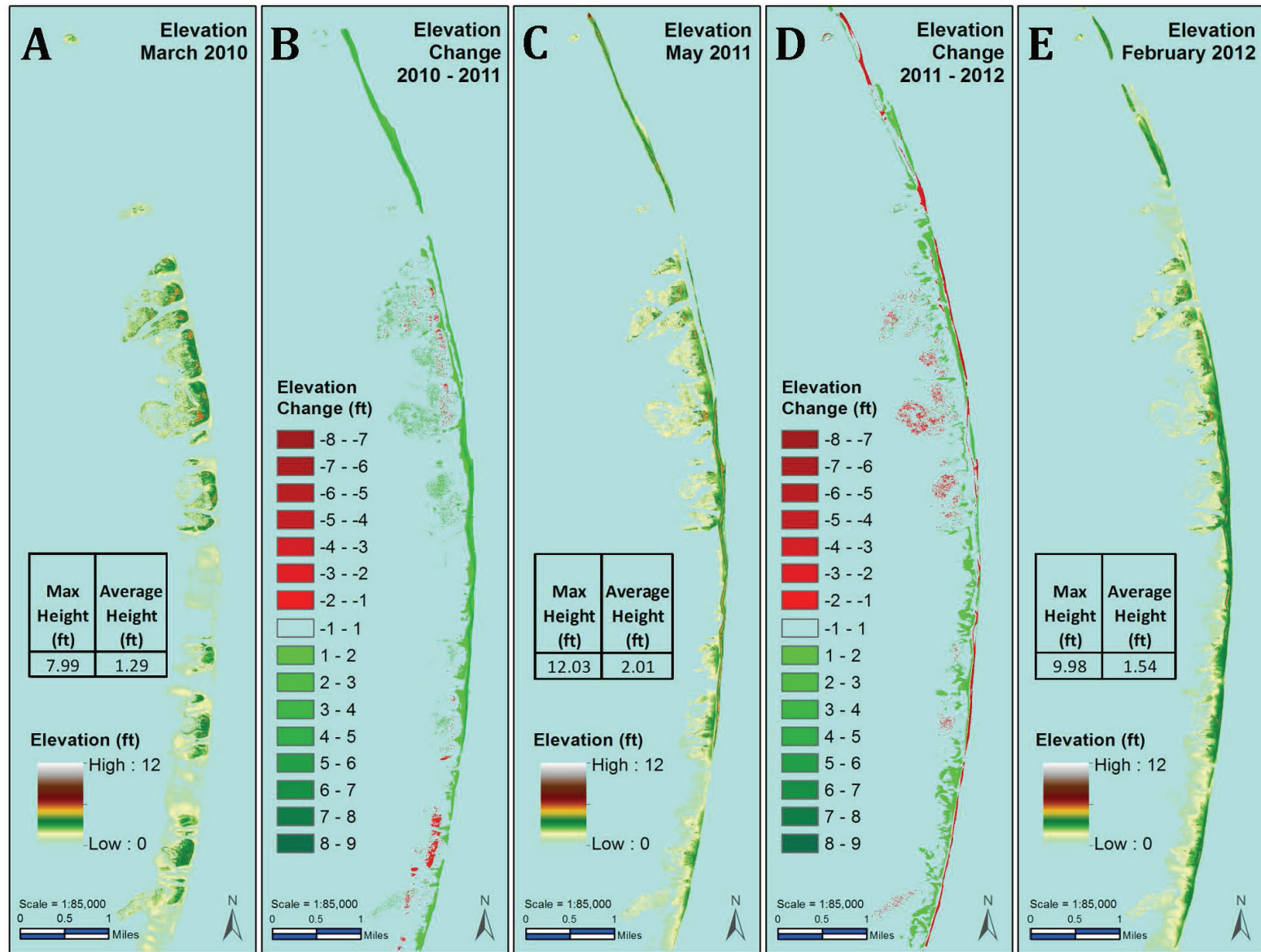
distribution of sediment to areas in close proximity to the berm. These new areas of increased elevation appear as green features along the berm footprint (many are landward of the berm) in Panel D (Figure 4).

3.1.2 Survey elevation

Table 2 and Figure 5 provide survey elevation summary statistics, elevation surfaces, and elevation change for each survey date and periods of analysis, respectively. Data are provided based on the entire survey area and the berm specific footprint. Panels A, C, E, F, H, and J of Figure 5 represent the pre-construction, as-built, and 30-, 90-, 180-, and 360-day post-construction survey elevation data, respectively. These color-ramped layers range from -35.2 ft (NAVD) elevation (dark blue) near the depth of closure, to +7.8 ft elevation (orange) along the highest berm and island features. Areas that are $\geq +3$ ft elevation are represented in these panels by the dark umber color. Panel A (Figure 5) shows that only two very small areas (approximately 200 acres) exhibited elevations above +3 ft. This total pre-construction landscape had a maximum elevation of +5.8 ft (+3.9 ft within berm footprint) and an average elevation of -13.1 ft (-1.92 ft within berm footprint; Figure 5 and Table 2). The as-built berm, visible in Panel C (Figure 5), had a maximum elevation of +7.8 ft and an average elevation of +1.97 ft. Similar to the LiDAR data, the survey elevation data show that over the course of a year (panels E, F, H, and J) (Figure 5), the northern section of the berm experienced thinning and breaching, while the middle and southern sections experienced more localized movement of sediment, resulting in widening of the sand berm.

Table 2 shows the maximum and average heights (shown in parentheses) of the berm were measured at +7.4 (+2.16 average), +6.7 (+0.87), +5.4 (+0.79), and +5.2 (+0.71) ft for the 30-, 90-, 180-, and 360-day post construction surveys, respectively. Discrepancies in maximum heights between the LiDAR and survey elevations are possibly due to the spacing of the survey transects and the small and isolated areas of maximum height (mounds) along the berm. By the 360-day survey, less than half of the survey points within the 400 ft wide berm footprint retained elevations above the +1.8 ft Mean High Water (MHW) mark. It should be noted that with time the locations of maximum elevations changed from within, to outside of the berm footprint.

Figure 4. Chandeleur Islands sand berm project area Light Detection And Ranging (LiDAR) elevations and elevation change between March 2010 and February 2012.



These changes (movement of berm sediment) are observed in panels B, D, G, and I of Figure 5, which represent elevation change assessments performed for each period of survey analysis. Panel B (Figure 5) shows the increase in elevation that resulted from the construction of the berm (dark green). By the 30-day survey (panel D) (Figure 5) the redistribution of berm sediments began, resulting in reduced elevations (pink areas) along the berm (specifically within the middle section) and increased elevations (green areas) beyond the berm footprint. The redistribution of berm sediment continued, as observed in the 90- to 180-day and 180- to 360-day post construction elevation change assessments (panels G and I) (Figure 5). However, the extent of change (elevation and location) slowed considerably by the 180- and 360-day surveys. This may have been the result of: (1) berm sediment stabilization, (2) sediment redistribution into thin layers across the island platform (elevation changes of ± 1 ft omitted from assessment), (3) redistribution of sediment into the shallow back island bay, (4) sediment transported outside of the system, or (5) a combination of these processes.

Table 2. Survey elevation summary statistics
(modified from CB&I Coastal Planning & Engineering, Inc. 2012b).

Survey	Total Survey Area			Berm Footprint†		
	Minimum Elevation (ft)	Maximum Elevation (ft)	Mean Elevation (ft)	Minimum Elevation (ft)	Maximum Elevation (ft)	Mean Elevation (ft)
Pre-Construction	-35.2	5.8	-13.10	-8.2	3.9	-1.92
As-Built	-34.1	7.8	-13.41	-3.6	7.8	1.97
30-Day Post	-23.7	7.4	-7.97	-5.7	7.4	2.16
90-Day Post	-23.8	7.1	-10.13	-6.9	6.7	0.87
180-Day Post	-22.4	6.6	-9.92	-7.2	5.4	0.79
360-Day Post	-29.3	7.1	-10.80	-7.8	5.2	0.71

† Berm construction area above -2 ft NAVD.

Figure 6 provides a more detailed depiction of elevation changes that occurred within and beyond the berm over the course of the as-built to 360-day post-construction period of analysis. This figure shows that the northern, central, and southern reaches of the berm experienced significant reductions in elevation within the berm footprint. Only the northern reach of the “southern section” retained any significant areas of elevation. This is primarily due to the fact that the southern section of the berm was constructed directly on the island’s beaches. The vast majority of increases in elevation occurred along, yet outside of the berm footprint. These changes

indicate that the sediment that was used to construct the berm was redistributed by coastal processes both landward and seaward of the berm footprint. These findings are similar to those by Sherwood et al. (2014), who observed storm surge caused significant scour channels and seaward cross-barrier transport of berm sediment into the shallow nearshore of the island. Some small areas within the larger reaches of elevation loss either maintained their elevation, or experienced alternating segments of minor losses and gains. These changes are indicative of breaching and overtopping of the berm.

Figure 5. Chandeleur Islands sand berm project area survey elevations and elevation change from pre-construction to 360-day post-construction.

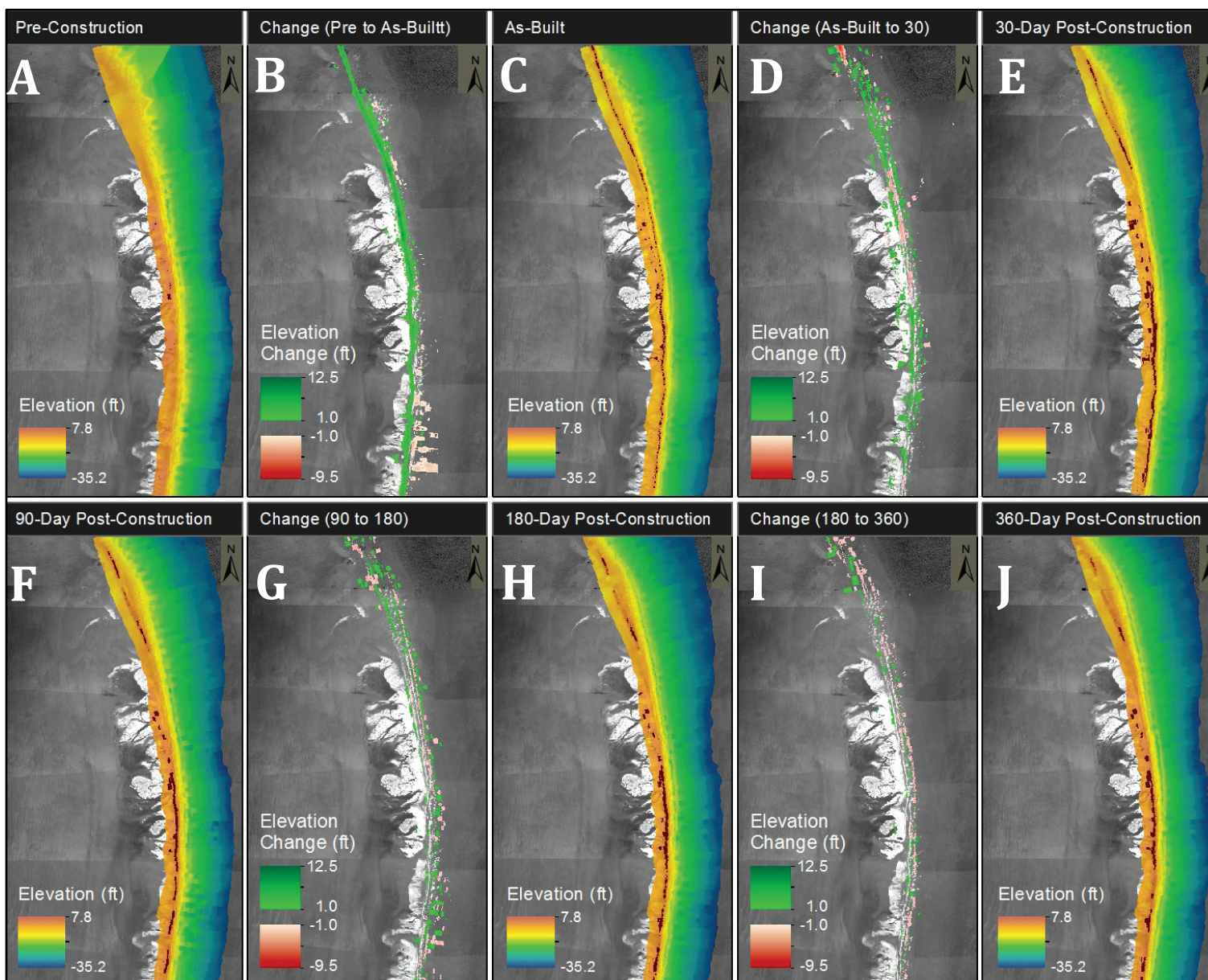
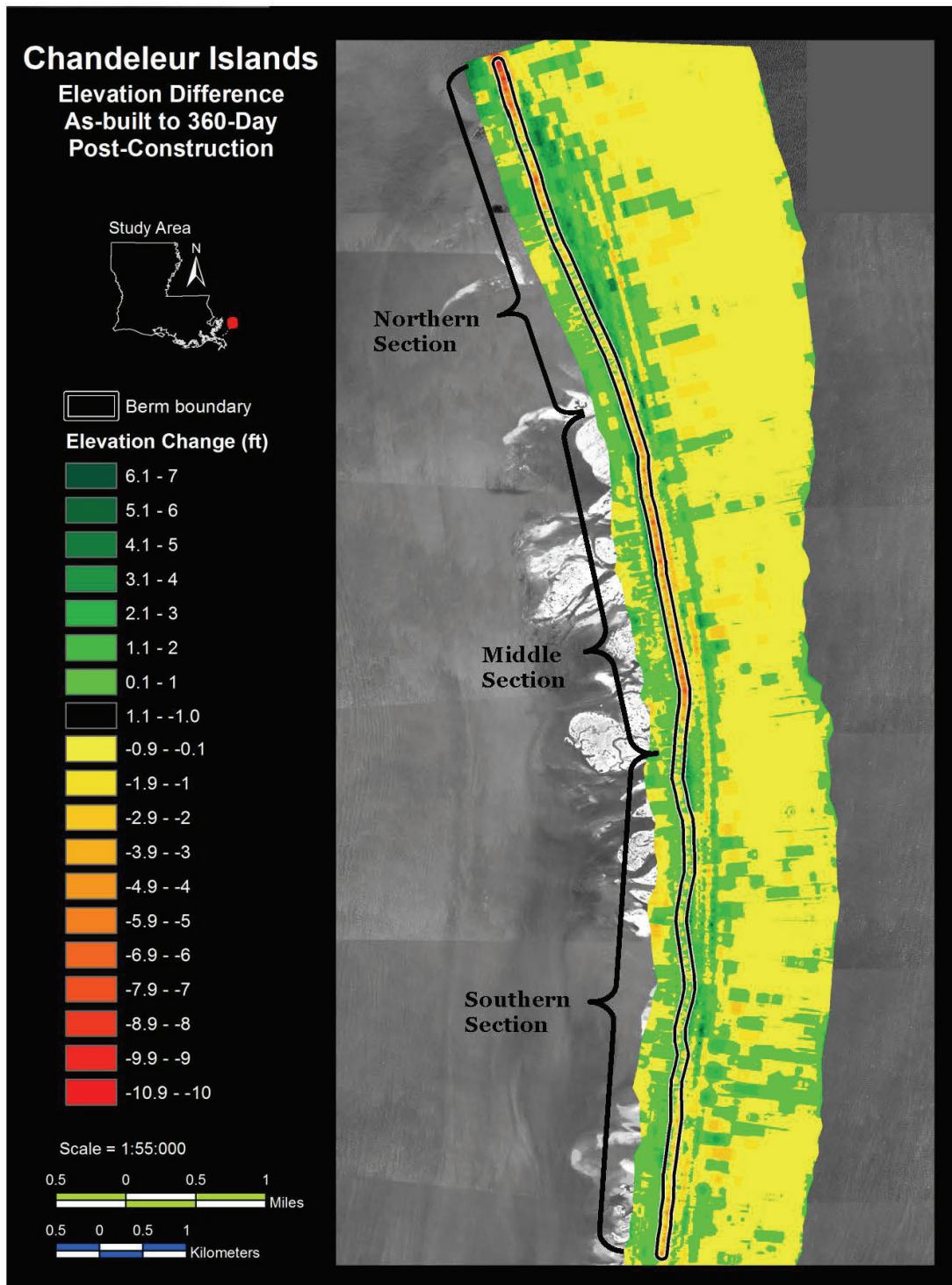


Figure 5. Chandeaur Islands sand berm project area survey elevation change from as-built to 360-day post-construction. The berm boundary represents the berm footprint above the -2 ft NAVD (Figure 2).



3.2 Berm Length

Berm length estimates from the higher resolution Digital Mapping Camera (DMC) imagery were used to corroborate the berm length findings by Plant and Guy (2013a; 2013b; 2013c). Figure 7 shows berm length observations, by section, using DMC, SPOT 4, SPOT 5, Landsat 5 and 7, and LiDAR data collected between 5 September 2010 and August 2013. These assessments of subaerial berm segments provide measures, change in length, inference to frequency of breaching, and overall description of berm evolution over time. In addition to the daily coastal processes acting upon the berm, two tropical storms impacted the Chandeleur Islands after the berm was constructed. Tropical Storm Lee (59 mph) and Hurricane Isaac (80 mph), made landfall in Louisiana on 3 September 2011 (+5.25 ft peak wave height, Mean Lower Low Water [MLLW]) and 28 August 2012 (+11 ft peak wave height, MLLW), respectively (Figure 8). Maximum wind gusts measured at NOAA's Shell Beach tide station (located approximately fifty miles due west of the Chandeleur Islands) were 55.7 mph (48.44 knots) and 78.7 mph (68.41 knots) for Tropical Storm Lee and Hurricane Isaac storm events, respectively (Figure 8). Significant reductions in berm length were observed after the landfall of these storms (represented by vertical bars in Figure 7).

The northern (upper panel) and southern (lower panel) sections (Figure 7) represent a berm that remained relatively stable through the construction period, but experienced significant reduction in length due to the effects of Tropical Storm Lee. Post Tropical Storm Lee, the Northern and Southern sections experienced continuous reductions in berm length, until full eradication by Hurricane Isaac. The changes in berm length within the middle section (middle panel) (Figure 7) were different than those observed in the northern and southern sections. The berm in the middle section underwent rapid post construction degradation, decreasing from 11,122 ft (total length) on 17 November 2010 to 3274 ft on 30 August 2011. The berm length assessments show that by 6 September 2011, Tropical Storm Lee's forces fully eliminated all subaerial segments of the sand berm within the middle section. The high resolution DMC data show that though 373 ft of berm were observed in April of 2012 (possible reworking of berm sediment), there were no subaerial segments observed in August of 2013. Ultimately, elevation and change data, in conjunction with visual assessments of three additional high resolution airborne images (orange circles in Figure 7), corroborate the berm length findings by Plant and Guy (2013a; 2013b; 2013c).

Figure 6. Time series of berm-length measurements from moderate- and high-resolution data sources (modified from Plant and Guy 2013a, 2013b, and 2013c). The upper, middle, and lower panels represent the northern, middle, and southern sections of the sand berm, respectively.

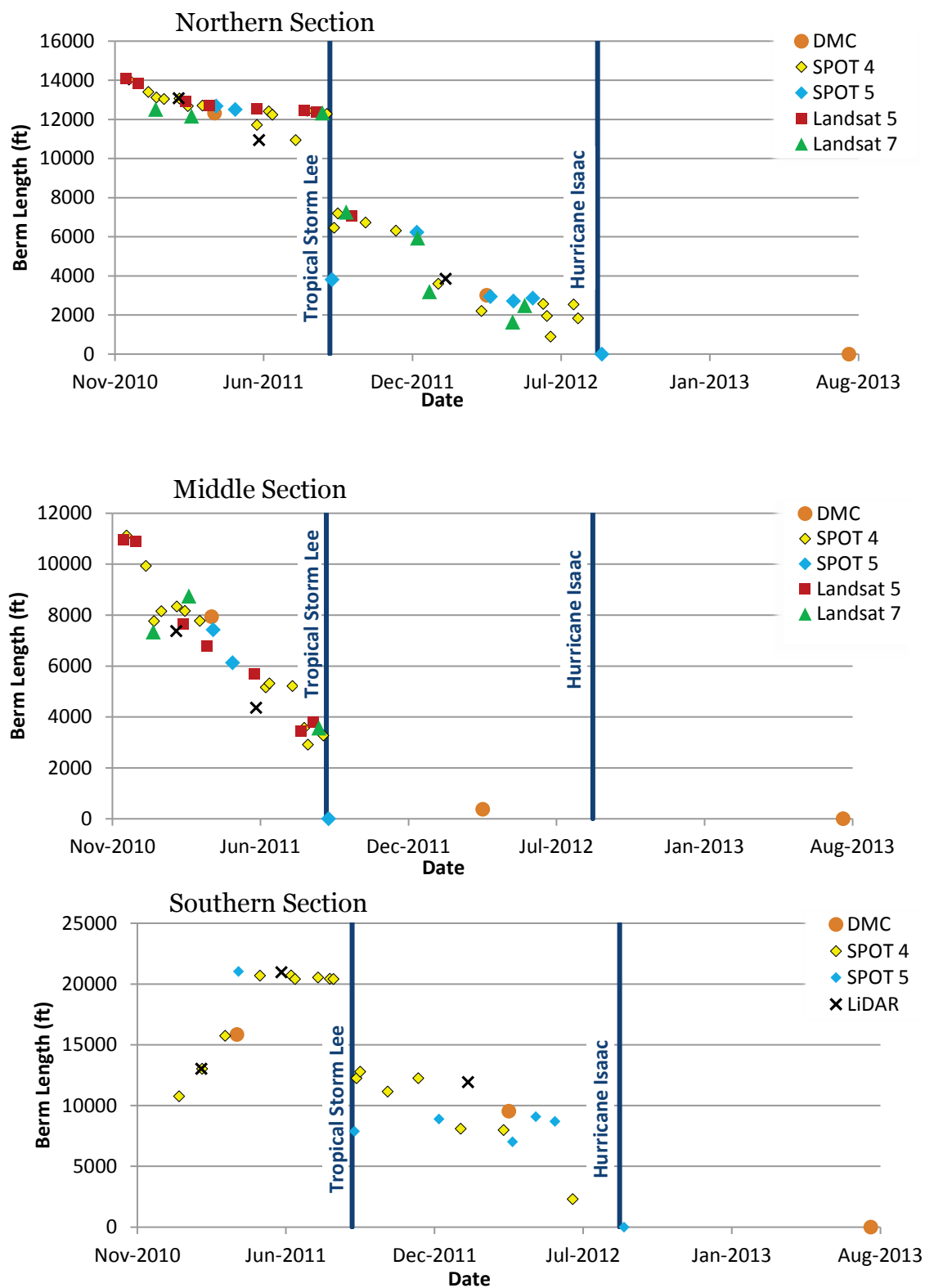
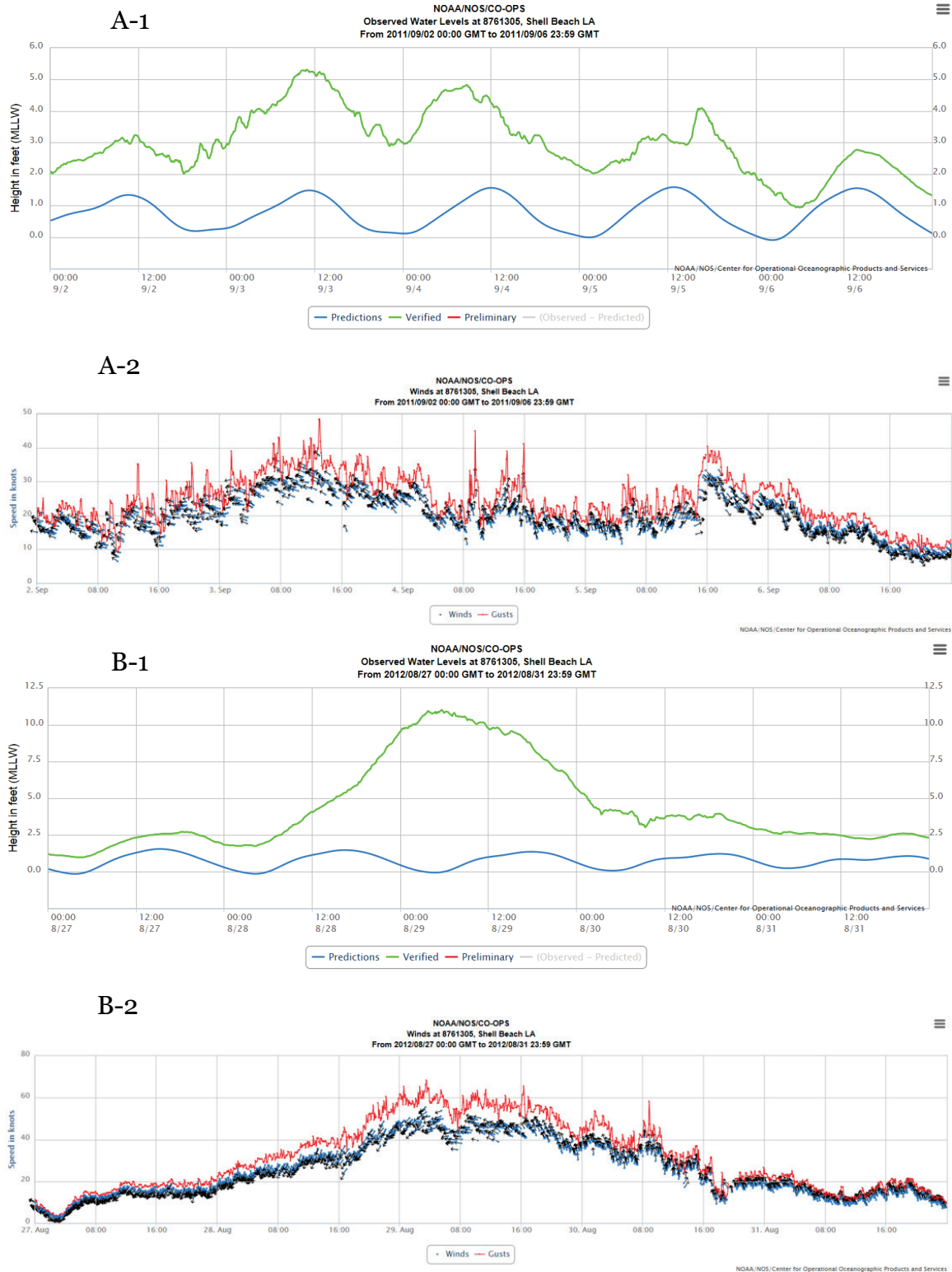


Figure 7. Observed water level heights and wind speeds and direction from the 8761305, NOAA tide station in Shell Beach, Louisiana. Water heights and wind data related to Tropical Storm Lee are in panels A-1 and A-2, respectively, while water heights and wind data related to Hurricane Isaac are shown in panels B-1 and B-2.



3.3 Landscape

3.3.1 *Habitat*

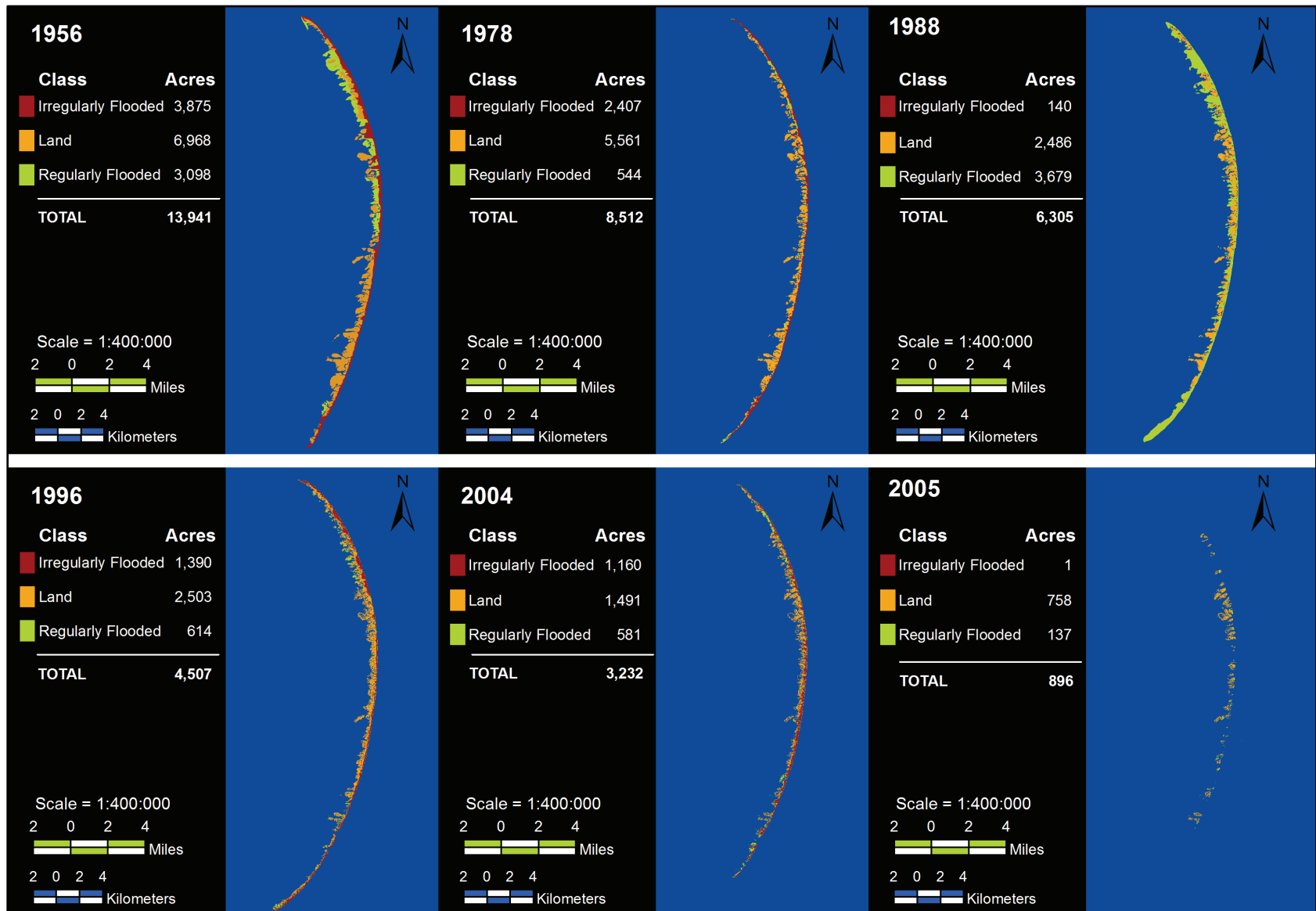
The landscape assessments performed as part of this study utilized existing “historical” habitat data, as well as “recent” habitat data derived specifically for this study. Table 3 and Figure 9 provide a historical perspective on the type, extent, and change of habitat (modified to coincide with recent habitat classifications) along the northern Chandeleur Islands. The northern Chandeleur Islands were once a stable and productive island system, consisting of approximately 7000 acres of saline marsh and scrub/shrub habitat, and approximately 7000 acres of unconsolidated shores, between 1855 and 1956 (Martinez et al. 2005b) (Figure 9).

Table 3. Habitat change acres and rates for the Chandeleur Islands.

Period	Habitat Change (acres)	Habitat Change Rate (acres/year)
1956-1978	-5,429	-247
1978-1988	-2,207	-221
1988-1996	-1,798	-225
1996-2004	-1,275	-159
2004-2005	-2,336	-2,336

Martinez et al. (2005a) report that the Chandeleur Islands habitat loss rates were on the order of tens of acres per year (acres/year) during the late nineteenth century to early twentieth century. However, largely due to the forces of Hurricane Camille (165 mph; 17 August 1969), the island experienced significant erosion and high habitat loss rates (-247 acres/year) between 1956 and 1978 (Table 3 and Figure 9). The rate of change remained relatively constant in subsequent periods, until reaching a rate of -2,336 acres/year between 2004 and 2005. The rate of habitat loss within this period was directly related to storm impacts induced by Hurricanes Katrina (174 mph; 29 August 2005) and Rita (177 mph; 24 September 2005).

Figure 8. Modified National Wetlands Inventory and Barrier Island Comprehensive Monitoring habitat data in the sand berm project area for the years 1956, 1978, 1988, 1996, 2004, and 2005.



Figures 10, 11, and 12 show the recent habitat analyses performed for this study; and provide pre-, as-built, and post-construction habitat data. Figure 10 shows that the island consisted of 2664 acres in 2008, a 1768 acre recovery after the hurricane events of 2005. The majority of those new acreages consisted of irregularly exposed (681 acres; pink areas in Figure 10) and regularly flooded (1458 acres; green areas in Figure 10) unconsolidated shores. By 2011, the sand berm was constructed and the total habitat area increased to 5055 acres (Figure 11). The berm, which consisted of approximately 650 newly constructed acres (LOCPR 2011), accounted for the majority of the 879 acres of irregularly flooded habitat. The berm (red areas in Figure 11) is clearly visible along the eastern edge of the island. However, the dominant feature (based on area) in 2011 was the 2926 acres of irregularly exposed habitat. These areas (pink) are indicative of sediment used in the construction of the sand berm but were quickly redistributed landward (west) of the berm. The 2013 habitat data in Figure 12 reveal the same landscape conditions observed in the elevation and berm length assessments. Visible are areas of berm breaching and reductions in elevation that resulted in a 350 acre loss in irregularly flooded habitat (berm) and a 978 acre increase in irregularly exposed habitat (continued redistribution of berm sediment landward of the island).

The focus of the historical and recent landscape assessments were primarily to show the historical trends along the Chandeleur Islands and the recent changes brought on by the construction of the berm and subsequent redistribution of those sediment within, and possibly out of, the island system. Figure 13 shows the Island habitat acreage (both land and unconsolidated shores) plotted against time, over the entire period of analysis (1956–2013). Figure 13 also illustrates the rapid decline in island habitat over the historical period (1956–2005) for both the land and unconsolidated shores classes. However, with the introduction of dredged sediments for berm construction, reductions in the land loss rate and an increase in the area of unconsolidated shores have been observed.

Figure 9. Chandeleur Islands sand berm project area 2008 modified habitat classification.

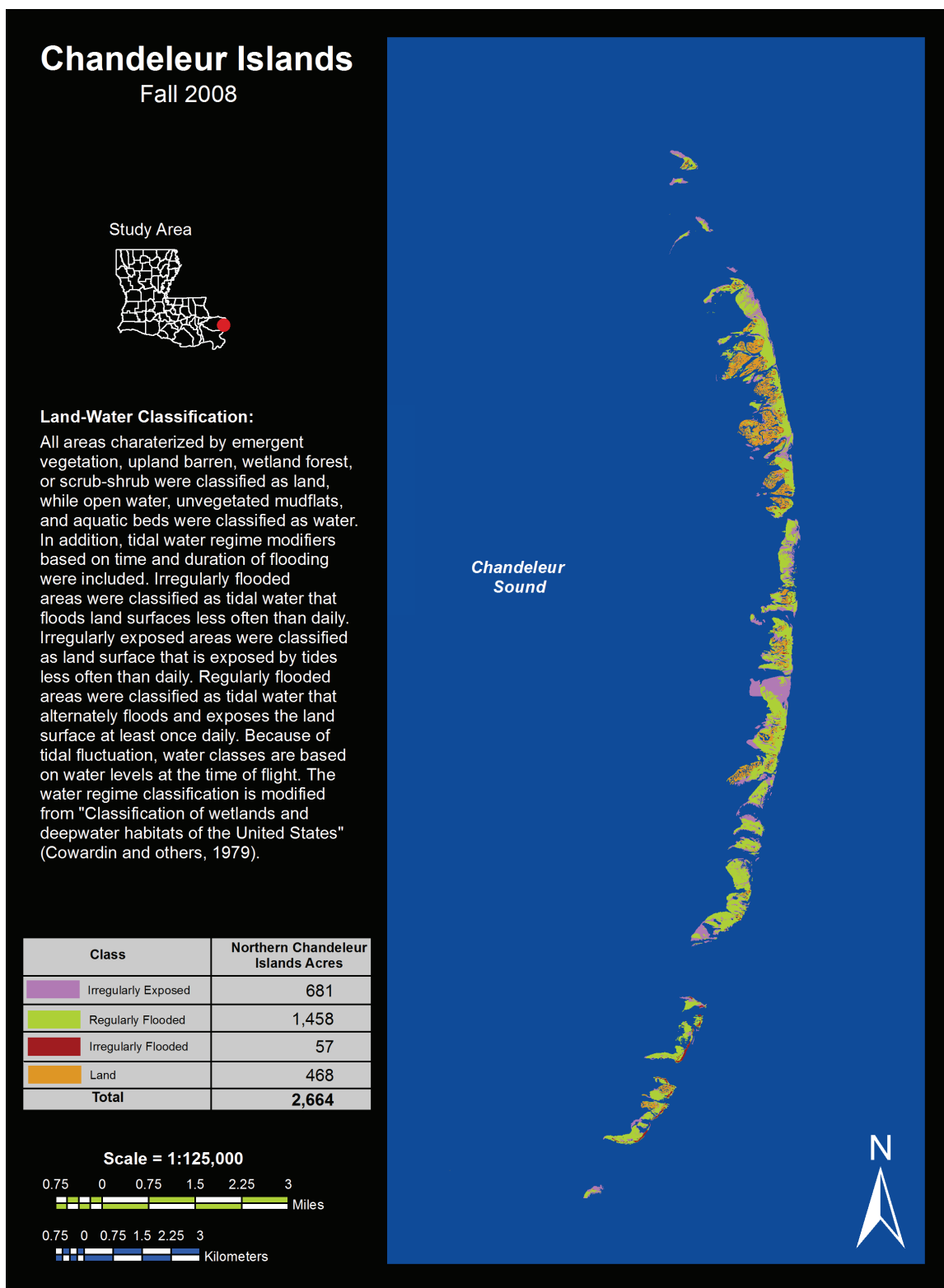


Figure 10. Chandeleur Islands sand berm project area 2011 modified habitat classification.

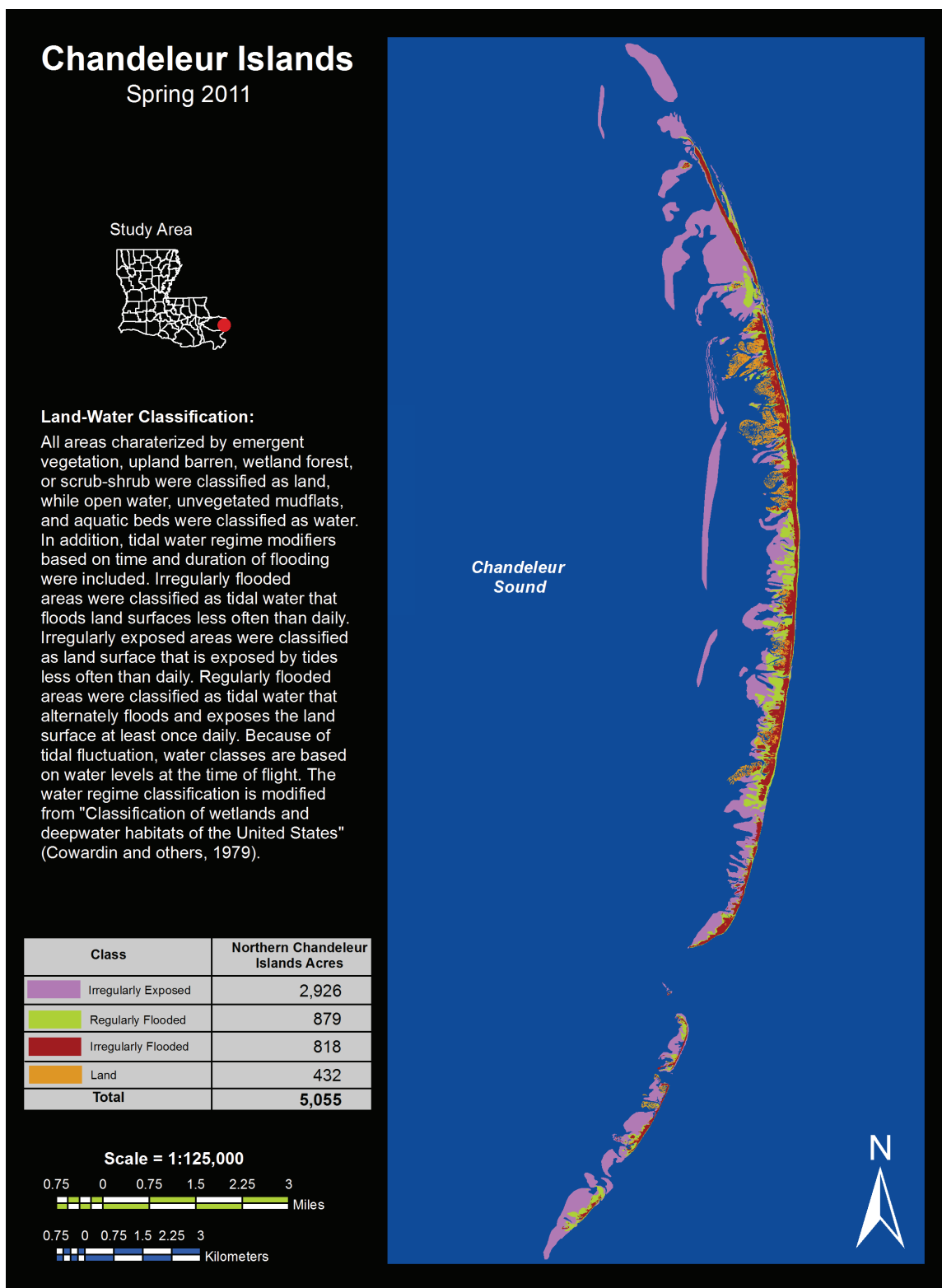


Figure 11. Chandeleur Islands sand berm project area 2013 modified habitat classification.

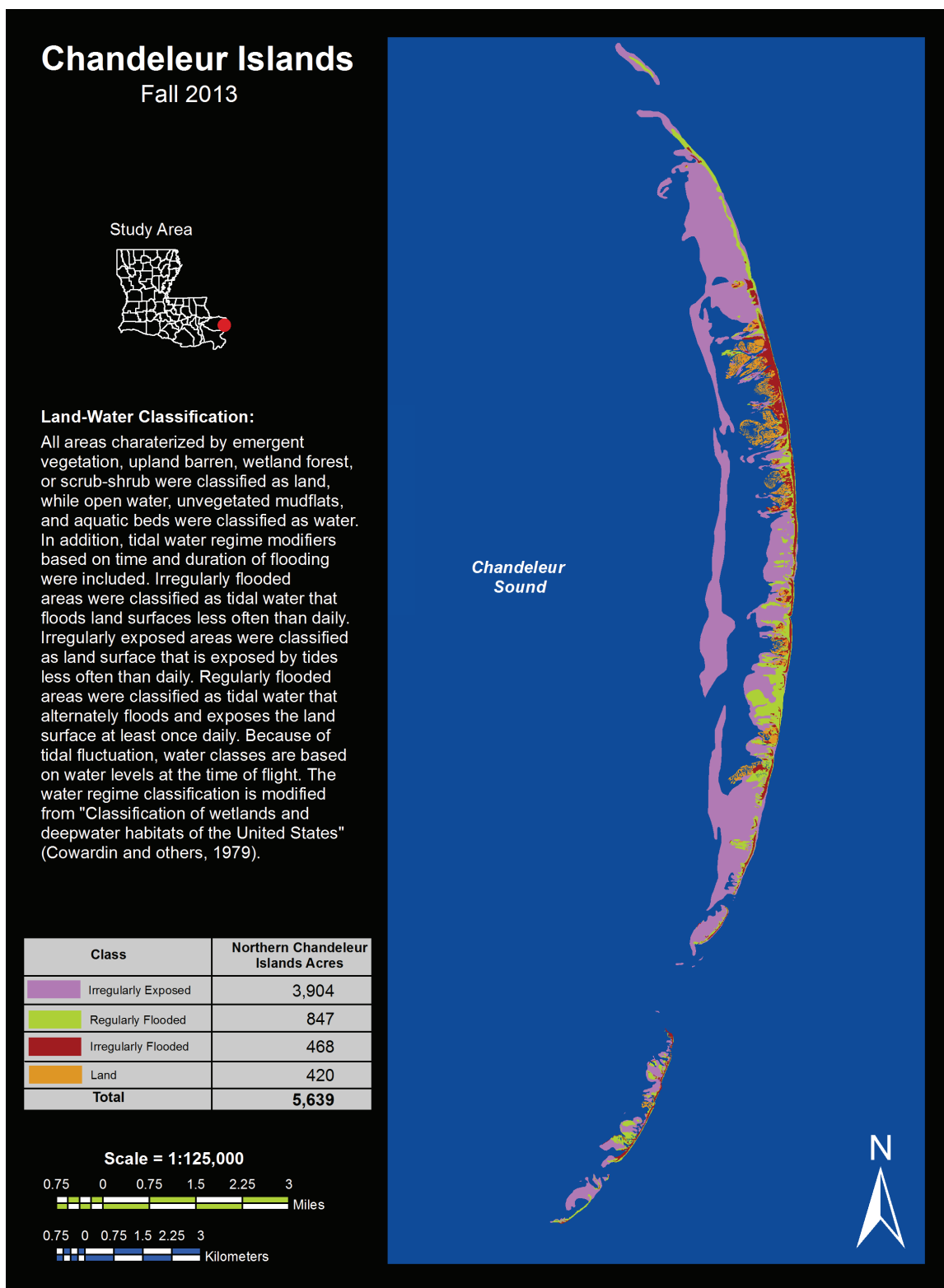
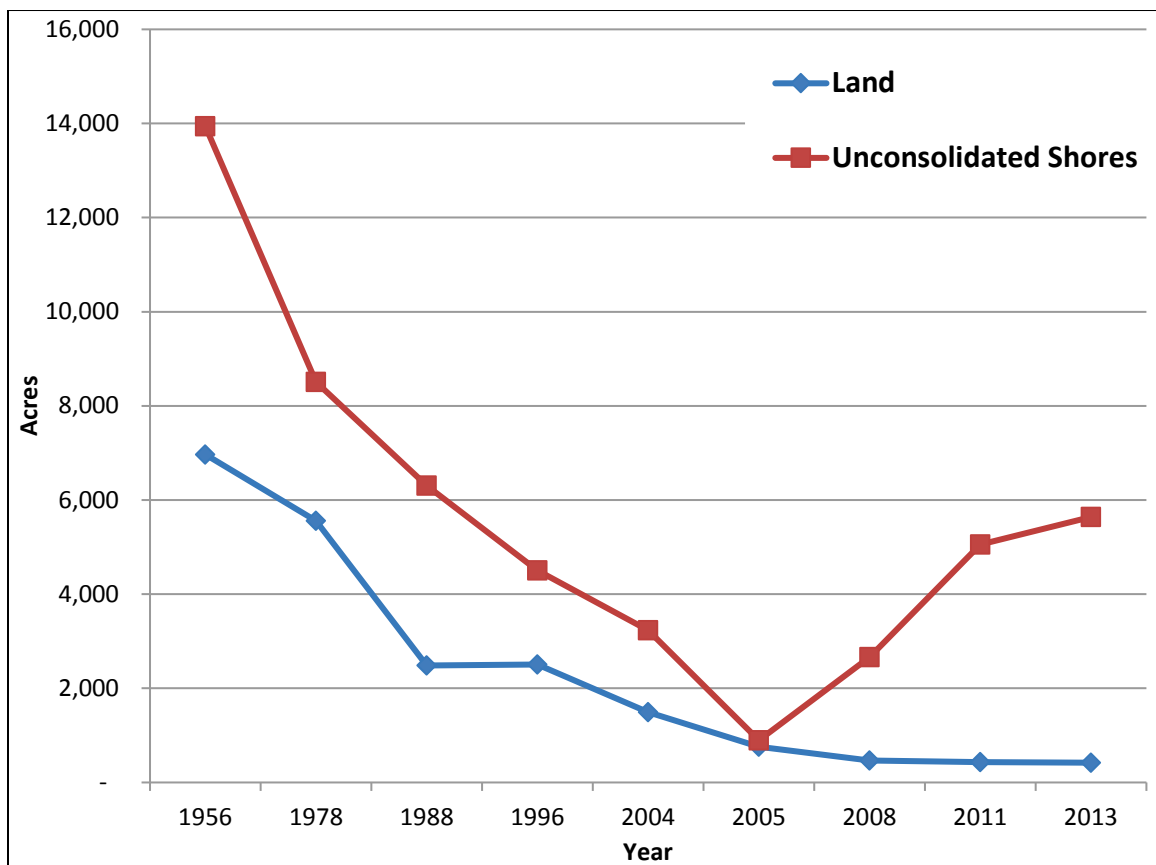


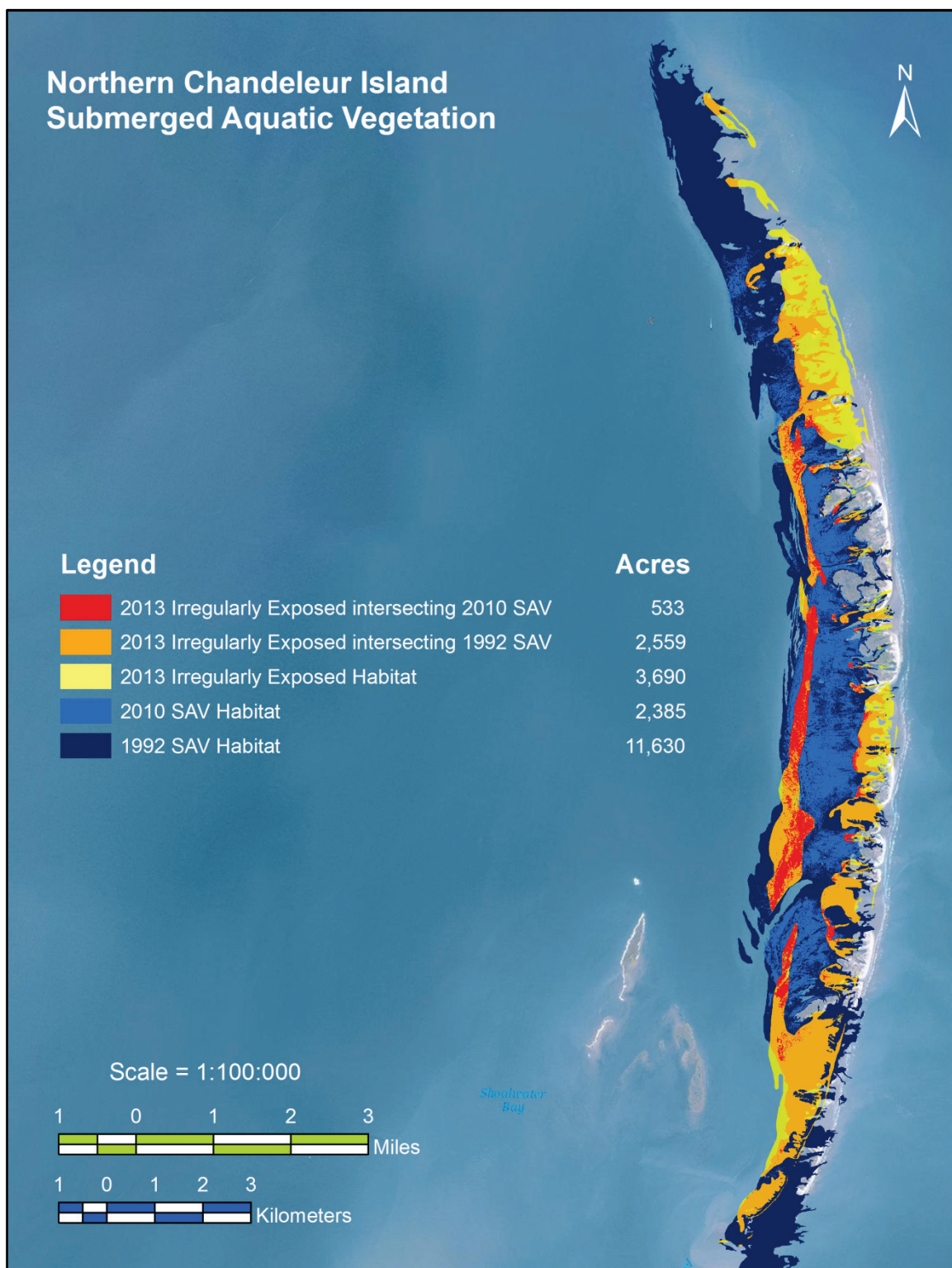
Figure 12. Summary of change in historical and recent habitat (modified) acreages along the northern Chandeleur Islands. Unconsolidated shores include beach, shore and flats (from historical data sets), and the irregularly flooded, regularly flooded, and irregularly exposed classes (derived from recent data sets).



3.3.2 SAV

The Chandeleur Islands chain is sediment starved and could potentially benefit from the introduction of sediment. One benefit could be newly created shoal waters, which can provide substrate for SAVs to colonize in areas previously too deep (Handley et al. 2007). However, the placement and redistribution of sediments can also have negative ecological impacts. High levels of suspended sediments or even direct burying of SAV by sediments can cause stress to, and ultimately significant decline in, SAV populations (Pulich and White 1991). Figure 14 illustrates the location of SAV communities surveyed in 1992 (dark blue) and 2010 (bright blue), the 2013 Irregularly Exposed classified habitat (yellow), and the convergence of those habitat (orange and red). Of the 3690 acres of Irregularly Exposed habitat, only 533 coincide with areas identified as SAV in the 2010 survey (red areas in Figure 14). However, 2559 acres coincide with areas previously identified as SAV in the 1992 survey (orange areas in Figure 14).

Figure 13. Sand berm sediment relocation into areas of Submerged Aquatic Vegetation (SAV).



3.4 Shoreline

As with the landscape analyses, the shoreline assessments were divided into historical (1855–2005) and recent (2008–2013) periods. The historical shoreline assessments, which were conducted and published by the BICM program, consist of shoreline data from 1855, 1922, 1996, 2004, and 2005. Table 4 provides the historical rates of shoreline change for the entire Chandeleur Islands chain for the Historical (1855–2005), Long Term (1922–2005), Short Term (1996–2005), and Near Term (2004–2005) periods of analysis. The overall loss rate of -20.4 ft/year, increased with a move towards nearer-term periods of analysis. The maximum shoreline change rate, -663.2 ft/year, includes the direct impacts from Hurricanes Katrina and Rita. Figure 15 shows historical gulf- and bay-side shoreline pairs for comparison by individual periods of analysis. These comparisons show the shoreline retreat and the step-wise thinning and migration of the island from period to period.

Table 4. Historical shoreline change rates for the Chandeleur Islands
(modified from Martinez et al. 2005b).

Reach	1855-2005	1922-2005	1996-2005	2004-2005
Name	Avg. (ft/year)	Avg. (ft/year)	Avg. (ft/year)	Avg. (ft/year)
Chandeleur Islands	-20.4	-28.1	-107.7	-663.2

Figure 16 includes the historical and recent shoreline locations and average step-wise shoreline change rates. For the recent shoreline change analysis, only transects that intersected shorelines for both beginning and ending dates within the period of analysis were included. This provides conservative estimates, but still allows for relative comparisons between historical and recent periods. In general, the rates of change were typically less than -22 ft/year, unless a significant event directly impacted the island chain. This is evident in the 2004–2008 period where nine named tropical storms (Arlene, Bonnie, Cindy, Dennis, Edouard, Katrina, Mathew, Rita, and Ivan) tracked in close proximity to the island. The rate of shoreline loss increased from less than -22 ft/year (for all periods prior to 2004) to -203.4 ft/year during the 2004–2008 period. The 2008–2011 period included the construction of the seaward berm and therefore experienced a 164 ft/year seaward migration of the gulf-side shoreline. The final period, 2011–2013, included two storms (Isaac and Lee), which in turn induced rapid shoreline retreat and an average shoreline change rate of -123 ft/year.

Figure 14. Shoreline changes of north Chandealeur Islands, Louisiana, from 1855 to 2005 (Martinez et al. 2005b).
The gulf-side shoreline is generally the eastern side of the island and the bay-side shoreline is the western side.

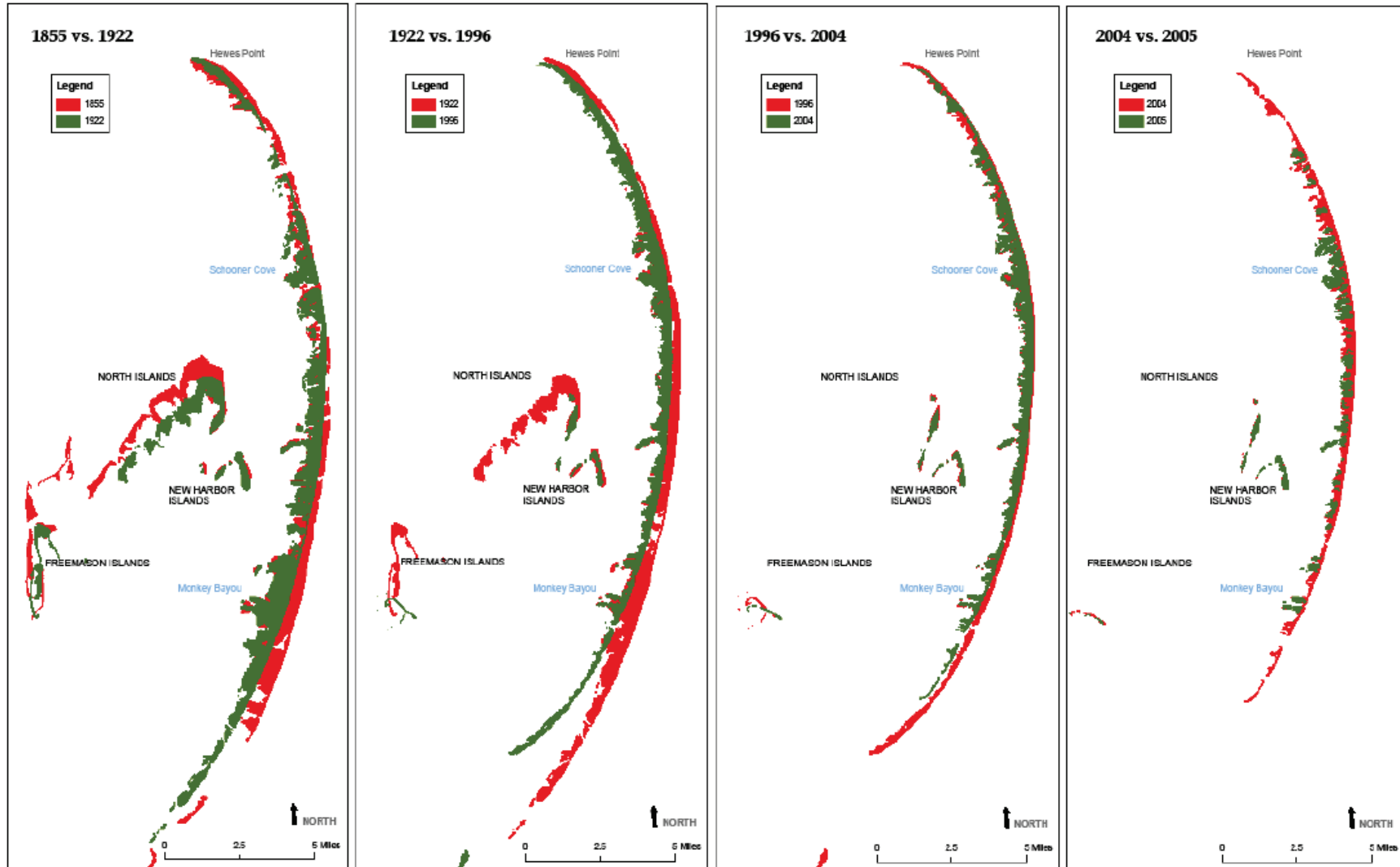
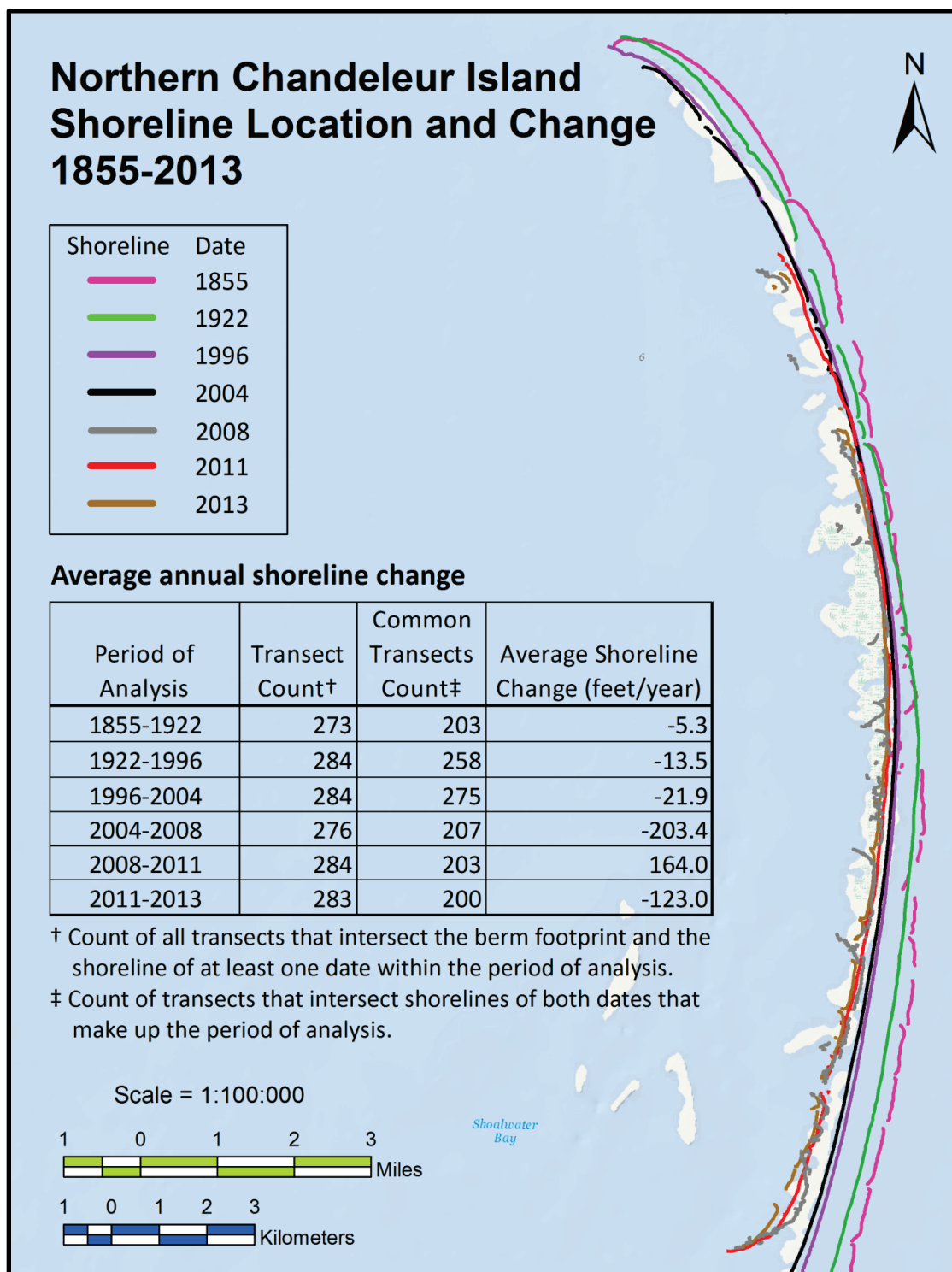


Figure 15. Generalized shoreline position and average annual shoreline change along the northern Chandeleur Islands, Louisiana.



3.5 Nearshore berm as beneficial use of dredged material

USACE is practicing and is planning to expand practice of placement of nearshore berms as a beneficial use of dredged material (BUDM) from navigation dredging operations. The goal of this section is to evaluate how the Chandeleur nearshore berm morphed with the island and how it provided benefit to the long-term health of the island. As described in Section 3.3, the berm quickly dissipated and did not provide protection from the oil spill. This dissipation is consistent with known nearshore berm processes and is one of the benefits of BUDM (the sediment quickly migrates from the placement site to the resource (shoreline) it was intended to nourish). The questions posed in this section are (1) did the berm provide land or habitat acreage to the Chandeleur Islands and (2) can the lessons learned be used to improve BUDM practices.

The Chandeleur Islands sand berm monitoring permits analysis of berm placement that would be consistent with BUDM practices, especially for the portions of the berm placed offshore of the island in the Middle Section (Figure 6). The placement itself is typical of how a nearshore berm might be designed. However, the surrounding environment is somewhat different. Most BUDM nearshore placement would occur near beach/dune systems that are much more robust than the system at the central Chandeleur Islands. The beach/dune system at this location has a maximum elevation of 5.8 ft (Table 2) and is therefore much lower than most mainland and barrier island beach/dune systems where BUDM would be practiced. In addition, there are many gaps in the beach/dune system which can permit sediment to easily pass to the back side of the island. These morphologic features, combined with an active wave climate permits overtopping and transport of berm sand over and through the island. This condition would be rare for locations where BUDM is practiced. Given the ground conditions for this placement, one would not expect significant beach accretion. Rather, as expected, most land mass and elevation increase occurred behind the original beach.

Figure 11 is post-berm placement island morphology. The west side of the island has expanded significantly since the 2008 survey (Figure 10). The placed sand berm is shown as an irregularly flooded feature in an arc running the length of the island. It can be seen in Figure 11 that the berm is already fragmented by the time of the spring 2011 survey. Sediments placed during the early part of the construction period have already moved landward and deposited west of the land mass. This created the additional

irregularly exposed habitat when compared to the 2008 survey. By 2013 (Figure 12), this berm has dissipated and much of the sediment has moved westward, generating a significant amount of regularly flooded and irregularly exposed habitat. This added habitat is due to two factors: (1) natural recovery of the island after Katrina and (2) sand from the berm building project. Construction of the berm added 86 million ft³ (3.17 million cubic yards [yd³]) of sand to the local sediment system surrounding the islands. Much of this sediment (Figure 6) remained in the system 1-year post-placement. Figure 6 indicates a trend of berm sediment accreting on both east and west sides of the original footprint. Figure 13 shows that the loss of land became relatively stable after the berm placement while the amount of unconsolidated shores increased significantly. This can only happen with a sediment supply to the island's local sediment system. It can be surmised that some, if not most of this sediment was contributed from the 5.7 million yd³ introduced to the system by the berm placement. Significant amounts of the sand berm moved westward onto and behind the islands, thus demonstrating the benefit of nearshore berm placement on nourishment of adjacent habitat.

4 Conclusion

The purpose of this study was to provide general measures of the oil-spill-mitigation sand berm's resilience, performance, and potential impacts to the Chandeleur Islands. To satisfy these objectives, GIS and remote sensing data and techniques were used to (1) analyze historical elevation, landscape, and shoreline conditions and trends, (2) monitor and quantify the physical extent and movement of berm sediment, and (3) evaluate the berm's short- and near-term impacts to the island system.

The sand berm provided short-term benefits, primarily through the introduction of sediment into a sediment- and elevation-deficient system. The berm also provided short-term advancement of the island's shoreline position and briefly increased the areal extent of vital island habitat. However, the majority of those benefits were ephemeral since the berm experienced almost immediate degradation due to compaction of underlying soils, storm induced scouring, breaching, over-washing, and redistribution of berm sediment (some out of the littoral system; CB&I 2012a). Combined, the elevation, berm length, landscape, and shoreline assessments performed as part of this study indicate that degradation of the berm began within 30-days post-construction (Figure 5) and the berm was largely eroded within 18-months of construction (Figures 7, 12, and 16). The speed and degree of degradation were primarily the results of storms Lee and Isaac, and berm placement in a high energy open water environment.

Daily Synthetic Aperture Radar data (Figure 1) suggests the berm was not successful in providing a barrier to retard oil from reaching the island or oil migrating into Chandeleur Sound and beyond. This is corroborated by the National Oil Spill Commission Report to the President, which estimates that the berm captured, at most, approximately 31,500 gal of oil (National Commission on the BP Deepwater Horizon Oil Spill and Off-shore Drilling 2011). Even if the berm did initially provide a barrier that collected oil, the majority of berm sediments (and any oil that they collected) were ultimately transported onto existing island features or across the island and into Chandeleur Sound. This potentially created additional impacts since these sediments and oil could cover and impair SAV communities present in the back bays of the Chandeleur Islands. Future monitoring

may be necessary to assess the long-term impacts of berm sediment and oil on existing critical and sensitive Chandeleur Islands habitat.

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14. ABSTRACT The failure of the Macondo-252 well and explosion of the Deepwater Horizon oil rig resulted in the release of approximately 185 million gallons of crude oil into the Gulf of Mexico (Wilde and Skrobialowski 2011). As part of the emergency response plan, the Louisiana Office of Coastal Protection and Restoration proposed (and subsequently constructed) sand barriers to reduce the amount of oil from reaching the Chandeleur Islands and inland wetlands; thereby protecting these sensitive ecosystem resources. This study was conducted to provide general measures of the sand berms resilience, performance, and potential impacts to the Chandeleur Islands. To satisfy these objectives, Geographic Information System (GIS) and remote sensing techniques were used to quantify changes in sand berm areal extent over time; provide shoreline, habitat, and landscape assessments of the Chandeleur Islands; and assess elevation changes and potential reworking of berm sediment into the island system. The sand berm provided short-term benefits and short-term advancement of the island's shoreline position, but the majority of those benefits were ephemeral since the berm experienced rapid degradation. Data show that the degradation of the berm began within 30-days post-construction, and the berm was largely eroded within 18-months post-construction. The speed and degree of degradation were primarily the results of Tropical Storm Lee (5 September 2011) and Hurricane Isaac (28 August 2012), and the construction of the berm in high-energy open water environments. Additionally, berm sediments were redistributed to areas of known submerged aquatic vegetation communities, potentially impairing these critical habitats. Ultimately, the berm was not successful in providing a barrier to retard oil from reaching the island or oil migrating into Chandeleur Sound and beyond.					
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Barrier islands--Louisiana

Dredging spoil

Sand berm evaluation

Coastal sediments

Sand berm benefits

Sand

Environmental degradation

Sand berm resilience

Inland protection with sand berms

Shore protection

Coastal restoration

BP Deepwater Horizon Explosion and Oil Spill, 2010

Oil spills--Containment