Louisiana Barrier Island Comprehensive Monitoring Program 2015-2019 Coastal Surface-Sediment Characterization Analysis: Methods and Results

Submitted to:

Coastal Protection and Restoration Authority

Prepared by:

Ioannis Y. Georgiou, Tara Yocum, Mike Amos, Mark Kulp, Jim Flocks

Pontchartrain Institute for Environmental Sciences

University of New Orleans

December 2019

Louisiana Barrier Island Comprehensive Monitoring Program 2015-2019 Coastal Surface-Sediment Characterization Analysis: Methods and Results

Recommended Citation:

Georgiou, I.Y., Yocum, T.E., Amos, M.L., Kulp, M.A., Flocks, J., 2019. Louisiana Barrier Island Comprehensive Monitoring Program 2015-2019 Coastal Surface-Sediment Characterization Analysis: Methods and Results. Prepared for the Louisiana Coastal Protection and Restoration Authority (CPRA), Pontchartrain Institute for Environmental Sciences, University of New Orleans, New Orleans, LA, 38pp.

Table of Contents

List of Figures

List of Tables

Introduction and Background

It is widely recognized and well documented that barrier islands and deltaic headland shorelines of the Louisiana Coastal Zone are rapidly retreating landward and degrading (e.g. LCA, 2005; Kulp et al., 2011). High rates of delta plain subsidence, ongoing eustatic sea-level rise, low sediment supply, and other processes such as storm impacts collectively contribute to this shoreline loss as shoreline sediment is eroded or becomes inundated by marine waters (Penland and Ramsey, 1990; Kulp et al., 2011). The magnitude of shoreline retreat along coastal Louisiana varies from progradational (over historic time in the Chenier Plain) to widely erosional for modern times, and has been shown to be as much as 40 m/yr locally (Williams et al., 1992; Martinez et al., 2009; Byrnes et al., 2018); this retreat contributed to more than 100 km^2 of annual land loss that has been documented for some select historic time frames across the region (Barras et al., 2003; Couvillion et al., 2011).

To more effectively identify the magnitude, rates, and processes of shoreline change a Barrier Island Comprehensive Monitoring program (BICM) has been developed by the Louisiana Department of Natural Resources (LDNR), and implemented by LDNR, University of New Orleans-Pontchartrain Institute for Environmental Sciences (UNO-PIES), and the U.S. Geological Survey (USGS) as a framework for a coast-wide monitoring effort (Kulp et al., 2011). This program is now overseeing by the Coastal Protection and Restoration Authority (CPRA). One part of BICM is the sediment sampling and analysis, which supplements other aspects of the program, including shoreline, seafloor and habitat change analysis. The advantage of BICM over current project-specific monitoring efforts is that it provides long-term morphological datasets on all of Louisiana's barrier islands and shorelines; rather than just those islands and areas that have received restoration (Kulp et al., 2011). BICM additionally specifically provides a larger proportion of unified, long-term datasets that will be available to monitor constructed projects, plan and design future barrier island projects, develop operation and maintenance activities, and assess the range of impacts created by past and future tropical storms. The development of coastal models, such as those quantifying littoral sediment budgets, and a more advanced knowledge of mechanisms forcing large-scale coastal evolution becomes increasingly feasible with the availability of BICM regional datasets.

The BICM Program was established in 2006 to provide long-term data on Louisiana’s barrier island systems for planning, design, evaluation, and maintenance of barrier islands restoration projects. The first phase of BICM was completed in 2012, culminating with a workshop on program successes, the initial development process, and lessons learned from data collection and analysis (Kulp et al., 2011; Kindinger et al, 2014). Phase II of BICM stared in 2015, and is projected to be completed in 2020 with similar products and analysis as in Phase I.

Grain size analysis in coastal systems is commonly used to determine the distribution of clastic sediments, provide insight into local and regional sediment transport trends, and help distinguish among geomorphic environments (e.g. dune, berm, beach face). As noticeable differences in grain size distribution do exist as one proceeds from the dune base, across the beach, and continues offshore (Bascom, 1951; Dean and Dalrymple, 2002), reported changes between environments, or within environments over time (if data exists over time), can be used to infer coastal change, sediment transport trends, and generally used as proxies for regional to local sediment change (Stauble, 2003; Georgiou et al., 2018, 2019).

Purpose

Grain-size characteristics have significant impacts on the accuracy of sediment budget calculations and modeling of cross-shore and longshore transport processes along beaches (Dean and Dalrymple, 2002; Limber et al., 2008). They possess documented roles in assessing regional sediment transport pathways in conjunction with other datasets, including bathymetry and resulting seafloor change, and shoreline change analysis (Georgiou et al., 2011, 2018, 2019; Fenster et al., 2016). This report outlines effort funded as part of BICM Phase II. The purpose of this report is to document potential changes in sediment characteristics using grain size statistics from BICM Phase I in 2008 (Kulp et al., 2011A, Kulp et al., 2011B) and BICM Phase II in 2015/16 (Kulp et al., 2015, 2015A, Georgiou et al., 2017, 2017B). The report focused first on developing a crosswalk to standardize datasets from 2008 and 2015/16 efforts; this included re-developing statistics and metrics common to both periods, recreating geodatabases with new developed attributes, and finally undertaking a sediment change analysis, focusing primarily on percent sand, and median grain diameter of sediment for all BICM Regions sampled.

Terminology and Classification

For the purpose of this report the following terminology is listed and described below, as well as in Table 1, Figure 1, and Figure 2. Various terms where used in the past to describe the sample environments. For simplicity we grouped and reduced these terms to the following:

Backbarrier: Samples collected behind the dune or barrier island, between the barrier and the mainland. Can be land or water samples.

Dune: Samples collected proximal to dunes near the dune toe.

Berm: Samples collected on the first berm encountered, landward of the beach face.

Beach face: Samples collected close to the water and swash zones.

Inlet: A breach in a barrier where water is exchanged between the backbarrier lagoon and open marine water.

Shoreface: Upper, middle, and lower shoreface are offshore points (outside the surf zone), with the upper shoreface closest inshore, and the lower shoreface, farthest offshore. Upper shoreface samples are in depths < 5m, middle shoreface samples fall between 5 - 7m deep, and lower shoreface samples are in depths > 7m.

D_{50}: Designates the median grain size, or diameter, in micrometer.

Sorting: The sorting value describes the distribution of sediment grain sizes within a sample; well-sorted sediments have similar grain sizes and a low sorting value (< 1.6), moderately-sorted sediments range from 1.6 - 2, and anything > 2 is poorly sorted.

Skewness: Designates the skewness value; negative "coarse" skewness indicates coarser material, while positive "fine" skewness indicates finer material. A symmetrical sample is one that is not skewed in either direction (-0.1 - 0.1), indicating an even distribution of sediment.

Kurtosis: Designates the kurtosis value, which describes the concentration of sediment sizes in a sample. High concentration of one size is leptokurtic (strongly peaked) with a kurtosis value > 1.1. Platykurtic (relatively flat) is when sediment sizes are more evenly distributed with a kurtosis value < 0.9. Mesokurtic (normal distribution) ranges from 0.9 - 1.1.

Mud: Sediment that is finer than 63µm (sand) and includes silt and clay sized particles.

Table 1: Terminology and classification for sampled environments.

	Past Terms	Definition	This report
Either	Marsh, Overwash, Backbarrier, Tidal Flat, Backshore, Prairie	Behind the barrier can either be on land or in the water.	Backbarrier
Onshore	Dune, Dune Toe, Backshore, Overwashed Dune	The part of the beach that starts from the berm and extends to the dune	Dune
	Berm, Shell Berm, Back Berm, Land, Storm Berm	Generally unvegetated section of beach between the dune and beach face, step like feature.	Berm
	Swash, MLW, Chenier	Where waves interact with the shoreline	Beach Face
Offshore	Offshore, Water	A breach in a barrier where water is exchanged between the backbarrier and open water.	Inlet
	Offshore, Water, Upper Shoreface	Samples are collected at depth seaward of the shoreline, no deeper than 5m.	Upper Shoreface
	Offshore, Water, Middle Shoreface	Samples are collected at depth seaward of the shoreline, between 5 - 7m deep.	Middle Shoreface
	Offshore, Water, Lower Shoreface	Samples are collected at depth seaward of the shoreline, deeper than 7m.	Lower Shoreface

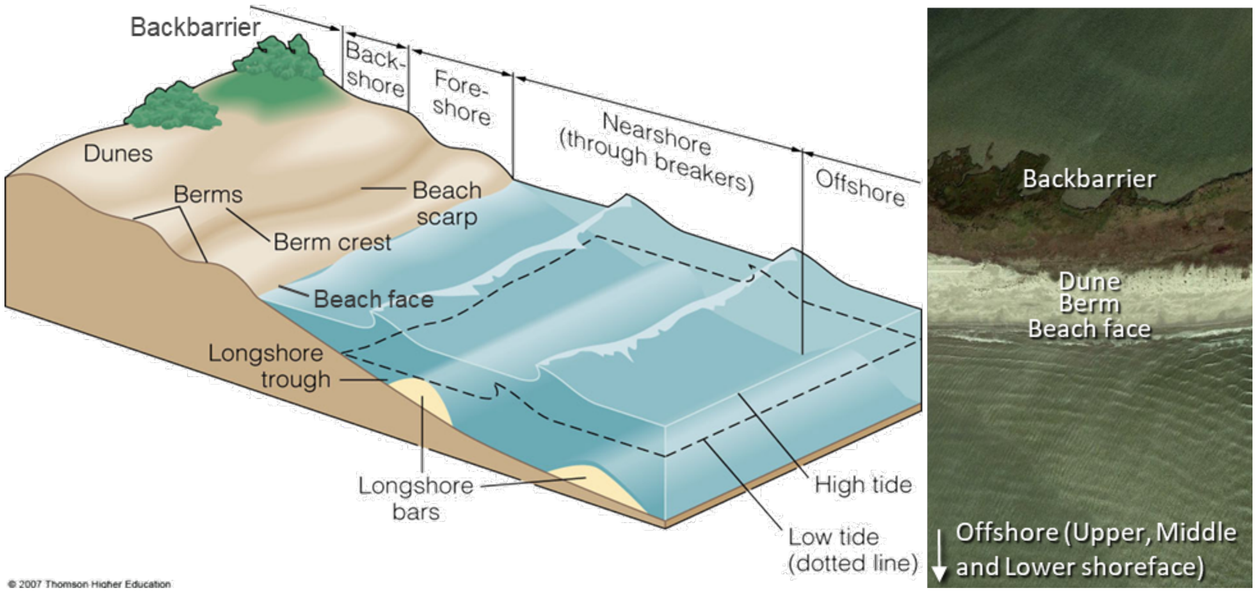


Figure 1: Left: Beach profile edited from Davis and FitzGerald (2018). Right: Plan view of the backbarrier, dune, berm, beach face, and offshore (upper, middle, and lower shoreface).

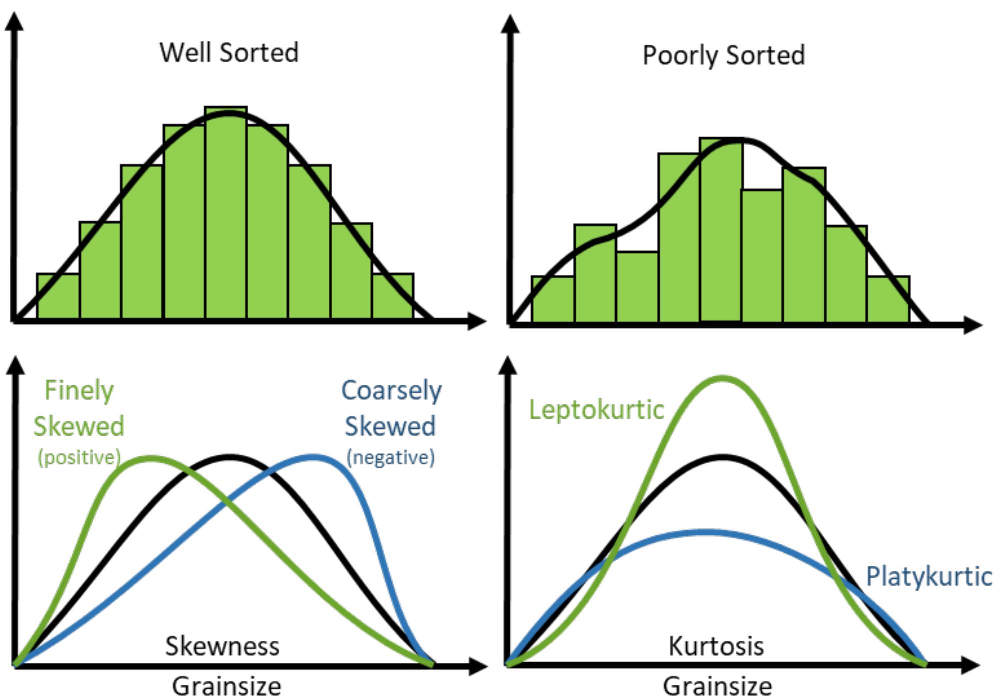


Figure 2: Schematic representation of sorting, skewness, and kurtosis (Georgiou et al. 2018).

Project Area

Sediment samples are collected along coastal Louisiana for "sandy" BICM regions show in Figure 3. For details on the specific methods we direct the reader to reports by Kulp et al. (2011), Kulp et al., (2015A, B) and Georgiou et al., (2017A,B).

Figure 3: Base map depicting the Barrier Island Comprehensive Monitoring Program regions edited from Kulp et al. 2015.

Methods

In 2008 and 2015 the cross-shore range of environments sampled include: 1) Backbarrier, 2) dune, 3) berm, 4) beach face, 5) Inlet, 6) upper shoreface, 7) middle shoreface, and 8) lower shoreface (Figure 2). The sample locations, collection and analysis methods were completed prior to this report (Kulp et al., 2011B and 2015). Using the prior analysis we evaluated differences in median grain size diameter, sand content, sorting, skewness, and kurtosis from 2008 to 2015, along five of the nine BICM regions shown in Figure 3.

Results

The following sections provide results of change analysis completed in 5 of the 9 BICM regions; Western Chenier, Early Lafourche, Late Lafourche, Modern Delta, and the Chandeleur Islands. The results below include the differences in D_{50}, sand content, sorting, skewness, and kurtosis, between comparable points from 2008 to 2015. For this report comparable points are defined as sample locations that were sampled in both 2008 and 2015, and had 70 % sand or more for both years (i.e. analyzed in both years). In addition, terrestrial and nearshore locations were mapped at the more recent position (i.e. for shorelines experiencing erosion and landward migration, changes in dune, berm and beach face samples were mapped at their 2015/16 location.

Western Chenier

Along the Wester Chenier region 285 samples were taken at the same locations in 2015 as in 2008, 121 of those samples were analyzed in both years with only two located offshore. The average grain size (D_{50}) of all comparable points, both onshore and offshore, increased slightly from 2008 (202µm) to 2015 (224µm) both still in the fine sand class (Table 2). The largest increase from 2008 to 2015 was onshore at the beach face around 460000 m E, where D_{50} increased from 147µm (fine sand) to 416µm (medium sand). The dune and berm also increased the most around the same location, from 209µm to 374µm and from 163µm to 388µm respectively. This was attributed to the direct placement of approximately 1.98 million cubic yards of offshore sediment onto the shoreline as part of the Cameron Parish Shoreline Restoration Project (CS-33). The sediment source for CS-33 was approximately 18-20 miles offshore from the Sabine Banks shoal system, which explains the coarser sediment diameter. Another location we documented increases in D_{50} was around 430000 m E; at this location the dune grain size increased by 92µm, the berm by 169µm, and the beach face by 187µm (Figure 4). Along with having the largest increased in D_{50} from 2008 to 2015, the beach face also had the largest decrease in D_{50} around 450000 m E decreasing by approximately 95µm.

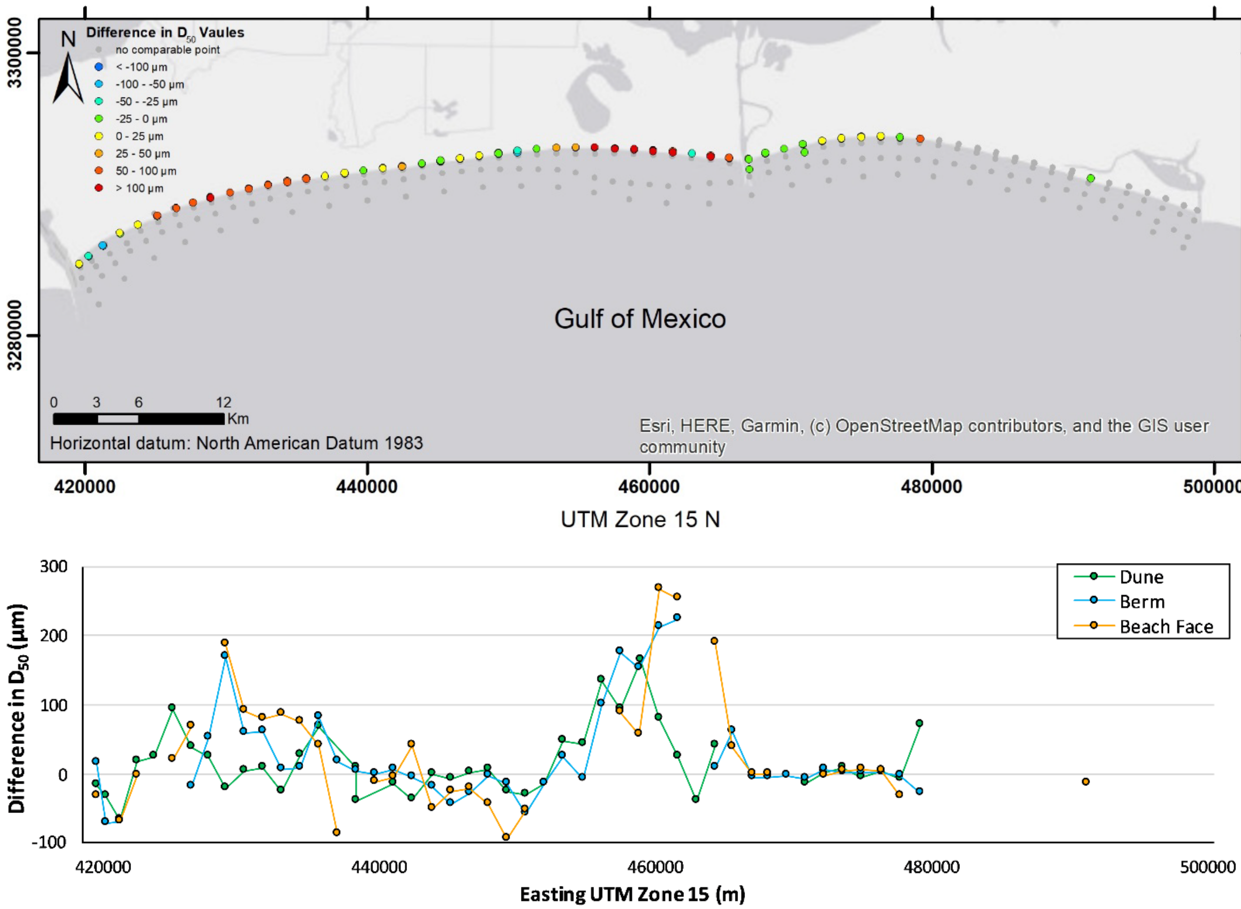


Figure 4: The difference in D_{50} along the Western Chenier from 2008 to 2015 in plan view (top) and graphically (bottom) for onshore environment (dune, berm and beach face).

The average percent sand along the Western Chenier decreased slightly from 2008 (99%) to 2015 (97%, Table 2). There was little change in the western portion of this region (420000 to 460000 m E) fluctuating by ± 4% at most. Most of the change is located from 460000 m E eastward, starting with the highest increase in percent sand at 460000 m E (6.7%). Average percent sand then decreases eastward to the largest decrease in percent sand which was just before 4800000 m E (-9%, Figure 5).

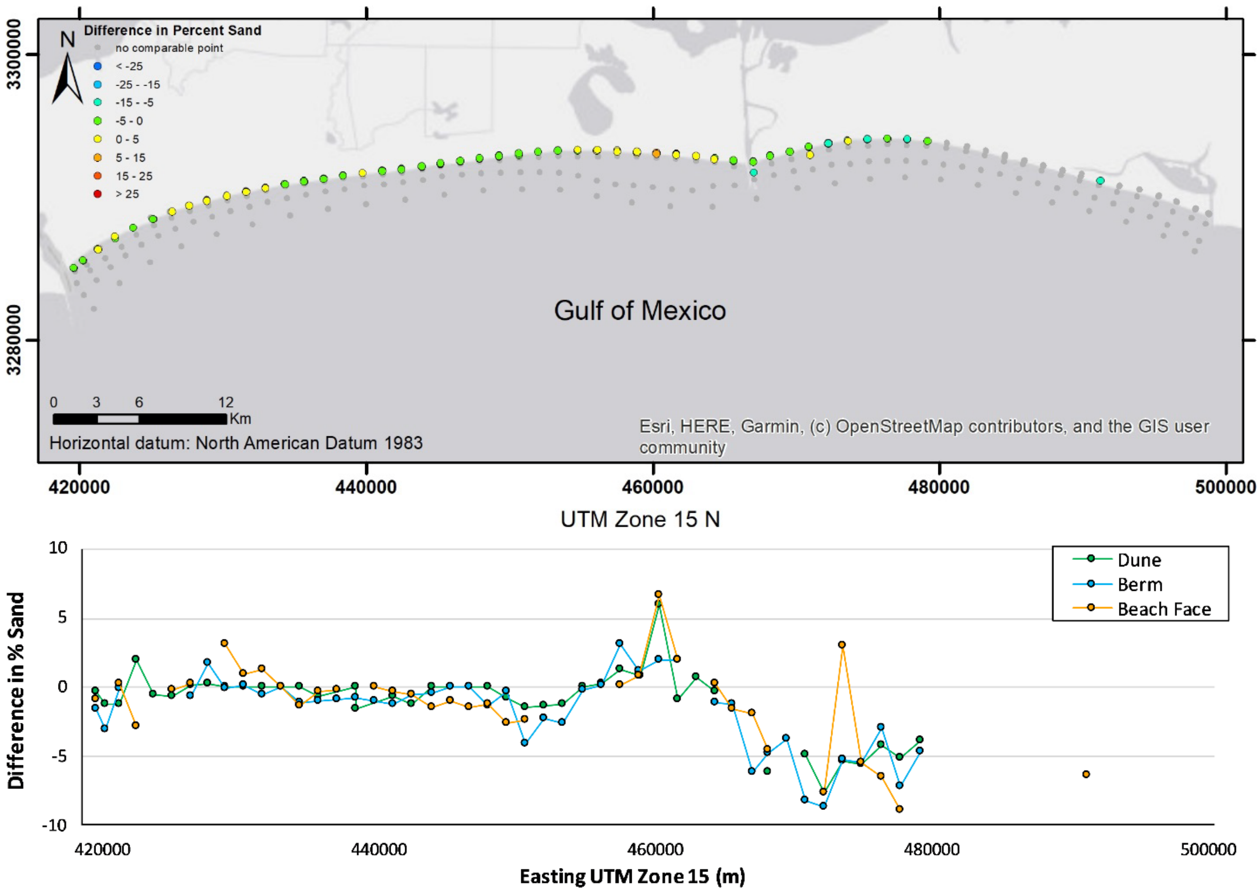


Figure 5: The difference in sand content along the Western Chenier from 2008 to 2015 in plan view (top) and graphically (bottom) for onshore environment (dune, berm and beach face).

Sediment along the Wester Chenier region in 2008 was moderately well sorted (1.53), coarsely skewed (0.12), and leptokuric (1.22, Figure 6, Table 2). In 2015 the overall average sediment sorting increased slightly but remained moderately well sorted (1.59), skewness decreased becoming symmetrical (0.02), and kurtosis increased to very leptokuric (1.51). Although sorting in 2015 increased for all of the onshore environments, they remained in the same sorting category as in 2008 (i.e. dune and berm were moderately well sorted, and beach face was moderately sorted for both periods). Sorting offshore decreased by ~0.18 changing classification from moderately, to moderately well sorted. Skewness became more symmetrical throughout all environments, decreasing in onshore environments and increasing in offshore environments. The largest decreases in skewness values were for berm and beach face environments, where average sediment was coarsely skewed in 2008 and symmetrical in 2015.

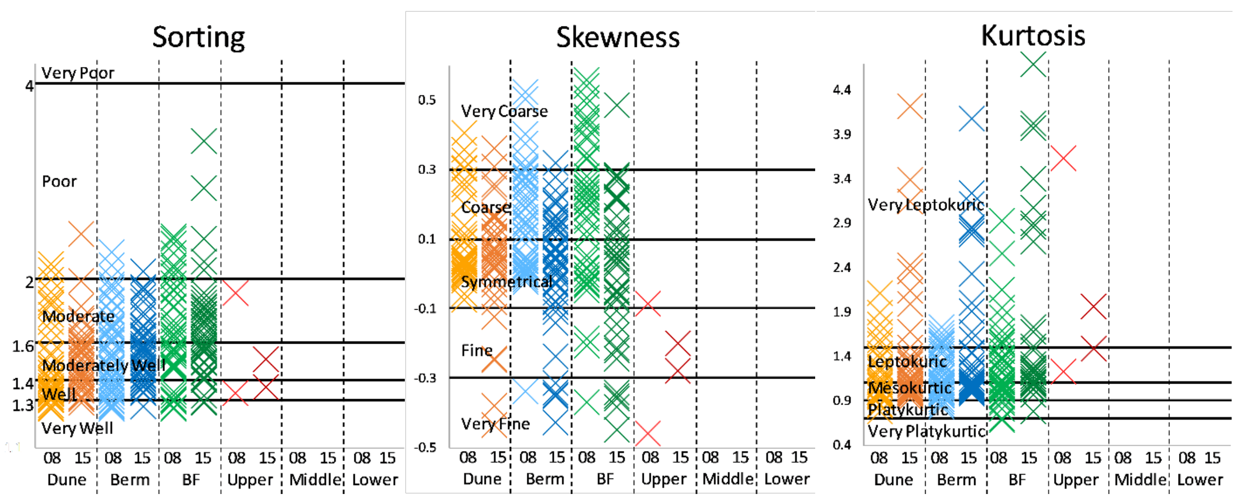


Figure 6: Sorting (left), skewness (middle), and kurtosis (right) values of comparable points along the Western Chenier in 2008 and 2015 by environment (dune, berm, beach face, upper shoreface, middle shoreface, and lower shoreface).

Table 2: Summary of Western Chenier grain size statistics of all comparable points in 2008 and 2015 (n = number of samples used in average).

Environment	Year	n	D_{50}	% Sand	Sorting	Skewness	Kurtosis
Backbarrier	2008	0	N/A	N/A	N/A	N/A	N/A
	2015		N/A	N/A	N/A	N/A	N/A
Dune	2008	42	Fine Sand (211µm)	99%	Moderate Well (1.45)	Symmetrical (0.09)	Leptokurtic (1.16)
	2015		Fine Sand (225µm)	98%	Moderate Well (1.53)	Symmetrical (0.05)	Leptokurtic (1.39)
Berm	2008	42	Fine Sand (202µm)	99%	Moderate Well (1.50)	Coarse (0.15)	Leptokurtic (1.20)
	2015		Fine Sand (227µm)	97%	Moderate Well (1.57)	Symmetrical (0.00)	Very Leptokurtic (1.51)
Beach Face	2008	35	Fine Sand (197µm)	98%	Moderate (1.67)	Coarse (0.16)	Leptokurtic (1.32)
	2015		Fine Sand (227µm)	97%	Moderate (1.71)	Symmetrical (0.02)	Very Leptokurtic (1.63)
Inlet	2008	0	N/A	N/A	N/A	N/A	N/A
	2015		N/A	N/A	N/A	N/A	N/A
Upper Shoreface	2008	2	Very Fine Sand (94µm)	89%	Moderate (1.62)	Fine (-0.27)	Very Leptokurtic (2.42)
	2015		Very Fine Sand (91µm)	88%	Moderate Well (1.44)	Fine (-0.24)	Very Leptokurtic (1.72)
Middle Shoreface	2008	0	N/A	N/A	N/A	N/A	N/A
	2015		N/A	N/A	N/A	N/A	N/A
Lower Shoreface	2008	0	N/A	N/A	N/A	N/A	N/A
	2015		N/A	N/A	N/A	N/A	N/A
Total Average	2008	121	Fine Sand (202µm)	99%	Moderate Well (1.53)	Coarse (0.12)	Leptokurtic (1.24)
	2015		Fine Sand (224µm)	97%	Moderate Well (1.59)	Symmetrical (0.02)	Very Leptokurtic (1.51)
Onshore Average	2008	119	Fine Sand (204µm)	99%	Moderate Well (1.53)	Coarse (0.13)	Leptokurtic (1.22)
	2015		Fine Sand (226µm)	97%	Moderate (1.60)	Symmetrical (0.02)	Leptokurtic (1.50)
Offshore Average	2008	2	Very Fine Sand (94µm)	89%	Moderate (1.62)	Fine (-0.27)	Very Leptokurtic (2.42)
	2015		Very Fine Sand (91µm)	88%	Moderate Well (1.44)	Fine (-0.24)	Very Leptokurtic (1.72)

Early Lafourche Delta

There are 98 comparable samples/locations along the Early Lafourche Delta, 53 onshore and 45 offshore. The average D_{50} of all comparable samples decreased slightly from 2008 (184µm) to 2015 (180µm, Figure 7, Table 3). The average D_{50} by environment (backbarrier, dune, berm, beach face, upper shoreface, middle shoreface, and lower shoreface) experienced small changes of the order of $\pm$ 10µm from 2008 to 2015, except for inlet samples, which decreased by 19µm. The inlet decrease influenced the overall statistics for D_{50} because of the larger volume of inlet samples (which includes flood- and ebb-deltas) compared to other environments, along with the larger decrease (Table 3). The average grain size by environment was fine sand except for the middle and lower shoreface which were very fine sand.

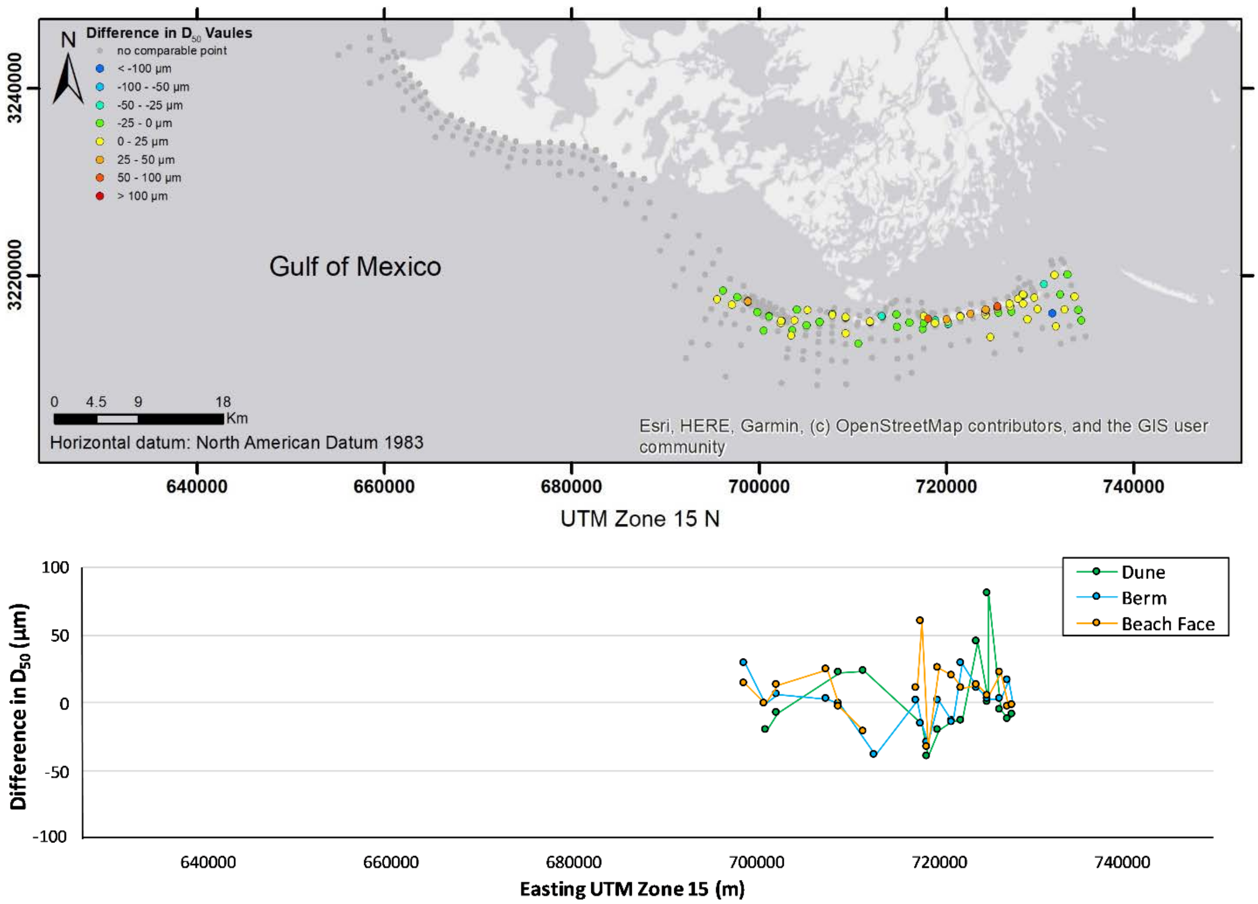
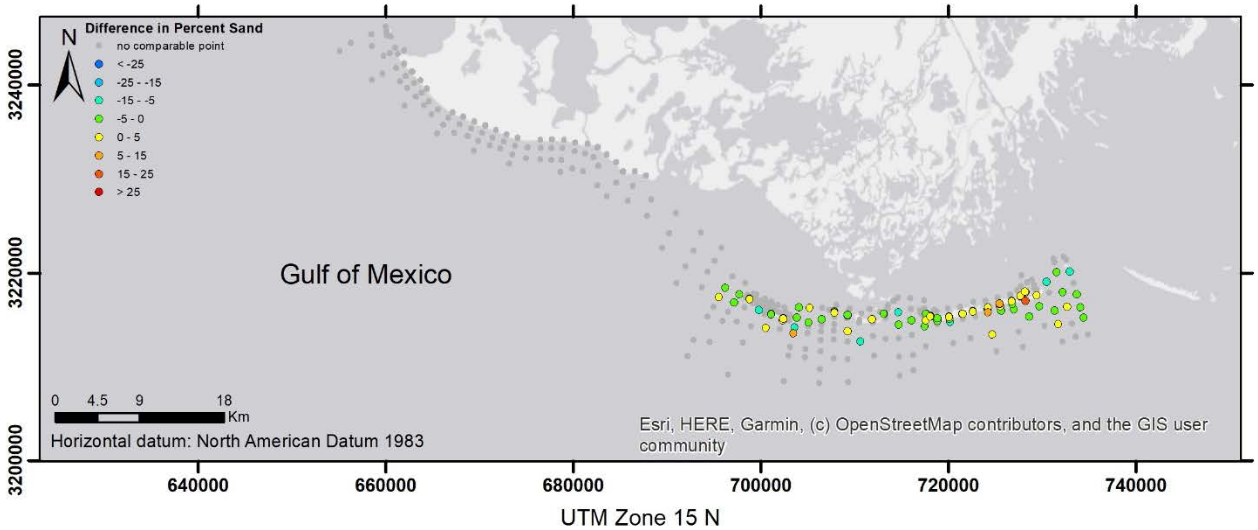


Figure 7: The difference in D_{50} along the Early Lafourche Delta from 2008 to 2015 in plan view (top) and graphically (bottom) for onshore environment (dune, berm and beach face).

Overall percent sand along the Early Lafourche Delta remained at 96% from 2008 to 2015 (Figure 8, Table 3). Average percent sand by environment changed very little if at all (±2%) and the inlet environment was the only environment to decrease (95% to 93%). The largest increase was found in the upper shoreface environment around 730000 m E (+18%), while the largest decrease was found in the middle shoreface environment around 720000 m E (-11%, Figure 8).



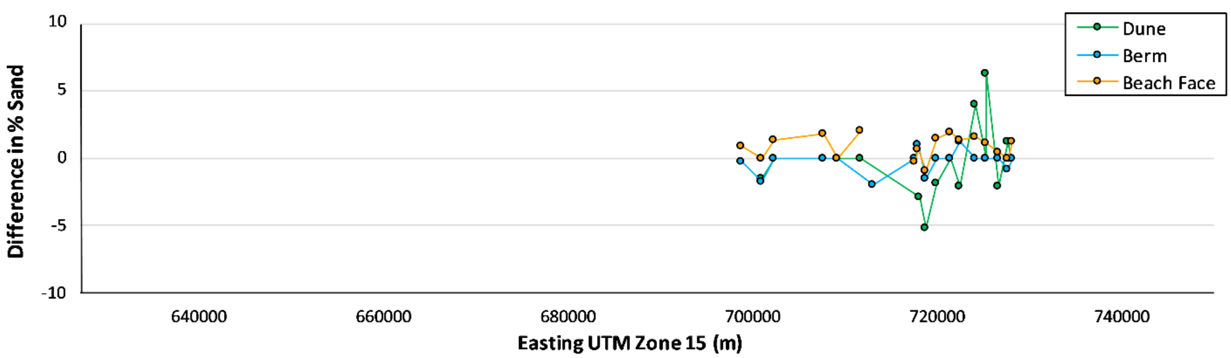


Figure 8: The difference in sand content along the Early Lafourche Delta from 2008 to 2015 in plan view (top) and graphically (bottom) for onshore environment (dune, berm and beach face).

Sediment along the Early Lafourche Delta in 2008 was moderately well sorted (1.52), symmetrical (-0.03), and leptokurtic (1.29). Remaining the same in 2015 (moderately well sorted, symmetrical and leptokurtic), sorting and skewness decreased slightly (1.50 and -0.07), while kurtosis increased by 0.1 (Figure 9, Table 3). The dune (well), berm (well), beach face (moderately well), and middle shoreface (moderate) environments stayed in their respective sorting categories from 2008 to 2015. While the backbarrier sorting decreased from moderately well (1.47) to well (1.39) and the upper shoreface decreased from moderate (1.69) to moderately well (1.52), the inlet and lower shoreface sorting both increased from moderately well (1.57, 1.56) to moderately (1.67, 1.62 [Figure 9, Table 3]). The largest average change in skewness by environment was in the backbarrier, where sediment skewness decreased by 0.1 changing from coarsely skewed in 2008 to symmetrical in 2015. The remaining environments stayed in the same skewness categories from 2008 to 2015, decreasing in sorting values by 0 to 0.07 (Table 3). Kurtosis changed the most at the middle shoreface, inlet, and backbarrier environments. The middle shoreface kurtosis increased by 0.31, very leptokurtic for both years. Inlet kurtosis increased by 0.29 changing from leptokurtic to very leptokurtic and backbarrier kurtosis stayed leptokurtic, however the kurtosis value decreased by 0.14 (Table 3).

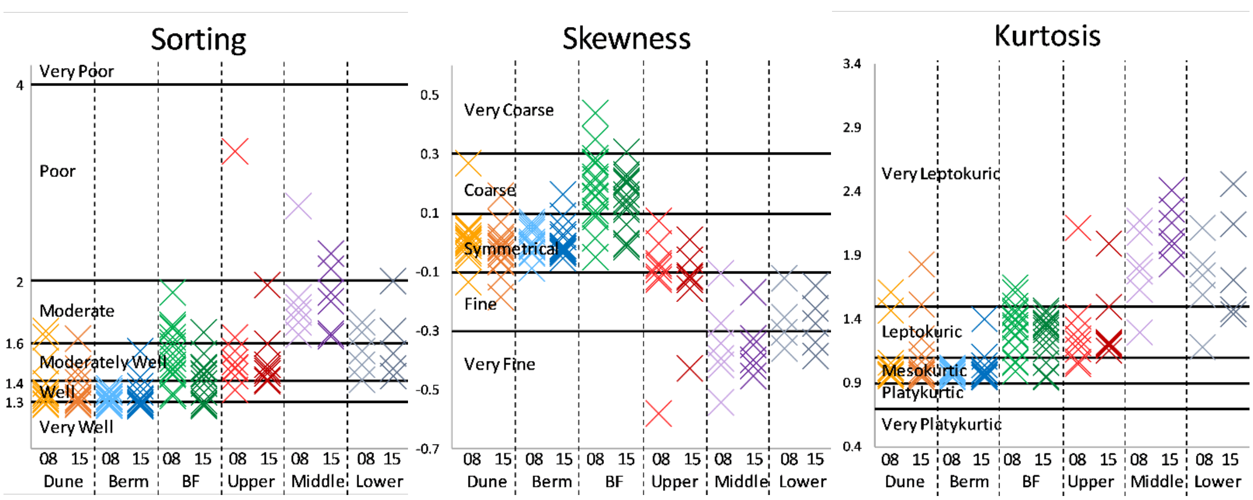


Figure 9: Sorting (left), skewness (middle), and kurtosis (right) values of comparable points along the Early Lafourche Delta in 2008 and 2015 by environment (dune, berm, beach face, upper shoreface, middle shoreface, and lower shoreface).

Table 3: Summary of Early Lafourche grain size statistics of all comparable points in 2008 and 2015 (n = number of samples used in average).

Environment	Year	n	D_{50}	% Sand	Sorting	Skewness	Kurtosis
Backbarrier	2008	4	Fine Sand (217µm)	99%	Moderate Well (1.47)	Coarse (0.15)	Leptokurtic (1.29)
	2015		Fine Sand (207µm)	99%	Well (1.39)	Symmetrical (0.05)	Leptokurtic (1.15)
Dune	2008	15	Fine Sand (202µm)	99%	Well (1.38)	Symmetrical (0.01)	Mesokurtic (1.06)
	2015		Fine Sand (203µm)	99%	Well (1.35)	Symmetrical (-0.02)	Leptokurtic (1.10)
Berm	2008	17	Fine Sand (203µm)	100%	Well (1.31)	Symmetrical (0.00)	Mesokurtic (0.97)
	2015		Fine Sand (203µm)	100%	Well (1.32)	Symmetrical (0.00)	Mesokurtic (1.01)
Beach Face	2008	17	Fine Sand (202µm)	99%	Moderate Well (1.54)	Coarse (0.18)	Leptokurtic (1.32)
	2015		Fine Sand (211µm)	100%	Moderate Well (1.42)	Coarse (0.14)	Leptokurtic (1.23)
Inlet	2008	26	Fine Sand (182µm)	95%	Moderate Well (1.57)	Fine (-0.11)	Leptokurtic (1.42)
	2015		Fine Sand (163µm)	93%	Moderate (1.67)	Fine (-0.18)	Very Leptokurtic (1.71)
Upper Shoreface	2008	8	Fine Sand (147µm)	94%	Moderate (1.69)	Fine (-0.12)	Leptokurtic (1.32)
	2015		Fine Sand (153µm)	95%	Moderate Well (1.52)	Fine (-0.14)	Leptokurtic (1.33)
Middle Shoreface	2008	6	Very Fine Sand (118µm)	85%	Moderate (1.91)	Very Fine (-0.34)	Very Leptokurtic (1.79)
	2015		Very Fine Sand (113µm)	86%	Moderate (1.89)	Very Fine (-0.35)	Very Leptokurtic (2.10)
Lower Shoreface	2008	5	Very Fine Sand (119µm)	91%	Moderate Well (1.56)	Fine (-0.23)	Very Leptokurtic (1.69)
	2015		Very Fine Sand (117µm)	91%	Moderate (1.62)	Fine (-0.27)	Very Leptokurtic (1.84)
Total Average	2008	98	Fine Sand (184µm)	96%	Moderate Well (1.52)	Symmetrical (-0.03)	Leptokurtic (1.29)
	2015		Fine Sand (180µm)	96%	Moderate Well (1.50)	Symmetrical (-0.07)	Leptokurtic (1.39)
Onshore Average	2008	53	Fine Sand (203µm)	99%	Moderate Well (1.41)	Symmetrical (0.07)	Leptokurtic (1.13)
	2015		Fine Sand (206µm)	99%	Well (1.37)	Symmetrical (0.04)	Leptokurtic (1.11)
Offshore Average	2008	45	Fine Sand (160µm)	93%	Moderate (1.64)	Fine (-0.15)	Leptokurtic (1.48)
	2015		Fine Sand (150µm)	92%	Moderate (1.66)	Fine (-0.20)	Very Leptokurtic (1.71)

Late Lafourche Delta

The Late Lafourche Delta had an average D_{50} of 169µm (fine sand) in 2008; in 2015, D_{50} increased to 171µm, which is also fine sand (table 4). All environments were in the fine sand classification during both periods except for the middle shoreface, which was very fine sand. By environment, the average D_{50} did not change appreciably from 2008 to 2015; the most significant change by environment from 2008 to 2015 was the beach face (191µm to 201µm, Figure 10). The increase in D_{50} onshore along the Caminada Headland (~780000 m E) is the result of beach nourishment projects BA-0045 and BA-0143. These projects were not completed until 2016, but by 2015, sediment was already added to the western half of headland to ~783000 m E (Georgiou et al., 2018).

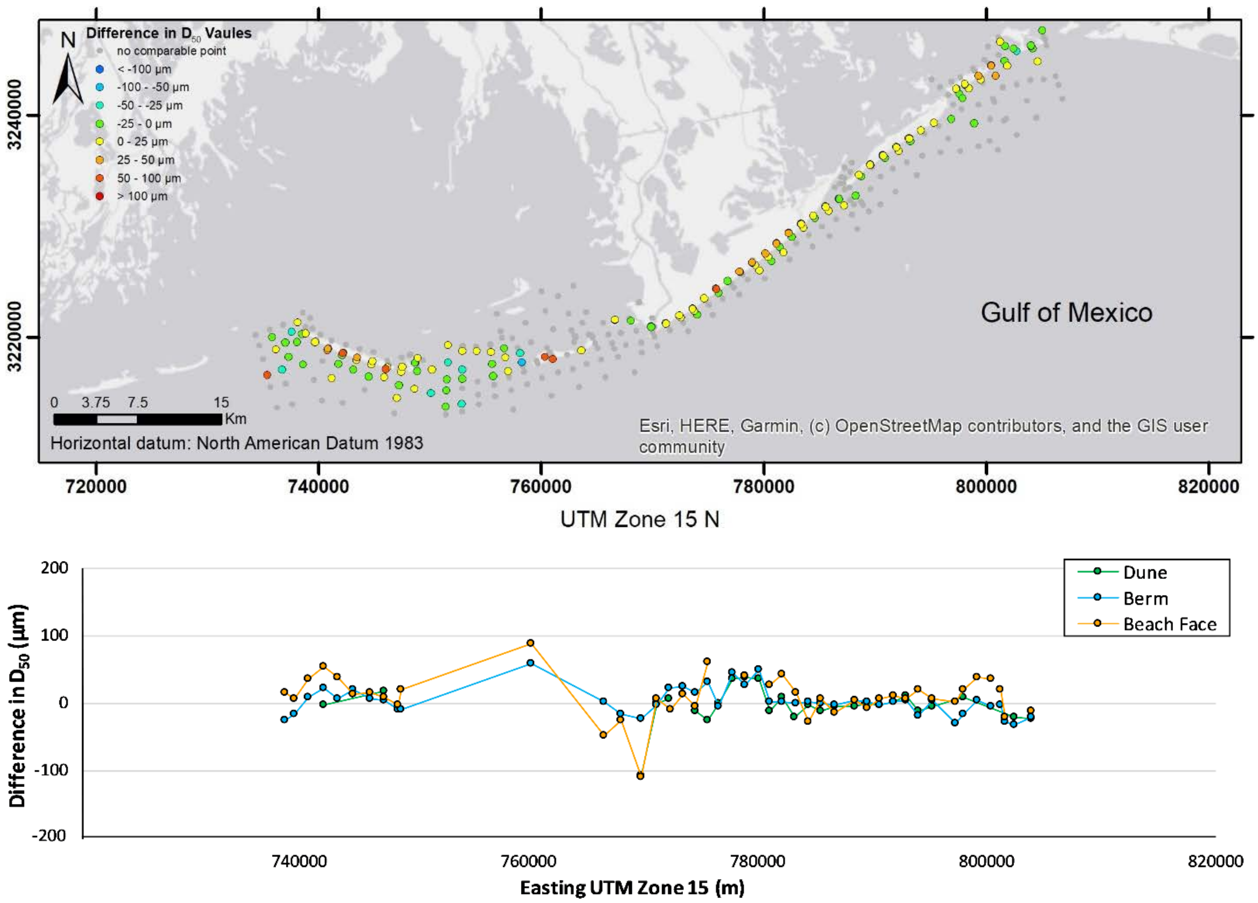


Figure 10: The difference in D_{50} along the Late Lafourche Delta from 2008 to 2015 in plan view (top) and graphically (bottom) for onshore environment (dune, berm and beach face).

Average percent sand of all comparable points along the Late Lafourche Delta decreased by 1% from 2008 (96%) to 2015 (95%), even with some restoration events. There was very little change in sand content by environment (±2%). For the onshore environments, the most significant decrease in sand content was around 770000 m E (on the west side of Belle Pass), where the dune, berm, and beach face decrease by 22%, 13%, and 22% respectively (Figure 11, Table 4). Likely due to dredging disposal activities along this section of shoreline from the West Belle Pass channel maintenance. However, from this area west along the Belle Pass Headland, a restoration effort did not change the grain size or sand content significantly.

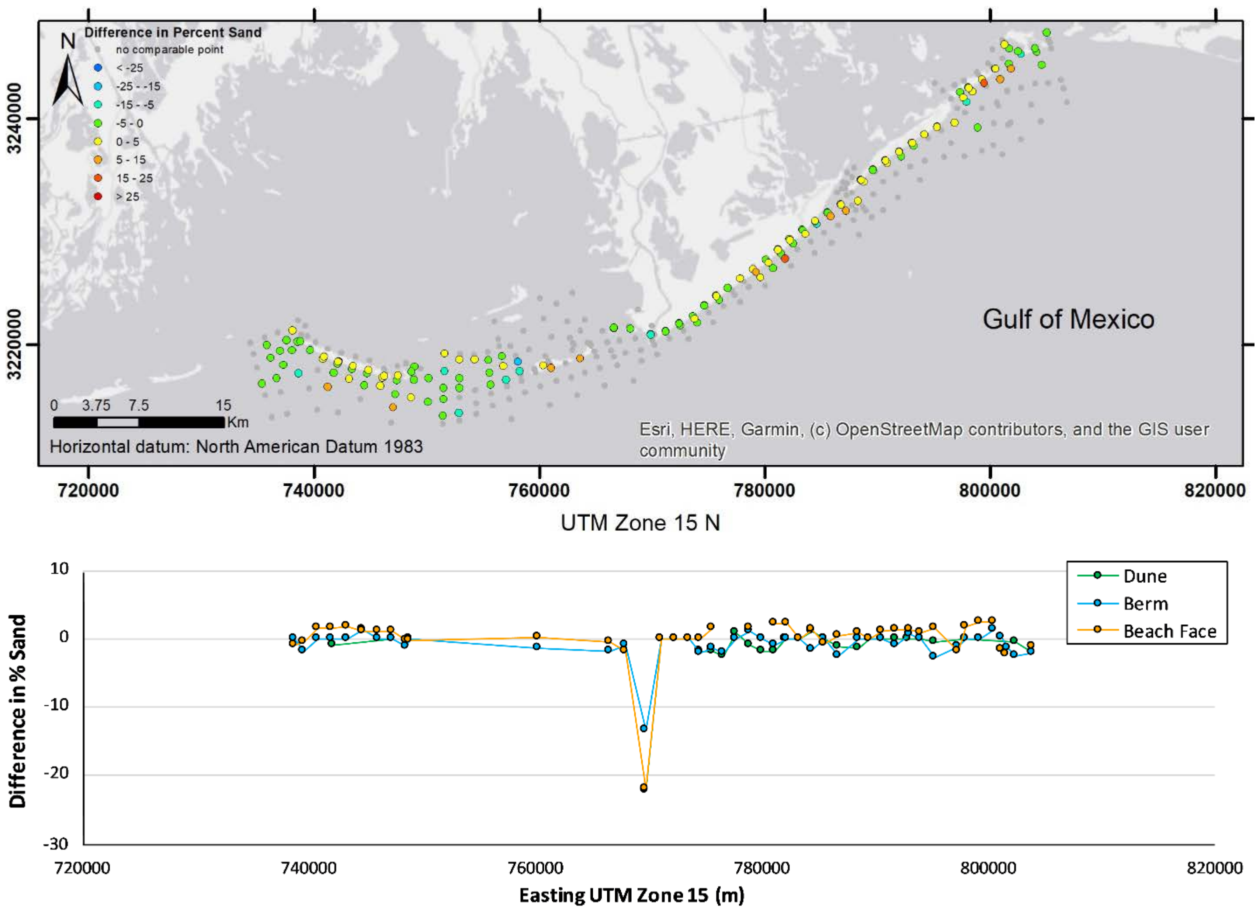


Figure 11: The difference in sand content along the Late Lafourche Delta from 2008 to 2015 in plan view (top) and graphically (bottom) for onshore environment (dune, berm and beach face).

Along the Late Lafourche Delta, the sediment was moderately well sorted, symmetrical and leptokurtic in both 2008 and 2015. Sorting and kurtosis increased slightly (1.44 to 1.47, 1.18 to 1.22), while skewness decreased (-0.07 to -0.09, Table 4). Sorting by environment (dune [well], berm [well], beach face [moderately well], upper shoreface [moderately well], lower shoreface [moderate]), remained within their respective sorting categories from 2008 to 2015, fluctuating ±0.08. The middle shoreface sorting decreased by 0.13 going from moderately to moderately well sorted, and average inlet sediment sorting increased by 0.11 changing from moderately well to moderately sorted. Sediment from the three onshore environments were symmetrical in both years, the dune and berm had not experienced change from 2008 to 2015, while the beach face decreased by 0.03. Offshore environments (inlet, upper shoreface and middle shoreface) were finely skewed, and lower shoreface was very finely skewed in both years. Skewness for the inlet environment changed the most, decreasing by 0.09. The upper, middle and lower shoreface changed by ±0.02 skewness values from 2008 to 2015. The only environment that experienced change in kurtosis (2008-2015) was the middle shoreface, where kurtosis value increased by 0.11, from leptokurtic to very leptokurtic (Figure 12, Table 4).

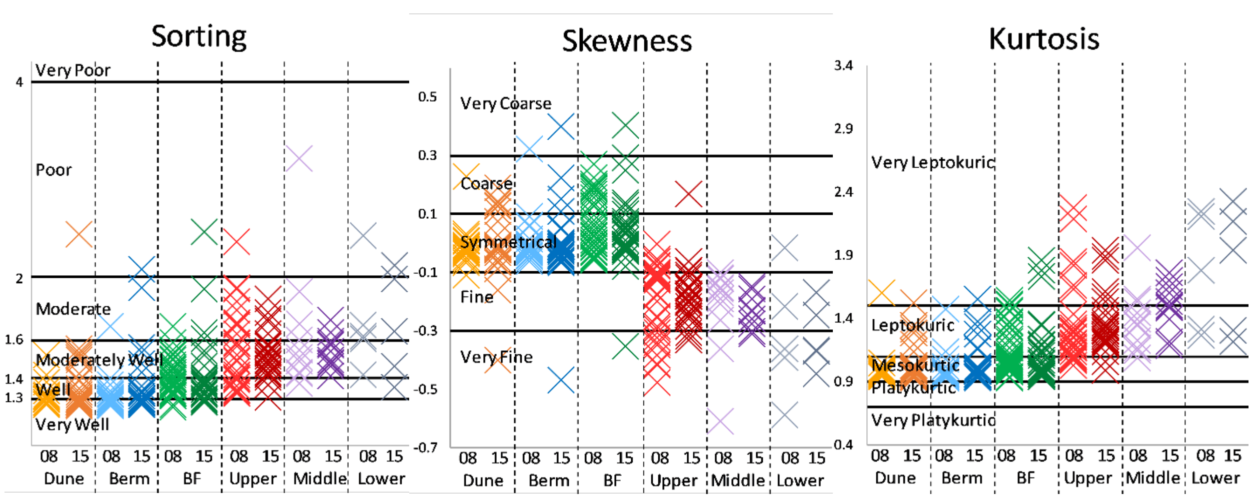


Figure 12: Sorting (left), skewness (middle), and kurtosis (right) values of comparable points along the Late Lafourche Delta in 2008 and 2015 by environment (dune, berm, beach face, upper shoreface, middle shoreface, and lower shoreface).

Table 4: Summary of Late Lafourche grain size statistics of all comparable points in 2008 and 2015 (n = number of samples used in average).

Environment	Year	n	D_{50}	% Sand	Sorting	Skewness	Kurtosis
Backbarrier	2008	1	N/A	N/A	N/A	N/A	N/A
	2015		N/A	N/A	N/A	N/A	N/A
Dune	2008	27	Fine Sand (198µm)	100%	Well (1.31)	Symmetrical (-0.01)	Mesokurtic (0.99)
	2015		Fine Sand (194µm)	98%	Well (1.39)	Symmetrical (-0.01)	Mesokurtic (1.06)
Berm	2008	44	Fine Sand (197µm)	100%	Well (1.30)	Symmetrical (-0.01)	Mesokurtic (0.97)
	2015		Fine Sand (199µm)	99%	Well (1.35)	Symmetrical (-0.01)	Mesokurtic (1.01)
Beach Face	2008	40	Fine Sand (191µm)	99%	Moderate Well (1.41)	Symmetrical (0.07)	Leptokurtic (1.16)
	2015		Fine Sand (201µm)	99%	Moderate Well (1.40)	Symmetrical (0.04)	Leptokurtic (1.10)
Inlet	2008	33	Fine Sand (148µm)	93%	Moderate Well (1.54)	Fine (-0.14)	Leptokurtic (1.32)
	2015		Fine Sand (142µm)	91%	Moderate (1.65)	Fine (-0.23)	Leptokurtic (1.46)
Upper Shoreface	2008	32	Fine Sand (130µm)	91%	Moderate Well (1.56)	Fine (-0.20)	Leptokurtic (1.33)
	2015		Fine Sand (135µm)	92%	Moderate Well (1.53)	Fine (-0.18)	Leptokurtic (1.35)
Middle Shoreface	2008	11	Very Fine Sand (110µm)	88%	Moderate (1.67)	Fine (-0.22)	Leptokurtic (1.39)
	2015		Very Fine Sand (109µm)	89%	Moderate Well (1.54)	Fine (-0.24)	Very Leptokurtic (1.50)
Lower Shoreface	2008	5	Fine Sand (113µm)	86%	Moderate (1.73)	Very Fine (-0.31)	Very Leptokurtic (1.77)
	2015		Fine Sand (109µm)	87%	Moderate (1.71)	Very Fine (-0.32)	Very Leptokurtic (1.80)
Total Average	2008	193	Fine Sand (169µm)	96%	Moderate Well (1.44)	Symmetrical (-0.07)	Leptokurtic (1.18)
	2015		Fine Sand (171µm)	95%	Moderate Well (1.47)	Symmetrical (-0.09)	Leptokurtic (1.22)
Onshore Average	2008	112	Fine Sand (195µm)	99%	Well (1.34)	Symmetrical (0.02)	Mesokurtic (1.04)
	2015		Fine Sand (198µm)	99%	Well (1.38)	Symmetrical (0.01)	Mesokurtic (1.06)
Offshore Average	2008	81	Fine Sand (133µm)	91%	Moderate Well (1.58)	Fine (-0.18)	Leptokurtic (1.36)
	2015		Fine Sand (133µm)	91%	Moderate Well (1.59)	Fine (-0.22)	Leptokurtic (1.44)

Modern Delta

The average grain size in the Modern Delta region increased by 12µm from 2008 to 2015, attributed to several restoration projects along various reaches of this region restoration sites. This increase is most evident in the eastern part of the region near Pelican and Scofield Islands, where the highest average increase by environment was observed; 46µm in the beach face (Figure 13, Table 5). While all of the onshore environments increased in average grain size from 2008 to 2015 (dune 7µm, berm 23µm, and beach face 46µm), all of the offshore environments decreased by ~10µm or less (see Hymel et al., 2019 for information beach restoration in the area).

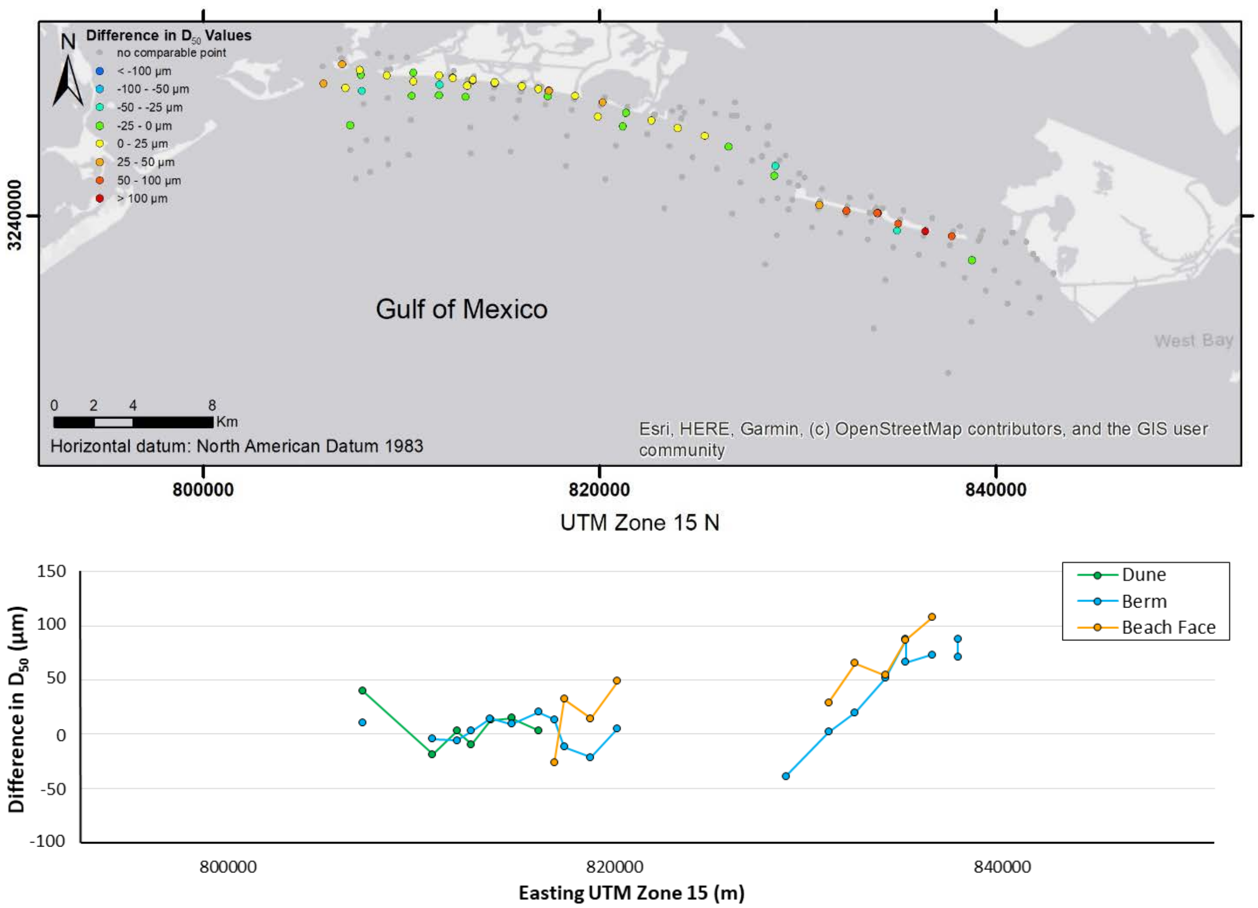


Figure 13: The difference in D_{50} along the Modern Delta from 2008 to 2015 in plan view (top) and graphically (bottom) for onshore environment (dune, berm and beach face).

Sand content in the Modern Delta region remained 96% from 2008 to 2015. The beach face was the only environment to increase in percent sand from 2008 to 2015 (98% to 99%). All other environments either did not change or decreased by ~1% (Figure 14, Table 5). The most substantial increase in sand content was 13% in the upper shoreface around 820000 m E, while the most significant decrease was around 81000 m E in the lower shoreface (-15%).

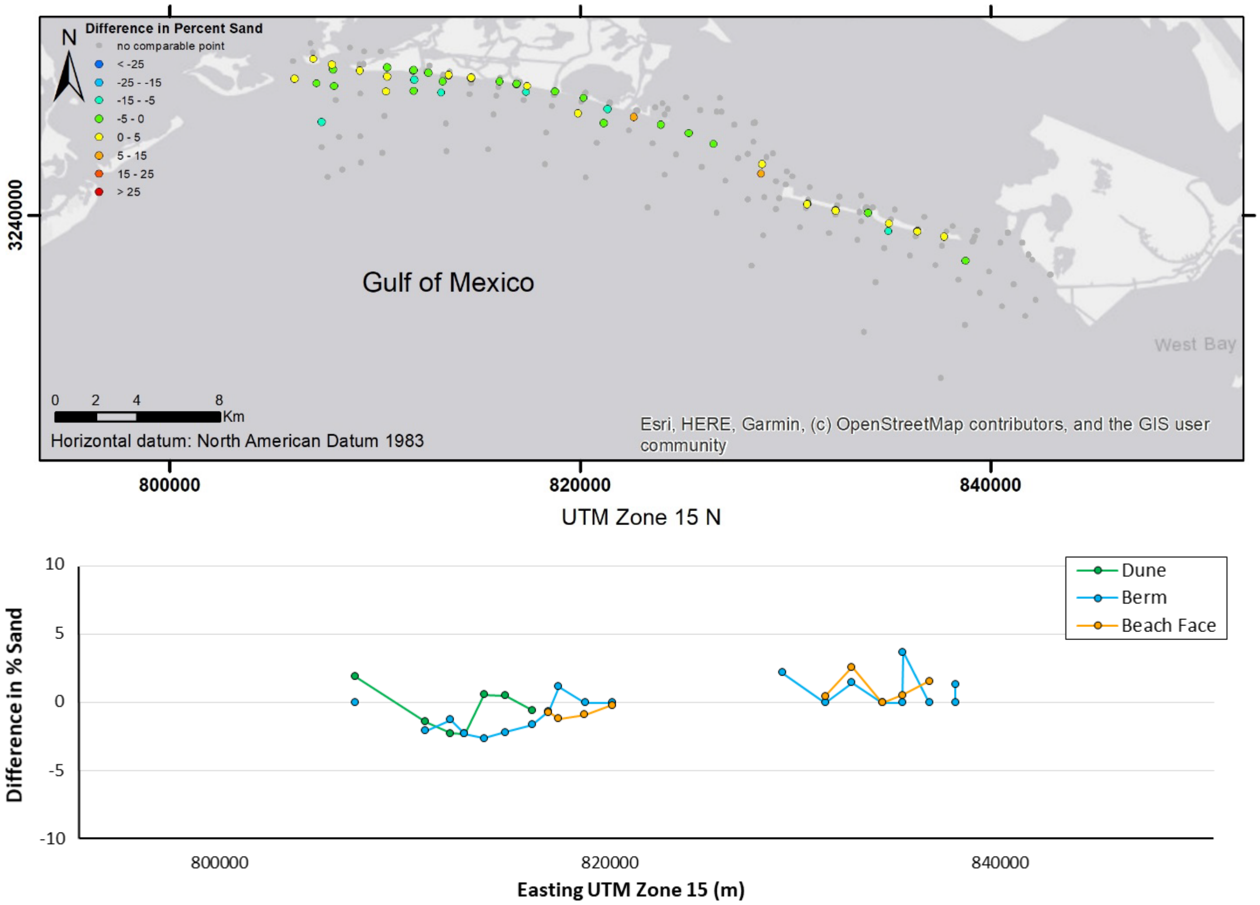


Figure 14: The difference in sand content along the Modern Delta from 2008 to 2015 in plan view (top) and graphically (bottom) for onshore environment (dune, berm and beach face).

In 2008 and 2015, sediment in the Modern Delta region was moderately well sorted (1.46, 1.44), symmetrical (-0.05, -0.09), and Leptokurtic (1.29, 1.26). Sorting between 2008 and 2015 changed very little if at all in the dune (+0.01), berm (-0.05), beach face (0), inlet (+0.01), and middle shoreface (-0.08) environments (Figure 15, Table 5). The most substantial change in sorting value was in the upper shoreface, where average sorting decreased by 0.12, changing from moderately sorted to moderately well. Skewness decreased in all of the environments except for the middle shoreface. The middle shoreface skewness value increased from very finely skewed to finely (+0.06). Lastly, kurtosis values increased the most in the inlet and upper shoreface (+0.14) and decreased the most in the middle shoreface (-0.40, Figure 15, Table 5).

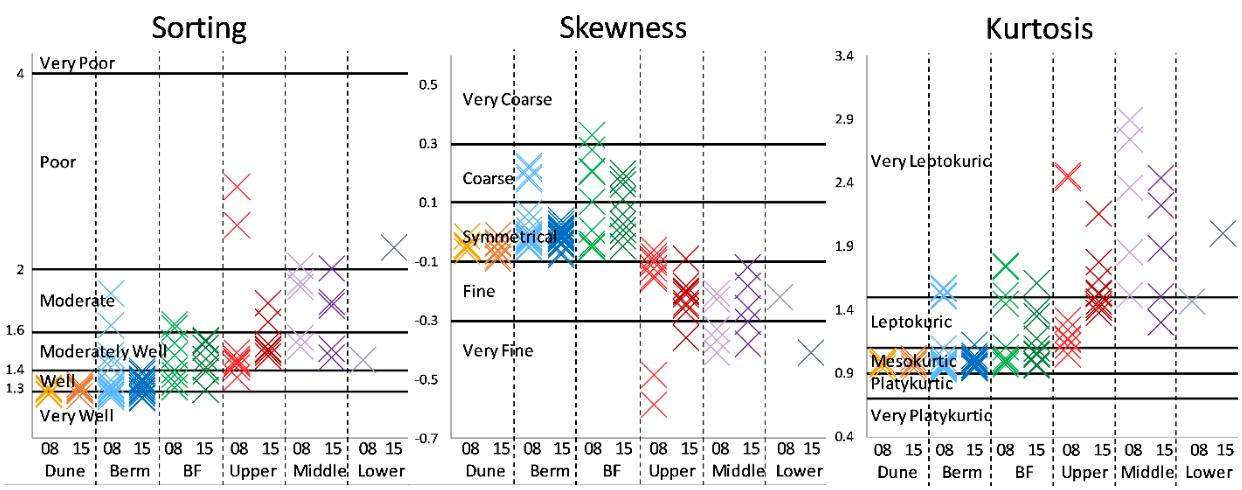


Figure 15: Sorting (left), skewness (middle), and kurtosis (right) values of comparable points along the Modern Delta in 2008 and 2015 by environment (dune, berm, beach face, upper shoreface, middle shoreface, and lower shoreface).

Table 5: Summary of Modern Delta grain size statistics of all comparable points in 2008 and 2015 (n = number of samples used in average).

Environment	Year	n	D_{50}	% Sand	Sorting	Skewness	Kurtosis
Backbarrier	2008	0	N/A	N/A	N/A	N/A	N/A
	2015		N/A	N/A	N/A	N/A	N/A
Dune	2008	7	Fine Sand (177μm)	99%	Well (1.30)	Symmetrical (-0.04)	Mesokurtic (0.97)
	2015		Fine Sand (184μm)	98%	Well (1.31)	Symmetrical (-0.05)	Mesokurtic (0.98)
Berm	2008	20	Fine Sand (190μm)	99%	Well (1.37)	Symmetrical (0.03)	Mesokurtic (1.08)
	2015		Fine Sand (213μm)	99%	Well (1.32)	Symmetrical (-0.02)	Mesokurtic (0.99)
Beach Face	2008	9	Fine Sand (169μm)	98%	Moderate Well (1.45)	Coarse (0.11)	Leptokurtic (1.28)
	2015		Fine Sand (215μm)	99%	Moderate Well (1.45)	Symmetrical (0.08)	Leptokurtic (1.18)
Inlet	2008	9	Fine Sand (143μm)	96%	Moderate Well (1.42)	Symmetrical (-0.07)	Leptokurtic (1.27)
	2015		Fine Sand (140μm)	95%	Moderate Well (1.43)	Fine (-0.20)	Leptokurtic (1.41)
Upper Shoreface	2008	9	Very Fine Sand (122μm)	91%	Moderate (1.67)	Fine (-0.20)	Leptokurtic (1.45)
	2015		Very Fine Sand (112μm)	90%	Moderate Well (1.55)	Fine (-0.22)	Very Leptokurtic (1.59)
Middle Shoreface	2008	5	Very Fine Sand (104μm)	88%	Moderate (1.78)	Very Fine (-0.31)	Very Leptokurtic (2.27)
	2015		Very Fine Sand (101μm)	87%	Moderate (1.70)	Fine (-0.25)	Very Leptokurtic (1.87)
Lower Shoreface	2008	1	N/A	N/A	N/A	N/A	N/A
	2015		N/A	N/A	N/A	N/A	N/A
Total Average	2008	60	Fine Sand (160μm)	96%	Moderate Well (1.46)	Symmetrical (-0.05)	Leptokurtic (1.29)
	2015		Fine Sand (172μm)	96%	Moderate Well (1.44)	Symmetrical (-0.09)	Leptokurtic (1.26)
Onshore Average	2008	36	Fine Sand (182μm)	99%	Well (1.37)	Symmetrical (0.04)	Leptokurtic (1.11)
	2015		Fine Sand (208μm)	99%	Well (1.35)	Symmetrical (0.00)	Mesokurtic (1.04)
Offshore Average	2008	24	Fine Sand (126μm)	92%	Moderate Well (1.59)	Fine (-0.18)	Very Leptokurtic (1.56)
	2015		Very Fine Sand (120μm)	91%	Moderate Well (1.57)	Fine (-0.23)	Very Leptokurtic (1.60)

Chandeleur Islands

The Chandeleur Islands decreased in average grain size from 173µm in 2008 to 158µm in 2015 (Figure 16, Table 6). We observed this decrease across all environments, with the most significant average decrease in the back-barrier environments (202µm to 169µm) followed by the berm and beach face (-27µm and -23µm). The largest decreased in D_{50} was in the back-barrier around 3300000 m N, here the D50 decreased by 500µm. The most substantial increase was in the lower shoreface around 3260000 m N (+147µm).

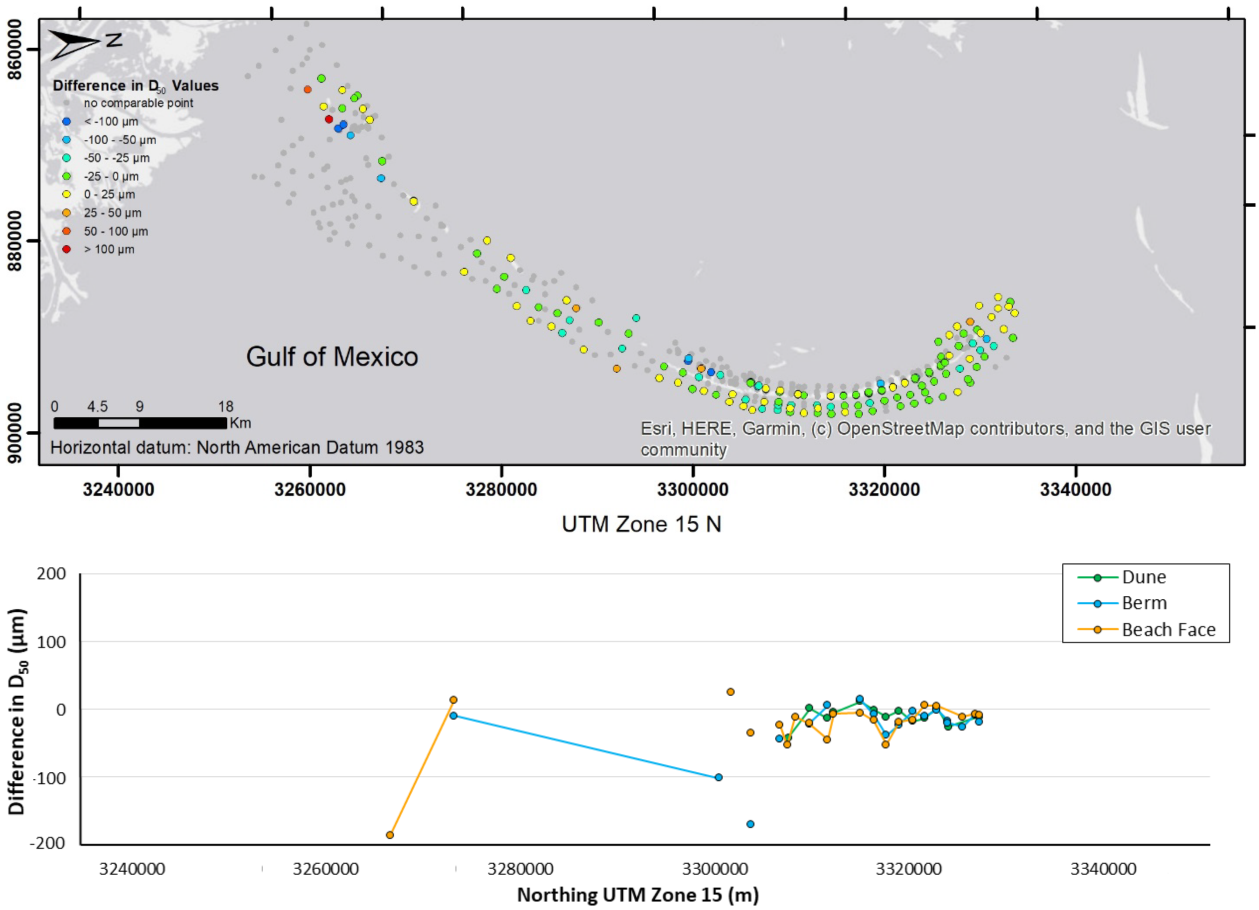


Figure 16: The difference in D_{50} along the Chandeleur Islands from 2008 to 2015 in plan view (top) and graphically (bottom) for onshore environment (dune, berm and beach face).

The average sand content along the Chandeleur Islands decreased from 96% to 93% from 2008 to 2015 (Figure 17, Table 6). Like average grainsize in this region, average sand content decreased across all environments. The backbarrier, dune and berm environments decreased by 1%, middle shoreface decreased by 2%, beach face and upper shoreface by 3%, and the lower shoreface decreased by 5%. The largest decreases were around the 3260000 m N in the lower shoreface (Figure 17).

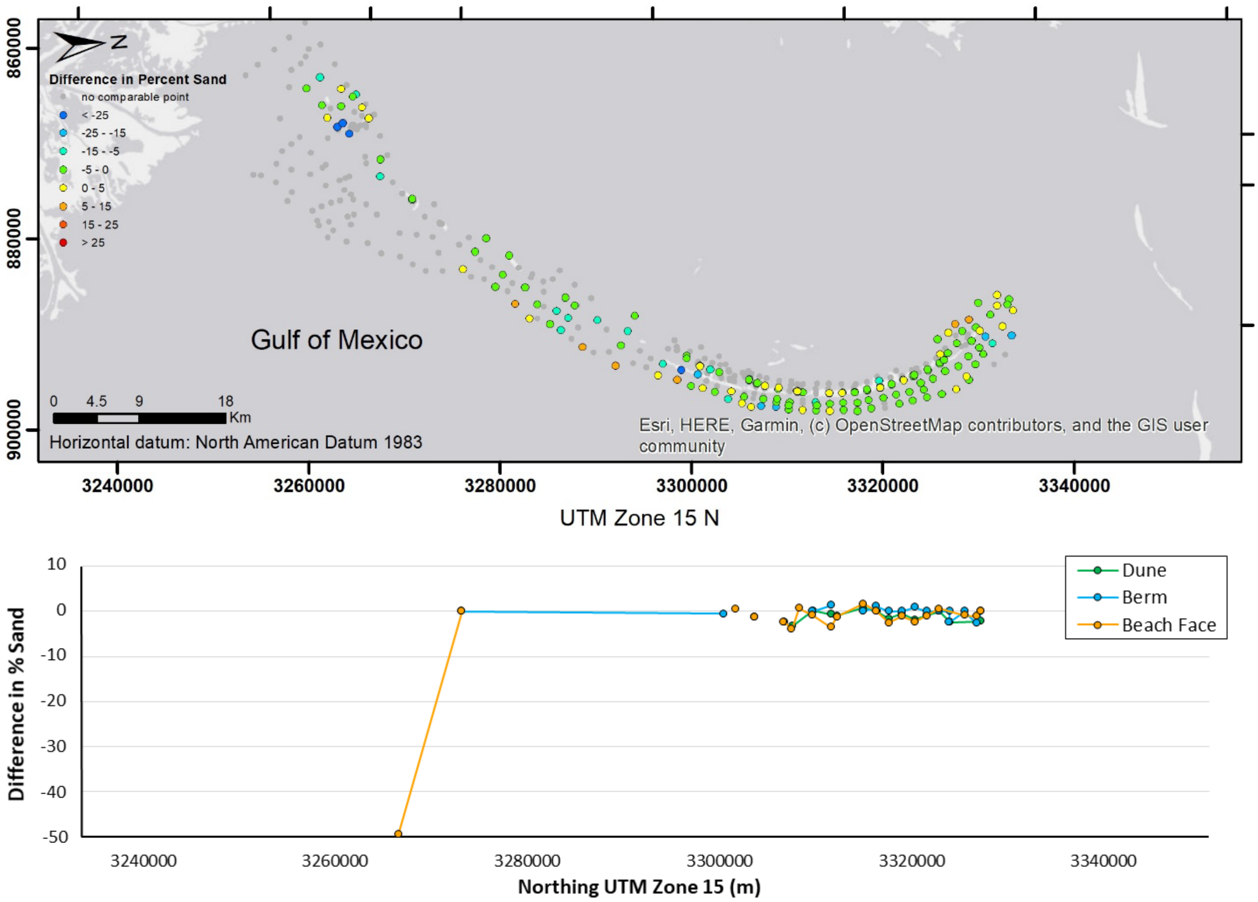


Figure 17: The difference in sand content along the Chandeleur Islands from 2008 to 2015 in plan view (top) and graphically (bottom) for onshore environment (dune, berm and beach face).

The average sediment along the Chandeleur Islands in 2008 was moderately well sorted (1.44), symmetrical (-0.01), and leptokurtic (1.22). In 2015 the sorting increased but remained moderately well sorted (1.58), sorting decreased becoming finely sorted (-0.15), and kurtosis remained leptokurtic increasing to 1.32 (Figure 18, Table 6). The average sorting by environment increased for all environments except for the berm (-0.09). While the average sorting increased, average skewness decreased across of the environments with the highest decrease by environment in the beach face (-0.11). All of the environments stayed in their respective skewness categories (backbarrier, middle, and upper shoreface were fine, while dune, berm and beach face were symmetrical) from 2008 to 2015, except for the upper shoreface (symmetrical to fine). The average kurtosis value changed by ±0.10 in the backbarrier, dune, berm, beachface, and middle shoreface. The upper shoreface kurtosis increased by 0.14, changing from mesokurtic to leptokurtic, and the lower shoreface became very leptokurtic increasing by 0.26 from 2008 to 2015 (Figure 18, Table 6).

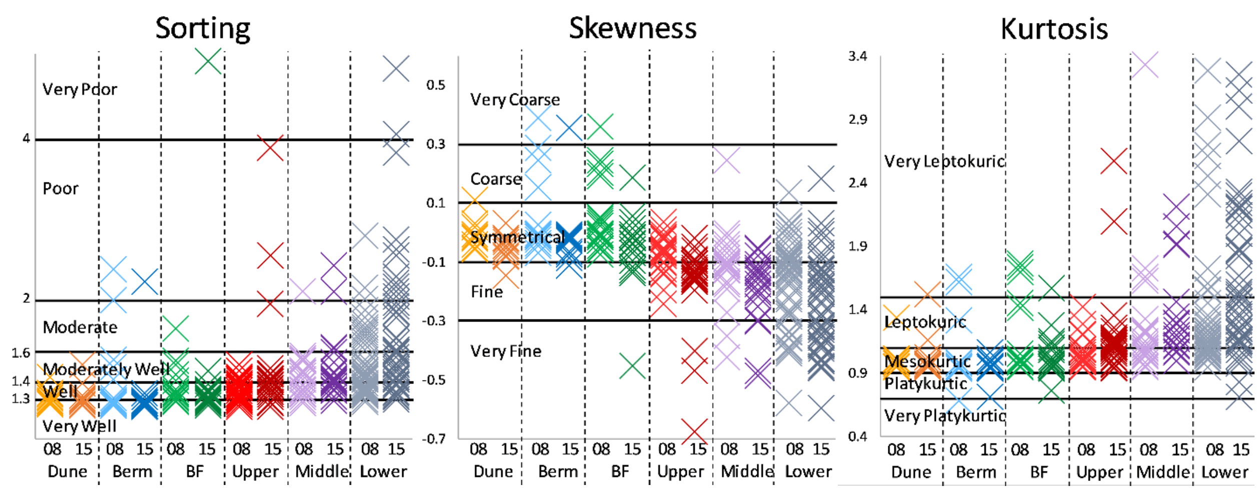


Figure 18: Sorting (left), skewness (middle), and kurtosis (right) values of comparable points along the Chandeleur Islands in 2008 and 2015 by environment (dune, berm, beach face, upper shoreface, middle shoreface, and lower shoreface).

Table 6: Summary of Chandeleur Islands grain size statistics of all comparable points in 2008 and 2015 (n = number of samples used in average).

Environment	Year	n	D_{50}	% Sand	Sorting	Skewness	Kurtosis
Backbarrier	2008	20	Fine Sand (202µm)	96%	Moderate Well (1.52)	Fine (-0.13)	Leptokurtic (1.38)
	2015		Fine Sand (169µm)	95%	Moderate Well (1.53)	Fine (-0.17)	Leptokurtic (1.47)
Dune	2008	13	Fine Sand (199µm)	100%	Well (1.31)	Symmetrical (-0.01)	Mesokurtic (1.00)
	2015		Fine Sand (189µm)	99%	Well (1.32)	Symmetrical (-0.05)	Mesokurtic (1.03)
Berm	2008	18	Fine Sand (221µm)	100%	Moderate Well (1.42)	Symmetrical (0.05)	Mesokurtic (1.02)
	2015		Fine Sand (194µm)	99%	Well (1.33)	Symmetrical (-0.01)	Mesokurtic (0.95)
Beach Face	2008	20	Fine Sand (199µm)	99%	Well (1.37)	Symmetrical (0.06)	Leptokurtic (1.14)
	2015		Fine Sand (176µm)	96%	Moderate Well (1.54)	Symmetrical (-0.05)	Mesokurtic (1.04)
Inlet	2008	0	N/A	N/A	N/A	N/A	N/A
	2015		N/A	N/A	N/A	N/A	N/A
Upper Shoreface	2008	27	Fine Sand (162µm)	97%	Well (1.36)	Symmetrical (-0.08)	Mesokurtic (1.06)
	2015		Fine Sand (147µm)	94%	Moderate Well (1.53)	Fine (-0.16)	Leptokurtic (1.20)
Middle Shoreface	2008	23	Fine Sand (143µm)	95%	Moderate Well (1.44)	Fine (-0.12)	Leptokurtic (1.28)
	2015		Fine Sand (137µm)	93%	Moderate Well (1.50)	Fine (-0.19)	Leptokurtic (1.34)
Lower Shoreface	2008	50	Fine Sand (147µm)	93%	Moderate Well (1.53)	Fine (-0.16)	Leptokurtic (1.37)
	2015		Fine Sand (140µm)	88%	Moderate (1.84)	Fine (-0.25)	Very Leptokurtic (1.63)
Total Average	2008	171	Fine Sand (173µm)	96%	Moderate Well (1.44)	Symmetrical (-0.08)	Leptokurtic (1.22)
	2015		Fine Sand (158µm)	93%	Moderate Well (1.58)	Fine (-0.15)	Leptokurtic (1.32)
Onshore Average	2008	71	Fine Sand (206µm)	99%	Moderate Well (1.41)	Symmetrical (-0.01)	Leptokurtic (1.15)
	2015		Fine Sand (181µm)	97%	Moderate Well (1.44)	Symmetrical (-0.07)	Leptokurtic (1.14)
Offshore Average	2008	100	Fine Sand (150µm)	95%	Moderate Well (1.47)	Fine (-0.13)	Leptokurtic (1.27)
	2015		Fine Sand (141µm)	91%	Moderate (1.68)	Fine (-0.21)	Leptokurtic (1.45)

Discussion

The evaluation of grain size, sand content, and grain size statistics reveals a slight overall increase in grain size and a slight decrease in sand content along the 5 comparable BICM regions during the study period. The grain size increase is most prominent in the Western Chenier and Modern Delta regions, both regions with large restoration projects during this period. Overall, sediment in the five comparable BICM regions was moderately well sorted, symmetrical, and leptokurtic.

The observed Chenier Plain increases in average grain size, sorting, and kurtosis, westward of 460000 m E were primarily due to the Cameron Parish Shoreline Restoration (CS-0033). At the same time, for the rest of the Chenier Plain, the results were also influenced by an increase in sand-size shell fragments and detrital content. There was little change observed in the D_{50} eastward of 460000 m E from 2008 to 2015 except for a small decrease of sand and detrital content. This trend can be explained by shoreline progradation on this portion of the Cheniers from 2008 to 2015, the newer sediment having detrital content reducing the volume of sand-size particles.

The increase in grain size in the Modern Delta region is likely the result of several restoration efforts, particularly restoration at Pelican and Scofield Islands (BA-0038-2 and BA-0040), which both took place between 2011 through 2013 (Hymel et al., 2018, CEC, Inc. 2014). Although grain size increased in this region because of the restorations projects, the projects did not dramatically change the sand content or grain size statistics. Sediment remained moderately well sorted, symmetrical and leptokurtic, indicating that the source of the sediment used for restoration was similar to the local sediment characteristics.

The Chandeleur Islands experienced the most substantial decrease in average grain size and sand content from 2008 to 2015, most of which occurred in back-barrier and terrestrial environments. Along with a decrease in average grain size, sediment in the Chandeleur Islands region became finely sorted from 2008 to 2015, while sorting and kurtosis remained the same. The ongoing transgression at the Chandeleur Islands, coupled with the absence of restoration, except the northern part where nourishment took place during the installation of the sand berm in 2010, is the likely cause.

The Early Lafourche and Late Lafourche Deltas exhibited far less change compared to the other studied regions. For the Early Lafourche delta, this result is somewhat surprising, considering that the Isle Dernieres barrier chain received restoration pre-2008 sampling efforts. However, the lack of significant change in the overall sediment statistics, including sand content between 2008 and 2015, suggests that significant events (e.g., storms) driving geomorphic change were likely absent. Furthermore, the insignificant changes in the median grain diameter (D50) corroborate further the positive influence of the restoration efforts and the lack of storms to redistribute the sediment. The late Lafourche system received restoration post-2008, with phase-I (BA-0045) completed by 2015 (CEC, 2016). Georgiou et al. (2018) reported noticeable and statistically significant differences between pre- and post-restoration sediment characteristics using sampling that took place in 2017 following completion of phase-II (BA-0143). In a more recent report, however, Georgiou et al. (2019) reported that sediment change analysis characteristics were transient, and by 2019 the Caminada Headland sediments resembled 2008 pre-project statistics. Taken together, the lack of trends in regions were restoration took place to suggest that sand remained in the system, mainly due to the absence of more significant events to produce perturbations.

For successful interpretation of future sediment trends, the program may benefit from additional sampling in regions not sampled in 2008 and 2015. We support that the program may continue to benefit from sampling in the five BICM regions analyzed herein. We also recommend that the program adopts supplemental analysis for samples containing less than 70% sand. Analyzing more samples from the shoreface provides transitional data that would help connect nearshore to offshore environments. Moreover, the additional datasets build a framework to help facilitate an in-depth understanding of nearshore and shoreface sediment trends along the Mississippi River Delta Plain and continue to evaluate the regional impacts of restoration projects.

References

Barras, J., Beville, S., Britsch, D., Hartley, S., Hawes, S., Johnston, J., Kemp, P., Kinler, Q., Martucci, A., Porthouse, J., Reed, D., Roy, K., Sapkota, S., and Suhayda, J., 2003, Historical and projected coastal Louisiana land changes— 1978–2050: U.S. Geological Survey Open-File Report 2003-334, 39 p.

Bascom, W. N., (1951). The relationship between sand size and beach face slope. Eos, Transactions American Geophysical Union, 32(6), 866-874.

Byrnes, M.R., L.D. Britsch, J.L. Berlinghoff, and R. Johnson, 2018. Determining Modern Subsidence Rates in Barataria Basin, Louisiana: Implications for Engineering and Design of Coastal Restoration Projects. Prepared for Louisiana Coastal Protection and Restoration Authority (CPRA) by Applied Coastal Research and Engineering, Baton Rouge, LA and Mashpee, MA, in cooperation with CDM Smith, Baton Rouge, LA, 67 p. including appendices.

Coastal Engineering Consultants Inc. (2014). Riverine Sand Mining / Scofield Island (BA-40) Project Completion Report. Baton Rouge, LA: CEC.

Couvillion, B. R., Barras, J. A., Steyer, G. D., Sleavin, W., Fischer, M., Beck, H., Trahan B., and Heckman, D. (2011). Land area change in coastal Louisiana from 1932 to 2010.

Dean, R., & Dalrymple, R. A., (2002). Coastal processes with engineering applications Cambridge University Press. New York.

Fenster, M. S., Dolan, R., and Smith, J. J. (2016). Grain-size distributions and coastal morphodynamics along the southern Maryland and Virginia barrier islands. Sedimentology, 63(4), 809-823.

Georgiou, I. Y., H. D. Weathers, M. A. Kulp, M. Miner and D.J. Reed. 2011. Interpretation of Regional Sediment Transport Pathways using Subsurface Geologic Data. Final Report submitted to US Army Corps of Engineers, CESU Contract # W912HX-09-2-0027.

Georgiou, I.Y., Yocum, T.E., and Brown, M.A., 2018. Caminada Headland Beach and Dune Restoration Increment 1 (BA-0045) and Increment 2 (BA-0143): Restoration Impacts to Sediment Characteristics. Prepared for Louisiana Coastal Protection and Restoration Authority (CPRA) by the Pontchartrain Institute for Environmental Sciences, University of New Orleans, New Orleans, LA, 55 p.

Georgiou, I.Y., Yocum, T.E., Brown, M.A., Tevis, L.B., 2019. Caminada Headland Beach and Dune Restoration Increment 1 (BA-0045) and Increment 2 (BA-0143): Restoration Impacts to Sediment Characteristics Part II. Prepared for Louisiana Coastal Protection and Restoration Authority (CPRA), Pontchartrain Institute for Environmental Sciences, University of New Orleans, New Orleans, LA, 65 p.

Georgiou, I.Y., Kulp, M.A., Brown, M., Courtois, A., Flocks, J.G., Tuten, T., 2017, Louisiana Barrier Island Comprehensive Monitoring Program (BICM) Phase 2 - 2016 Characterization of Surficial Sediments in the Western and Eastern Chenier Plain and Atchafalaya and Wax Lake Delta Regions: Part A - Data Collection, Sample Processing and Products. Prepared for Louisiana Coastal Protection and Restoration Authority (CPRA) by Pontchartrain Institute for Environmental Sciences, Baton Rouge, LA and New Orleans, LA, 15 p.

Georgiou, I.Y., Kulp, M.A., Brown, M., Courtois, A., Flocks, J.G., Tuten, T., 2017B, Louisiana Barrier Island Comprehensive Monitoring Program (BICM) Phase 2 - 2016 Characterization of Surficial Sediments in the Western and Eastern Chenier Plain and Atchafalaya and Wax Lake Delta Regions: Part B - Data Collection, Sample Processing and Products. Prepared for Louisiana Coastal Protection and Restoration Authority (CPRA) by Pontchartrain Institute for Environmental Sciences, Baton Rouge, LA and New Orleans, LA, 7 p

Hymel, M. K., B. S. Beasley, and B. J. Richard. 2019. 2018 Operations, Maintenance, and Monitoring Report for Barataria Barrier Island Complex: Pelican Island and Pass La Mer to Chaland Pass Restoration (BA-0038). Coastal Protection and Restoration Authority of Louisiana, New Orleans, Louisiana. 123 pp.

Kulp, M.A., Miner, M., Weathers, D, Motti, J.P., McCarty, P., Brown, M., Labold, J., Boudreaux, A., Flocks, J., and Taylor, C., 2011A, Louisiana Barrier Island Comprehensive Monitoring Program (BICM) Volume 6, Part A: Characterization of Louisiana Coastal Zone Sediment Samples: Backbarrier through offshore samples of the Chenier Plain, South Central Barrier Island Systems and Chandeleur Islands, LA Coastal Protection and Restoration Authority, 10 pp.

Kulp, M.A., Miner, M., Weathers, D, Motti, J.P., McCarty, P., Brown, M., Labold, J., Boudreaux, A., Flocks, J., and Taylor, C. 2011B, Louisiana Barrier Island

Comprehensive Monitoring Program (BICM) Volume 6, Part B: Characterization of Louisiana Coastal Zone Sediment Samples: Backbarrier through offshore samples of the Chenier Plain, South Central Barrier Island Systems and Chandeleur Islands, LA Coastal Protection and Restoration Authority, 39 pp.

Kulp, M.A., Georgiou, I.Y., Brown, M., Courtois, A., Flocks, J.G., and Tuten, T., 2015, Louisiana Barrier Island Comprehensive Monitoring Program (BICM) Phase 2 - 2015 Characterization of Surficial Sediments in the Early Lafourche Delta, Late Lafourche Delta, Modern Delta, and Chandeleur Islands Regions: Part A - Data Collection, Sample Processing and Products. Prepared for Louisiana Coastal Protection and Restoration Authority (CPRA) by Pontchartrain Institute for Environmental Sciences, Baton Rouge, LA and New Orleans, LA, 16 p.

Kulp, M.A., Georgiou, I.Y., Brown, M., Courtois, A., Flocks, J., and Tuten, T., 2017B, Louisiana Barrier Island Comprehensive Monitoring Program (BICM) Phase 2 - 2015 Characterization of Surficial Sediments in the Early Lafourche Delta, Late Lafourche Delta, Modern Delta, and Chandeleur Islands Regions: Part B – Sediment Sample Distribution Maps, submitted to Louisiana Coastal Protection and Restoration Authority 10 pp.

Limber, P. W., Patsch, K. B., and Griggs, G. B., (2008). Coastal sediment budgets and the littoral cutoff diameter: a grain size threshold for quantifying active sediment inputs. *Journal of Coastal Research*, *24*(sp2), 122-133.

Martinez, L., O'Brien, S., Bethel, M., Penland, S., and Kulp, M., (2009) Louisiana Barrier Island Comprehensive Monitoring program (BICM), vol 2. Shoreline changes and barrier island land loss 1880s to 2005. Univ New Orleans Pontchartrain Inst Environ Sci Tech Rep.

Penland, S., and Ramsey, K. E. (1990). Relative sea-level rise in Louisiana and the Gulf of Mexico: 1908-1988. Journal of Coastal Research, 323-342.

Stauble, D. K., (2003). The use of shoreline change mapping in coastal engineering project assessment. Journal of Coastal Research, 178-206.

Willams, S.J., Penland, S., and Sallenger, A.H., (eds.), 1992. Atlas of Shoreline Change in Louisiana from 1853-1989. U.S. Geo- logical Survey, Miscellaneous Investigation Series I-2150-A, 103