Shoreline Change Analysis of Oiled and Treated Shorelines in Upper Barataria Bay

James C. Gibeaut
Harte Research Institute
Texas A&M University – Corpus Christi
Corpus Christi, TX 78412
james.gibeaut@tamucc.edu

Zachary Nixon
Research Planning, Inc.
1121 Park Street, Columbia, SC 29201
znixon@researchplanning.com

Shahrokh Rouhani
NewFields
1349 W. Peachtree Street, Suite 2000
Atlanta, GA 30309
srouhani@newfields.com

INTRODUCTION

Prior studies concluded that heavy oiling following the *Deepwater Horizon* (DWH) spill accelerated marsh edge erosion at specific sites and that some intensive shoreline cleanup treatments may have further accelerated marsh erosion (Silliman et al. 2012, McClenachan et al. 2013, Zengel et al. 2015). Given the amount of oiling and oil removal treatment of mainland marsh shorelines that took place in Barataria Bay in Louisiana following the DWH well blowout in 2010, it became important to determine if marsh edge erosion was accelerated over a broader area and if so by how much over erosion caused by ongoing processes such as waves, tides, and subsidence. This study sought to determine if the most heavy oiling conditions plus intensive oil removal treatment impacted the shoreline (marsh edge) rate of change across upper Barataria Bay.

METHODS

In this evaluation, we used high-resolution aerial photography acquired in fall 2010 and spring 2013 in a control-impact paired approach. Using the *Deepwater Horizon* Shoreline Oiling Exposure Database (Nixon, Michel, and Zengel, In Prep), 20 sites along shoreline segments longer than 50 meters (m) that were classified as having received heavier persistent oiling and treatment were randomly selected. Heavier persistent oiling is defined as heavy to moderate oiling that persisted on the shoreline for at least 12 weeks (Nixon, Michel, and Zengel, In Prep). Shoreline cleanup treatments included varying combinations of manual and mechanical removal of oiled wrack and oiled vegetation mats, cutting and raking of vegetation, raking and scraping of thick oil deposits from the marsh substrate, and application of loose organic sorbents (Zengel and Michel 2013, Zengel et al. 2015). Treatments were primarily conducted between February and September 2011, with some localized maintenance treatments occurring in winter 2011-2012 and 2012-2013.

Selection of impact sites was also constrained so that they were at least 250-m apart alongshore to ensure their independence. For each impact site, a nearby paired control site was selected so that the effects of variation in factors other than heavier persistent oiling and treatment that may cause differences in shoreline retreat were reduced (e.g., geologic setting, wave exposure, etc.). The following rules were used to select paired control sites:

1. Each control site must be within 1 kilometer (km) of its impacted site pair.
2. Each control site must be farther than 10 m alongshore from locations either identified for treatment or known to have been treated.
3. Each control site must be farther than 70 m alongshore from any previously selected control site.
4. Each control site must be similar in relative wave exposure to its impact site. This was defined as the control site having a mean-based relative exposure index value of within 5,000 of its impacted site pair, which is approximately 20 percent of the range of this index in upper Barataria Bay. The mean-based relative exposure index serves as an indication of the relative wave energy the shoreline segment was exposed to from 2010 through 2012. Index values were calculated by Nixon (In Prep) using mean wind speeds for 8, 45 degree directional bins and fetch lengths for each bin following an approach modified from Keddy (1982).
5. Each control site must have an approximate shoreline orientation within +/- 90 degrees of its impacted site pair.
6. Each control site must have the lowest oiling exposure category possible given the above constraints.
7. Each control site must consist of ≥ 50 m of shoreline.

The above control site selection criteria was designed to reduce the effects of geologic setting (rule 1) and wave energy (rules 4 and 5) that cause variation in shoreline change. Rule 2 ensures a control site is not impacted by the effects of an impacted shoreline extending beyond its boundary as well as addressing uncertainty in the mapping accuracy of oiling degree and treatment locations. Rule 3 ensures control sites are independent of each other. Rule 7 provides multiple shoreline change measuring points needed to address the alongshore variability observed in short-term change (1 to 3 years) occurring on an alongshore scale as fine as 5 m. The control sites were not treated but they had received heavy oiling, although generally to a lesser degree than the impact sites (rule 6). Selection of oiled control sites was required to ensure confounding factors causing erosion were reduced. There simply are no untreated, unoiled sites in upper Barataria Bay meeting the selection criteria.

Initially, 40 candidate impact sites were generated, and control sites were selected in sequential order for each one. If a previously selected control site occupied the best candidate location for a subsequent control site, the next most appropriate control site was used. If no suitable control site existed, the impact site was dropped. Fifteen sites were dropped during this process leaving 25 site pairs that were investigated further using the DOQQQ imagery. The initial site selection process used the *DeepWater Horizon* Shoreline Oiling Exposure Database (Nixon, Michel, and Zengel, In Prep), which has as its base an older (2008) and lower resolution shoreline compared to the DOQQQs. Inspection of the selected sites on the DOQQQs resulted in 5 additional pairs being rejected for the following reasons: (1) a shoreline eroded prior to 2010; (2) a shoreline segment at least 50-m long could not be defined; (3) a control site was in the fill area of an old canal; and (4) one pair had an impact site and another pair a control site episodically retreat about 50 m during the summer of 2012 resulting in highly fragmented and unmappable shorelines in 2013. Furthermore, these later two sites retreated at about 20 times the average rate of the other sites and well landward of oiling and cleanup impacts, which indicates that erosion processes other than oiling and treatment overwhelmed these sites making them unsuitable for this analysis.

Shorelines were mapped using high-resolution imagery acquired and geo-referenced by BP contractor, AeroMetric, Inc., using a Digital Mapping Camera in the fall of 2010 and spring of 2013. AeroMetric created Digital Orthophoto Quarter Quarter Quads (DOQQQ) in UTM coordinates from individually rectified images. The 8-bit ortho-imagery has a 0.3 m ground pixel size and is represented in four bands, the near infrared, red, green, and blue portions of the spectrum, with numeric values ranging from 0 to 255. These DOQQQs generally meet the American Society for Photogrammetry and Remote Sensing (ASPRS) large-scale planimetric map accuracy standards for Class 2, 1:2,400-scale maps.

The 20 impact-control pairs occur on 8 different DOQQQs and to improve quantitative shoreline comparisons, we determined error in the co-registration between the 2010 and 2013 DOQQQs by selecting 16 to 24 common point features visible in imagery from each time period and computing mean offsets in Easting (x) and Northing (y) coordinates. Shorelines mapped from the 2013 imagery were shifted by the mean offsets determined for the pertinent DOQQQ, but the images were not shifted. The Root Mean Square Error (RMSE) was computed for each DOQQQ after applying the x and y shifts and all were 0.8 m or less.

The shoreline feature mapped for this study is the edge of vegetation, whether oiled or unoiled. This feature is more consistent than the edge of the marsh platform which could be submerged or have low contrast with the water. Compared to the other bands and band combinations, the near infrared band proved to be the most consistent for delineating the shoreline feature, and was therefore, used in the mapping process. Shorelines were mapped site by site in a semi-automated process where an approximate shoreline was buffered 20 m landward and bayward and a histogram of near infrared pixel values from the buffer zone created. These histograms are bimodal reflecting the low-reflectance water pixels and the high-reflectance vegetated land pixels. The frequency values of the peak of the high-reflectance mode and the trough toward low reflectance pixels (water) were determined. Ten percent of the difference between the peak and trough was added to the trough value and where that value intersected the rising edge of the peak, the corresponding reflectance value was chosen as the shoreline reflectance value. This value was then contoured on the infrared imagery to represent the shoreline feature. In some cases, the histograms were tri-modal with the middle mode indicating an area between the water and well-vegetated marsh that may be sparsely vegetated or have oiled vegetation. In these situations, the middle mode was used to pick the shoreline reflectance value.

Shoreline change from fall of 2010 to spring of 2013, a period of 2.6 years, was determined every 5 m alongshore within each shoreline segment of at least 50-m length. The marsh shorelines are typically curvilinear and often crenulated on a scale of 5 m or less reflecting variation in shoreline change rates. A baseline was drawn manually to follow the trend of the 2010 shoreline, and virtual transects were automatically constructed perpendicular to the baseline segments. The distances between shorelines where they intersect the transects were automatically calculated.

Statistical analysis was performed on the amount of change from fall of 2010 to spring of 2013. An ANOVA procedure and t-test of significance was performed to determine if the average change of the control sites was different from the average change of the impact sites.

RESULTS

A total of 20 control-impact site pairs from upper Barataria Bay were evaluated. Table 1 presents the statistical analysis based on shoreline change measured along the individual transects. The impacted sites eroded at an average rate of -1.36 meters per year (m/yr) whereas the control sites eroded at an average rate of -0.94 m/yr, which was a 0.41 m/yr difference between fall 2010 and spring 2013. The 0.41 m/yr of additional erosion at treated, heavier persistent oiling sites (the impacted sites) compared to untreated, less-oiled sites (the control sites) is statistically significant at a 2.9% level.

DISCUSSION

Across upper Barataria Bay from the fall of 2010 to the spring of 2013, shorelines that received heavier persistent oiling and intensive treatment tended to retreat at a higher rate than they otherwise would have without oiling and treatment. The 0.41 m/yr average increase in the erosion rate translates to a loss of marsh of 1.07 meters per meter of impacted shoreline over the 2.6-year measurement period. Comparison with decadal-scale shoreline change analysis serves to place the current, short-term changes in context. Penland et al. (2001) classified GIS land-loss data produced by a U.S. Army Corps of Engineers project (Britsch and Dunbar, 1993) into various processes causing loss from the 1930's to 1990. The 2001 Penland study shows natural wave erosion to be the primary process causing shoreline retreat in upper Barataria Bay. A selection from upper Barataria Bay of all shoreline locations in the Penland database spaced 50-m apart and corresponding to treated, heavier persistent oiled locations in 2010 have a long-term mean change rate of -1.07 m/yr (retreating). This mean has a standard deviation of 0.57 m/yr and was computed using 347 locations. The long-term retreat rate is statistically indistinguishable from the current study's control site rates. This result provides confidence that the control-impact pairs are representative of the shoreline dynamics in upper Barataria Bay, which allows us to extrapolate the impact results to the entire 11 km of shoreline with heavier persistent oiling and intensive treatment. This control-impact pair selection, however, does not allow the effects of heavier persistent oiling and intensive treatment to be evaluated individually.

Table 1. Results of control-impact pair analysis of shoreline change in upper Barataria Bay. Values are in meters or meters per year where noted and negative values are retreating (eroding). Averages for control and impact areas for each site are averages of the change observed at transects spaced 5 m alongshore.

Site	Control Average	Control SD	Control Count	Impact Average	Impact SD	Impact Count	**Yearly Diff I-C**
Site 06	-2.73	0.98	13	-2.85	0.67	13	**-0.05**
Site 11	-3.81	1.58	14	-0.39	1.03	14	**1.32**
Site 12	-0.99	1.57	12	-2.14	0.71	13	**-0.44**
Site 15	-0.50	0.39	13	-0.89	0.58	14	**-0.15**
Site 21	1.07	1.87	9	-2.01	1.03	13	**-1.19**
Site 8	-4.15	1.40	12	-2.65	1.31	12	**0.58**
Site 2	-2.91	1.08	12	-5.45	0.97	9	**-0.98**
Site 9	-4.09	1.79	14	-6.33	2.31	14	**-0.86**
Site 10	-4.36	0.84	17	-9.17	5.33	31	**-1.85**
Site 19	-5.46	2.86	16	-11.95	5.54	12	**-2.50**
Site 23	0.34	0.45	13	-0.49	0.91	12	**-0.32**
Site 24	-1.23	1.39	23	-3.51	2.18	26	**-0.88**
Site 27	-1.42	0.74	12	-3.27	0.97	15	**-0.71**
Site 28	-3.20	1.35	12	-5.91	2.20	14	**-1.04**
Site 03	-2.84	0.98	13	-2.20	1.22	14	**0.25**
Site 17	-7.50	5.61	48	-2.76	2.30	54	**1.82**
Site 16	-1.05	0.71	13	-1.60	1.65	14	**-0.21**
Site 26	-3.33	2.01	13	-5.06	0.99	14	**-0.67**
Site 14	-0.51	0.73	15	-2.01	2.00	13	**-0.58**
Site 5	-0.45	0.63	11	-0.04	0.39	15	**0.16**
Yearly Average	**-0.94**			**-1.36**		**Yearly Averages**	**-0.41**
						SE of Averages	**0.22**
						Significance	**2.9%**

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