Wetland erosion in Delacroix and Hopedale from hurricanes this decade and the impact of the Caernarvon Freshwater Diversion

Pat Fitzpatrick[1], Sachin Bhate[1], Yee Lau[1], Valentine Anantharaj[1], and Suzanne Shean[2]

[1]Mississippi State University, Geosystems Research Institute; [2] Mississippi State University, Northern Gulf Institute

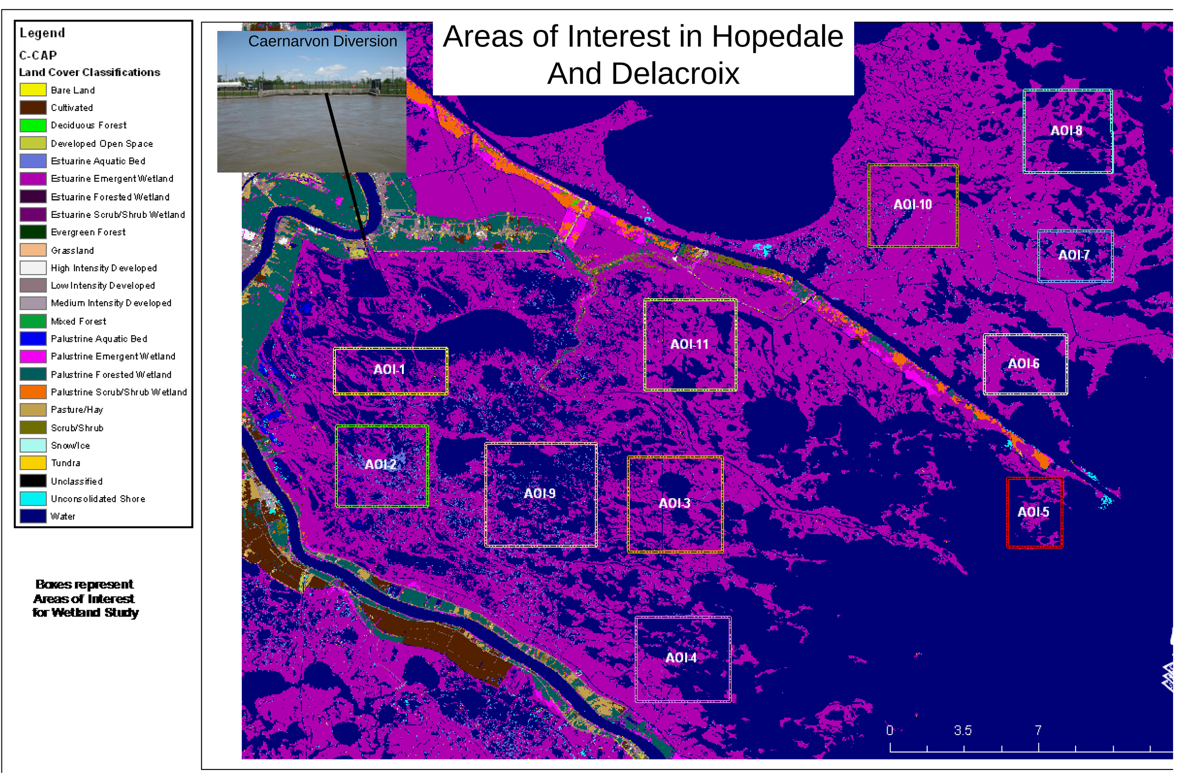

Table 1. Percentage water coverage for the 11 Areas of Interest in 1996, Pre-Katrina, and Post-Katrina, based on the C-CAP dataset.

	C-CAP Percentage water		
Area Of Interest (AOI)	1996	Pre-Katrina (August 2005)	Post-Katrina
1	11.7	13.5	52.5
2	11.6	14.0	37.7
3	37.1	38.1	41.8
4	66.5	67.1	69.1
5	72.6	72.9	75.3
6	49.6	49.6	51.1
7	38.4	38.5	40.1
8	48.8	49.0	50.9
9	54.1	56.1	68.4
10	12.0	13.0	14.5
11	29.7	30.9	34.1

Table 2. Mean percentage water coverage for the 11 Areas of Interest for Pre-Katrina, Post-Katrina, and Post-Gustav, based on classifications from Landsat 5 TM data derived from the Normalized Difference Water Index and Normalized Difference Vegetation Index, and screened for cloud coverage. Data sample number is shown.

	MSU Mean Percentage Water		
Area Of Interest (AOI)	Pre-Katrina (n=15)	Post-Katrina (n=19)	Post-Gustav (n=11)
1	12.8	36.8	51.5
2	20.8	40.8	54.3
3	38.0	43.2	43.1
4	68.0	69.6	69.6
5	79.8	81.3	80.5
6	53.5	56.5	56.4
7	43.3	45.5	46.3
8	51.1	52.7	53.3
9	57.5	73.5	80.0
10	14.0	15.6	15.7
11	29.4	35.2	37.2

Table 3. Statistical significance results using Wilcoxon Rank-Sum test between Landsat 5 AOIs water coverage before and after Katrina and Gustav. ^ denotes $0.15 > p \geq 0.05$, * denotes $0.05 > p \geq 0.01$, ** denotes $0.01 > p \geq 0.001$, and *** denotes $p < 0.001$.

	Wilcoxon Rank-Sum Significance Test Difference in Water Coverage	
Area Of Interest (AOI)	Pre-Katrina vs. Post-Katrina	Post-Katrina vs. Post-Gustav
1	***	*
2	***	**
3	***	
4	**	
5	*	
6	***	
7	**	
8	***	^
9	***	
10	*	
11	***	^

Background

The wetlands in coastal Louisiana have experienced substantial erosion since the 1930s. Mississippi River levees have deprived the region of land-sustaining sediments, and is the primary contributor to wetland loss. Man-made canals, faults activated by energy drilling, tropical cyclones, and sea-level rise have also accelerated this land loss. As water bodies enlarge, wave action has also contributed to the erosion. An additional feedback from this erosion is saltwater intrusion, which changes the local ecology and is hypothesized to devastate wetlands.

One tool for countering Louisiana's wetland erosion is river diversions. Diversions are designed to infuse freshwater into existing wetlands with limited sediment, while others are land-building projects. Peak flow rates range from 8000-10,650 cfs. Among them are the Caernarvon Fresh Water Diversion Project in upper Breton Sound east of the Mississippi River, which is a nourishment project opened in 1992 designed to alter salinity conditions. The goal of Caernarvon is to bring the 5 ppt and 15 ppt salinity lines back to historical averages (Louisiana Department of Natural Resources, 2006). Caernarvon dramatically changed the nearby land characteristics, increasing freshwater marsh plant coverage near the diversion, and growing intermediate marsh plants in the formerly brackish areas.

However, the altered landscape may not be resilient to hurricane storm surge. Hurricanes Gustav (2008), Ike (2008) Rita (2005), and Katrina (2005) caused erosion of the Louisiana marshes (Barras 2006, 2007). The 2008 and 2005 hurricanes occurred within weeks of each other, and each can essentially be treated as combined events. One area that experienced serious damage was the Delacroix region, particularly in the fresh and intermediate marsh regions near the Caernarvon. The damage consisted of expanded ponds; compressed, rolled, or inverted marsh; scoured and denuded marsh; and shoreline erosion.

The goal of this research is to quantify the marsh degradation areas: 1) north of the Mississippi River Gulf Outlet (MRGO) in an area known as the Biloxi marsh (consisting of intermediate and saltwater marsh); 2) the saline outer marsh of Delacroix near Black Bay; and 3) the interior Caernarvon brackish and freshwater marsh in Delacroix. This analysis is performed for pre-Katrina/Rita, pre-Katrina/Rita, and post-Gustav/Ike using data from NOAA's Coastal Change Analysis Program (C-CAP) program [distributed by the Coastal Services Center], and from the Landsat 5 Thematic Mapper (TM) satellite sensor. Interviews and a boat tour of the Delacroix marsh were also conducted with Mr. "Buddy" Melerine and his grandson Philip Mones, two commercial fishermen.

Methodology

The C-CAP program provides a nationally standardized database on land cover and habitat change, typically in 5-year cycles starting in 1996 (Dobson et al. 1995). A special dataset was also developed for pre- and post-Katrina. C-CAP utilizes Landsat 5 and Landsat 7 TM scenes on days lacking clouds, haze, or extreme humidity, consisting of 15-22 satellite scenes. Landsat resolution is 30 m, sufficient for capturing marsh features. Land-water classification was determined from a Classification and Regression Tree (CART) scheme, then further refined by hand-editing. This resulted in 25 land attributes as shown in the top left figure.

Because no C-CAP data was available post-Gustav, MSU developed a methodology to investigate this storm's impact on Delacroix and Hopedale. We also utilized this scheme to examine Katrina's impact as a redundancy check against the C-CAP data. Landsat 5 TM data were first calibrated to a sensor radiance and then the TOA reflectance values were calculated (Chander et al. 2009). We then derived the Normalized Difference Water Index (NDWI) and Normalized Difference Vegetation Index (NDVI) where NDWI = (SWIR - Red) / (SWIR + Red) and NDVI = (NIR - Red) / (NIR + Red). The shortwave infrared (SWIR) channel (Band 5) exhibits a strong contrast between land and water features due to the high degree of absorption of mid-infrared energy by water, even turbid water (Alesheikh et. al 2007). The near-infrared (NIR) channel is Band 4, and visible red channel is Band 3. The computed values of NDWI and NDVI, ranging between -1 and +1, were converted to digital numbers (DN) in the range of 0 - 255. The classification technique used was in the following sequential order: 0≤NDWI≤100, "water"; 0≤NDVI≤100, "vegetation/not-water"; 100≤NDWI≤120, "probably water"; and 140≤NDWI<150, "probably land/not-water". Other pixels were unclassified, and often associated with clouds.

However, producing a single composite dataset from multiple Landsat images is difficult. Pixel brightness values for wetland classification schemes are affected by seasonal and annual phenological vegetation cycles; cloud coverage and cloud shadows; tide stage; water levels; sun angle; calibration issues; earth/sun distance; atmospheric conditions, and sun/target/sensor geometry (phase angle). Therefore, our approach consisted of qualitative quality control to remove datasets with excessive cloud coverage. The data is then subsetted into 11 Areas of Interest (top left figure), and statistical significance tests are calculated for water coverage change before and after Katrina and Gustav. Because the data is not normally distributed, the nonparametric Wilcoxon rank-sum test is used. Wilcoxon arranges two samples in ascending (or descending) value orders, a rank is assigned to each value, and the ranks are added for each sample. The significance is then assessed (through a p value) based on the size difference between the cumulative rankings. A small p value is generally interpreted as evidence against the null hypothesis, which is to reject the premise of no difference between the two samples. Generally, the following interpretations are used by statisticians as evidence against the null hypothesis: $0.15 > p \geq 0.05$, suggestive but inconclusive; $0.05 > p \geq 0.01$, moderately convincing; $0.01 > p \geq 0.001$, convincing; and $p < 0.001$, very convincing. These four situations are tabulated as ^, *, **, and ***, respectively.

Results

Table 1 shows wetland erosion results based on C-CAP data. The largest erosion rates [calculated as 100X(Pre-value-Post-value)/Pre-value]from 1996-2005 occurred near the diversion in AOI-1 and AOI-2 of 14.5% and 20.9%, respectively. Additional notable 1996-2005 rates include: AOI-10, 8.1%; AOI-9, 3.9%; AOI-11, 3.9%; and AOI-3, 2.7%. Other regional changes were negligible. Katrina caused erosion throughout the region, but the biggest proportional changes are in the diversion area. AOI-1 changed from 13.5% to 52.5% water coverage, a 289.4% increase; and AOI-2 from 14.0% to 37.7% water coverage, a 168% increase. The intermediate marsh suffered degradation as well but not as large with AOI-9 from 56.1% to 68.4% water coverage (a 22.0% increase). Other regions range from 3-11% water coverage increase due to Katrina's impact.

The MSU methodology shows similar results. The mean water coverage is shown in Table 2, but because the data contains scatter some regional values are different than Table 1. Histograms of these plots are attached to this poster. Its more appropriate to use the statistical significance tests to assess wetland coverage change (Table 3). Table 3 shows statistically significant changes to all diversion regions at a very convincing level. Also note that Hurricane Gustav caused the largest water percentage increase in AOI-1, AOI-2, and AOI-9. Because of scatter, the significance levels are not as high, but the areas closest to the diversion have the smallest p-values. An example of Landsat land-water classification is shown in the top right figures for Pre-Katrina and Post-Gustav. Note the increased open water and marsh shearing patterns near the diversion region from both hurricanes.

These results suggest that the current Caernarvon implementation for land restoration may be flawed since it does not consider hurricane impacts. It is clear that regions near the diversion experienced large amounts of land loss relative to areas near Black Bay and north of MRGO after the 2005 and 2008 hurricanes. We hypothesize that the freshwater species composition hasn't become diverse enough, and currently consists of mostly floating species instead of rooted plants. This type of vegetation is not hurricane-resilient nor does it protect sediment, which then gets transported to the levee system as shown in the lower-right picture. The result is land loss, the opposite of its intended purpose. The primary cause is possibly the manipulation of nature through a narrow canal system instead of allowing a riverine, sediment-rich bank overflow. Given enough time, saline-hardy, rooted freshwater vegetation may become established in western Delacroix with the Caernarvon diversion. However, the return period in this region is 2-6 years for tropical storms, 6-10 years for Category 1 hurricanes, and 24-43 years for Category 3 hurricanes (National Hurricane Center 2010, Emanuel and Jagger 2010). Therefore, establishment of a hurricane-hardy wetlands in the freshwater marsh regions may not occur, and suggests that freshwater diversion concepts need to be re-engineered possibly into a multiple "leaky levee" concept supplemented by sediment pipes and prioritized land re-creation. It is further noteworthy that the largest erosion rates before Katrina were also in the diversion region. This work also suggests that the negative perception of saltwater intrusion in wetland restoration be re-examined. Certainly saltwater intrusion can have negative consequences, but we propose that an assessment of wetland resiliency is just as important before freshwater is reintroduced into an area. The Biloxi Marsh north of Hopedale is an example of a stable saltwater marsh environment that adjusted to habitat change from the MRGO.

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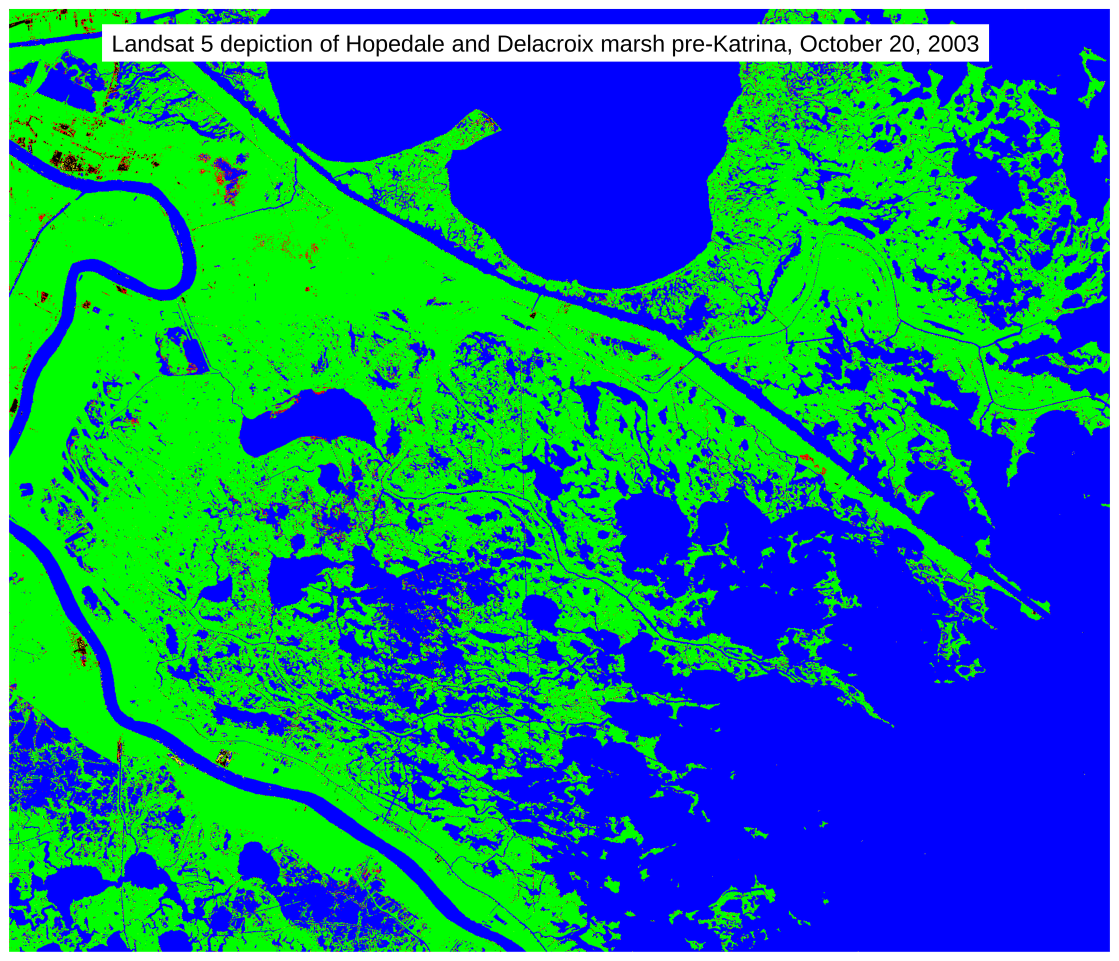
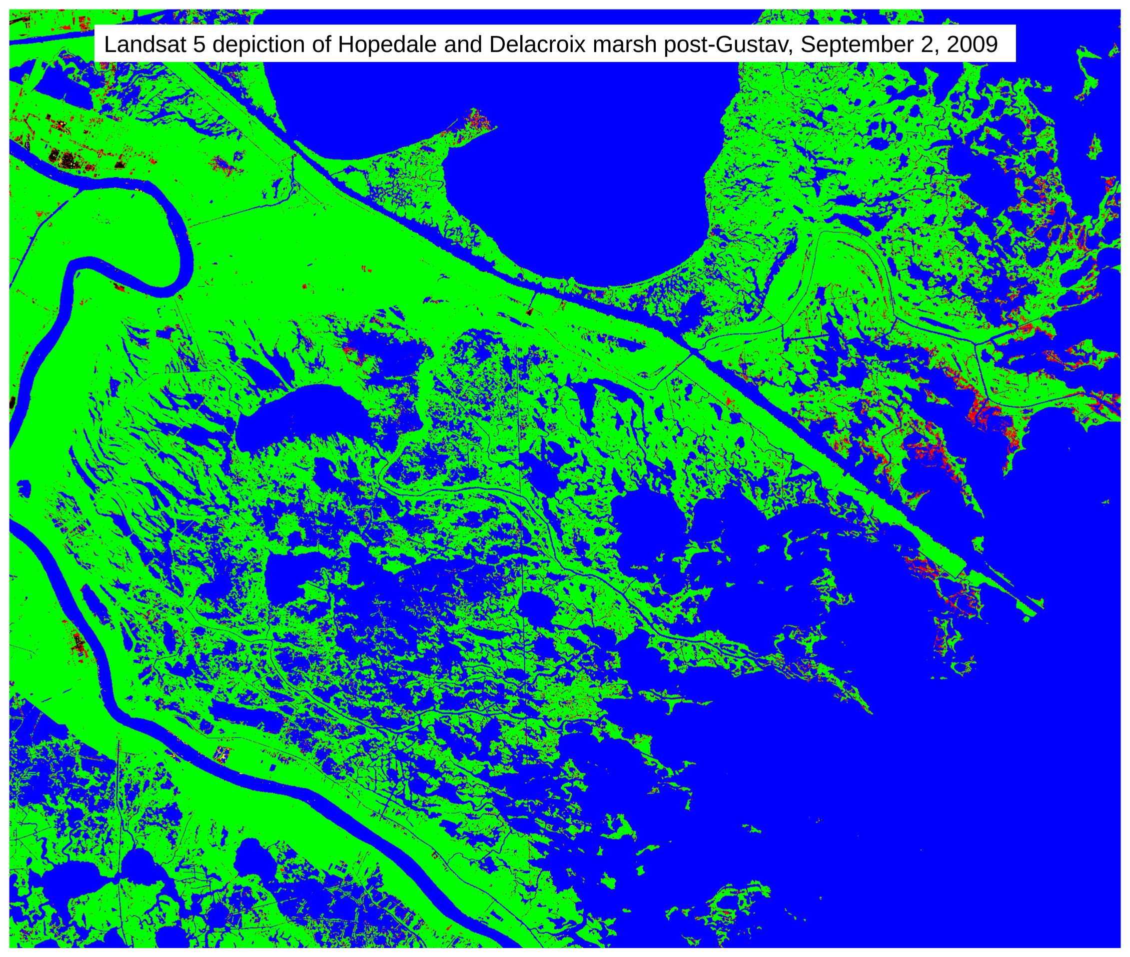
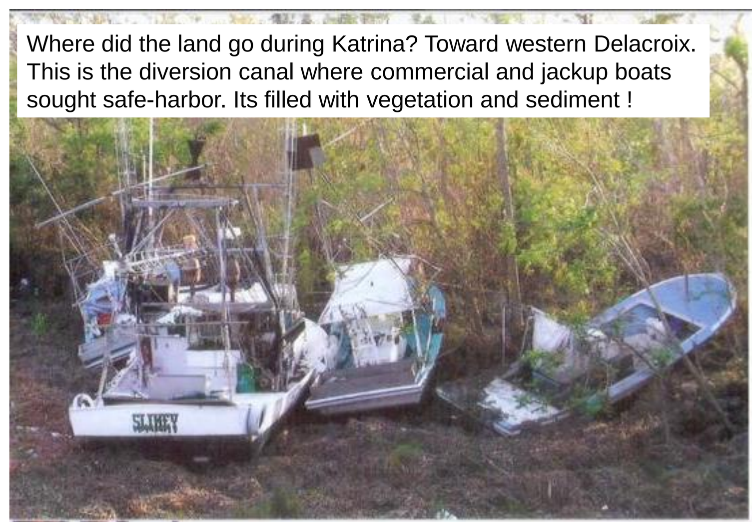


Landsat 5 depiction of Hopedale and Delacroix marsh pre-Katrina, October 20, 2003



Landsat 5 depiction of Hopedale and Delacroix marsh post-Gustav, September 2, 2009



Where did the land go during Katrina? Toward western Delacroix. This is the diversion canal where commercial and jackup boats sought safe-harbor. Its filled with vegetation and sediment !

Diversion canal today after dredging

78-year old "Buddy" Melerine, a life-long commercial fisherman in Delacroix, gave detailed background information on the diversion impact during the interview process.

Buddy's grandson Philip Mones provided a boat tour of the diversion area and adjacent marshes

Philip shows a region which used to be land that now he crabs on. This Is about 5 miles from the diversion, near AOI-1.

GRI

MISSISSIPPI STATE UNIVERSITY

NGI Northern Gulf Institute