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Land Loss Due to Recent Hurricanes in Coastal Louisiana, U.S.A.

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ABSTRACT

Palaneasu-Lovejoy, M.; Kranenburg, C.; Barras, J.A., and Brock, J.C., 2013. Land loss due to recent hurricanes in coastal Louisiana, U.S.A.. *In:* Brock, J.C.; Barras, J.A., and Williams, S.J. (eds.), *Understanding and Predicting Change in the Coastal Ecosystems of the Northern Gulf of Mexico,* Journal of Coastal Research, Special Issue No. 63, pp. 97–109, Coconut Creek (Florida), ISSN 0749-0208.

The aim of this study is to improve estimates of wetland land loss in two study regions of coastal Louisiana, U.S.A., due to the extreme storms that impacted the region between 2004 and 2009. The estimates are based on change-detection-mapping analysis that incorporates pre and postlandfall (Hurricanes Katrina, Rita, Gustav, and Ike) fractional-water classifications using a combination of high-resolution (<5 m) QuickBird, IKONOS, and GeoEye-1, and medium-resolution (30 m) Landsat Thematic Mapper satellite imagery. This process was applied in two study areas: the Hackberry area located in the southwestern part of chenier plain that was impacted by Hurricanes Rita (September 24, 2005) and Ike (September 13, 2008), and the Delacroix area located in the eastern delta plain that was impacted by Hurricanes Katrina (August 29, 2005) and Gustav (September 1, 2008). In both areas, effects of the hurricanes include enlargement of existing bodies of open water and erosion of fringing marsh areas. Surge-removed marsh was easily identified in stable marshes but was difficult to identify in degraded or flooded marshes. Persistent land loss in the Hackberry area due to Hurricane Rita was approximately 5.8% and increased by an additional 7.9% due to Hurricane Ike, although this additional area may yet recover. About 80% of the Hackberry study area remained unchanged since 2003. In the Delacroix area, persistent land loss due to Hurricane Katrina measured approximately 4.9% of the study area, while Hurricane Gustav caused minimal impact of 0.6% land loss by November 2009. Continued recovery in this area may further erase Hurricane Gustav's impact in the absence of new storm events.

ADDITIONAL INDEX WORDS: *Global mean sea level, relative sea level, sea-level rise, coast, climate change, coastal erosion, barrier island, coastal vulnerability, adaptation, coastal hazards.*

INTRODUCTION

Earlier works on coastal Louisiana wetland loss have focused on decadal or greater timespan comparisons either to identify changes in land and water area spatial configuration or to directly map land loss (Barras *et al.*, 2003, Britsch and Dunbar, 1993). Couvillion *et al.* (2011) investigated 17 data series between 1932–2010 in coastal Louisiana to estimate net land loss. These studies lacked the spatial resolution necessary to discriminate between hurricane-induced losses, seasonality and losses occurring from other processes. More recently, the impacts of Hurricanes Katrina (August 29, 2005), and Rita (September 24, 2005), and Hurricanes Gustav (September 1, 2008) and Ike (September 13, 2008) were investigated using medium-resolution (30 m) Landsat Thematic Mapper (TM) satellite imagery (Barras, 2006 and 2009). Land/water areas were classified using a thresholding technique of Landsat TM band 5 (midinfrared) followed by complex manual editing. The method is fast, but is biased towards identifying land (Palaseanu-Lovejoy *et al.*, 2011). Water reflectance ranges between high and low depending on the bottom substrate or suspended sediment. Medium-resolution Landsat TM imagery lacks the spatial resolution to resolve small tidal creeks, canals, ponds, and fragmented marsh. These features are represented as mixed classification pixels for which the classification is not 100% one category (called mixels) and bias moderate resolution land/water classifications and land loss estimates. Tests over pilot areas in southern Louisiana have revealed that high-resolution satellite imagery has the potential for more accurate mapping that likely will improve estimates of episodic land loss due to extreme storm events (Nayegandhi *et al.*, 2008).

The main objective of this study is to improve land loss estimates in coastal Louisiana after the hurricanes of 2005 and 2008 using a change detection analysis incorporating fractional water classifications based on multiple high- and medium-resolution satellite images. Two study areas were selected—the Hackberry area (1,961 square kilometers) located in the southwest chenier plain that was impacted by Hurricanes Rita and Ike, and the Delacroix area (1,208 square kilometers), located in the central delta plain that was impacted by Hurricanes Katrina and Gustav (Figure 1).

To address our objectives, the Methodology section describes data sources and analysis approaches. Land loss analysis and

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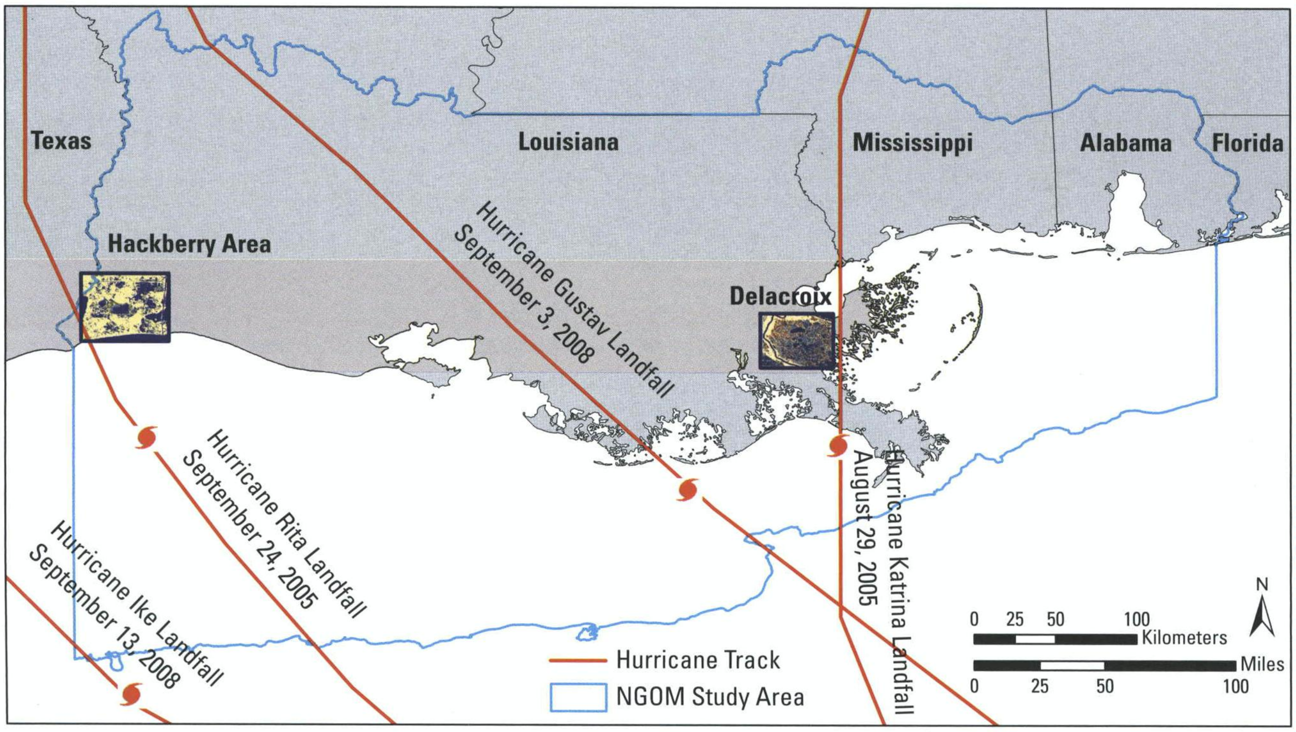

Figure 1. Location of study areas relative to the tracks of 2005–2008 hurricanes in southern Louisiana.

comparisons between the two areas of study, potential sources of errors, impacts and causes, interpretation of change analysis, and exploration of possible reasons for the changes we have detected are presented in the Results and Discussion section.

METHODOLOGY

The satellite imagery dates and extents used for the two study areas are presented in Figure 2. The land loss estimates are based on change-detection analysis that incorporates pre and posthurricane landfall fractional-water classifications using a combination of high-resolution (<5 m) QuickBird, IKONOS and GeoEye-1 images, and medium-resolution (30 m) Landsat images. The fractional-water maps are the result of regression tree modeling in which the dependent variables are derived from high-resolution imagery and the independent variables from 30-m resolution Landsat imagery. The continuous fractional-water maps are classified into land and water categories using the maximum Kappa coefficient as an optimizer (Figure 3) (Palaseanu-Lovejoy *et al.*, 2011).

The dependent variables consisted of a series of vegetation and water indices and transforms, some of which were adapted for use with only 4 bands from the high-resolution imagery (Horne, 2003; Jensen, 2007; Navulur, 2006; Wales, 2005; Yarbrough *et al.*, 2005; Xu, 2006; Zha *et al.*, 2003), and two new transforms developed specifically for the IKONOS images (Palaseanu-Lovejoy *et al.*, 2011). These indices and transforms were classified into land/water categories and used to determine percent water values for each pixel of the corresponding Landsat medium-resolution image. The independent variables consist of the six thematic bands of the Landsat imagery, Haralick texture (Haralick *et al.*, 1973) features for each Landsat band (second moment, correlation, contrast, dissimilarity, entropy, homogeneity, mean, and variance), principal components (PCA), independent components (ICA), tasseled cap transformation (TCT) components, and an expanded set of water and vegetation indices derived from the Landsat image such as blue ratio, Braud index, green normalized difference vegetation index (GNDVI), green normalized difference water index (GNDWI), normalized difference vegetation index (NDVI), normalized difference water index (NDWI), simple and inverse ratio, and near infrared (NIR) ratio. Finally, in order to derive a land/water map at the 30-m scale, the resulting fractional-water maps are classified into land/water categories using an optimization procedure (Atkinson and Mahoney, 2004; Wirtschaftsuniversität Wien, 2010) to determine the threshold at which the maximum Kappa coefficient occurs. A more detailed description of fractional-water map and classification procedures and methodology can be found in Palaseanu-Lovejoy *et al.* (2011) and the methodology flowchart in Figure 4.

Quantification of the percent land change from pre to posthurricane land/water classification maps was done by subtracting one classification from the other. Classified water area variations caused by tidal and meteorological differences between the classification maps were ignored. Water levels were checked for imagery acquisition dates and times at several distinct Coastal Reference Monitoring System (CRMS) water stations for both study areas. The water levels varied between

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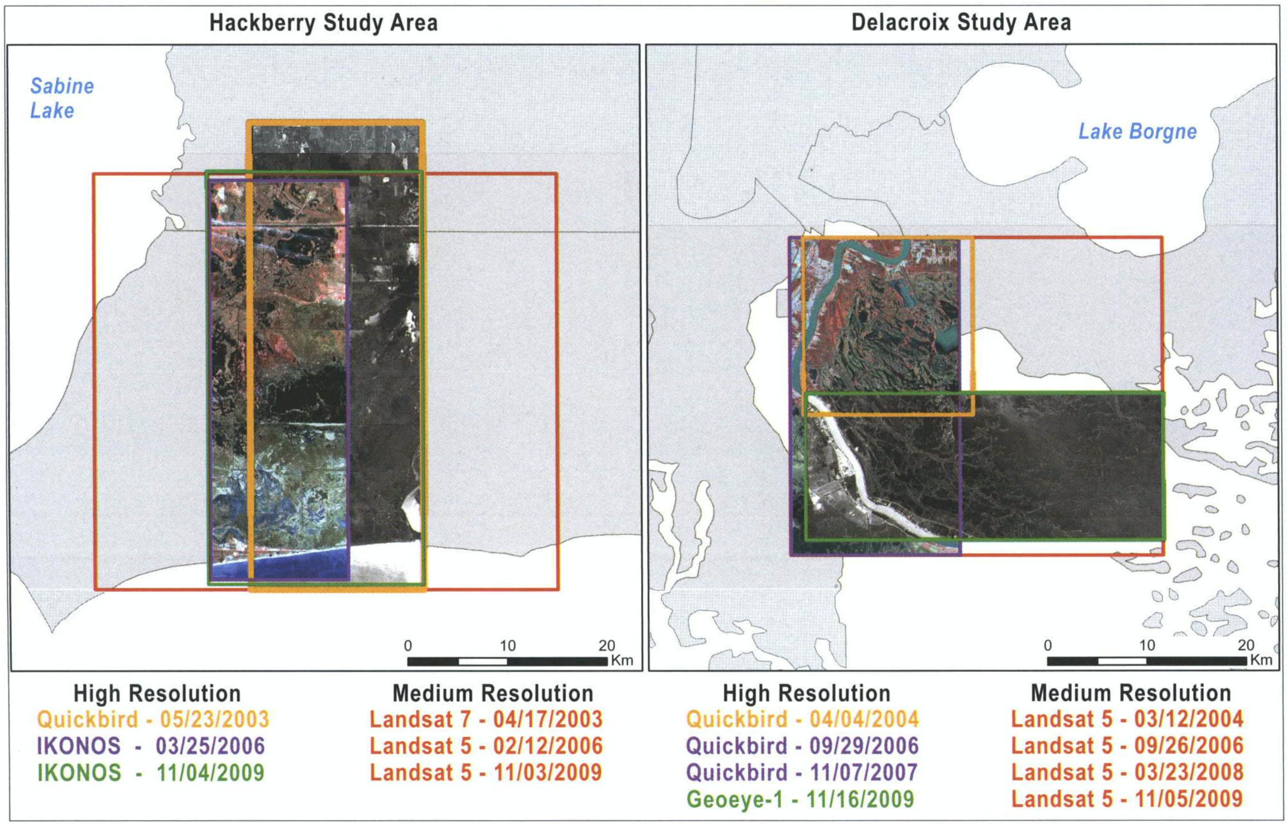

Figure 2. Map showing the types and extents of satellite imagery used for each study area.

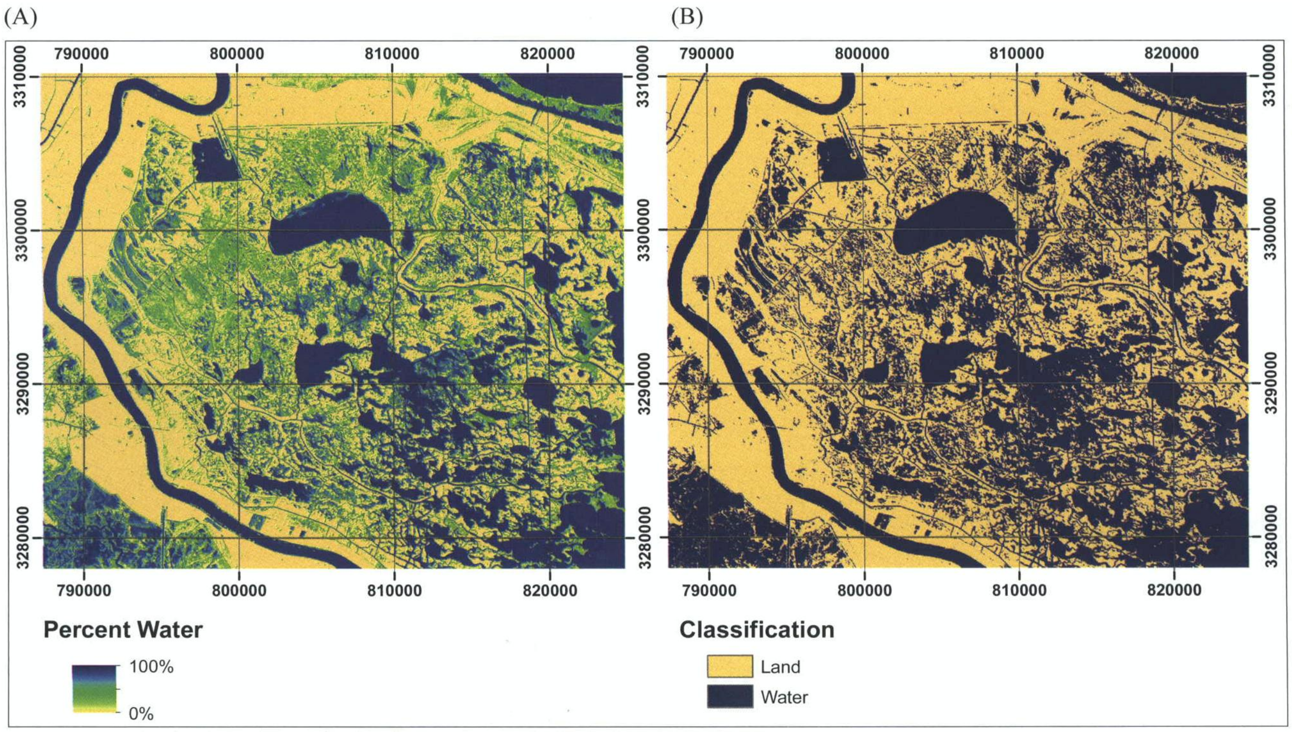

Figure 3. Example of (A) continuous fractional water map, and (B) classified land/water map, Delacroix, Louisiana (2006 data).

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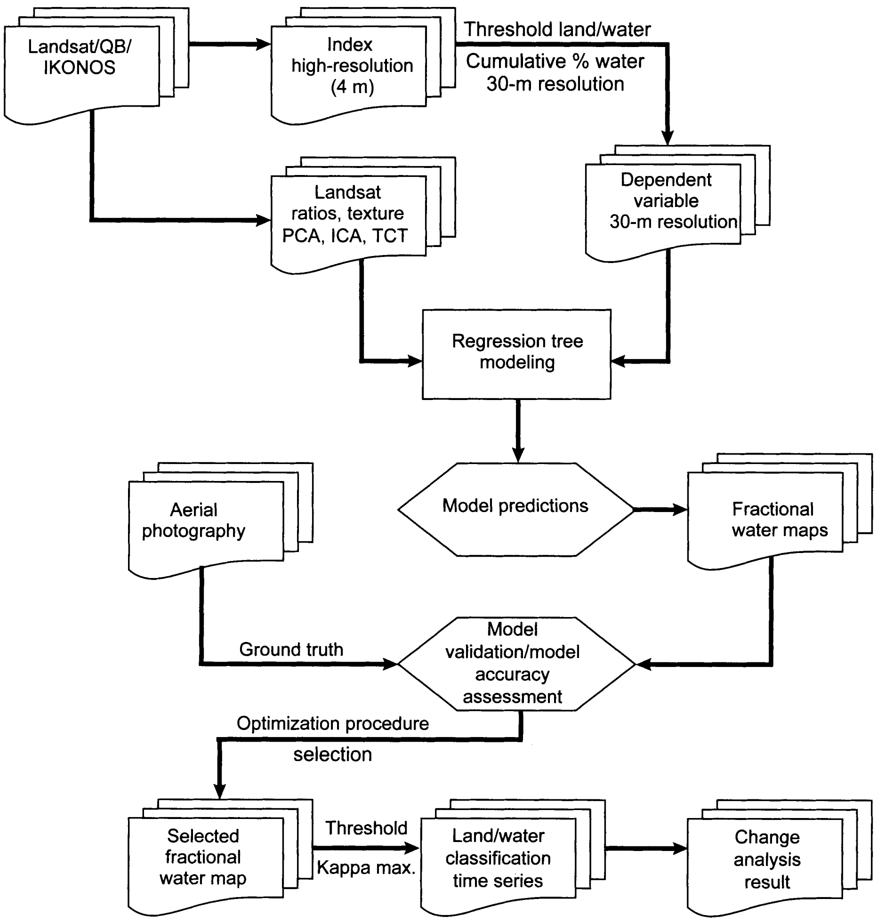

Figure 4. Methodology flowchart for creation of fractional water maps. Principal Component Analysis (PCA), Independent Component Analysis (ICA), Tasseled Cap Transformation (TCT).

-7.6 cm (-3 in) to +6 cm (+2.4 in) in the central and northern part of the study area and between +8 cm (+3.1 in) to +19 cm (+7.5 in) in the south, towards the Gulf. Examining land/water classification at each pixel through the time series classifications assists in identification of persistent and transient change. A pixel that changed from land to water after a storm event and remained water in subsequent years represents persistent land loss due to that storm event. A pixel that changed from land to water and then back to land within our time series represents transient change and is attributed mainly to vegetation seasonality. The left half of the legend for time series change analysis maps (Figures 5, 6, 8, and 10) indicates all the unique possible classification combinations for each pixel over that time period and the right half gives the possible interpretation and percent area change.

RESULTS AND DISCUSSION

Hurricane Katrina induced loss was greatest east of the Mississippi River while Hurricane Rita affected areas west of the river (Barras, 2007, 2009). Similarly, Hurricane Ike impacted western coastal Louisiana, while Hurricane Gustav impacted mainly the eastern and central part of coastal Louisiana (Barras *et al.*, 2010, East *et al.*, 2008, McGee *et al.*, 2008).

In the Hackberry study area, 9.4% of the area was converted from land to water, and 2.6% was converted from water to land in the aftermath of Hurricane Rita (Figure 5A). The corresponding changes due to Hurricane Ike are 10.2% and 3.3%, respectively (Figure 5B). In both cases land changes were either persistent or temporary, but only for Hurricane Rita can we discriminate between persistent changes still present after four years, and temporary changes. Thus, 6.5% is considered persistent new water areas and less than 0.7% persistent land gain (Figure 6), indicating that 5.8% of the area can be considered persistent land loss related to Hurricane Rita.

Areas of transient land change due to Hurricane Rita are areas that changed classification from water in 2003 to land in 2006 and back to water in 2009 and represent 1.92% of the study area. After Ike, 10.2% of the areas that were previously classified as land were classified as water. Therefore, we can estimate that actual land area transformed into water by Hurricane Ike is a little less than 8.3% of the study area. New land areas present in 2009 but not in 2006 or 2003 (0.4%) are mostly the result

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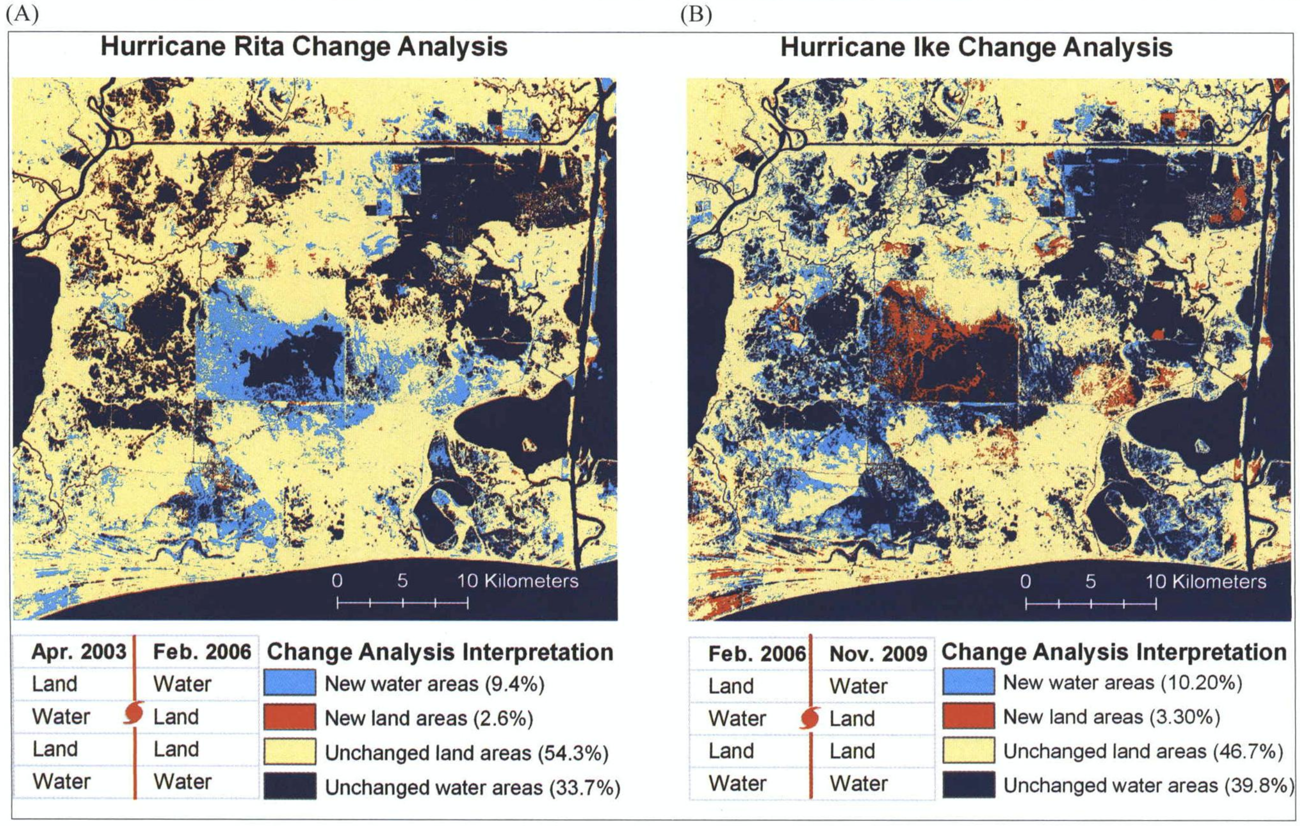

Figure 5. Change analysis maps for (A) Hurricane Rita and (B) Hurricane Ike showing new water areas and new land areas created from each storm, Hackberry, Louisiana.

of several marsh restoration projects in the eastern part of the study area (USGS, 2008), or the result of drainage of previously flooded areas (Figure 6). Transient Rita-related land (1.9%) and water (2.9%) areas represent recovery areas, where the landscape changed and then returned to its pre-Hurricane Rita composition by 2009. With time we expect the area to recover further, but if the recovery is similar to that which followed Hurricane Rita, then we anticipate about 3–5% of the area will remain persistently impacted by Hurricane Ike.

A particularly difficult section to interpret in this region is the Five Lakes area impoundment (highlighted in cyan on Figure 7A). This area is composed of freshwater marsh that was flooded by saltwater during Hurricane Rita, and drainage was obstructed by wrack deposited on the southern edge of the impoundment by the hurricane. As a consequence, the vegetation suffered prolonged inundation and severe chemical burn. By February 2006, the flooded area due to Hurricane Rita was a little over 42% of the Five Lakes impoundment, amounting to 2.3% of the total Hackberry study area. By November 2009, about half of the inundated area of the Five Lakes drained, and Hurricane Ike added only 7.22% new water in the impoundment, which represents only 0.4% of the total chenier plain study area. We have reason to expect that some of the new water areas created by Hurricane Ike will recover in the future, but it is likely the damage done by Hurricane Rita still present in 2009 will persist, unless specific recovery efforts are implemented in the Five Lakes impoundment.

The effects of Hurricane Katrina in the Delacroix study area are comparable to those of Hurricane Rita in the Hackberry study area, with 11.8% of the area being transformed from land to water, and only 5.6% converting from water to land (Figure 8A). These changes involve a very dynamic environment influenced by seasonality and water levels (*i.e.* microtidal, precipitation, wind and water management practices). Changes between September 2006 and March 2008 are attributed to normal variability in the area since no extreme storm events occurred within this time period. The increase in water area (3.76%) is attributed to either aquatic vegetation senescence or Katrina-related debris removal or dispersal. The land area increase (3.75%) is attributed to water-level fluctuation and drainage (Figure 8B). These changes reflect short-term natural variation rather than new land change.

Hurricane Gustav made landfall on September 1, 2008 approximately 80–100 km west of the Delacroix study area. Its impacts are very comparable in magnitude and spatial distribution to the natural land/water oscillations observed between 2006 and 2008. Changes from land to water after Hurricane Gustav represented 3.84% of the area, while another 3.94% reverted from water to land, indicating almost no net land loss as a result within this study area (Figure 8C).

Vegetation seasonality, water-level fluctuation and the effects of water management practices are apparent in the rectangular pond and its environs in the northwest section of the study area

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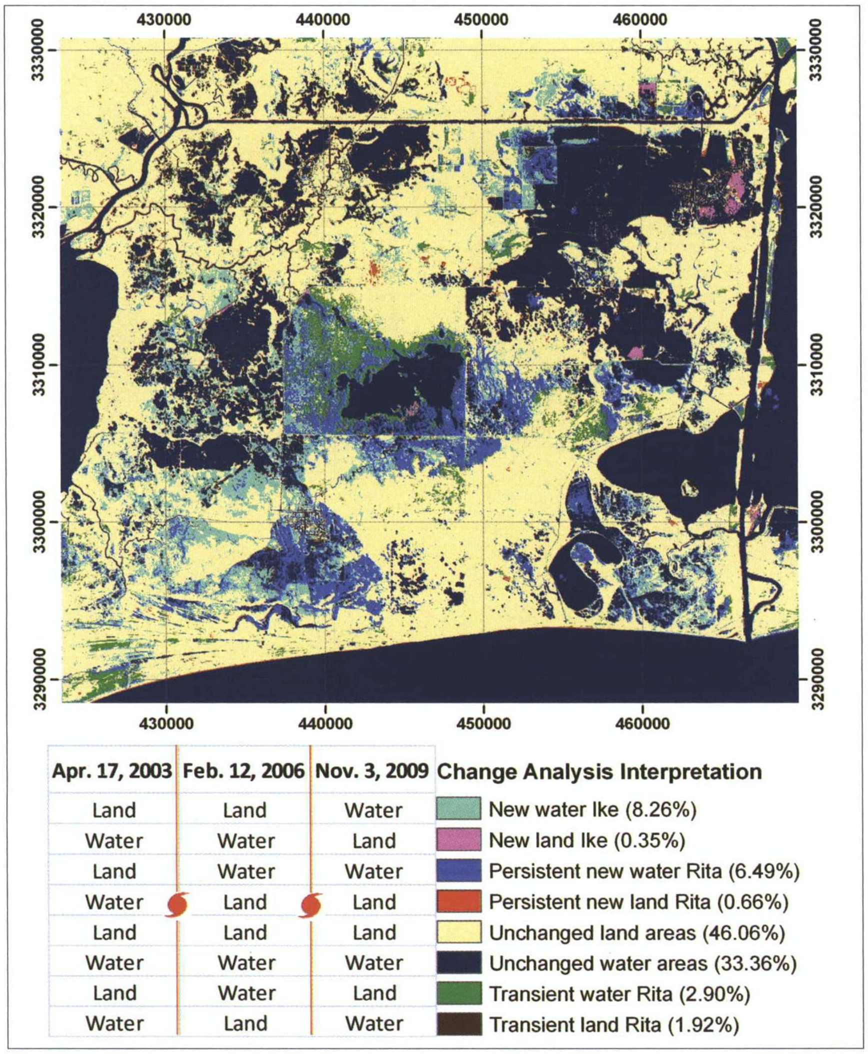

Figure 6. Change analysis interpretation map for the Hackberry area (2003–2009) showing whether or not new land (or new water) areas created after Hurricane Rita reverted to their original state after Hurricane Ike. Areas that remain unchanged from their post-Rita state are considered areas of persistent change while areas that revert to their original state are considered transient effects of Hurricane Rita.

(highlighted in yellow on Figure 7B, Figure 9). The pond, known as Big Mar, contains the outfall for the Caernarvon Freshwater Diversion (CFD), one of two major freshwater diversion projects in coastal Louisiana. Large amounts of displaced marsh were deposited within Big Mar by Hurricane Katrina's surge (Barras, 2007b) and half of the pond was covered by vegetation by September 2006. The vegetation consisted of the marsh deposits from Katrina's surge and floating aquatic vegetation. By March 2008, the aquatic vegetation had senesced and is classified as "New Water Areas 2008" (Figure 9). Some floating aquatic vegetation was present by November 2009 although it was not as extensive as in September 2006. The CFD was active in March 2004, March 2008, and November 2009. The turbid water from the diversion caused the interpretation to be biased towards land. Freshwater delivered by the CFD often causes extensive growth of seasonal floating and submerged aquatic vegetation in the northwest portion of the study area during late spring through midfall. The aquatic vegetation usually remains until it is killed by successive freezes. The aquatic vegetation can be confused with land on satellite imagery, depending on the acquisition date.

Hurricane Katrina caused extensive marsh erosion in the Delacroix region. Large expanses of marsh were removed to the underlying clay or were partially removed to the root mat (Barras 2007b). These eroded areas form extensive shallow ponds containing large amounts of floating and submerged aquatic vegetation during the late spring through midfall that can be misidentified as land. Compared to Hurricane Katrina, Hurricane Gustav caused minimal land loss in Big Mar.

Analyzing the changes in classification of each pixel during the 5-year time period, allows us to discriminate between

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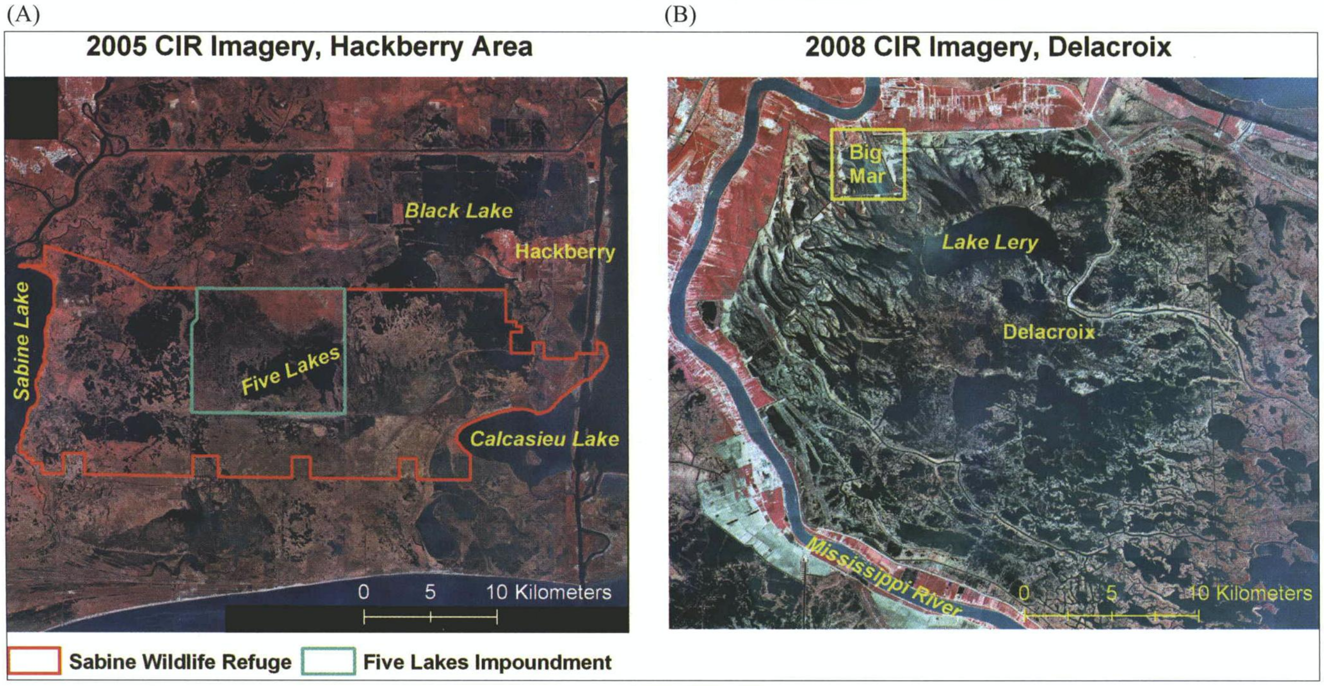

Figure 7. Color-Infrared (CIR) imagery showing the heterogeneous land/water composition of the (A) Hackberry and (B) Delacroix study areas.

persistent and temporary land/water changes due to Hurricane Katrina, vegetation seasonality, drainage, possible erosion and the immediate effects of Hurricane Gustav (Figure 10). For example, if a pixel changes classification from land to water after Hurricane Katrina, and remains water until the end of the time series, it is considered persistent land loss. If a pixel classification changes from land in 2004 to water in 2006 and back to land for 2008 and 2009, then this can be considered marsh recovery after Hurricane Katrina (Figure 10). The left half of the legend for Figure 10 indicates the sixteen possible unique classification combinations over the 5-year time series. Although the change analysis suggests that there is a 3.25% persistent land gain due to Hurricane Katrina, some of this represents artifacts of image resolution (especially along canals and small streams), water-level variability either exposing or submerging shallow ponds and hurricane-scoured marsh, and misclassification of aquatic vegetation. The large post-Katrina land gain in the central eastern portion of Figure 10 is an emergent marsh area that was burned prior to Katrina's landfall causing it to appear as water.

Overall, 77% of the total Delacroix study area remains unchanged, 11.42% is considered persistent change due to Hurricane Katrina (8.17% land loss, and 3.25% land gain), 2.4% represents recovery after Katrina, and about 6.3% indicates vegetation seasonality, drainage, flooding and (tidal/meteorological) water-level fluctuations, whereas only 2.14% of the change can be attributed to Hurricane Gustav (0.75% as temporary new land, and 1.39% as temporary new water) (Figure 10). Further, 0.74% of the change can be interpreted as erosion due to Gustav, as the classification changed from water in 2004 to land in 2006 after Hurricane Katrina, and remained land for the next 3 years until Hurricane Gustav, at which time the land reverted back to water (Figure 10). Hurricane Gustav therefore, reactivated the land loss morphology caused by Katrina. The 2006 imagery contained some recovery marsh vegetation and abundant aquatic vegetation colonizing the original, shallow, Katrina-formed ponds. Gustav's surge basically removed Katrina's transient recovery vegetation and reshaped some of these areas. Comparison of the post-Katrina imagery with the post-Gustav imagery shows minor changes from the post-Katrina landscape with minimal new Gustav-induced land loss. Gustav's impact includes both persistent and temporary changes, and more recovery can be expected.

While the effects of Hurricanes Rita and Katrina on the two study areas are very comparable, the effects of Ike and Gustav are very dissimilar, even though the strength, intensity and distance of their trajectory in relation to the two study areas were very similar (Table 1). The effects of Hurricane Ike were similar to Hurricane Rita. Land loss occurred in the same areas of the eastern and western chenier plain from both of these storms while the effects of Hurricane Katrina and Gustav were dissimilar in the delta plain.

The pattern and spatial distribution of land loss in the study areas are different as well. In the chenier plain, new water areas, from either Hurricane Rita or Hurricane Ike, are associated with expansion of existing ponds, or were formed in previously stable contiguous marsh such as south of Sabine National Wildlife Refuge (Barras 2007a, 2007b; Barras *et al.,* 2010). The majority of the land loss occurred in the fresh and intermediate marshes (Figure 11A). Hurricane Ike formed ponds in stable marshes in the southwestern part of the study area, or expanded ponds previously formed by Hurricane Rita in the south central and southeastern study area. The surge-formed and surge-modified

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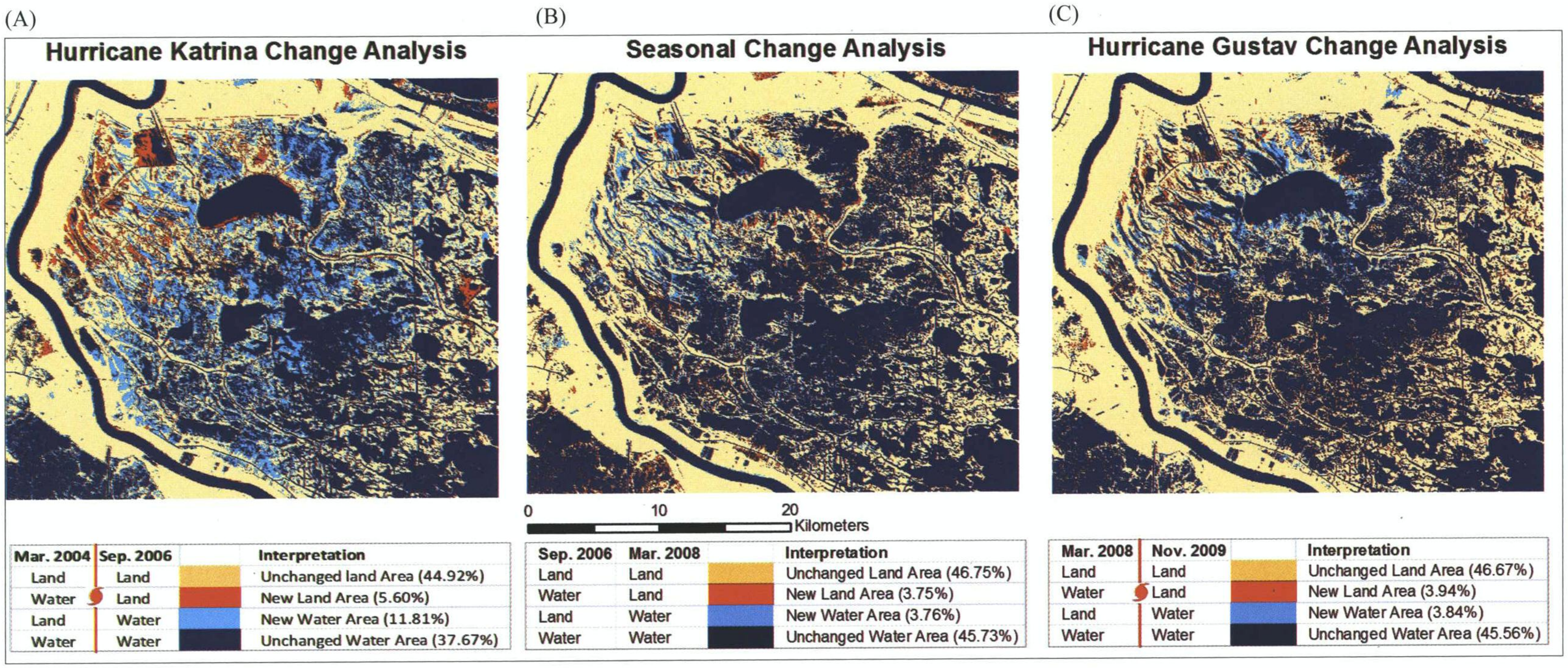

Figure 8. Change analysis maps demonstrating hurricane effects vs. natural variability. (A) and (C) show land/water changes as a result of Hurricanes Katrina and Gustav respectively, (B) shows changes occurring from September 2006 to March 2008; these changes are attributed to natural seasonal effects as there were no extreme storms during this period.

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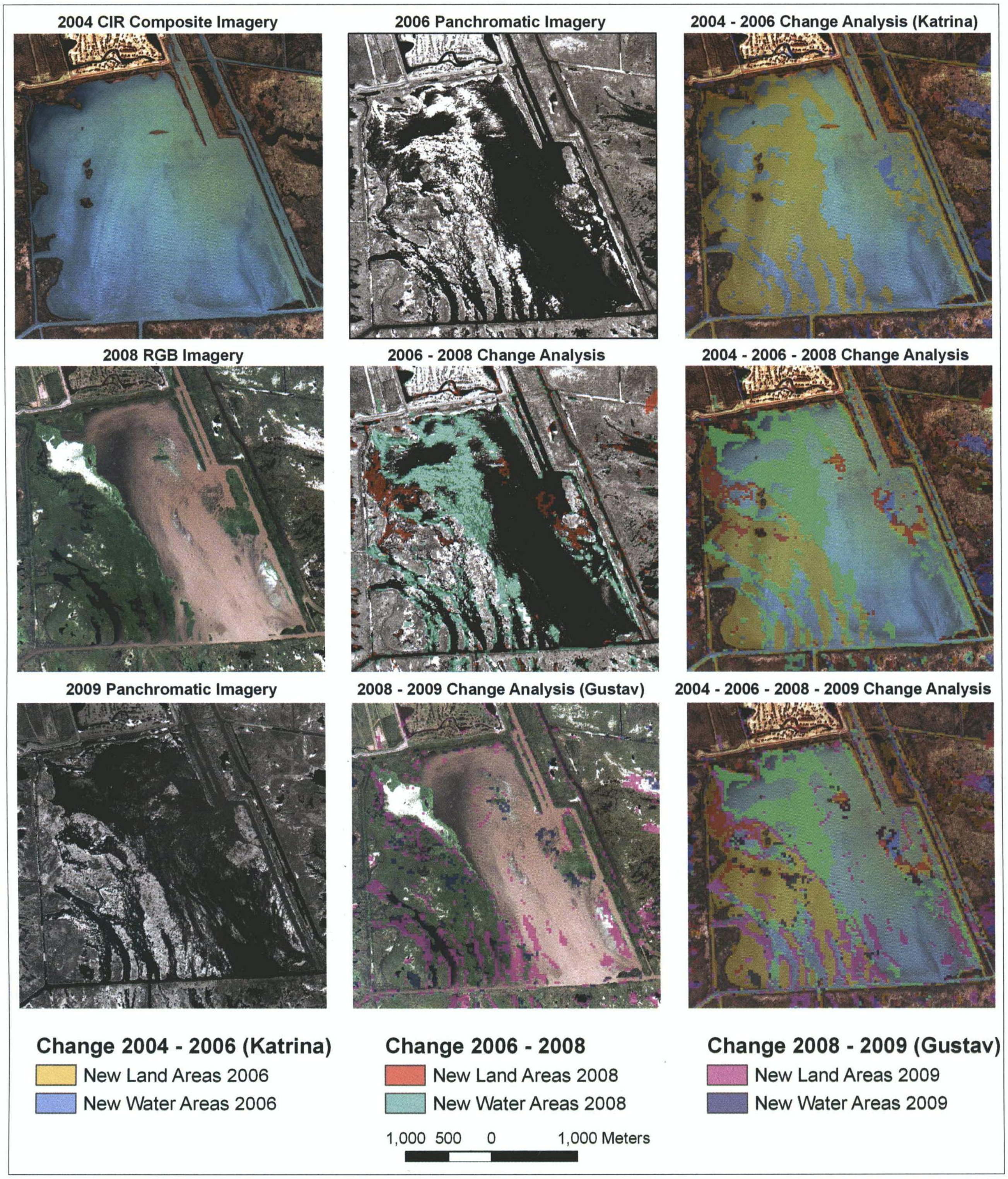

Figure 9. Land change analysis focused on Big Mar Pond, Delacroix, between 2004–2009. Aerial imagery for each year are presented in the first column and first image of the second column, change analysis between 2 consecutive aerial images are presented in the second column and first image of the third column and overall change analysis results in the last 2 images of the third column.

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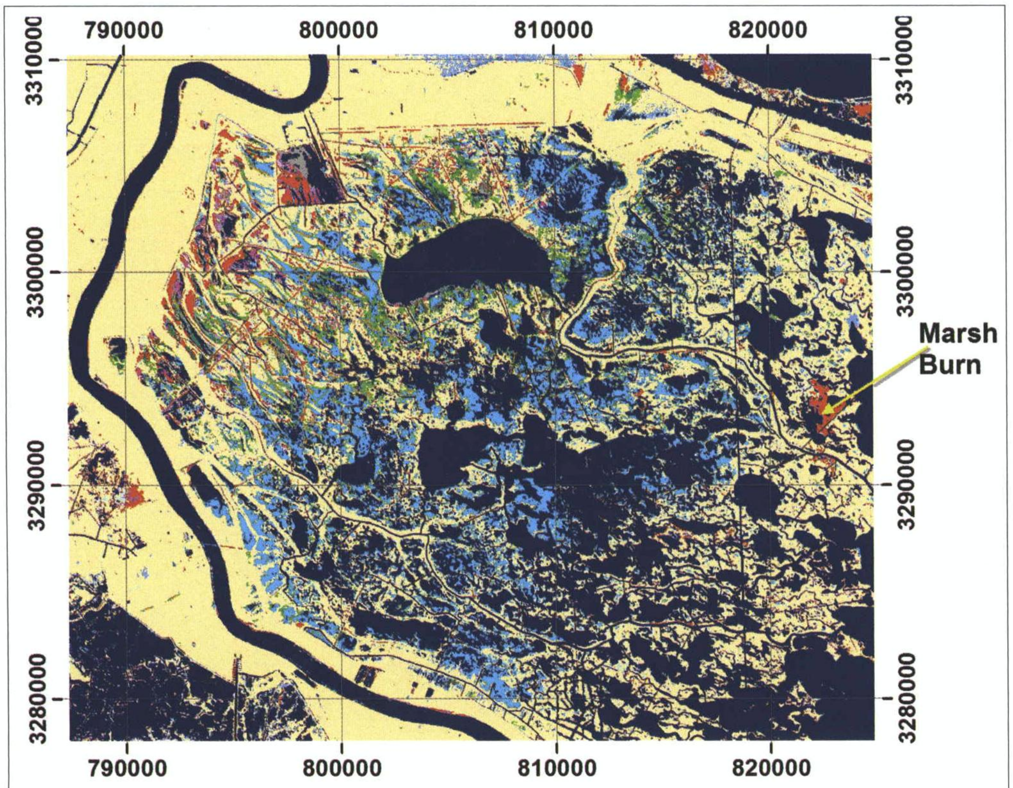

Mar. 2004	Sep. 2006	Mar. 2008	Nov. 2009	Change Analysis Interpretation
Land	Land	Land	Land	Unchanged land (41.37%)
Water	Land	Land	Land	Permanent new land Katrina (3.25%)
Land	Water	Land	Land	Transient water Katrina (1.48%)
Water	Water	Land	Land	Drained fields after 2006 (0.55%)
Land	Land	Water	Land	Water level fluctuation 2008 (1.32%)
Water	Land	Water	Land	Vegetation seasonality (0.69%)
Land	Water	Water	Land	Water level fluctuation (1.18%)
Water	Water	Water	Land	New land Gustav (0.75%)
Land	Land	Land	Water	New water Gustav (1.39%)
Water	Land	Land	Water	Erosion Gustav (0.74%)
Land	Water	Land	Water	Post storm flooding (0.97%)
Water	Water	Land	Water	Drainage in 2008 (0.74%)
Land	Land	Water	Water	Died-out vegetation after 2006 (0.84%)
Water	Land	Water	Water	Transient new land Katrina (0.92%)
Land	Water	Water	Water	Permanent new water Katrina (8.17%)
Water	Water	Water	Water	Unchanged water (35.63%)

Figure 10. Change analysis interpretation for each classification permutation in the 4-image time series (2004–2009), Delacroix, Louisiana.

ponds have recognizable morphologies (Morton and Barras, 2011). Orthogonal-elongated ponds are found to the southwest and east of the Five Lakes impoundment (Figure 6). Amorphous ponds from both storms are found south of the Five Lakes impoundment, elongated ponds are found throughout the entire southern study area and denuded marsh can be observed in the southern study area. The orthogonal-elongated ponds tend to form in the more organic intermediate marshes while the amorphous ponds are found in brackish and brackish–intermediate marshes closer to the Gulf of Mexico. It is interesting to note that the marsh around the open water ponds in the northwestern part of the Hackberry study area was not severely impacted by the hurricanes, the small changes in the area likely are more related to water-level fluctuation (tidal/meteorological) and seasonality than induced by extreme storm events.

In the Delacroix study area, the majority of the marsh was

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Table 1. Comparison of the effects of Hurricane Rita to Katrina and Ike to Gustav. Transient changes are those areas that change from one class (land or water) after the first storm and then revert to their original class after the second storm. Persistent changes are those areas that change class after the first storm but retain that new class after the second storm event. New land/water are those areas that change class after a storm, but not enough time has passed to determine if the changes are persistent or transient.

Category	Hackberry area		Delacroix area	
Unchanged water	33.36%		35.63%	
Unchanged land	46.06%		41.37%	
	Rita Sept. 24, 2005	Ike Sept. 13, 2008	Katrina Aug. 29, 2005	Gustav Sept. 1, 2008
Persistent new water	6.49%		8.17%	
Persistent new land	0.66%		3.25%	
Persistent land loss	**5.83%**		**4.92%**	
Transient new water	2.90%		1.48%	
Transient new land	1.92%	NA	0.92%	NA
Transient land loss	**0.98%**		**0.56%**	
New water		8.26%		1.39%
New land	NA	0.35%	NA	0.75%
New land loss		**7.91%**		**0.64%**

predominantly impacted by Hurricane Katrina, while Hurricane Gustav did minor damage in comparison. Persistent water areas due to Hurricane Katrina represent either enlargements of previous water bodies (amorphous ponds in the central part of the study area, Figure 10) or new orthogonal-elongated ponds (central western part of the study area, Figure10). In Delacroix land loss increased from east and southeast towards the north and west up to the agricultural/urban area boundary. This trend mirrors the salinity gradient of the marshes in the study area (Figure 10, Figure 11B).

Saline marshes were minimally affected by Hurricane Katrina despite being closer to the eye of the storm, while brackish and intermediate marshes further inland were substantially impacted. Howes *et al.* (2010) attribute the robustness of saline marshes to hurricane impacts to their deeper root system and higher shear strength of the underlying soil. On the other hand, fresh marshes

(A) (B)

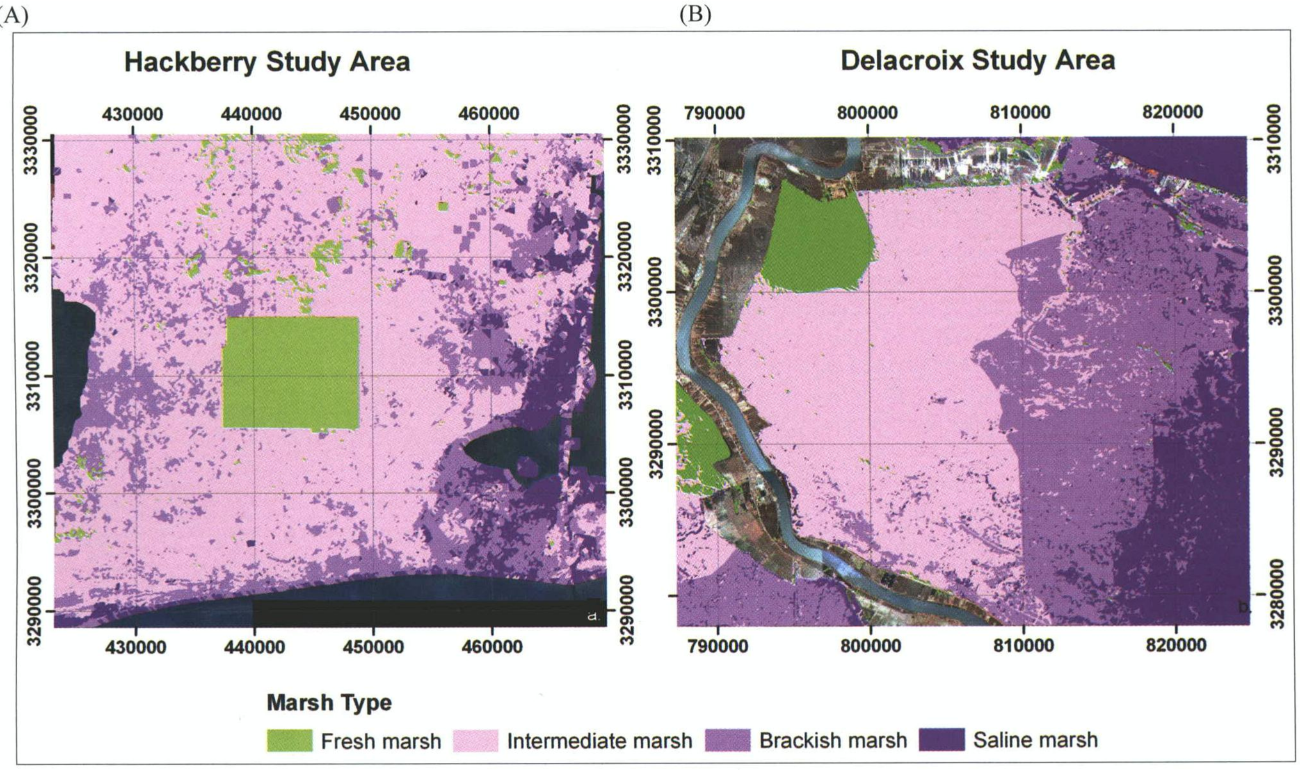

Figure 11. Salinity-based marsh type classification for (A) Hackberry and (B) Delacroix study areas.

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exhibit a highly sinusoidal land variation trend representative of vegetation seasonality and meteorological conditions that conceal extreme storm event impacts. Land loss in the Delacroix study area related to the extreme storm events of 2005–2008 is substantial for intermediate and brackish marshes, is marginal for saline marshes and is obscured by vegetation seasonality and water-level fluctuation in fresh marshes. During the growing season, the storm-formed ponds may become choked with floating aquatic plants like water hyacinth (*Eichhornia crassipes*) or duckweed (*Lemna L.*) thereby appearing recovered.

CONCLUSIONS

The two study areas responded differently to impacts from similar intensity hurricanes. We attribute this mostly to differences in physiographic setting, marsh type, and land management practices, between the chenier plain and delta plain study areas. The chenier plain area consists of broad expanses of low elevation wetlands separated by narrow west trending relict beach ridges, or cheniers, bounded by the Gulf of Mexico to the south and Pleistocene uplands to the north. The higher elevation cheniers and Pleistocene uplands contain developed and agricultural areas while the low elevation marshes contain numerous canals and leveed impoundments that are managed for farming and grazing during the spring and summer and for hunting and fishing during the fall and winter. The resulting landscape is a heterogeneous patchwork of relatively contiguous impounded and nonimpounded wetlands. The Delacroix study area primarily consists of embayed interdistributary wetlands with developed and agricultural areas limited to the natural levees of the east bank of the Mississippi River to the west and the abandoned Bayou La Loutre distributary to the north. These wetlands are separated from the higher elevation distributary ridges by bounding storm protection levees. The storm protection levees bounding the Delacroix area to the west and north were greater impediments to surge flow than the smaller impoundment levees present in the chenier area. The presence of these impediments to Hurricane Katrina's surge likely enhanced land loss in the west-central Delacroix area. The smaller magnitude levees present in the chenier plain area likely allowed greater dispersion of Hurricane Rita's storm surge within the area and reduced loss as compared to the Delacroix area. The hurricanes' impact in the chenier plain is mostly represented by the expansion of existing ponds in already fragmented marsh areas, or the creation of new orthogonal-elongate ponds and amorphous ponds in more stable marshes. The elongated finger-like ponds appear only in a small area east of the Five Lakes impoundment, while in Delacroix these features are prominent in the west-central part of the study area.

Hurricanes Rita and Katrina had similar effects with 5.8% and 4.9% persistent land loss in the chenier plain and Delacroix study areas, respectively. The recovery after the 2005 hurricane season was relatively small, less than 1% for the chenier plain site and slightly more than 0.5% for the Delacroix area. If the effects of Hurricanes Rita and Katrina were similar, Hurricanes Ike and Gustav had very different impacts although both were Category 3 storms on the Saffir-Simpson scale, and their trajectories were approximately 80–100 km to the west of the study areas. Both study areas will probably continue to recover from the 2008 hurricane season, but while Delacroix may one day recover, at least to the extent of aquatic vegetation growth, if not the regrowth of the marsh that characterized the area prior to the removal by storm surge, it is expected that the chenier plain has sustained more persistent land loss due to Hurricane Ike. New land loss attributed to Hurricane Ike in the chenier plain is over 7.9% while Hurricane Gustav caused minimal land loss in the Delacroix area (0.6%). Intermediate and brackish marshes in both study areas experienced the most land loss, while saline marshes were less impacted and fresh marshes showed evidence of vegetation seasonality change and regrowth, which concealed the hurricane impacts.

Fractional-water estimates based on high-resolution imagery greatly improved the accuracy of the land/water classification at the 30-m medium-resolution scale. Classification methodologies based on fractional-water maps have the advantage of allowing different optimization methods to be used to obtain the desired classification, as well as relatively swift evaluation of hundreds of possible classifications. The methodology is also highly reproducible and depends less on local skilled knowledge, thus being highly transferable.

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