

Freshwater river diversions for marsh restoration in Louisiana: Twenty-six years of changing vegetative cover and marsh area

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[1] The restoration of Louisiana's coastal wetlands will be one of the largest, most costly and longest environmental remediation projects undertaken. We use Landsat data to show that freshwater diversions, a major restoration strategy, have not increased vegetation and marsh coverage in three freshwater diversions operating for ~19 years. Two analytic methods indicate no significant changes in either relative vegetation or overall marsh area from 1984 to 2005 in zones closest to diversion inlets. After Hurricanes Katrina and Rita, these zones sustained dramatic and enduring losses in vegetation and overall marsh area, whereas the changes in similar marshes of the adjacent reference sites were relatively moderate and short-lived. We suggest that this vulnerability to storm damage reflects the introduction of nutrients in the freshwater diversions (that add insignificant amounts of additional sediments), which promotes poor rhizome and root growth in marshes where below-ground biomass historically played the dominant role in vertical accretion. **Citation:** Kearney, M. S., J. C. A. Riter, and R. E. Turner (2011), Freshwater river diversions for marsh restoration in Louisiana: Twenty-six years of changing vegetative cover and marsh area, *Geophys. Res. Lett.*, 38, L16405, doi:10.1029/2011GL047847.

1. Introduction

[2] The dramatic loss of one-fifth of Louisiana's wetlands present in the 1930s [Britsch and Dunbar, 1993], is one of the world's major ecological disasters. These losses threaten wetland-dependent Gulf of Mexico fisheries, make coastal Louisiana more vulnerable to hurricanes, and deprive millions of migratory birds of over-wintering habitats [National Research Council, 2006]. A modeling study suggests that the collapse of weakened marsh plants during Hurricane Katrina compromised their ability to mitigate storm surge flooding of New Orleans [Resio and Westerink, 2008], implying that storm damages will be worse if a projected increase in intense hurricanes from climate change is realized.

[3] Since the enactment of the Coastal Wetland Protection, Planning and Restoration Act (CWPPRA) in 1990, 151 projects have been undertaken in the Louisiana Coastal Area (LCA). Freshwater diversions from the Mississippi River represent the largest restoration initiatives in terms of the scale of impact. They are also the most costly. The Davis Pond diversion, for example, cost \$106 million to build

(U.S. Army Corps of Engineers, <http://www.mvn.usace.army.mil/pao/dpond/davispond.htm>) and another \$100 million to repair. The Myrtle Grove diversion, planned for completion in 2013 could cost ~\$417,000,000 [U.S. Army Corps of Engineers, 2010] (Table S1 in the auxiliary material).¹ Future costs aside, the State of Louisiana is committed to building diversions as the best way to "reconnect the river to the deltaic plain" [Day et al., 2007], reasoning that the greater freshwater influx would lower salinity, and increase accretion and plant vigor because of the higher suspended sediment and nutrient inputs.

[4] The scientific basis for the benefits of freshwater diversions is not settled. A recent model [Blum and Roberts, 2009] suggests that the deltaic plain will shrink by 13,500 km² by 2100 because of sediment deficits and accelerated sea level rise. Nonetheless, it is not certain whether diversions would provide any additional mineral sediment to brackish marshes, where some of the greatest losses occurred [Barras et al., 2008]. Further, the available data indicate that vertical accretion is correlated with *in situ* organic accumulation (principally root and rhizome material), not mineral sediment inputs [Nyman et al., 1993; Turner et al., 2000]. Excessive nutrient influx into the Caernarvon diversion marshes (the largest freshwater diversion created) is linked to the widespread occurrence of low soil strength (by field shear vane tests), indicating that these marsh sediments are potentially highly erodible; in fact, land losses from Hurricane Katrina were especially high [Howes et al., 2010]. The strong support given diversions by some local wetland scientists [Boesch, 2006; Day et al., 2007] has been reason enough for policy makers to commission feasibility studies for future diversions [National Research Council Committee on the Review of the Louisiana Coastal Protection and Restoration Program, 2009].

[5] The effectiveness of diversions to mitigate marsh loss has not been quantitatively evaluated. However, three major diversions, Caernarvon, West Point a la Hache, and Naomi, have operated since the early 1990s (Figure 1 and Table S1), providing an opportunity to assess trends in plant condition and total marsh area before and after diversions began. The vegetation in all three diversions spans the common marsh types in the LCA, including fresh (*Panicum hemitomon*, *Sagittaria lancifolia*), intermediate (*Leptochloa fusca*, *Panicum virgatum*), brackish (*Spartina patens*, *S. cynosuroides*), and saline marshes (*Spartina patens*, *Distichlis spicata*) [Sasser et al., 2008]. Invasive species like Chinese tallow (*Triadica sebifera*) and water hyacinth (*Eichornia crassipes*) are also common. The Caernarvon diversion is more directly influenced by the Gulf of Mexico through Breton Sound than are

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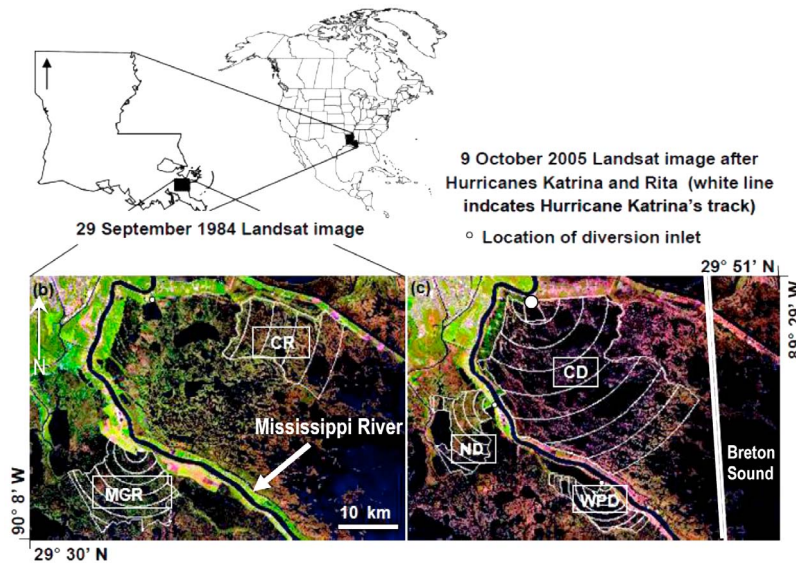


Figure 1. (a) Study area location (black rectangle) in southeastern Louisiana, USA. The locations of zones (b) in the reference sites and (c) in the diversions are indicated by the white lines and the letters in rectangles identify individual diversions and reference sites. CD = Caernarvon diversion; CR = Caernarvon reference site; ND = Naomi diversion; WP = West Point a la Hache diversion; MGR = Myrtle Grove reference site.

the smaller Naomi and West Point a la Hache diversions, and has substantially greater river freshwater inputs. Hurricane Katrina (2005) passed directly east of it in Breton Sound.

[6] We use Landsat Thematic Mapper imagery in a spectral mixture model developed in studies of low salinity, microtidal marshes [Kearney *et al.*, 2002], which was cross-referenced with comparisons from aerial photography to analyze changes in marsh vegetation cover and total marsh area since 1984 for these three diversions. The inherently wide geographic capture of changes afforded by high resolution satellite imagery provides a spatial and temporal perspective on the conflicting ideas about the efficacy of diversions to restore marsh.

2. Data and Methodology

[7] We analyzed twelve Landsat TM/ETM+ data sets (Path 22 Row 39) collected between 1984 and 2009. The criteria used for selection were: 1) dates coinciding with peak or near-peak vegetation growth; 2) a tidal stage near mean low low water (MLLW); 3) high atmospheric clarity (little haze or cloud cover); 4) regular intervals between observations; and 5) the inclusion of scenes bracketing major hurricanes (Table S2).

[8] The spectral mixing model is based on spectral indices for vegetation, soil, and water. It more consistently characterizes marsh spectra end members than the more common principal components approach [Rogers and Kearney, 2004]. Three indices were calculated by normalizing the difference between Landsat bands to produce a spectral space (NDX) that approximates the optimal spatial model for spectral unmixing and, thus, more tightly defines the following vegetation, water and soil spectral end members: $NDVI = (\text{band } 4_{NIR} - \text{band } 3_{Red}) / (\text{band } 4_{NIR} + \text{band } 3_{Red})$; $NDWI = (\text{band } 3_{Red} - \text{band } 5_{IR}) / (\text{band } 3_{Red} + \text{band } 5_{IR})$; and $NDSI = (\text{band } 5_{IR} - \text{band } 4_{NIR}) / (\text{band } 5_{IR} + \text{band } 4_{NIR})$ [Rogers and Kearney, 2004].

[9] We calculated radiance for twelve, co-registered Landsat TM and ETM+ scenes using standard remote sensing techniques and equations [Jensen, 2002; Chander *et al.*, 2009]. Atmospheric correction of the imagery was undertaken by the FLAASH module for deriving spectral surface reflectance [Berk *et al.*, 2002]. The unsupervised, K-means algorithm in the ENVI image processing software was used to classify Landsat bands 3, 4, and 5 composite data into two classes, marshland (vegetation + soil) and water, with the former used as an indicator of overall change in marsh coverage.

[10] Although the spectrally unmixed Landsat data yield percent spectral reflectances derived for vegetation, water, and soil, we present only the data for pixels dominated by the vegetation spectral reflectance index (estimated to be 40% or more based on previous work in mid-Atlantic coast marshes [Kearney and Riter, 2011]). Lastly, we used ArcGIS software to calculate the percentages of pixels dominated by vegetation spectra, and those classified as marshland within pre-selected zones in the diversions and in two reference areas (Figure 1).

3. Results

[11] We examined whether demonstrable changes occurred in vegetative cover after diversion operations began by comparing changes in the relative percent vegetation cover before and after the diversions opened, while excluding the period after Hurricanes Katrina and Rita. The percent vegetation in the diversions and the Caernarvon reference site was highest in the zone closest to the diversion inlets (Zone 1 in Figures 2a–2e). Field observations and Landsat imagery collected from 27 August 1995 to 22 August 2005 indicate that this phenomenon is mostly a response to algae and floating vegetation in the open water areas, rather than to the presence of deeply-rooted marsh vegetation. The most salient aspect in the trends in percent vegetation cover, a nominal

