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# Sediment and Nutrient Tradeoffs in Restoring Mississippi River Delta: Restoration vs Eutrophication

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Environmental problems (e.g., eutrophication, unsustainable fisheries, wetland loss, climate change, etc.) are inherently complex, with increasingly dominant effects of human systems on natural system dynamics (Vitousek et al. 1997). The 21st century will be critical as we face the transition from the past era of technology to a new era, which has been referred to as the anthropocene, of adaptation in both natural and social systems. The vulnerability of environmental systems to human effects depends of the ability of the natural system to adapt to land use changes within highly engineered landscapes (Odum 1974). Riverine environments of all kinds have the additional complexity that they are linked over large scales by the river network, so that problems in downstream locations may be affected by decisions made thousands of kilometers upstream. Coastal landscapes, particularly deltaic systems, represent some of the most impacted and altered ecosystems worldwide and they integrate the effects of processes over their entire catchment, making them prime examples of environmental teleconnections that require systemic solutions to water resource problems.

Hurricane Katrina, along with the river floods in the upper river basin, brought international attention to the major environmental changes in the nearly 1.3 million square mile watershed of the Mississippi River over the past century, including conversion of more than 80 percent of forested wetlands to agriculture and urban areas, channelization, and construction of dams and levees (Goolsby et al. 2000). The lower Mississippi deltaic plain has also been engineered by construction of a massive structure that maintains the relative flow of the Mississippi and Red Rivers down two specific channels, Mississippi and Atchafalaya Rivers, along with continuous levees that restrict sediment and freshwater supply to river flood plains (Kesel 1988). These changes have been especially damaging to the more than 12,000 square miles of coastal wetlands associated with the Mississippi River delta including 40 percent of the total coastal salt marsh in the conterminous U.S. (Baumann et al. 1984). These wetlands are disappearing at an average rate of 17 square miles per year or about 50 acres per day, and more than 1,000 square miles of freshwater wetlands in Louisiana have already been converted to other habitats (Gooselink 1998, Conner and Day 1988, Barras et al. 2003). Wetland loss rates over the next 20 years in coastal Louisiana, due to the combination of sea-level rise and disruption of coastal processes, will continue to convert land to open water, threatening the region's enormously valuable fisheries, aquaculture, and coastal agriculture, as well as navigation and other industries located near the coast (Barras et al. 2003, Day et al. 2007). As a result of the water management system, the Mississippi River delta is a threatened wetland landscape whose sustainability is critically at risk, particularly given scenarios of sea level rise and hurricane intensity and frequency projected for the Gulf Coast Region (Day et al. 1994, Twilley et al. 2001, Day et al. 2007).

Extensive engineering of water management systems in the Mississippi River basin constrain how economic and ecological systems can adapt to proposed features of integrated protection and restoration planning objectives. Deltaic environments, such as wetlands of the Mississippi

River floodplain, receive sediments during floods that were delivered historically in pulsed events (Day et al. 1994). In these river-dominated deltaic coasts, wetland soil formation is dependent on mineral inputs that also produce large amounts of organic matter from plant production contributing to increased surface elevation. River management systems, such as levees and flow diversions, have reduced river-pulsed events and the delivery of sediment to floodplain wetlands, decreasing the ability to form soil and increase elevation (Baumann 1984). Public works projects, largely constructed to reduce risks of communities and economic assets to river flooding, interfered with regional hydrology and coastal processes important to sustaining natural structure, function and extent of wetland ecosystems (Boesch et al. 1994).

Consequently, the goal of reducing risks to society from events such as the 1927 flood and other events over the last 50 years have caused increased risks to ecosystems and natural resource capital in the Mississippi River deltaic plain. Hurricanes Katrina and Rita brought attention to the irony that these public works projects have also reduced the capacity of nature to protect human settlements. Extensive wetland ecosystems, particularly coastal forests, are a buffer against storm damage and a nursery area for fish and crustaceans. Louisiana ranks first among all states in the commercial harvest of menhaden, oysters, and crabs and is a major producer of shrimp. The delta region is also a working coast; approximately 17 percent of the nation's oil and 25 percent of its natural gas come from Gulf coast waters. The ports of New Orleans, South Louisiana, Baton Rouge, and Lake Charles together handle more than 20 percent of the nation's foreign waterborne commerce. Now a more integrated system of structural and non-structural approaches to protecting this built infrastructure and populated communities is challenged to consider the restoration of 'green' infrastructure that must parallel efforts to increase protection from hurricane flooding events.

Delta restoration – system design toward a resilient, self-sustaining delta – is a generic environmental problem worldwide in which human and natural dynamics are strongly and inherently coupled. The urgent need for wetland restoration and rehabilitation at large spatial scales have been addressed through the diversion of riverine water from the Mississippi River (Day et al. 2003, Mitsch et al. 2005, Mitsch and Day 2006). This management strategy aims to deliver sediment-laden water to declining wetlands areas and promote wetland productivity (Delaune et al. 2008) using human water control structures in major basin areas undergoing wetland loss (e.g., Barataria Bay, Breton Sound) (Day et al. 2005, Lane et al. 2006, Keddy et al. 2007). The conflict to resolve ecosystem needs of river and coastal processes to sustain the delta with demand for structural features from levees and floodgates to protect people and infrastructure has always historically favored investments in resiliency of the social system at the expense of the natural system (Barry 1997). However, reductions in sediment loading to the deltaic region and restricted distribution of river flow across wetland landscapes constrain resources needed to have any chance of stabilizing some wetland footprint in this area (Reed 2009).

The challenge to develop bold new ideas of river management to reintroduce sediment to the coast are further complicated by how the chemistry of the river has changed over the last four decades. The Louisiana coastal region is at the receiving end of a large input of nitrate from upstream agricultural activities (Coleman et al. 1998, Turner 2001, Rabalais et al. 2002a). Because of large nitrogen loading through the Mississippi River basin, there is increasing coastal eutrophication and the development of a large hypoxia zone (up to 21,000 km$^2$) (Rabalais et al. 2002b, Scavia et al. 2004, Hyfield et al. 2008, Turner et al. 2008). As nitrogen is delivered to coastal waters, there is a risk of exacerbating eutrophic conditions through seasonal algae blooms, some of which are toxic, excess organic matter production, low oxygen concentrations in water and sediments, and long term nitrogen and phosphorous accumulation (Brown et al. 2006). As more freshwater diversion projects are planned along major waterways throughout the state of Louisiana, there is concern that this new constituent of nitrate will contribute to reduced water quality conditions of shallow bays and estuaries of the delta. Concerns about creating large human health risks as a result of toxic algal blooms induced by increasing nitrogen inputs, underscore the difficulty of implementing large-scale restoration plans in coastal regions (e.g., Sklar et al. 2005).

Denitrification is a major pathway for the removal of inorganic nitrogen in lakes, rivers, and coastal estuaries. This reduction is biologically mediated through a series of intermediate gaseous products to $N_2$ representing a direct loss of nitrate to the atmosphere (Seitzinger 1988, Burgin and Hamilton 2007). This conversion of nitrate to nitrogen gas is currently considered a critical ecological function for the removal of highly enriched N from anthropogenic sources (Galloway et al. 2004, Howarth and Marino 2006, Seitzinger et al. 2006). Since nitrate is generally the dominant form of excessive nitrogen entering coastal regions, it is potentially viable to ameliorate water quality problems through the reduction of nitrate via direct denitrification (Mitsch et al. 2001, Galloway et al. 2003, Mulholland et al. 2008). As nitrate-enriched water masses flow through the landscape, the presence of riparian, headwater streams, and coastal wetlands can efficiently remove reactive nitrogen. Comparative studies of wetland and riparian ecosystems along the Mississippi River basin suggest that those habitats can retain up to 70 percent of nitrate inflow (Mitsch et al. 2005). However, large-scale managed input of nutrient-enriched Mississippi waters into wetlands and open waters has been controversial since its implementation in coastal Louisiana (Turner 2001, Lane et al. 2003, Turner et al. 2006a, Day et al. 2007, Turner et al. 2007). Presently there is no clear consensus on whether restoring wetlands with sediment from the river will also enhance the capacity of nitrate removal, thus reducing risks of eutrophication.

Delta restoration involves one or more carefully sited, partial river diversions (controlled avulsions, in a sense) that set in motion the natural processes that created the delta, but in a controlled manner that either builds new land area or nourishes existing wetlands preventing them from drowning. With increased nitrate concentrations over the last four decades, the reintroduction of river water into coastal areas may potentially contribute to harmful algal blooms and increased incidence of hypoxia. Social benefits will depend on how these increments of river input will alter existing physical, biological, and chemical characteristics to degrees of river flow (Laska et al. 2005). These natural science processes are coupled to human dynamics through tradeoffs such as displacing marine fisheries with freshwater species, or hard versus soft forms of coastal protection, or threats of hypoxia versus new wetland formation. In the end, these tradeoffs will determine the level of delta restoration (magnitude of river input) that will take place under various incremental scenarios of river management.

In summary, the Mississippi River delta faces another round of human control through expanded public work projects following the catastrophic realities of hurricanes in 2005 and 2008. The challenge is even greater with complex interactions of land use change throughout the catchment to the coast that must be resolved to accommodate bold new river management plans in concert with structural protection. First, expansion of engineered landscapes to reduce risks to hurricane flooding may further reduce the opportunities provided by systems-level approaches to river management using diversion structures to replenish sediment to the deltaic plain. Second, agricultural practices of land use and fertilization in the Mississippi River basin further complicate the opportunities provided by changing river management, since nitrogen enrichment contributes to expanding eutrophication problems in the region. Thus, urgent solutions to post-Katrina issues in the Mississippi River involve providing increased protection to communities while expanding river processes to restore wetland landscapes, which will also require changing approaches to agricultural land use to reduce nitrogen load and risks of eutrophication. This juxtaposition of protection, wetland restoration, and eutrophication, all linked to bold new approaches to river basin management, has all been highlighted by the post-Katrina challenges for a sustainable coast. Managing all these competing tradeoffs to sustain the economic and natural resources of this region are representative of how we must consider new approaches to coastal catchments throughout the world. Water resource quantity and quality are largely determined by highly engineered landscapes of public work projects and agricultural land use interacting with a changing global hydrologic cycle. Thus water resource planning is arguably one of the most important features of national security, public health, economic development, and natural resource management in the next century. Ecosystem services derived from healthy natural resources will support our national wealth depending on how well we manage the finite water resources to satisfy our social needs.

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