Summary and Conclusions: The Cost of Inaction and the Need for Urgency

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Abstract

The delta process is inherently dynamic, but no one alive today has ever witnessed a healthy period of stability through offsetting growth and decay. Consequently, only a full scientific understanding of how the Mississippi delta once formed and functioned under natural conditions can guide future restoration efforts. As the foregoing essays argue, living on the Delta means living with change. They present strong evidence that sediment diversions designed to restore wetlands in the Mississippi River delta will be effective and beneficial. Similarly, they argue that large-scale restoration will shift the locations of the major fisheries, but may represent the only hope of maintaining sustainable fisheries. And they explain why the system of levees and flood protection that currently provides crucial protection for human habitation must to be supplemented by extensive wetland regrowth. Additionally, they describe how the highly dynamic and changing coast is also impacted by subsidence, climate change, and sea level rise. Finally, they show that increasing energy costs will likely limit what can be done. Only by honestly examining the full range of challenges, and determining the best practices for adaptation, can policy-makers formulate informed decisions about the future of the Delta. We hope this book can make a substantial contribution to the success of this important process.

Keywords

Mississippi river delta · Wetland · Coastal restoration · River diversion · Delta cycle · Flood control · Adaptation culture · Climate change · Sea-level rise

Introduction

An understanding of how the Mississippi delta formed and functioned under natural conditions greatly informs restoration efforts. Liviu et al. (2014) and Condrey et al. (2014) describe the processes that led to the formation of the delta and how the delta functioned before significant human impact. Liviu et al. (2014) describe the development of the Mississippi delta. Mississippi delta restoration is informed by delta dynamics worldwide. In their natural state, all deltas were highly dynamic and interactive on a hierarchy of spatial and temporal scales.

Formation of the Mississippi delta began about 7,000 years ago when sea level stabilized at near its present level after rising nearly 150 m from a low stand about 15,000 years ago. The delta formed as a series of overlapping delta lobes. The Mississippi delta, like all deltas, is a result of a very complex set of processes acting at different temporal and spatial scales. There was an increase in wetland area in active deltaic lobes

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and wetland loss in abandoned lobes. But overall, there was an overall net increase in the area of wetlands over the past 7,000 years because the forces leading to delta growth were greater than the forces leading to delta deterioration.

The functioning of deltas is affected by a hierarchy of energetic forcings that occur on different spatial and temporal scales and affect the morphology and evolution of these systems as well as enhance their productivity (Day et al. 1997, 2007). These energetic events range from waves and daily tides to switching of river channels in deltas that occur on the order of every 1,000 years, and include frontal passages and other frequent storms, normal river floods, strong storms, and great river floods. The primary importance of the infrequent events such as channel switching, great river floods and very strong storms such as hurricanes is in sediment delivery to deltaic wetlands and in major spatial changes in geomorphology. The more frequent events such as annual river floods and frontal passages also are important in sediment dynamics on smaller spatial scales. Much of the human-caused deterioration of the delta can be understood as a reduction in these energetic forcings by such activities as leveeing and pervasive changes in hydrology.

Condrey et al. (2014) use historical information from early explorers in the late sixteenth and seventeenth centuries to paint a picture of deltaic functioning just prior to the beginning of significant human impact by European settlers. They explore the historic record for a description of the last naturally active delta complexes of the Mississippi River (LNDM) as the most appropriate restoration model for Louisiana's coast. Based on descriptions by the explorers Chaves, Barroto, Iberville, Evía, and Dumain, they conclude that the LNDM was a vast seaward-advancing arc that occupied, through four distributaries, all of the five most recent deltaic complexes of the Mississippi River and extended across all of coastal Louisiana east of the Chenier Plain. It was characterized by plumes of freshwater that extended for more than 10 km into the Gulf of Mexico during the spring flood of the Mississippi River and by a vast offshore oyster reef which functioned as both an impediment to navigation and an offshore harbor. Implications of their findings are discussed in light of Louisiana's current coastal restoration plans.

Restoration plans are informed by how people understand the coast. Muth (2014) discusses how there is no living memory of a natural delta. But whatever view people have of the river and delta, the real world teaches us one thing: the Mississippi River can build deltas. It is somewhat surreal to listen to opponents of river re-introduction insist that the river, re-directed by diversions into the collapsing delta, will not build land. The very ground beneath their feet belies their statements. Their fear of change is rooted in the false impression created by the shifted biophysical baseline that is their sole experiential reference point. We as humans did not evolve the innate capacity to comprehend physical changes taking place on a geological time scale—changes that take eons. But just as importantly, we have no innate capacity to internalize gradual change, such as happens in the natural cycle of delta building and decay. From a geological perspective, delta geology is instantaneous, but it is not so for humans. We are comfortable with stasis. Incredibly, during the last century in south Louisiana we managed to speed up the delta cycle to a pace that became noticeable even to us. Our reaction was to clamor for stability, for a return to a delta we remembered. But deltas don't work that way. Delta lobes grow, or delta lobes shrink. It is the delta process that gives stability, with offsetting growth and decay. No one alive in south Louisiana has lived in such a deltaic environment. But in the future, society can. And if the river is allowed to rebuild such a delta, our grandchildren might even get a glimpse of the abundance of wildlife and fish among which Native Americans once lived and which stunned the first visitors from the old world upon their arrival 300 years ago.

Bentley et al. (2014) discuss the potential for river diversions. River diversions have been proposed as major tools for coastal restoration. This is based on the idea that reconnecting the river to the deltaic plain mimics the way the delta functioned naturally.

But the suitability of diversions for land building has been the subject of vigorous scientific and policy debate. However, it is important to recognize that some diversions in Louisiana are designed for salinity and flood control, and not to build land. The land-building capacity of a diversion is fundamentally dependent on sediment supply, limited by the sediment retention rate, relative to subsidence, sea level rise, and compaction. If sediment supply amounts exceed these sink processes, then land will be built. Sediment diversions, designed to maximize sediment delivery, are being proposed as potentially important tools for land-building in the Mississippi River Deltaic Plain. Several current diversions show that such diversions can build land.

Part of the reason that diversions have been questioned is because of the size of diversions implemented thus far and potential impacts of river water on receiving basins. Thus, what can be said about the size and location of diversions. It is clear that they must be much larger than the Caernarvon and Davis Pond diversions and they must deliver more sediments, both fine and coarse, than these two diversions. Future diversions should approximate the size of the numerous natural diversions that occurred along the distributary channels as well as the Bonnet Carré Spillway, that regularly flowed at rates of 5,000 to 10,000 m^3/sec. The history of these diversions shows that large diversions need not function every year to be effective land builders. The Bonnet Carré has been opened about once a decade and elevations in the spillway between U.S. 61 and the lake have risen as high as 2.0 m, far outstripping subsidence and sea level rise. Information from the Atchafalaya/Wax Lake deltas, West Bay other sub-deltas in the Birds Foot delta, and Bonnet Carre serve as examples of how diversions can build land.

Climate projections indicate that if no aggressive action is taken, most coastal wetlands will disappear by 2100. This indicates that an aggressive program of very large diversions will be necessary to offset the projected large-scale loss of wetlands. Large diversions should be located as far inland within deltaic basins as possible. This would lead to a greater capture of sediment and restoration of coastal forested wetlands that are rapidly degrading. Building a series of very large diversions in the next decade would be a defense against rising energy costs because diversions like the Bonnet Carré Spillway can operate for more than a century with little energy subsidy following construction.

Questions have been raised that the effects of nutrients in the Mississippi River may have negative impacts on wetlands. Morris et al. (2014) address this question. It is generally accepted that the introduction of sediments per se will build wetlands, but the effects of nutrients and toxins may have unintended consequences that contravenes the benefits of sediment. However, sediment cores document alternating mineral and organic phases supports a model of a delta cycle in which peat marshes occur at end of delta cycle. Hence, peat marshes by definition are not sustainable in the delta.

Coastal wetlands maintain equilibrium with sea level, within limits, by sedimentation of inorganic and organic matter. Critical variables that determine sedimentation rate are the concentration of suspended sediment, primary productivity, relative elevation or flood duration, and kinetic energy. In estuaries where relative sea level is high, as in a subsiding delta, the concentration of suspended sediment in flood water and mineral sedimentation are critical to sustaining healthy marshes. When flooding with sediment laden water is low, relatively marsh elevation declines. There is ample empirical evidence that documents the fact that vegetation typical of coastal wetlands can thrive when sedimentation rates are experimentally raised. Or course the effectiveness of sediment diversions for marsh restoration in the delta will depend on how the sediments are distributed. Impounded wetlands are isolated from surface flow and will not benefit from diversions external to the impoundments.

Plant developmental processes and growth are greatly affected by nutrient loading. Generally, it is observed that plant root:shoot ratios decline as nutrient loading increases. However, with few exceptions, the absolute production of roots and shoots increases with nutrient loading. This is supported by numerous experimental works and field observations. Production of rhizomes also increases with nutrient enrichment. Plant species do not benefit equally from nutrient enrichment, and it can be anticipated that river diversions will result in shifts in plant community composition. Nitrophilous species such as Phragmites will in many cases replace native species. Moreover, river diversions will reduce salinity, and this too will shift species composition in places away from species typical of salt or brackish water habitats, e.g. Spartina spp. to less salt-tolerant species.

Gas flux measurements from the field indicate that respiration rates (CO_2 flux from the soil surface) increases with nutrient enrichment, but it is not clear if this is from increased root and rhizome respiration, decomposition of labile carbon, or decomposition of refractory carbon. Only if nutrients increase the decay of refractory carbon will it affect long-term accretion of organic matter. In equilibrium, the quantity of labile carbon is constant and therefore it does not increase the volume (elevation) of soil. There is evidence that phosphorus limits microbial production in some marshes, but this is not universal and its significance for overall decomposition and carbon sequestration is uncertain. Nitrate is an energetically favorable electron acceptor, close to O_2 in energy yield, and sediment diversions that are rich in NO_3 could actually stimulate the decay of organic matter that typically would resist decay under anaerobic conditions. However, this should only be a significant factor only in peat marshes, which represents an ephemeral stage in a deltaic system. Moreover, the effect of NO_3 could be compensated by dissolved and particulate organic matter in river water. This is an area that requires more research.

Primary production in coastal wetlands is limited primarily by the availability of nitrogen, and secondarily in some salt marshes by phosphorus. Empirical evidence documents that nutrient enrichment increases flooding tolerance in some wetland species. Further, nutrients appear to increase the salt tolerance in some species, but not in others. Ammonium is the dominant form of nitrogen available to wetland plants, but there are publications that show that nitrate is equally as good a source of nitrogen to marsh vegetation as is ammonium.

Nitrogen and phosphorus enrichment of "assimilation wetlands", wetlands receiving waste water, is not uncommon in the delta and provides a model, albeit an extreme case, for impacts of nutrients associated with sediment diversions. Research in assimilation wetlands documents that there are effects due to herbivory (e.g. nutria). Nitrogen fixation provides a major source of nitrogen to natural wetlands, probably in excess of what is derived from flood water. Typically there is more ammonium available in marsh pore water than there is nitrate and ammonium in flood water. The fate of most inorganic nitrogen applied to wetlands is either assimilation by plants or denitrification.

The biogeochemistry and distribution of inorganic nitrogen in marsh sediments varies with salinity. The cation exchange properties of soil changes dramatically with salinity. Sea water cations completely occupy the exchange sites on silts and clays at the salt water end of an estuary, effectively outcompeting ammonium for exchange sites. Consequently, at the salt water end of an estuary ammonium is largely free in solution, while at the freshwater end of the estuary ammonium is largely sorbed onto exchange sites. Moreover, sea water cations compete with ammonium for carriers on the root membrane and decrease the efficiency of ammonium uptake, i.e. the half-saturation constant for ammonium uptake increases. This explains why vegetation can be nitrogen-limited in an environment rich in ammonium.

In summary, there is strong evidence that sediment diversions designed to restore wetlands in the Mississippi River delta will be effective and beneficial. Wetland plant productivity should increase with nutrient enrichment, increasing the efficiency of sediment trapping and raising marsh surface elevation. There likely will be shifts in plant community composition, especially toward the freshwater end of the delta. Highly productive, nitriphilous species like Phragmites will likely replace less productive species and further increase sediment building capacity. There is good empirical evidence that nutrient enrichment will stimulate root and rhizome production, but to a lesser extent than aboveground production. The impact of nutrients on the preservation of soil organic matter is less certain, especially the effect of nitrate. However, this potential impact is a factor only in peat marshes, and the geological evidence suggests that peat is an ephemeral stage at the end of a delta cycle. Mineral sediment and nutrients will likely change plant community composition in peat-dominated wetlands, resulting in a marsh community that is sustainable and more resilient to disturbance.

Numerous investigations have demonstrated the relationship between fisheries yields and the high primary productivities that are typical of estuaries and estuarine plume ecosystems. Along with the loss of wetlands, presumably so goes the loss of the various functions related with them such as commercial harvests of fisheries. However, perhaps the most perplexing aspect of the Mississippi River delta ecosystem is the fact that there is little indication that fisheries productivity has decreased despite high rates of wetland loss. Why aren't landings decreasing? It is likely that fisheries of today reflect a degraded ecosystem attributable to environmental damages that began in the 1920s or earlier but that accelerated during the twentieth century. There are a few thorough reviews of differential use of habitat by estuarine fishes from other deltaic ecosystems that may allow us to speculate about how the loss of habitat in Louisiana may impact fisheries production. Greater than 75 % of the species that support fisheries in Louisiana are considered to be estuarine-resident or –dependent, and therefore it is likely to end badly for the Sportsman's Paradise if large-scale restoration is not possible, or if possible, not undertaken. Large-scale restoration will cause shifts in the locations of the major fisheries but it may be the only hope of maintaining sustainable fisheries. Cowan et al. (2014) address these issues.

It is widely understood that the artificial separation of the Mississippi River from its delta in Louisiana has caused ecological collapse and loss of thousands of square miles of wetlands. Emerging evidence indicates that current Mississippi River management is on a collision course with the biophysical trajectory of this iconic ecological and economic asset. An aspect that has received less national attention is the growing likelihood of economic dislocations caused by interruptions of navigation through the mouth of the river, one of the world's busiest shipping channels.

Most of the population of South Louisiana needs flood protection from both hurricanes and river floods. Risk from flooding grows with the continuing loss of a coastal wetland buffer; wetlands behind levees are threatened. The placement of levees is critical both for flood protection and for wetland health. There is growing recognition that levees ultimately put areas at more risk to dramatic events in exchange for protection for more frequent and moderate events. Coastal scientists and coastal levee system managers recognize that levees require substantial wetlands in front of them to reduce risk to storm wave action degrading them. Kemp et al. (2014) address issues of navigation and flood control.

Bailey et al. (2014) discuss adaptation and change within human communities in Louisiana. These communities are facing a highly dynamic and changing coast impacted by subsidence, climate change, sea level rise, rising energy prices, and financial constraints on governments. Some areas of the coast will be lost while others may be able to survive, at least for a while. People and communities will take actions and make choices based on knowledge of place and commitment to community. Support for communities should be oriented toward encouraging internal community support for risk awareness and risk reduction response, utilizing the communities' own social capital. The serious question for applied social scientists concerned with coastal Louisiana is can the local communities make a commitment to comprehensive non structural adaptive mitigation fast enough to keep up with the increasing risk to which they are subject? And can applied social and physical scientists make a contribution to this achievement? Scientists should clearly present the full range of challenges facing the coast, including climate and energy scenarios, and best practices for non structural/mitigation/adaptation methods so that informed decisions can be made. However, the window for learning about the threat and for appropriate responses is closing rapidly due to the escalating pace of increased risk.

In order to make informed decisions, communities need information on the likely impact of climate change and sea level rise on specific communities and the limitations of structural approaches to coastal protection, including high and recurring operation costs that may not be sustainable politically or otherwise. Without a realistic and overarching appreciation of the changes that are occurring, it may be that the protective actions that are taken have the effect of increasing risk. Constructions of elaborate levee systems are likely to encourage further investments behind those levees in homes and businesses that will be at risk when the levee systems fail. Coastal policies designed to confront rather than work with natural deltaic forces may send the wrong message to coastal residents, that it is safe to stay rather than continue the process of gradual retreat from the most vulnerable parts of the Louisiana coast.

Scientists concerned with human adaptation to change need to focus attention on issues of public policy and identify those parts of public policy that undermine the ability of coastal communities to have a voice in their futures, or result in investments that favor one set of actors over others. The role of scientists should be to clearly and honestly present information on climate, energy, ecosystem dynamics, human social system processes and large economic forces, that may make certain community resiliency options much more difficult, if not impossible, within current planning horizons. The role of scientists and policy planners is not be to tell communities what they must do, but to help them explore and implement risk-reducing options in as timely a manner as possible.

Cost of Restoration

Batker et al. (2014a) show that the cost of Mississippi delta restoration is high but so are the costs of no action. When coastal land disappears, the resources, the economic activities, and the communities that depend on it disappear as well. The ecology and economy of coastal Louisiana are at risk of being lost without changes in the way that the river and coastal wetlands are managed. The cost of delta protection and restoration has been debated for at least a decade, with estimates ranging from $ 14–150 billion. The Gulf Coast currently faces an annual expected loss of $ 14 billion if there is no action on restoration; losses are expected to increase in the future. The impact of the Mississippi River Delta is huge by conventional measures of employment and income. Economic activities related to the river account for nearly 2 million jobs and around $ 20 billion in annual income. The Gulf Coast is vulnerable to growing environmental risks today with $ 350+ billion of cumulative expected losses by 2030 due to hurricane damage that is directly related to wetland loss. In coastal Louisiana almost all economic activity is related directly or indirectly to the Mississippi River, its delta and the coastal wetlands of the Chenier Plain. The economic value of the Mississippi River Delta restoration can be documented through standard indices of economic activity such as GDP and jobs, and through the value of ecosystem goods and services. *Economic collapse on a large scale looms in the near future unless dramatic steps are taken to reverse the deterioration of the Mississippi River Delta.* Restoration of the delta is required to maintain its economic value. Batker et al. (2014b) estimate the value of ecosystem goods and services of the Mississippi delta to be at least $ 12–47 billion in benefits annually. Assuming this flow of services into the future, the delta's minimum capital asset value would be $ 330 billion to $ 1.3 trillion.

Between 80–90 % of Louisiana's economy, food, and quality of life is linked to coastal ecosystem goods and services. The economic health of the United States also depends on sustaining the navigation, flood control, energy production, and seafood production functions of the Mississippi Delta and river system, making Mississippi River Delta restoration critically important. These systems are at risk due to the degradation of coastal wetlands. The Mississippi River Delta ecosystems provide at least $ 12–47 billion in ecosystem goods and services benefits to the people of the United States every year. The economics are clear, an investment in costs to modernize the Mississippi River delta in ways that allow it to gain ground, and to sustain critical infrastructure far into the future is justified. A new emphasis on coastal restoration is required to maintain the economic vitality of this region.

Day and Moerscbaecher (2014) show that global climate change and increasing energy cost and scarcity pose significant threats to ecological and social systems of the coastal zone and to the restoration of the coast. In coming decades, these two factors will affect how much land can be built and maintained and dictate how sediment is delivered to the delta plain. They will also impact the ability of society to maintain navigation and flood control systems. In this section we review climate and energy issues and discuss their significance for coastal restoration.

Information on climate trends documented by atmospheric scientists when coupled with projections of energy cost indicate that the way the Mississippi River and delta are currently managed is not sustainable and that new approaches that involve less energy intensive approaches may be necessary. Maintaining the current flood control and navigation system is very energy intensive. Climate change will likely lead to accelerated sea-level rise, more intense hurricanes, highly variable flow of the Mississippi River with both more large floods and very low water years. As indicated in Chap. 5, the river is seeking a different outlet and preventing this will become more difficult and expensive in the future. If this is quickly recognized and addressed, however, it is likely that a sustainable trajectory can be achieved that will lead to a less ecologically destructive scheme for river management that also improves the long-term economic survivability of deep-draft navigation and protection from storms and the economy of south Louisiana in general. Such a trajectory can also lead to a more sustainable restoration of the coast.

Studies have projected that almost all deltaic wetlands will disappear by 2100 given current management and projected sea-level rise. But an aggressive restoration plan involving large-scale introduction of riverine sediments can offset these projected losses. New and re-engineered existing river diversions can be used with the Atchafalaya/Wax Lake deltas and Bonnet Carre Spillway serving as prototypes that can be improved upon. But management should factor in other already observed climate change effects in the Mississippi River watershed, including alternating severe floods and droughts. Finally, it will be necessary to come up with energy-efficient projects that require less fossil energy for operation and maintenance as possible so that performance is not hampered by energy scarcity or cost in the future. Increasing energy scarcity will likely make energy intensive activities such as building and maintaining levees, and pumping slurried sediments much more costly. This argues for river diversions rather than marsh creation via pipeline as a primary restoration device. Diversions take advantage of the natural energy of the River, particularly during high flow periods, to move sediment. Thus, they can operate effectively even if the price of energy goes up significantly. The more delta restoration and river management can depend on natural processes, the more cost-effective (from both economic and energy perspectives) restoration will be.

Because of escalating climate change impacts and increases in the cost of energy, time is of the essence in terms of jumpstarting a large-scale sediment-reintroduction restoration program. This evidence indicates that there will be a window of time in the next one to two decades when climate impacts and energy costs are still moderate. This is the time to put resources into improving existing diversions and building new ones.

Final Conclusions and Recommendations

This paper has reviewed a number of the pressing questions about coastal Louisiana restoration. While the challenges are technically, economically and socially complex, we believe there are solutions and that taking no action will result in a creeping disaster of continued land loss, disruption of major navigation operations, billions in economic losses and the degradation of one of the most ecologically important deltas in the world.

Although there has been a significant reduction in the sediment load to the Mississippi River Delta, there is a considerable amount of sediment remaining in the system. Redesigning river operations, including the use of diversions, while maintaining navigation could help restore fairly large areas of coastal Louisiana. It is also possible that the amount of sediment reaching the Delta will increase, as the area behind upstream sediment retention wing dams fills. Moreover, if climate results in drier condition over the Missouri basin, then we can expect that erosion will increase for drier soils. In the upper Mississippi and Ohio basins climates projections are for more precipitation and thus more water coming down carrying more sediments. In a future of energy scarcity, we will have to rely on gravity to move sediments to a greater extent.

Diversions are important for rebuilding and restoring the coast, but there are issues of scale and design and conflicts with other resources. Diversions will have to become larger and specifically designed to carry more sediment. Recent experience with Wax Lake, Big Mar, and West Bay show that new land can be rapidly built after a period of subaqueous development. The orientation of the conveyance channel connecting the river to the diversion outfall area should be designed to mimic the way that water would naturally flow as it leaves the river. At West Bay, for example, the conveyance channel initially constructed pointed upstream. As the channel evolved over time, the orientation shifted towards a downstream direction. Thus, it is clear that diversion size, outlet design, and location are important factors the design of diversions. Such considerations should be incorporated into future diversions.

Questions have been raised on the impact of nutrient impacts on wetlands by reducing belowground root growth and soil strength. The evidence supporting this idea is not conclusive and more study is needed. There are a number of documented case studies where river input has not led to marsh deterioration, such as in marshes around Atchafalaya Bay and Fourleague Bay. Wetlands in the Bonnet Carré Spillway and sediment deposition after the 1927 man-made crevasse at Caernarvon provide additional documentation of the impacts of large diversions. Also, coastal wetlands in the Mediterranean with strong riverine input are healthier and have high rates of accretion. Future diversion projects should strive to enhance mineral sediment input. It is unclear whether marsh loss at Caernarvon during Katrina, for example, was more a factor of a large area of fresh to low salinity marsh that are inherently less stable rather than due to nutrient enrichment. In addition, nutria have been shown to strongly graze enriched marshes and thus can have a much stronger impact on root biomass than direct nutrient effects. At any rate, future diversions should strive to introduce as much sediments as possible.

The impact of restoration activities on fisheries is complicated by the fact that fishing pressure itself is perhaps the dominant impact on the community of organisms that are fished. Fisheries productivity has been related to a number of factors, including nutrient loads, wetland area, shallow depths, tidal mixing, and primary productivity. A complicating factor is that the large wetland loss in the Mississippi delta has not led, at least not yet, to a decline in fisheries. It has been suggested that one of the things that maintains the fishery is the length of the land water interface, which increases with wetland loss, at least up to a point. If however, most of the delta wetlands disappear, there will likely be major impacts on fisheries. As delta marshes disappear, many of the species that support fisheries now (shrimp, crabs, oysters, and a number of nekton) may become less abundant while those dependent on a phytoplankton food chain, such as anchovies, may become more abundant. Large river diversions for restoration could shift the spatial distribution of fishery species but not the overall productivity of coastal Louisiana fisheries.

In order to be politically and economically viable, coastal restoration must accommodate navigation needs. It is increasingly obvious, however, that the current navigation system is unsustainable. Increasing flow lines with the same discharge and the potential for the river to seek new outlets well inland of the head of passes are indications that the system is no longer functioning in the manner intended. Dredging and other costs are increasing, and the results are less satisfactory. Thus, a change in navigation and flood control is inevitable regardless of what is done with restoration. The 80 year-old approach of the MR&T focusing almost solely on navigation and flood control is incompatible with delta restoration, and unsustainable in and of itself. Increasing flow lines with the same discharge and the potential for the river to seek new outlets well inland of the head of passes are indications that the system is no longer functioning in the manner intended. Costs are increasing to achieve fewer results. Opportunities exist for restoration, navigation, and flood control to be managed compatibly but the process of transition is not being anticipated. The transition can be planned and orderly, but taking no action regarding restoration will likely to lead to a sudden and catastrophic loss of navigation capacity.

Flood protection in the delta must focus on flooding threats from both the river and hurricanes. For decades, coastal Louisiana relied on the use of earthen levees in an attempt to protect developed areas from these threats. But the aftermath of Katrina showed that there are many places in the delta where earthen levees are impossible to build and maintain at elevations high enough to sustain urban communities. Pile-supported structures are an option but raise the cost by an order of magnitude, making widespread use infeasible for most small towns. The use of levees to protect against hurricanes is probably too expensive without the buffering effects of wetlands. The effects of stronger hurricanes, sea-level rise and increasing energy costs will further increase the costs of reliance on levees. Levees often enclose large areas of wetlands that are leading to their deterioration. With deterioration, surge can build up within leveed areas thus partially negating the protection provided by levees.

Historically people settled in the coastal zone to take advantage of the subsistence and employment opportunities related to the harvest of renewable and non-renewable resources. Over generations, a group of coastal communities with unique relationships to the wetlands have developed. However, for the last several decades residents have been moving away from the coast because of the disruption of these wetlands by human induced and natural processes. The environmental setting is increasingly tenuous. Coastal peoples are adjusting in several ways: relocating; staying in place with structural and non-structural adaptations; altering their spatial, physical and social processes; and by only periodically occupying the coast for the harvest of natural resources and for navigation. Further adaptations of the physical and social structures may be required to continue living along the coast as increasing climate change, land loss and energy costs bring additional challenges to coastal communities.

Restoration costs will be very high but the current economy is not sustainable without restoration in some form. In coastal Louisiana almost all economic activity is related directly or indirectly to the Mississippi River and delta. Restoration of the delta is required to maintain this economic activity because of the importance of the high ecosystem service values. It is likely that the structure of the economy and how it is carried out must change as the viability of coastal communities decreases. If proper planning is not in place, then the economy will be faced with a series of catastrophes that will make the economy unstable. Thus proper and aggressive planning is fundamental to maintaining the economy.

The economic health of coastal Louisiana is important to the economic health of U.S. Louisiana is vital for U.S. energy supplies, exports of agricultural commodities and coal, fisheries, and tourism. These are all threatened by coastal deterioration. The environmental infrastructure (ecosystem goods and services) supports these economic activities. It is likely that maintenance of the coastal economy and its role in the national economy will sometimes involve a shift from a place where people live to a place where they go to work and play.

Climate-change impacts are projected to become more severe in coming decades. Sea-level rise by 2100 has been projected at one meter or more. There will likely be more intense hurricanes. Climate change may also result in more large floods on the Mississippi River. At the same time, energy prices will likely rise significantly. Thus, while climate change will make coastal restoration more challenging, energy costs will limit options. These two factors will impact all of the activities discussed thus far in this paper. Planning for management and restoration needs to specifically incorporate these two factors.

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