The Once and Future Delta

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Abstract

Coastal Louisiana faces an extraordinary and unprecedented challenge: millions of people and a vast industrial infrastructure located in a disappearing landscape. The sea is re-occupying delta lobes and a coastal plain cut off from the river that built them. The decline is inexorable. Without systemic changes, coastal Louisiana, having already lost 1,900 square miles in less than a century, will disappear. Faced with this challenge, Louisiana's people are hampered by an inherent difficulty to comprehend how much the biophysical baseline has shifted. We lack an historic perspective, unaware of just how much more productive the system was and could be again. Many are engaged in a futile effort to hold onto what is doomed or put back what is already lost, rather than allow what could be: a vibrant new river management system that reignites the process that built the delta and its vast productivity in the first place. The key is unleashing the potential of the Mississippi River to build land. The challenge is to accept and adapt to the dislocations that river reintroduction will bring to navigation, fisheries, and coastal communities. The difficulty of adapting pales beside the catastrophe that waits if we do not.

Keywords

Mississippi River Delta • Shifting Baseline • Ignorance-based Worldview • Knowledge-based Worldview • Louisiana's Comprehensive Master Plan

> *It seems that the time is ripe for an enormous development of the Louisiana wet lands along new and intelligent lines, the ideal conditions to be demonstrated by observation and research, and that this development should be included in a broad program of conservation which has for its object the restoration of those conditions best suited to an abundant marsh and swamp fauna, but under some degree of control at all times.*
>
> Percy Viosca, Jr. 1928

The Baseline

Southeast Louisiana is a delta. It is a place built by sediments transported by the Mississippi River and deposited into the shallow, nearshore Gulf of Mexico and coastal bays. Since the end of the last Ice Age, land steadily emerged above the water and was colonized by plants and animals (Blum and Roberts 2012). To these sediments from the river, biological processes added organic material, mollusks built shell reefs, and marine processes redistributed sands, silts, clays, shell and organic matter. Fundamentally, this is what is known—the physical baseline. Careful study, monitoring and modeling of contemporary alluvial and marine processes, as well as examination of the sedimentary, archeological, and written record, provides us with reasonable hypotheses for explaining how these processes took place. But the indisputable tangible record we have is the physical delta, built by the interaction of the river and the sea.

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It is now abundantly clear that we live in a diminished, unsustainable delta. Just as importantly, we live in a delta that diminished at an accelerating pace throughout much of the last century because of measurable anthropogenic actions, including canal and channel dredging, confining the passes within jetties, levee building, drainage and subsurface fluid withdrawal (Day et al. 2007). While there is evidence the pace has slowed (Couvillion et al. 2011), it is likely to accelerate again if sea level rise accelerates.

Can we stop the decline? Can we pick a baseline to hold to or a restoration goal to return to and then find enough money to get us there and hold to it? Is that really what we *should* do? Or should we begin again, using the maximum resources of the river to build a new delta and hold onto whatever we can of the old?

Causes of land loss and potential responses are many. But, in the end, there is a single solution *known to have built an ecologically functional delta*: alluvial deposition by the Mississippi River (Davis 2000). Since the end of the Pleistocene the river has deposited an estimated 2,790–3,450 billion t of sediment in the former valley and on the shelf, or about 230–290 million t per year (Blum and Roberts 2009). The average depth of the delta, measured to the older Pleistocene surface ranges from less than 10 m in far upstream reaches to greater than 100 m in depth in the Bird's Foot delta (Blum and Roberts 2012; Kulp 2000). Looked at three dimensionally, from Cairo, Illinois to the edge of the Continental Shelf and the cusp of the Mississippi Canyon, the river has built a formidable land mass since sea level reached its present stand about 7,000 years ago. And the Holocene sits atop countless layers of sediment laid down by proto-Mississippi Rivers since the Jurassic, 145 million years ago. The modern delta is perched atop a sedimentary wedge that increases to more than 4,000 m in thickness at the shelf margin (Blum and Roberts 2012; Woodbury et al. 1974).

A Shifting Baseline

The diminished delta is now the subject of a concerted effort to do something to fix it. Unfortunately, in making political, economic, social and scientific decisions today about how to respond to that diminishment, we suffer from the fact that we are victims of a shifting experiential baseline—our expectations start low and get lower. No one alive today remembers a healthy, natural delta. We have been living in a sick, steadily declining delta for so long that unfortunately many believe that the delta they remember was truly healthy, rather than just less sick. Indeed, many believe that the parts of the delta today that are the most stable constitute a healthy delta. They are wrong. The baseline keeps shifting downward. Now it is shifting so rapidly that one can watch marsh disappear over the course of a few annual fishing trips. Over the course of a decade we watch the view change dramatically from marsh to open water, from swamp to marsh, from forested ridge to dead trunks standing in the scrub. The maps in our GPS devices are outdated before we first turn them on. We cruise in our boats serenely through 5 ft of water where our GPS insists there are marshes. We no longer fail to notice the shift. But we do forget that we ourselves began in a place that was far, far below where it started.

A failure to understand the implications of the rapidly shifting biophysical baseline for the Mississippi River delta has profound implications for political actions going forward. Tremendous energy is devoted to trying, fruitlessly thus far, to hold on to what remains, rather than to allow what could be. Much of the rapidly disappearing delta is in its *final* evolutionary phase. Lacking sedimentary inputs, subsiding mineral soils are now overlain by low strength organic peat soils. Marshes growing in these peat soils break free from the mineral platform and have become floating or semi-floating. Their weakened surface is breaking apart, and the length of edge exposed to erosion is increasing exponentially. The balance between land and water is tipping to the final stage of the delta life cycle—re-occupation by the sea.

A similar process is taking place on the barrier islands and headlands. As the inside marsh disappears, the volume of water that must complete each tidal cycle requires larger and larger passes through the sandy barriers, shrinking the size of the islands and headlands. The feedback loop is inexorable, land area decreases, and the bays and passes expand. Eventually the remnants of the barrier system become stranded islets, playing little further role in system hydrology, as we see today in the Chandeleur and Derniere island chains. Prior to the construction of jetties and the closing of distributaries, the barrier island cycle was driven by the delta lobe cycle. Delta front sands (those deposited at the mouths of the distributary channels) provided the material for new barrier islands. Today, barrier islands are deteriorating because sand delivery by the river has dropped by half and most of what does reach the delta is lost to deep water rather then set adrift in the littoral zone.

Added to this erosive process is relative sea level rise, steadily taxing the resiliency of a sediment starved system. Soil formation cannot keep up, even in seemingly healthy brackish marshes, absent new sedimentary inputs. Increasingly organic soils lack structural resistance to daily erosive forces, and are prone to catastrophic collapse in response to perturbations (Howes et al. 2010). These perturbations may result from both systemic changes, such as changes in hydrology or nutrient input as a result of riverine introductions, or from high energy weather events, such as hurricanes, or from combinations of systemic and episodic events. These effects are cumulative in the majority of the delta, because most of the delta no longer has the capacity to repair itself. Freshwater vegetation growing in an active delta lobe can be stripped by waves or burned by saltwater during a tropical cyclone, but recovery on the surviving mineral soil platform is rapid. The effects in the delta's end stage marshes, where tearing reaches deep into the organic soils, are long lasting, and often permanent (Morton and Barras 2011).

Meanwhile, much of the structural underpinning of the delta, the sediment load of the river, is unavailable. The nexus between ocean going commerce and the nation's largest port system along the lower river is Southwest Pass, in the Bird's Foot. Channel training to maintain this deep draft navigation system shunts much of the sediment that reaches that point to near the edge of the continental shelf, where it eventually sinks into the abyss. And less sediment reaches the delta, a consequence of dam and lock construction, primarily on the Missouri and Upper Mississippi (Meade and Moody 2010).

Most federal and state effort to date has been expended in trying to patch deteriorating brackish marsh and the barrier system, rather than to address the underlying deficit—which is the loss of deltaic function. This is the natural response for us as victims of a shifting baseline to adopt—attempt to hold on to what is known, rather than imagine what could be. To understand what could be, we need to understand just how much has truly been lost. We cannot grasp that by using contemporary conditions, even as measured over a century past, as the real baseline.

The age groups from which decision makers are drawn today, those who are roughly 35–70 years of age, are old enough to have experienced vicariously the coast their parents and grandparents knew from the early twentieth century. Most land along the "the bayou"–natural levees along the river and abandoned distributaries below New Orleans—was used for agriculture: an economic circumstance that would be unimaginable today. When flying over the delta today we can see the field lines of those farms and plantations, now so submerged that marshes grow where food was raised. Or, if presently not inundated because of forced drainage, these once productive farm fields and orchards have become pasture or subdivisions, below sea level. Rainfall inundation, high water tables, saltwater intrusion in the water table and in surface water, plus frequent tidal and occasional storm surge inundation render the agriculture remaining increasingly unproductive. Where agriculture in the coastal zone under forced drainage failed, rectangular lakes now dot the delta.

But even using the coast that our early twentieth century ancestors knew as a baseline is a mistake. The baseline had been shifting downward at that point for 200 years. Our parents and grandparents were aware that they had seen the end of an era—the slaughter of any wild terrestrial creature that could be marketed or that preyed upon other marketable wildlife: ducks, geese, herons, egrets, the last of the Louisiana whooping cranes, beaver, white-tailed deer, red wolves, black bears and panthers. They saw the early but very noticeable effects of roads, levees, and canals, driven by the pressure of population growth. Despite these signs, they overwhelmingly shared the belief that the highest and best use of any place was to tame it for human use. Though they could no longer find the abundance they once knew, they believed it had been sacrificed for a higher good—to tame the landscape for human settlement and commerce. Yet the memory of their diminished landscape now seems idyllic to us, their heirs.

We need to go back even further. The ecologically rich coast experienced in the early twentieth century pales in comparison to the delta that arriving Americans experienced a century before. One March day in 1821 John James Audubon walked to the outskirts of New Orleans and witnessed about 200 gunners bring down (he estimated) 48,000 American golden plovers in a matter of hours. Near Audubon, one hunter alone killed 63 dozen (Audubon 1929). To put that into some kind of perspective, southeast Louisiana today is well east of the main spring migration corridor for this species, and presumably was then. An avid field observer today in southeast Louisiana would be fortunate to see a dozen golden plovers in a day, and a 100 in a season, as they migrated north on their journey from Patagonia to the Arctic. Using the most generous population estimate today of American golden plover, that one afternoon's kill represents 1 % of today's 5 million total world population (Byrkjedal and Thompson 1998). Yet Audubon witnessed 48,000 plovers shot in 1 day. The plovers are a proxy for any number of species for which we have no data from that period. But it is one of many reminders of how much lower our baseline has become.

Audubon, in the delta almost two centuries ago, was witness to the beginning of the end—even he did not get to see what the first wave of Europeans 100 years before had seen. The explorers and colonists of the early eighteenth century left a frustratingly incomplete descriptive record of what they experienced in the early delta. But it is clear that they encountered a place of remarkable fecundity. It is astonishing to consider, for instance, bison living then in a landscape where today there is open water, or if still marsh today, the footing is poor or impossible for humans. Yet that is what the French encountered—herds of bison in the marshes, on both sides of the river, from a few miles above Head of Passes to the swamps below the future site of New Orleans (Campanella 2008). Early French accounts mention Indians living in New Orleans who had fish traps that supplied so much fish that little effort was involved in a families' subsistence (Penicaut 1953). Le Page du Pratz, on his first voyage by canoe upriver in the early 1720s, ran out of powder shooting alligators and other wildlife on the bank between New Orleans and Baton Rouge. He was obliged to stop and obtain more from a settler, and was thereafter careful to shoot only game for the larder (du Pratz 1774). A century later, a passenger on a ship passing the Balize noted alligators so thick along the banks of the river and in the marshes that the roar of bulls calling "had a singular effect as it rose above the breeze" (Benwell 1857). The bison and much of the game

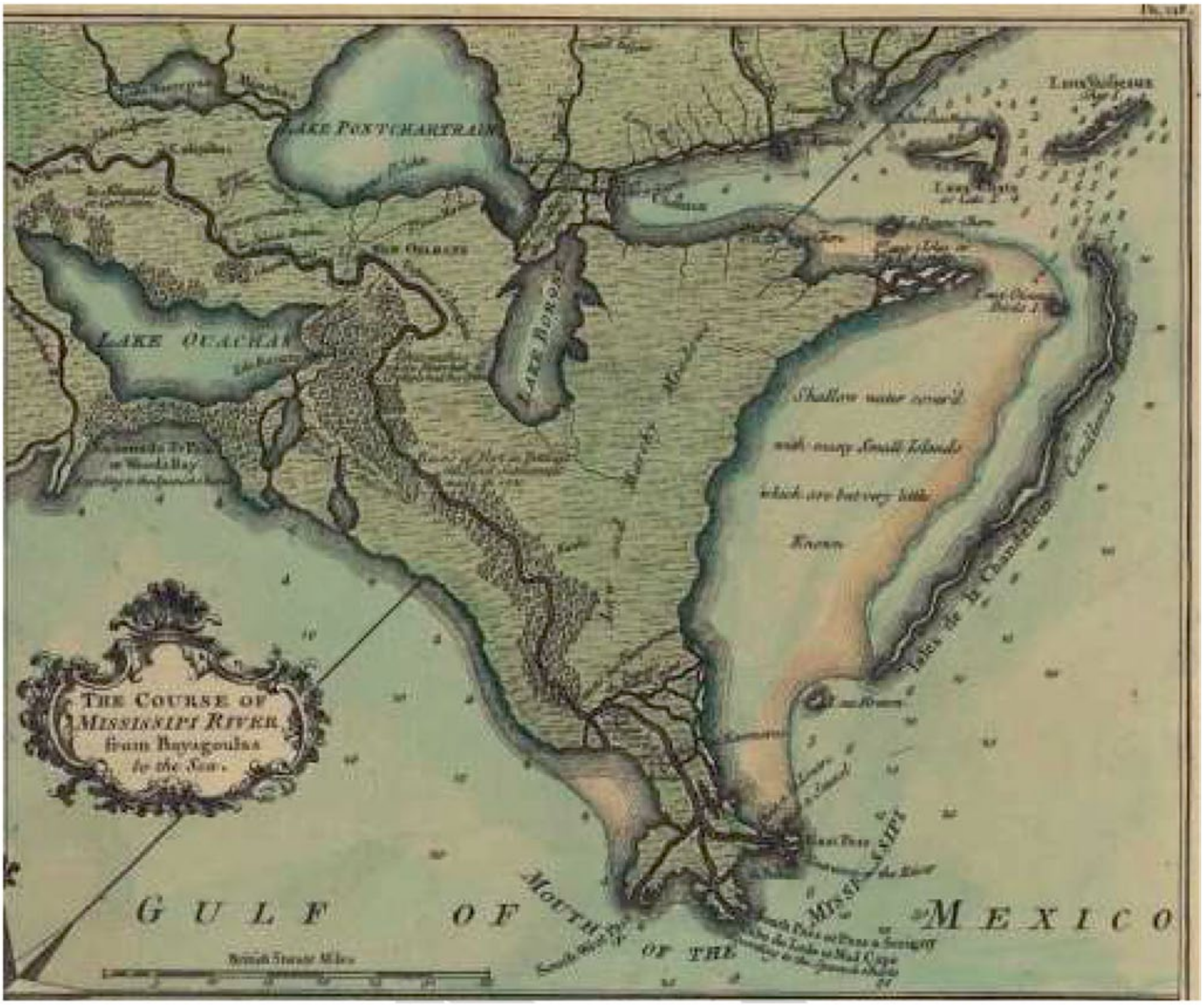

Fig. 1 The delta of the Mississippi River as depicted by Pierre Le Blonde de la Tour's survey of 1720. Lake Ouachas is Barataria Bay, Bayou Lafourche is just to its west

was gone by Audubon's time. And already by Audubon's time much of the lower river had been lined with levees, beginning the slow starvation of the delta.

The Anthropocene in the Mississippi River Delta

When France began its colonization of Louisiana in 1699, the delta covered approximately 15,000 km², with a half dozen or so major distributary channels: the Atchafalaya, Bayou Plaquemines, Bayou Manchac, Bayou Lafourche, Pass á Loutré, South Pass, and Southwest Pass. In many years the river rose and overflowed its banks to varying depths depending upon the height of the flood. During these periods of overbank flow numerous former distributaries presumably helped carry flood waters far from the main stem. The distributaries nourished virtually the entire delta with a range of freshwater and sediment inputs, which in turn mixed with seawater from the gulf to create the entire panoply of deltaic and estuarine ecosystems. Occasionally the river broke through its own confining natural levees, creating land-building *crevasses* that might flow for a season, for a decade, or might become long-lived distributaries, building new delta lobes (Fig. 1).

The French encountered two main active arms of the river, forking at present day Donaldsonville. Bayou Lafourche carried a small percentage of the flow southeast, but was navigable year round. The main stem swept broadly east past present day New Orleans, then southeast to the

Fig. 2 Terrebonne Parish, Louisiana as mapped in 1831 (Finley). Though not highly accurate, the small size of Timbalier (Tunballlier) Bay and the depiction of marsh occupying much of what is now Terrebonne Bay, indicate a landscape in which marsh dominated. Ship Island is depicted where today Ship Shoal is 12 ft deep

Bird's-foot. Each of these in turn forked into smaller active and intermittent distributary arms. To the west, the Atchafalaya, which emerged from the tangled confluence of the Red and Mississippi rivers, and Bayou Plaquemine, along with distributaries from Bayou Lafourche, like Bayou Terrebonne and its many forks, flowing towards Grand River, kept the Atchafalaya mouth fresh. As a result, there were three large areas of the delta near the gulf shoreline that were kept fresh by continuous riverine inputs: the Bird's Foot, the Lafourche delta, and the areas fed by Grand River and the Atchafalaya. In addition, smaller distributaries, crevasses, and spring overbank flooding provided steady input of river water into the vast swamps present in the upper estuarine basins—Pontchartrain—Breton (east of the main stem), Barataria (west of the main stem to the Bayou Lafourche natural levee), and Terrebonne-Atchafalaya. The river overflowed into swamps along the fringes of all of the distributary channels. From the swamps, river water filtered gulfward through freshwater marshes into pockets of brackish marsh. On the fringes of the most open bays and backs of the barrier island, saline marsh grew. Near the barrier islands and headlands, in the gulf and in the passes and bay openings—vast vertical oyster reefs grew in the brackish outflow from the estuaries, often extending miles into the Gulf. These shelf reefs formed a band from west of Vermillion Bay to Terrebonne Bay (see Chap. 4). They indicate that the ideal salinity range for oysters west of Bayou Lafourche, now found deep in the interior of the bays, used to be offshore (Fig. 2). To the east of the river, oysters occupied vast reefs in the open sounds.

European colonists, as they did everywhere they settled, set about trying to make the landscape look more like Europe. The fledgling settlement at New Orleans, laid out in 1718, had thrown up its first river levee by 1721. It became a requirement of French and later Spanish land grants that the grantees build and maintain levees along the river and its distributaries, beginning in 1722 (Smith et al. 2012). As the crown granted land in consecutive parcels near New Orleans, the man-made levee system emerged on both banks of the river, above and below the city (Fig. 3).

The man-made levee system protected the high, fertile natural levees from annual overbank flooding. Clearing for agriculture proceeded rapidly. By the time of the Louisiana Purchase in 1803 settlers had cleared the natural levees of the Mississippi from Baton Rouge to Head of Passes, and land grants indicate landowner-maintained river levees had been thrown up along the entire length (see USGS Topographical Maps). These levees failed frequently during river floods, leading to a period of less frequent but more catastrophic crevasses. The delta, though not experiencing riverine inputs during every flood, was nevertheless continuously replenished because the levee system was only as strong as its weakest, often feeble, links—plantation owner-maintained levees. And after each break, levees were rebuilt,

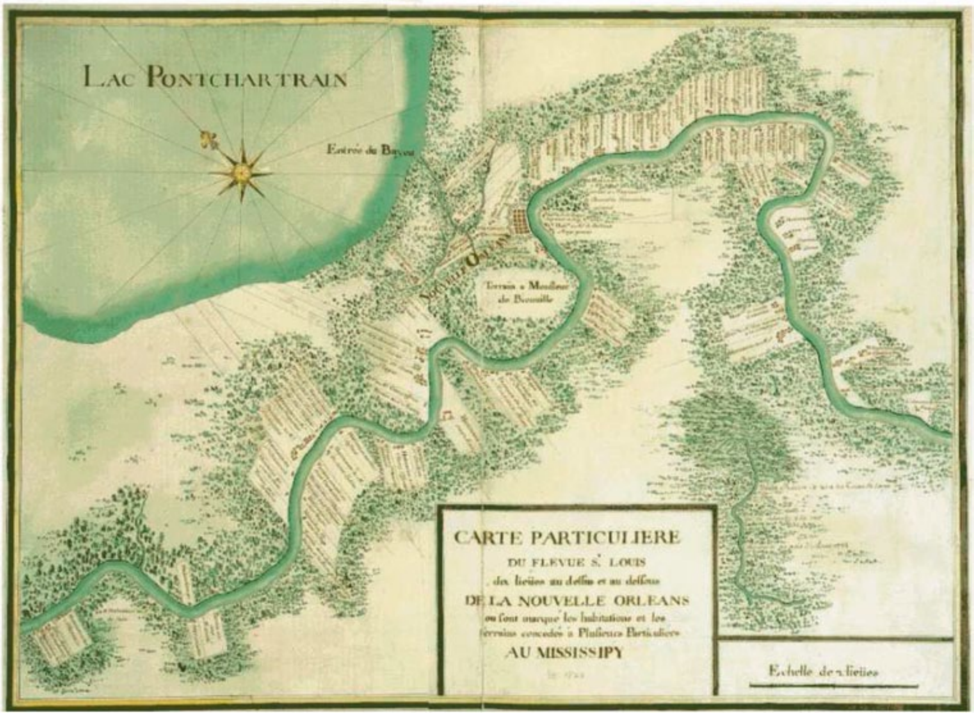

Fig. 3 Map of plantations in the New Orleans area, circa 1723. Land grants are arranged parallel to each other on the high forested natural levee, perpendicular to the river. Grantees were required to maintain an artificial levee and road along the river. Photo courtesy of The Newberry Library, Chicago. Call # Ayer MS Map 30, Sheet 80

often to improved specifications. The political and organizational response increased more or less steadily (except for a long period of decline during and after the Civil War). The frequency of system failures decreased, but the intensity of failures increased, building to the great flood of 1927.

At the same time as levee improvements were built, the many distributary channels were cut off from river flow, one by one. There are no records of the earliest closures. Presumably the intermittent distributaries like Bayou Metairie-Gentilly-Sauvage, Bayou des Familles-Barataria, Bayou Terre aux Bouefs-La Loutre, River aux Chene (east Plaquemines Parish), and Grand Bayou (west Plaquemines Parish), those that had been naturally abandoned by the main channel but presumably re-occupied in flood years, were leveed off from river overflow by individual landowners. The permanent distributaries followed: Bayou Plaquemines—1770; Bayou Manchac—1826; and in the period 1902–1904, Bayou Lafourche, the last and largest of them below Baton Rouge, was dammed (Doyle 1972). A final flurry of catastrophic crevasses during the great flood of 1927—including one created by dynamite at Caernarvon below New Orleans, led to Federal action. The Corps built a levee and spillway system that have effectively confined the river, cutting it off from two-thirds of its delta, for 80 years (Fig. 4).

In the meantime the land building capabilities of the river in the Bird's Foot were severely compromised by improvements to the navigation channels. Eventually, channel training of today's two main navigation passes, South and later Southwest, brought the channel mouths to the edge of the shelf. The effect has been to starve the rapidly subsiding Bird's Foot, perched 15 miles beyond the flanking headlands, of sustaining sediment (Blum and Roberts 2009).

Change in Worldview

Beginning with the Swamp and Overflowed Lands Act of 1849, the official policy of government at all levels (federal, state and local) in Louisiana (and nationwide) was that wetlands, including those of the delta, could and should be drained for economic use. Certainly, later national movements did lead to the establishment of small areas (refuges, parks, and wildlife management areas) to be preserved as *refugia* for ducks and other wetland dependent fauna deemed important. But it was not until the passage of landmark federal legislation including the National Environmental Policy Act (1969), the Coastal Zone Management Act (1972) and the Clean Water Act (1974), that the official support for wetland destruction began to wane.

Note that there was not just an official indifference to the fate of wetlands, as when government allowed oil companies to dredge canals. Rather, government at all levels used incentives and infrastructure development to encourage conversion of delta wetlands for settlement, agriculture and commerce. In Louisiana this included levees, drainage infrastructure, navigation canals and road building. Evidence of this can be found on interstate clover leafs that dead end in marsh in eastern Orleans Parish. During the period leading up to the shift in policy, a small minority of voices, scientists, conservationists, newly named "environmentalists", and key wetland resource

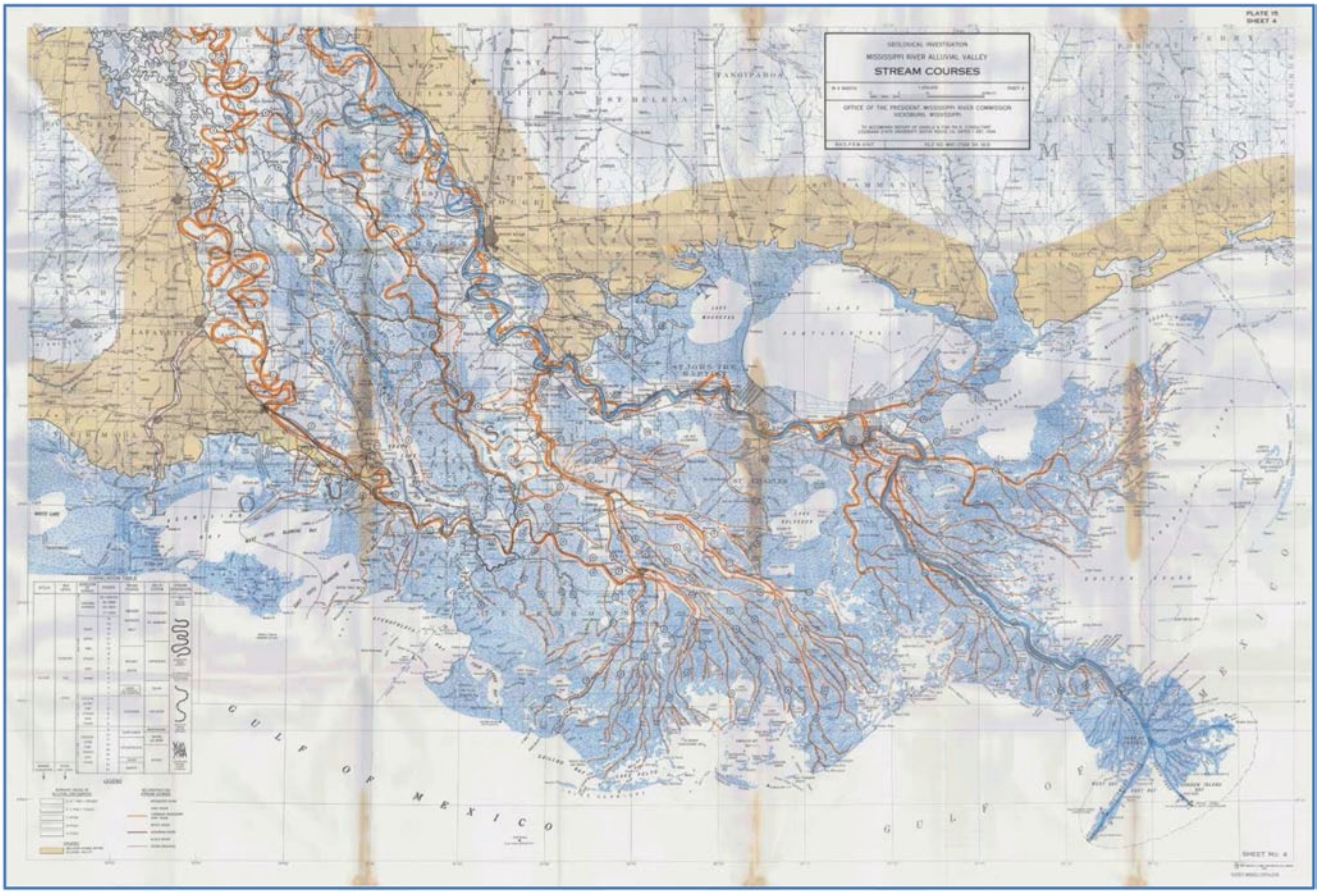

Fig. 4 Distributary courses of the Mississippi River as depicted by Fisk, 1944. Many but not all of these were still connected to the river when the French arrived to found the colony of Louisiana. Courtesy of the Mississippi River Commission

users—most notably oyster harvesters, began to raise the alarm about rapid land loss and conversion of wetlands in the delta.

It is instructive to recall that local parishes in the delta had official plans for draining most or all of their wetlands, and in some cases for draining coastal bays. Conceptually if not actually, the Dutch model was the underpinning of this way of viewing estuaries as a place to "reclaim" the land for commerce. These plans were rarely abandoned or repudiated, but were quietly superseded as the regulatory, economic and social landscape changed in the period 1980–2000. The evolution of a serious commitment to more than just paying lip service to wetland protection by state or local governments, some federal agencies, and elected representatives in Congress, took about 3–4 decades. Even when the rhetoric shifted towards environmental pieties, official actions rarely coincided, and deltaic wetlands continued to be treated as expendable nuisances. Perhaps more than anything else, measurable and predictable socio-economic costs, rather than ecosystem losses, have been the driving force behind the emerging consensus in favor of restoration.

The socio-economic future for delta communities and businesses is grim. Using only the loss rate of the past 50 years projected forward over the next 50 years, about 1,746 km^2 will be lost to erosion and subsidence (Barras et al. 2003). If moderate projections for relative sea level rise (1–1.5 m over the next century (Meehl et al. 2007)) are accurate, the current surface of the delta as a whole (10,000 and 13,000 km^2) will be inundated by 2100 (Blum and Roberts 2009). The only land left will be areas more than 1–1.5 m above mean sea level (msl), or areas behind structural flood-proofing: levees, seawalls and floodgates. Of course, the supposition that such "protected" areas might survive the loss of all fringing wetlands is conjectural, if not highly unlikely. It is entirely contingent upon the exigencies of future hurricanes, rate of sea level rise, and the level of infrastructure investment maintained over time. Increasing energy costs will likely make such systems unaffordable in the relatively near future. Thus, it is more likely that such protection will fail, as it did in Hurricane Katrina, and, unlike after Katrina, neither the money nor the national consensus will be found to rebuild it.

Despite these clear and devastating trends, everything about the delta and why it is disappearing and the potential efficacy of proposed solutions remains to varying degrees uncertain. The *relative* contributions of the various documented causes are uncertain: sea level rise; climate change; compaction of sediments; fluid withdrawal for oil and gas; fluid withdrawal for drainage; movement on geologic faults; effect of fluid withdrawal on pre-existing faults; dredging canals; saltwater intrusion; canal spoil banks; sheet flow interruption; nutrient starvation; nutrient overload; closing distributaries; preventing crevasses; blocking spring overflow with river levees; hurricane protection levees; clearing for agriculture, logging, urban, suburban and industrial development; channeling and concentrating upland runoff through pumping stations and outfall canals; point and non-point source water pollution; air pollution; exotic species; herbivory; jetties that interrupt near-shore sand transport; dredging the tidal passes for navigation; and shunting river sediment through navigation channels to the edge of the shelf. Causes abound.

Proposed solutions abound: nourish the barrier islands and headlands with sediment pumped from offshore, or from the river, or from distant shoals; build dunes; install sand-fencing; plant dune vegetation; narrow the tidal passes; divert freshwater from the river to block saltwater intrusion; stop freshwater diversion to prevent freshening of brackish marsh; move sediment from the river through pulsed diversions; re-plumb the deepwater navigation channel in the river to prevent loss of freshwater and sediment at the navigation passes; build new distributaries; re-open old distributaries; build new marsh with pumped sediments; dredge and pump sediment from the river through pipelines; require beneficial use of dredged sediment; transport sediment through long distance pipelines; nourish declining marsh or swamp with pumped sediment or with water and nutrients; deepen bays, lakes, bayous and canals by dredging and pump sediment into surrounding marsh; deny wetland development permits; require mitigation; allow more flow down the Atchafalaya; allow less flow down the Atchafalaya; remove or breach spillway guide levees; build more spillways; keeps spillways open; rebuild vertical oyster reefs; protect retreating shoreline with hard structures, or with soft structures; nourish swamps and marshes with treated sewage or with storm-water run-off; re-establish sheet-flow by degrading spoil-banks; back-fill canals; plug canals but leave spoil-banks in place; control exotics; control herbivory; remove jetties; build jetties parallel to shore; close passes with hard structures; reform agriculture to control nutrient inputs; control point source pollution from urban areas and industry; increase sediment availability in the lower river by finding ways to bypass dams and locks upstream; and fight climate change.

With this wide array of proposed causes and solutions, much of it contradictory, it is incumbent upon us to get to the heart of the ailment and seek to cure it. *The heart of the problem is anthropogenic interference in the physical functions of the delta.* The most obvious but most radical of proposed solutions involves diverting most or all of the river back into its delta. Diversions of a substantial portion of river flow promise to fundamentally alter the hydrology and salinity of the receiving estuaries. This will change water levels, change plant communities, and change the location and population of several species important to the seafood industry.

Primum Non Nocere

Disagreement over the nature of the problem, its seriousness, and the level of response needed, has led to a deep division over the efficacy of these so-called "diversions". In the 1960s, Congress, responding to petitions from the oyster industry and the states of Louisiana and Mississippi, authorized the Corps of Engineers to build freshwater diversions to restore optimal salinities for oyster production in the Pontchartrain, Breton, and Barataria basins, as well as in neighboring Mississippi Sound. The proposed diversions were insignificant—at between 8 and 15,000 cfs each; they would have amounted in aggregate to less than 5 % of the average spring flow of the river. But for marshes that had been becoming more saline for 250 years, even these small flows were capable of profound effects. In the end, the Corps built two. A diversion at Caernarvon into the Breton Estuary with peak flow of about 8,500 cfs opened in 1991, and another at Davis Pond into the Barataria Estuary with peak flow of 10,600 cfs opened in 2001.

Controversy erupted. Even in the decades between authorization and construction, both estuaries had undergone profound changes. Oyster beds had shifted inland—in many cases placed by oyster farmers on the platforms of marsh that had eroded away. The brown shrimp harvest had moved inland as well, as had the popular recreational fishery for speckled trout. Opening the diversions caused dislocations for all three species. Ironically, the evidence is strong that total productivity in the Caernarvon influence area for all three species is improving or un-affected; only the location of harvestable quantities has shifted (de Mutsert et al. 2012).

The two freshwater diversions grew in importance all out of proportion to their intent or design. Their purpose was to allow state fisheries managers to manipulate salinities to optimize oyster production. But as they sat on the drawing board, the extent of the coastal crisis became clear to all. The freshwater diversion idea was seized upon as one of the few tangible actions the Corps was authorized and funded to take that could help. Many believed that the diversions could actually help slow or even reverse marsh loss, because saltwater intrusion through navigation and oil and gas canals was thought to be the principle cause of marsh loss. The rhetorical enthusiasm for the diversions painted a naively optimistic vision for them in the minds of people desperate for a solution.

But they were not originally designed for nor intended to build land. In fact, the Corps designed them to *minimize* sediment transport from the river. The goal was fresh water—sediment would just clog the receiving water bodies and lead to ongoing maintenance costs. Nevertheless, new land is being built in both of the diversion receiving areas—in Big Mar at Caernarvon, and in the Davis Pond ponding area. Ironically, though, the fact that these non-sediment diversions may not be resulting in overall net land gain in the entire downstream estuarine basin has been repeatedly touted as proof that sediment diversions do not work, or will not work quickly enough.

In addition, some scientists have concluded that marsh losses in the receiving basins were caused by the diversions. That is, they contend that changes in hydrology and chemistry actually led to marsh loss. This contention is debatable. There is scientific evidence for and against it, with proponents and opponents, as well as those researchers who remain neutral (Teal et al. 2012). But that contention, along with the fact that low-sediment freshwater diversions can't outpace land loss in receiving basins, has been seized upon by political opponents of future diversions.

Diversion opponents contend that these supposed failed diversions argue against using diversions for restoration. They implore that we do nothing in restoration beyond what we have tested and know to work. We are exhorted to "first, do no harm." This aphorism has been invoked to question the efficacy of large scale river diversions, because, it is argued, to build a large diversion is to *do* something that we haven't done and haven't tested. Further, because modern river water diverted by existing micro-scale[1] freshwater diversions, polluted with agricultural run-off, *may* have caused deterioration in *some* existing marsh types, this *doing* is seen as a potential harm—an unwise action.

The axiom, *primum non nocere*, "first, do no harm," borrowed from medicine, cautions physicians to refrain from intervention for intervention's sake, or intervention that risks greater harm—to first observe and discover whether nature, as it runs its course, might lead to recovery, or, at least, a better death. But the aphorism is inapt in this case. The delta is near death *because the physician has already done the harm*, and there is no future for the delta without intervention. The marshes that may or may not be harmed by modern river water are already moribund, disappearing at alarming rates, and cannot survive over the next 50 years without fundamental changes in the system or a complete cessation of relative sea level rise (Blum and Roberts 2009).

In light of this reality, the only reasonable and justifiable intervention is to undo what we have already done, to unleash the river from the strictures we have placed upon it and let it have the freedom to recover its delta. We need to remove the tourniquet that a previous physician placed around the neck of the patient. In the known geophysical equation, not only can this not be construed as *harm*, it would be to do, in contrast to the errant physician who applied the tourniquet, nothing at all.

Ignorance-Based Versus Knowledge-Based World Views

Another argument has been made that we should adopt a scientifically defensible "Ignorance-based World View" (IBWV) when it comes to restoration of Mississippi River delta, as opposed to a "Knowledge-based World View" (KBWV). In this case, it is argued, a KBWV assumes facts not in evidence, i.e. that we know how to restore a delta. This argument has been advanced in opposition to building diversions that allow the Mississippi River to flow back through its delta (Turner 2009). Again, this argument against diversion is backward. We may in fact be ignorant of what is needed for humans to *restore* a delta. But we are not ignorant about what nature needs to *build* a delta. Nature needs freedom from anthropogenic constraints.

To adopt an authentic IBWV would require us to forswear all anthropogenic intervention, anything based upon the KBWV adopted by the French who built levees, closed distributaries and tried to open the bar, which has evolved and guided anthropogenic management of the river in its delta for almost 300 years. An IBWV would teach us to reject the entirety of the KBWV that has led us to this disastrous result. It would require, in other words, undoing anthropogenic changes to the system and allowing the river to return to its delta. A management scheme that concedes our fundamental ignorance requires us to divert the river back into the delta.

Let the river build a new delta. What could be more fundamental? All we really know is that the Mississippi River built and sustained the delta until the French arrived and began tinkering with it. The rest is guesswork based upon inadequate science—inadequate by its very nature because the one dispositive data set can only be obtained by running the experiment again.

Impediments to System Restoration

The three leading socio-political impediments to restoration of delta function each involve key aspects of contemporary life in the delta. The first is resistance to changing the fundamental structure of the deep draft navigation system at the mouth of the river, which has been in place since 1879. The second is the resistance to actions which will displace key commercially important estuarine organisms, primarily speckled trout, brown shrimp, and eastern oysters. Finally,

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[1] Less than 2 % of flow.

and most importantly, is coping with changes to water level that will affect communities physically located within the delta's marshes and swamps.

Deep Draft Navigation

The Mississippi is a relatively deep river with little shoaling of the main channel. Once in the river, ships in the eighteenth and nineteenth centuries were able to reach New Orleans (as long as they could find the channel, and [before steam] had sufficient wind). The mouths, however, were a different matter. Where the river emptied into the gulf, a sand bar formed. This was caused by the slowing current in a river having reached sea level and its release from the confining channel. Mariners were faced with a continuous, nagging problem—deep water in the gulf, deep water in the river channel, but the stubborn bar in between. Throughout the eighteenth and nineteenth centuries various temporary fixes were attempted. But an effective solution awaited the construction of the jetty system, completed at South Pass in 1879. The jetties worked much like a nozzle—constricting the flow to increase water pressure at the opening. The stream of water directed by the jetty nozzle scoured a channel through the bar.

Of course, no solution is perfect. Eventually enough sand accumulated beyond the mouth of the jetties to build a new bar. The response was to extend the jetties each time this happened. Eventually, the Corps extended the jetties in South and Southwest passes until they perched on the edge of the slope of the Continental Shelf. The sand bar that formed was in deep enough water so as not to impede navigation. Indeed, on the unstable slope, the bar tended to slough down towards the abyssal plain beyond the shelf, lost to the delta completely. (As do, of course, the rock jetties. The heavy rocks sink relatively rapidly through the poorly consolidated bar deposits, requiring constant layers of new rock.)

Navigation is now wed to this primitive arrangement. Ocean going ships moving commodities (mostly grain and petro-chemicals) in and out of the gulf have access to the largest port system (by volume) in the world, extending 230 miles upriver to Baton Rouge. Navigation interests are understandably leery of any change to the lower river that might negatively affect the rather delicate equilibrium required for the jetty system to work.

But the current system is not without performance issues. Ocean-going vessels have grown steadily larger, requiring deeper draft, over the last 130 years. Southwest Pass, now the one chosen by the Corps of Engineers to maintain for ocean going ships (to a depth of 45 ft), is not naturally that deep, and can't be maintained to that depth by jetties alone. The 19.5 mile long channel has to be continuously dredged—a cost born by taxpayers, that has been steadily rising. It is rising because of the inexorable increase in the cost of fuel, which outpaces inflation because demand is outpacing supply as population grows and the third world develops. But it has also been rising because of changes to the hydrological functioning of the Bird's Foot delta. Passes and small crevasses between Head of Passes and the downstream end of the river levees (Grand Pass, Baptiste Collette, etc.) are gradually capturing a higher percentage of the flow (Allison et al. 2012). As sea level has risen, the point at which gravity overcomes inertia has also crept upstream (Roberts et al. 2012). This is changing the amount and distribution of the sediment that clogs the navigation channel, and increasing the cost to the taxpayers of annual maintenance.

More ominously, a major course change becomes increasingly more likely as the hydrology changes. One of the growing passes upstream of Head of Passes could undergo rapid channel expansion during a major flood, leaving insufficient flow in Southwest Pass to keep it open to 45 ft. Such a course change would have dramatic and expensive effects on the ability of the ports to function, disrupting the world's economy.

Reliance on this nineteenth century system has other future costs. The Panama Canal is being expanded, and will by 2014 be able to handle ships that need a 55 ft draft (Lagrange 2011). If the ports of the lower Mississippi cannot be reached by such ships, they will lose traffic as the world's fleets switch over to vessels needing a 55 ft channel. Given the difficulty and cost of maintaining the 45 ft channel, the likelihood that the present system would be converted to a 55 foot system is low—assuming it is even technically feasible.

Given these trends, we can either move proactively towards building a navigation system that does not rely on nineteenth century innovation and design (like jetties), or we can wait idly as inexorable economic forces send the tonnage to other ports or over different transportation modalities.

Fisheries

Abundant, readily available, and relatively inexpensive seafood is a key component of south Louisiana culture. Its commercial, recreational and subsistence harvest enables a way of life. Its consumption provides essential protein in coastal communities. It helps define foodways, from the simplest family meal to creole, Cajun and *nouvelle haute cuisine*, helping to drive the tourist economy. Its export provides food to the nation and brings income to the state. The most important species, in terms of volume harvested and value, are estuarine, and entirely dependent upon the existence of the still vast marsh platform in each of the delta lobes. For many of these organisms, optimum habitat is achieved during the deteriorating phase of the delta cycle, rather than during the building phase (Baltz et al. 1993). The prehistoric delta included accreting lobes dominated by fresh river water, and deteriorating lobes dominated by saline seawater, and everything in between. In the beginning phase of European colonization, the only part of the estuary where salty conditions dominated was east of the river and upstream of Head of Passes to the lower Pontchartrain estuary. Today, salty conditions dominate from Lake Maurepas to Bohemia on the east side, throughout most of the Barataria and Terrebonne estuaries on the west side, and, because of ship channels, around lakes Calcasieu and Sabine in the Chenier Plain (Linscombe and Chabreck 1997).

Because of this present artificial imbalance in that equation, where little of the delta is now accreting or fresh, species that thrive in more saline environments during harvestable parts of their life cycle are both abundant and widespread throughout the estuaries. During the last century, these species have moved inland, getting closer to harvesters (Moore and Pope 1910; Reed et al. 2007; Salinas et al. 1986; VanSickle et al. 1976). Harvesters themselves have for the most part abandoned the semi-nomadic seasonal down-estuary settlements of the early twentieth century, and settled into permanent homes in communities farther from the immediate coast. Places that were marsh just 50 years ago have become oyster reefs, open water where shrimpers trawl and fishing grounds. Places that were too fresh then, now have optimal salinities.

This shifting *geographical* baseline is as deceptive as the shifting baseline for abundance and diversity seen in other species. It has gotten easier to harvest key species, because they are found closer to home and market. As a general rule, the quantity of harvestable fish and shrimp is related to both the total area of marsh, but also to the total linear distance of marsh edge, which increases as marsh deteriorates. Ironically therefore, despite the loss of marsh, the quantity of harvestable seafood has shown no comparable measurable decline perhaps because of this relationship: deteriorating marsh may be fueling seafood production. Organic marsh material might literally be being converted to shrimp, crabs, oysters and fish—vegetable becoming animal protein as it is processed up the food chain. But the trend is toward equilibrium, which is zero in a zero sum game—once the marsh is gone, fisheries fueled by deteriorating marsh would collapse. We are, as has often been observed, living off the principal, not the interest.

But this is a game that does not have to be zero sum. As long as the Mississippi River is the only outlet for runoff of much of the precipitation that falls on the interior of North America, and as long as the sun shines, the river can go on building deltas and the sea can go on destroying them. We could begin living off the interest again, with the river as the principal.[2]

A return to the prehistoric physical baseline—a building delta with large areas of freshwater swamp and marsh—will necessarily disrupt this seafood economy as now practiced. All of the species now harvested will remain, and will continue to thrive, but the *loci* of harvest for some will shift toward the gulf, and the geographic width of the harvestable niche will narrow. Species such as eastern oyster, brown shrimp, and speckled trout, which have benefited from the conversion of fresh to saline and the break-up of the intervening brackish marshes, will undergo the seaward shift and a narrowing band of ideal salinity.

But this is not true for all species. Those with a tolerance for a wide range of salinities, such as blue crabs and redfish, will continue to occupy large areas of the estuaries, with broad areas of overlap with current conditions. Freshwater species, such as largemouth bass, alligators and red swamp crawfish, will occupy a much greater area.

Resistance to these proposed changes has been fierce among some in the communities that exploit these resources. Many shrimpers, especially smaller operators that depend upon brown shrimp inland during the spring season, object to the freshening of estuaries during spring high water. They fear reductions in brown shrimp populations, and object to the prospect of having to go farther for the harvest. Louisiana also has a robust recreational shrimp harvest which would be similarly affected. Some recreational anglers, and the charter captains and marina owners that depend upon them, object to a similar displacement of speckled trout, a much sought after game species. And, of course, most oyster harvesters, dependent upon a sessile resource that is most productive in a narrow range of salinities, fear wholesale freshening of estuaries. The band of optimum salinities would narrow, and would be found near the passes and barrier islands, rather than inshore. Many of those who harvest estuarine species tend to work on low margins, and large increases in fuel and time costs could drive some out of business, and could reduce incomes for many.

But estuarine fisheries production is also a zero-sum game. Once the estuarine platform is gone, the estuarine-dependent fisheries will collapse. We can either take actions that cause dislocation and shifts in estuarine fisheries resources now, or we can preside over the slide to zero. There is no doubt that current fisheries will be forced to adapt or die in order to make sure there is anything left for the future.

Communities

No issue is more difficult than devising a strategy for existing communities in the coastal zone now under threat, or that will come under increasing threat as sea level rises.

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[2] To keep the analogy accurate, the river would really be building up principal in separate new accounts, while old accounts, and the interest they earn, are being depleted.

Many southeast Louisiana coastal communities grew rapidly during a period, roughly from Hurricane Betsy in 1965 to Hurricane Katrina in 2005, which experienced relatively little catastrophic tropical activity. At the same time, however, exposure to smaller tropical cyclones grew as buffering coastal wetlands deteriorated. Beginning with Category 1 Hurricane Juan in 1985, flooding of areas that had no experience of storm surge except in major storms began to occur more frequently. The natural response was to call for levees. But these communities are generally located deep in the coastal zone, on linear natural levees surrounded by marsh and open water. Their very existence is tied to easy access to coastal waters. The fact that assets are dispersed and linear rather than concentrated means that the length of levees and floodwalls needed per unit asset is very high. The solution has been to propose cross basin levees with navigation gates that protect numerous scattered assets, but must perforce enclose and cut off estuarine wetlands.

Cognizant of the effect that levees have on enclosed wetlands, planners have increasingly proposed so-called 'leaky levees'—levees with floodgates and tidal openings to allow hydrological exchange during normal tidal conditions. Such levees could theoretically provide adequate flood protection when closed during surge events, but allow normal estuarine functioning at other times. But there are serious concerns about whether levees can be designed that mimic the 'leakiness' of natural systems adequately enough to mitigate these challenges. Isolation of wetlands is occurring or will occur from massive cross basin levee projects such as *Morganza to the Gulf* in the Terrebonne Basin now under construction and with some of the proposed alignments of *Donaldsonville to the Gulf* in the Barataria Basin. A system to close the entire Pontchartrain-Maurepas Basin, nearly 1,000 square miles of embayment and wetlands, has been debated for decades. A proposed levee bordering the north side of I-10 between the Bonnet Carré Spillway to Ascension Parish in the Pontchartrain Basin would isolate large areas of wetland south of the levee and prevent effective diversions to wetlands north of the levee. Most of these wetlands are in a highly degraded state and declining rapidly; levees will make restoration much more difficult.

The placement of levees is critical both for flood protection and for wetland health. Wetlands behind levees are threatened. Wetlands not only require interchange of water and nutrients, they need sedimentary inputs (McKee and Cherry 2009; Turner et al. 2007). Cutting wetlands off from the riverine inputs with levees is an extremely destructive but routine case, but storm related deposition is also critical for longer term sustainability of estuarine wetlands located far from riverine input (Freeman 2010). Levees can reduce or eliminate deposition of resuspended sediments during high tides and storm surges. Relatively low levees can result in significant reduction of sediment input as evidenced by the LaBranche wetlands where a railroad embankment of about 6 ft has led to serious marsh break up (Day et al. In Review). The wetlands inside the hurricane levee system in Bayou Sauvage NWR in New Orleans, and the Central Wetlands of St. Bernard and Orleans parishes have shown steady decline since enclosure behind leaky levees. And both areas suffered catastrophic declines among freshwater dependent plants as a result of levee overtopping during Hurricane Katrina, and subsequent semi-impoundment of salty anaerobic waters for weeks after the storms.

In terms of sedimentary input it is not the height or breadth of levees, but the first few feet of levee that deprives the marsh. But it is the last few feet of elevation that determines whether flood protection succeeds or not. Ironically, then, a levee that fails to provide adequate flood protection during more catastrophic storm events may still cause marsh deterioration.

The evolution of these issues converges with the growing recognition that levees ultimately put areas at more risk to dramatic events in exchange for protection from more frequent and moderate events. Levees built to lower elevations, which are more affordable and can be constructed more quickly and maintained with locally funded assets, can reduce risk from routine tidal flooding. But the trade-off is that they increase the severity of flooding during less frequent but more catastrophic events. This is because the levees themselves trap water, isolate those who remain, complicate return after the storm, and have to be repaired before pumps can be employed to drain the basin. Levees also induce development and encourage structures that are less flood resistant. This was seen most dramatically in metropolitan New Orleans during Hurricane Katrina, but it has happened on a smaller scale on numerous occasions in coastal Louisiana. Where levees serve as the containment perimeter for forced drainage systems, as they do in metropolitan New Orleans, lower Plaquemines and Lafourche parishes, and elsewhere, they induce sub-surface lowering of the water table and subsidence (Yuill et al. 2009). In coastal Louisiana this has led to sections of communities as much as 10 ft below sea level. Such subsided communities are of course even more susceptible to catastrophic flooding if the protection system fails.

Leaky levees (of any height) that allow tidal interchange will not induce significant subsidence. However, in an era of rising relative sea level, there is another cost. One of the central purposes of leaky levees is to allow coastal communities to maintain navigable connections to the Gulf. But as sea level rises, the frequency of closures will increase. A time will come when floodgates will need to be closed continuously, cutting communities off from the very reason they exist in the first place—their connection to coastal resources (USACE 2013). Elevation and flood-proofing of structures, roads, utilities and infrastructure will be required in order to be able to keep the gates open. This will, of course, beg the question as to why this was not simply done in the first place, rather than going through the costly and futile interim step of levee and floodgate building.

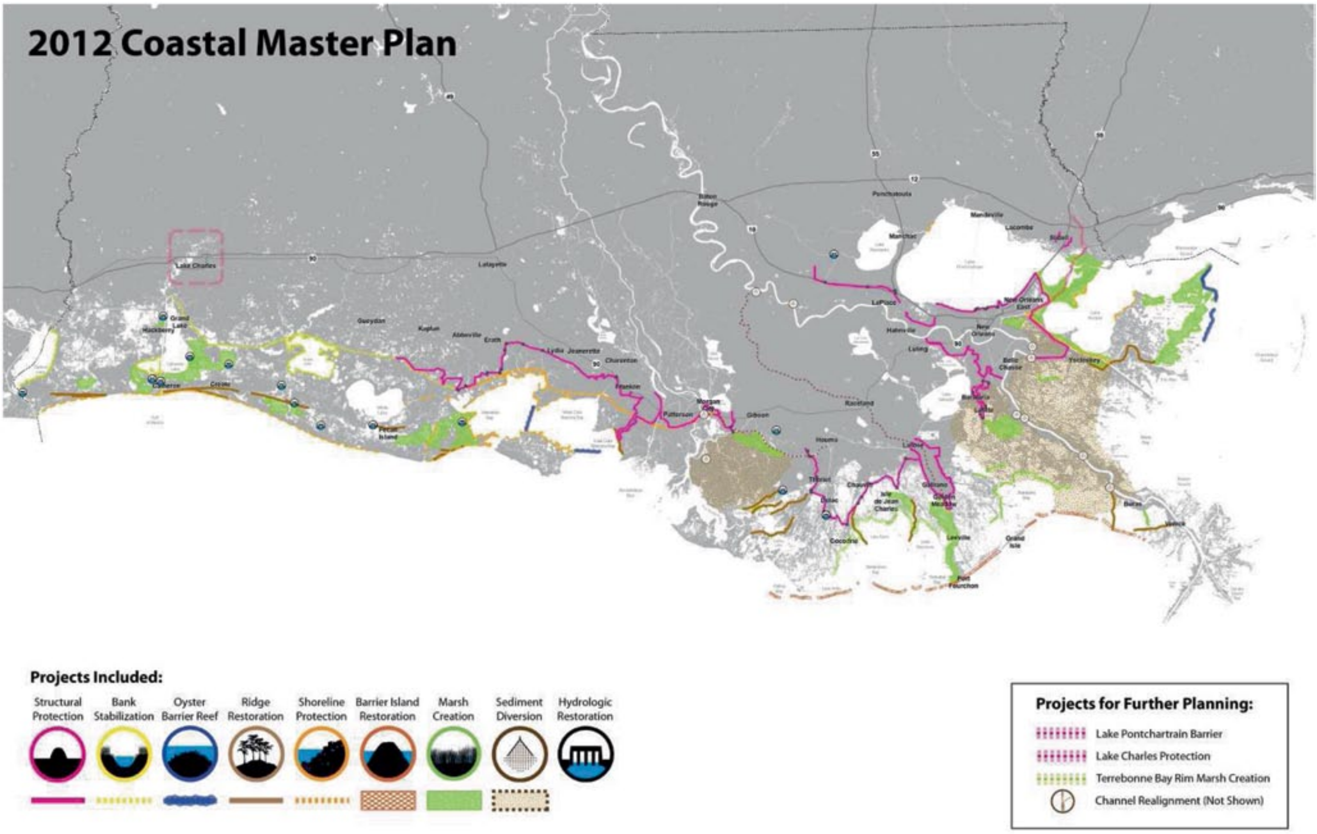

Fig. 5 Louisiana's 2012 Comprehensive Master Plan for a Sustainable Coast has identified 109 projects to facilitate sustainable, long term, large-scale restoration of Louisiana's coastal wetlands. Courtesy Louisiana Coastal Protection and Restoration Authority

Coastal communities face bleak choices. This is as true of New Orleans as it is of the smallest bayou town. Their continued viability is contingent. The future rate of sea level rise, the frequency and intensity of future hurricanes, the availability of public funding, the speed with which it is obtained so that risk reduction measures can be taken, the potential cost escalation in an energy constrained future, the cost of insurance, and the national response to future disasters, are all unknowns. And yet each of these variables could be the one to tip them from viability to decline or destruction.

Growth patterns in Louisiana's coastal zone over the last 50 years have been complex. While population has increased in larger metropolitan areas, it has tended to sprawl, following the suburban pattern seen nationwide. But compared to other southeastern states, Louisiana's growth has been anything but robust—it has lost two seats in the U.S. House of Representatives. Even this anemic growth somewhat masks in-state migration from parts of the coastal zone, driven by the relentless reoccupation of the delta by the sea. This migration from the coast is occasionally punctuated by mass relocations or dislocations after hurricanes, as especially after Hurricane Katrina in 2005. Historically, whole communities have migrated inland, as after the storms that wrecked Isle Derniere in 1856 and Chenier Caminada in 1893. Shrinking communities, or communities that grow more slowly than their counterparts, face increased competition for the very support needed to keep them viable.

As with navigation or fisheries, the choice for communities is either to adapt to living in a functional delta with all of its uncertainties or to abandon it and head to *terra firme*. Our uncertainties are compounded because we live during a period of rapid and accelerating sea level rise. But if we cling to the illusion that a delta can be frozen in time if only we spend enough money on dredges and levees, we will be overwhelmed. We could be overwhelmed anyway if we are unlucky with the timing of hurricanes and the rate of sea level rise, but at the very least we can leave behind a re-invigorated delta that provides at least some small measure of the ecosystem services that drew us here in the first place (Fig. 5).

We are on the cusp of returning to that delta. Louisiana's 2012 *Comprehensive Master Plan for a Sustainable Coast* lays out an achievable set of actions that will return about one half the peak flow of the Mississippi River to areas of the delta now in a free fall collapse, restoring deltaic function. It proposes a plausible set of aggressive, costly and energy intensive projects that could, with luck, good timing, and money, stave off destruction of coastal communities until the delta begins to show signs of recovery through natural land building. It lays out a path forward for capturing *more* than 50 % of the river in the future. It creates a process for remaining flexible as a state to respond to changing variables like sea level rise rates, costs, new science or lessons learned through adaptive management. There is broad political, economic, and social support for the plan, at least conceptually. And real dollars, enough to make a down payment on the plan, are in the pipeline from a number of sources. Fines and penalties available for restoration in Louisiana already exceed $ 1.2 billion from the Macondo oil spill. Billions more are possible. In addition, beginning in 2017, Louisiana's share of Federal Outer Continental Shelf revenues will increase substantially.

But resistance and magical thinking still remain.

A Narrative of Denial

We shouldn't do diversions because:

There is Not Enough Sediment

An argument that has become commonplace is that because of changes to the river, or because of the time requirement to build a delta, diversions will not work as a solution to coastal land loss. Arguments include the claim that "there is not enough sediment", or "the excess nutrients from farm run-off in the water will harm remaining marshes", or "it will take too long".

The proposed antidote is pipeline sediment delivery from dredges in the river, coastal bays, or offshore, mining the bed load of the river, or deepening the bays, or mining the shoals. This has been done successfully, and has resulted in new marsh platform and barrier island nourishment. "Creating" marsh is technically trivial. Dredge sediment and transport it to an area of open water. Fill the area to within a suitable range of elevations, and marsh or ridge or dune vegetation will colonize the sediment platform.

To extend the medical metaphor, this is the "treating the symptom" approach. Wetlands, ridges and barrier islands have disappeared, so put them back. This approach has a lot of appeal. It can be done relatively quickly—at least on a small scale and where a sediment source is available. It does not change salinity—fresh marsh can be built in freshwater areas, brackish marsh in brackish areas, and so on.

Despite the clear usefulness of this band-aid approach as a means of treating specific injury, it is not a substitute for the cure. Dredging bay bottoms to build adjacent marsh robs Peter to pay Paul, or to use another apt *cliché*, it is simply re-arranging the deck chairs on a sinking ship. Moving sediment from a bay bottom to build adjacent marsh results in no net gain to the system. Like a hole on a beach, the system immediately seeks equilibrium and the hole fills up, eroding adjacent shoreline.

Even when borrow is obtained from a distance, "outside" the system, from the river's bedload or from shoals far offshore, artificially created marsh still needs continuous riverine input in order to sustain itself. Otherwise it will begin to deteriorate under the same inexorable forces that destroyed the natural marshes in the first place. Additionally, energy costs will continue to rise, making the cost of pumping sediment eventually prohibitive. While diversions have higher upfront capital costs, the cost of operation and maintenance is relatively trivial (CPRA 2012).

Offshore shoals are finite resources, and their removal has ecological costs, as well as rising economic costs that track fuel prices and increase as transport distances increase. The river's bedload of sandy sediments is replenished relatively slowly. And even if *all* of the bedload sediment of the river could be harvested by dredge, that would still leave about 80 % of the river's annual available sediment unutilized. Dredges can capture the bedload, but the fine material that remains in suspension, the mud in the "Big Muddy," would be missed by the dredges. Without wholesale diversion of the river back into its delta, most of this 80 % would continue to be lost to the Gulf each year. The marsh creation band-aid is an important tool, but it has critical limitations. And it is simply incomprehensible to propose using only 20 % of the available sediment resource to rebuild the delta, especially considering that perhaps only 50 % of the peak nineteenth century sediment load is still carried by the river today.

There is Not Enough Time

Another argument touted in favor of mechanical marsh creation is that natural delta building is too slow a process. But this observation is another example of drawing conclusions from a shifted baseline. Proponents of this argument point to the relatively small scale land building going on in the Bird's Foot, and to the alleged slow pace of accretion in the Atchafalaya and Wax Lake deltas. However, both within the Bird's Foot and now at the Atchafalaya River Delta and Wax Lake Outlet Delta, successful land building is taking place despite the less than ideal depositional environment into which the river must discharge sediment.

The Bird's Foot was a natural anomaly—at the time of European discovery the river had forged a route far out onto the shelf. It had by whatever means largely confined itself between natural levees that pinned the channel seaward of flanking marshes.[3] It was truly shaped like a bird's foot—

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[3] The strangeness of the Bird's Foot receives little attention. But its position far out onto the shelf, having outrun, so to speak, the adjacent coastal marshes, give it a physical shape unlike the other extant Mississippi River delta lobes, and very unlike the classic deltas of the textbooks. There really seems to have been very little flanking marsh in the eighteenth century, and few or no small distributaries. One channel, three forks: today's Pass a Loutre, South Pass and Southwest Pass. Pass a Loutre, the channel with the highest carrying capacity when the French arrived, bifurcated near its mouth, but otherwise it was the river, the three passes, and their natural levees. It was as if the river had already fallen off an edge and was being held in place because subsidence was maintaining a favorable gradient.

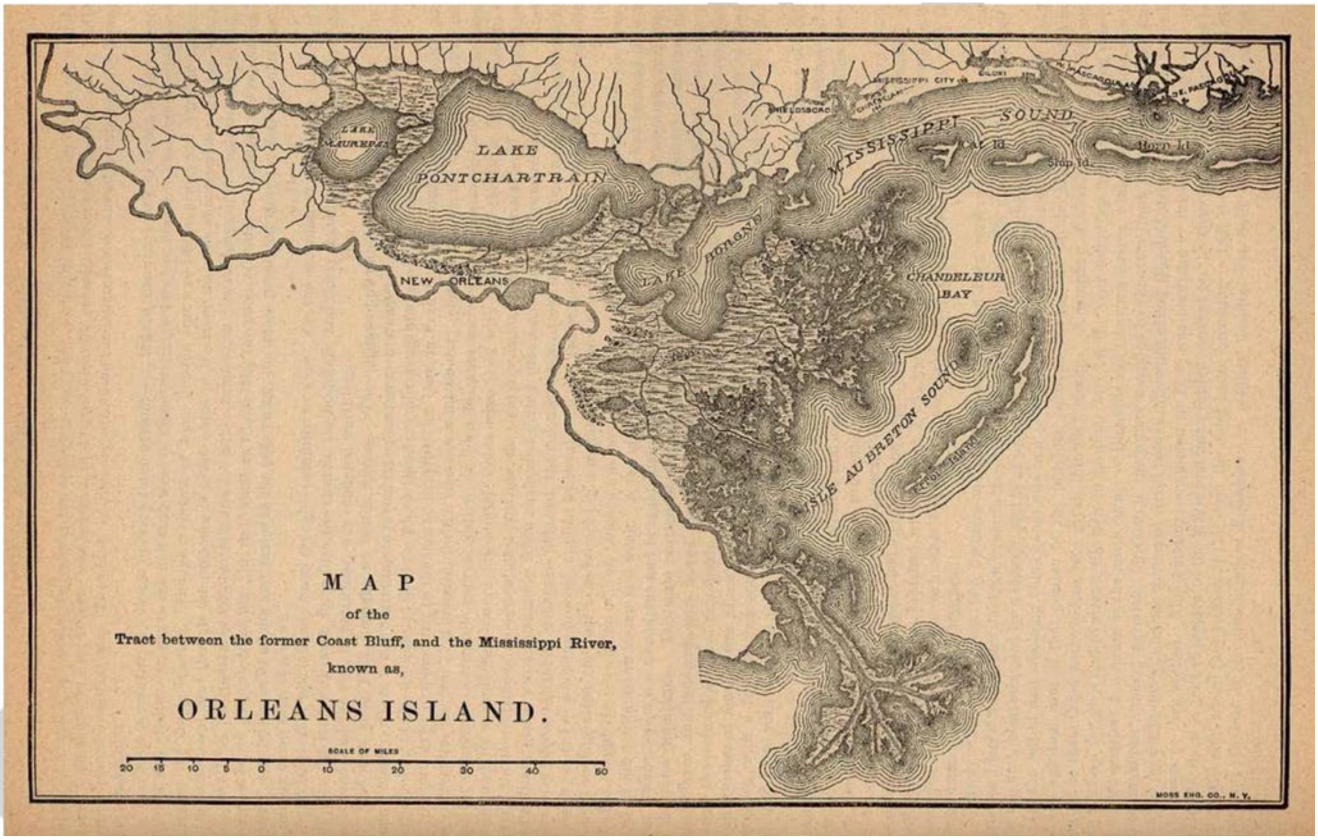

Fig. 6 1880 map of the Mississippi River delta. Note the extension far out onto the shelf, shaped like a classic bird's foot

the tarsus a 15 mile long narrow ribbon, with three narrow 10 mile long toes from Head of Passes. The main channels were so well confined that little sand escaped to the flanks to build fringing marsh. It was like a chicken's foot rather than like the webbed duck's foot we've known for much of the last 100 years—and, of course, it now has more toes, and two of the original three toes are much longer (Fig. 6). Above Head of Passes there were no major outlets—Main Pass, Grand Pass, and Baptiste Colette had not yet formed. In the first upriver European voyage, during the spring flood of 1699, the French Canadian explorer Iberville mentioned no outlets between Head of Passes and Bayou Lafourche, 174 miles upriver, except for Mardi Gras Bayou, on the east bank a day's voyage above Head of Passes.

During the historic period a series of mostly anthropogenic crevasses allowed the river to fill in the webs between the toes and to carve the new toes. These new crevasse splays included: The Jump (Grand Pass, Red Pass, Tiger Pass, etc.); Cubit's Gap (Main Pass, which created today's Delta National Wildlife Refuge); Baptiste Collette; West Bay off Southwest Pass; and the various splays off Pass a Loutre (which created today's Pass a Loutre Wildlife Management Area) (Coleman 1988; Roberts 1997). Throughout the last 200 years land has built, been cut off from flow either by natural levee buildup or channel work by the Corps, deteriorated, and then in some cases been rebuilt by re-opening to river flow. The net acreage has been large, but the gross acreage much larger. The principle difference between gross and net area gained is that the Bird's Foot experiences subsidence rates that average 2 m per century, caused by compaction and fault slippage (Figs. 7 and 8) (Dokka 2006; Gagliano et al. 2003; Kuecher et al. 2001).

It should also be understood that very little of the sediment reaching the lower river is accreted there. The Bird's Foot was perched in comparatively deep water when Europeans arrived, and every channel project undertaken for the last 300 years has pushed the river's mouth into deeper water. Deposition into deeper water requires more sediment on the vertical axis. But it also means that less can be captured, because finer sediments, the clays that built most of the delta, are transported far from the depositional environment (Roberts et al. 2012). Fine grains take a long time to settle even in a stilling basin—they can be carried for tens of miles by currents, such as those encountered in the gulf at the mouths of the passes, and even tidal fluctuations and wave energy prevent them from settling to the bottom. Capture of fine grains is best facilitated in shallow, low energy environments, where numerous impediments interrupt flow. In other words—marshes build more marsh.

So while net acreage at the Bird's Foot may seem to indicate insufficient sediment in the river to meaningfully offset our historic rates of land loss, this is only because where the

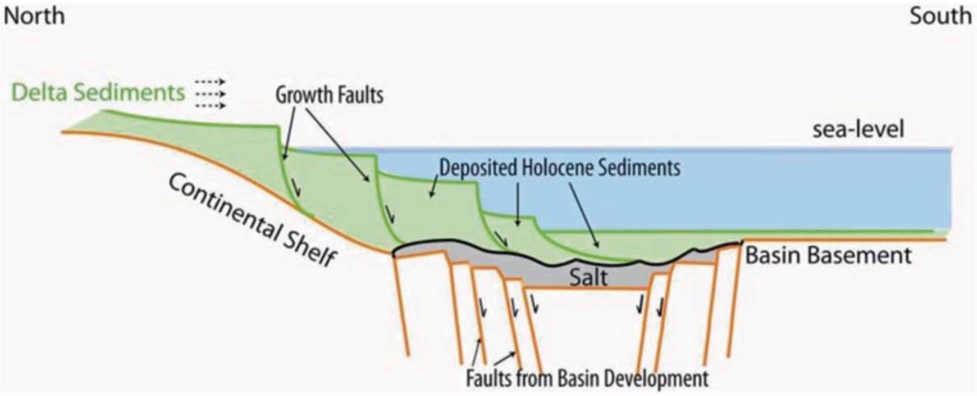

Fig. 7 Generalized faulting along coastal Louisiana and the Gulf of Mexico. One of the consequences of this geological substructure, is differential rates of subsidence. (From Yuill et al. (2009))

deposition is taking place today gives us a false impression. Diverting sediment laden river waters into shallower areas, with lower subsidence rates, lower hydraulic energies and more existing vegetated platform will result in concomitantly higher rates of sediment capture and deposition.

The Atchafalaya and Wax Lake deltas are accreting, building land into Atchafalaya Bay (Roberts et al. 2003). But compared to the magnitude of loss elsewhere, the gains appear modest. After all, 30 % of the total flow in the system eventually makes its way to these two sub-deltas. If that is all 30 % can give us, will the remaining 70 % added on be enough? Again, the Atchafalaya deltas are the wrong analogy. They are being built out into a large estuarine bay—a high energy environment where little of the fine material is trapped but is instead carried away and distributed far and wide. In addition, the Atchafalaya still has a floodplain that averages 15 miles wide and extends for more than 60 miles, about 600,000 acres in which the floodwaters can spread and sediment be trapped before it reaches the delta (Atchafalaya Trace Commission 2011).

Thirty per cent of the flow diverted into the existing delta platform, into broken marsh and very shallow interior ponds, would result in significantly higher rates of capture than now takes place in Atchafalaya Bay (Kim et al. 2009). Modeling for the 2012 Master Plan suggests that even against a sea level rise of 0.45 m in 50 years, diverting between 35 and 45 % (50 % of the river below Old River and 150,000 cfs from the lower Atchafalaya) of the total flow at peak flood into existing broken marsh would build or maintain about 300 square miles of marsh platform over 50 years.

Having lost 1,900 square miles in the last 100 years, 300 square miles seems inadequate. But it has to be measured against continued and accelerating future loss. Either the river builds land, or the sea takes it. By confining the river over the last 300 years, we gave up most of the delta landscape to the sea. We can't get that back. By expending extraordinary amounts of money we can move sediment around with dredges to temporarily fill holes. The 2012 State Master Plan proposes almost $ 20 billion to build less than 200 square miles over 50 years. But we'd all but literally be building sand castles in the face of a raging sea. On the other hand, for a modest investment, we can allow the river to resume the process of building land. The 2012 Master Plan models show costs of just under $ 4 billion to get those 300 square miles, against a moderate sea level rise scenario. But even if that estimate turns out to be half of what it actually costs, and even if sea level rise confines the net land gain to half the estimate, the investment is trivial compared to the benefit. The alternative is no delta at all. And the plan, in this iteration, leaves 50 % of the river's peak flood untapped for delta building. Creative re-engineering of the navigation channel would allow us to tap much of the remaining delta building potential, and increase the area of new delta we could build against the rising sea.

Conclusion: The Very Ground We Stand On

The real world teaches us one thing: the Mississippi River can build deltas. It is somewhat surreal to listen to my fellow citizens, opponents of river re-introduction, stand up in meetings held in New Orleans, Chalmette, Belle Chasse, Lafitte, Thibodaux, Houma, or any other southeastern Louisiana community, and insist that the river, re-directed by diversions into the collapsing delta, will not build land. The very ground beneath our feet belies these statements. Equally surreal are researchers and bureaucrats who continue to urge caution and delay on river reintroduction in the face of the overwhelming certainty of the disaster we face if we don't allow the one known delta building force to operate. It is a peculiar delusion—to grasp that one lives on and in a delta, but to somehow believe that the untapped river that courses through it without outlet can't do again what it so manifestly has already done. We are unconnected to the past and to the physical realities of our home. We fear changing what we know, even if what we know is a declining, indeed a collapsing, system. We are beset by magical thinking, confusing the efficacy of dredging and rock barriers on the small

Fig. 8 1874 U.S. coast survey map of the Mississippi delta

scale, with the reality of loss on the delta-wide scale. We fear the change that massive riverine re-introduction will inevitably bring. Resisting change and clinging to magical thinking are traits that have served individuals and our species well. It is the right evolutionary strategy most of the time. But not when the very geology is against us.

Our fear of change is rooted in the false impression created by the shifted biophysical baseline that is our 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 us. 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. None of us alive in south Louisiana has lived in such a deltaic environment. But we could. And if we allowed the river to rebuild such a delta, our grandchildren might even get a glimpse of the abundance of wildlife and fish among which American Indians once lived and which stunned the first visitors from the biologically depauperate old world upon their arrival 300 years ago.

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