THE IMPACTS OF THE MISSISSIPPI RIVER AND ITS DELTA ON THE OCEANOGRAPHY, ECOLOGY AND ECONOMY OF THE GULF OF MEXICO LARGE MARINE ECOSYSTEM

While it has long been recognized that the Mississippi River plays a dominant role in all aspects of oceanography within the Gulf of Mexico, few previous efforts have actively sought to summarize the multitude of the river's impacts.[1,2,3] The Mississippi River is important to the Gulf of Mexico, producing a plume of freshwater that extends 10,000 to 35,000 km^2 (3,800 to 14,500 mi^2) in area, as estimated by the 33 parts per thousand salinity contour.[4] The plume's extent is further influenced by dynamical and meteorological factors that govern its distribution.[4,5] The river's plume has important implications for the ecology of the Gulf of Mexico-it provides large nutrient loads that contribute to highly productive marine ecosystems, and yet it also fuels a seasonal hypoxic zone that is one of the largest such zones on earth.[6] However, recent publications indicate that the stimulatory impacts of the Mississippi River on fish populations outweigh the deleterious impacts of hypoxia- although research on this topic is still ongoing.[7] The Mississippi River plume is also an important source of food and sediment to benthic communities, although this delivery is irregular and this irregularity of river inputs influences the structure of benthic ecosystems.[8]

The delta of the Mississippi River and associated estuaries provide substantial impacts to the Gulf of Mexico. They are also a source of freshwater to the Gulf, although about 10-50 times smaller, than the river itself.[9] The delta and its estuaries provide important food, habitat, and nursery grounds for numerous species of ecologically and economically important species of vertebrates and invertebrates that live in the Gulf of Mexico.[10] However, the wetlands of the Mississippi River Delta are in a chronic state of land loss.[11] While the implications of this land loss are widespread, for the purposes of this review the most important impact is that Louisiana's degrading wetlands provide an important, but often localized, source of carbon and sediments to the Gulf of Mexico.[12] Small active deltas near the mouth of the Mississippi and Atchafalaya Rivers provide important, but localized, sinks for sediments, carbon and nutrients.[13]

Over the past century humans have had substantial impacts on the Mississippi River, its delta, and the way that these systems influence the Gulf of Mexico. Changes to the river include major hydrological changes to the channel of the Mississippi River that constrain its flow, the construction of dams in the river's watershed that reduce the river's sediment flux to the coast, and major increases in agriculturally-derived loads that both increase primary production, secondary production (e.g., fish) and hypoxia. Shifts to the delta include a range of geologic, geomorphic and ecosystem impacts that lead to wetland loss, which can increase the flux of carbon and sediments to the Gulf, and which can shift (both positively and negatively) available habitat for estuarine-dependent species.

In the decades ahead, the impacts of the Mississippi River and its delta on the Gulf of Mexico are likely to continue to change, largely (but not entirely) because of human-driven processes. Climate change, global sea level rise, channel aggradation, and continued land subsidence could cause shifts in the lowermost outlet of the Mississippi River, shifting the plume's distribution northward. The State of Louisiana is actively planning to partially divert the flow of the Mississippi River as a means to rebuild its wetlands.[14] These "river diversions" would also shift northward the plume of the Mississippi River, and this could trigger a suite of cascading impacts to the ecosystem. Such changes would have important societal impacts as the Mississippi River is a critical transportation pathway, and Gulf of Mexico fisheries are among the most economically important fisheries in the nation. Overall, it is the intention of this overivew to provide important supporting material to inform regional decision makers as they prepare for restoration that might occur in continued response to the Deepwater Horizon Oil Spill and future oil spills or large-scale perturbations, prepare to reverse decades of other environmental impacts such as wetland loss, and prepare for a future with a warming climate and rising sea levels.

THE MISSISSIPPI RIVER AND DELTA

For the purposes of this paper, the Mississippi River system (Fig.1) is considered to be any part of the Mississippi River and its distributaries that discharges into the Gulf of Mexico. This includes the river's mainstem, major distributaries (such as the Atchafalaya River), flood control structures that discharge into the estuaries (such as the Bonnet Carré Spillway), as well as additional sources of river water to the ocean (such as subterranean flow from the Mississippi River to the coastal zone). This summary considers the entirety of the Gulf of Mexico, including the five U.S. Gulf States, federal waters, as well as those sections of the Gulf of Mexico that are in Mexican, Cuban, and international waters. The Mississippi River system drains an area of 3.2×10^6 km^2 (1.2×10^6 mi^2), including the entirety or parts of 31 states and 2 Canadian provinces. The outlet of this river system is the Mississippi River Delta, a 38,600 km^2 (14,900 mi^2) region that contains a vast network of rivers, bayous, wetlands, lakes and open bays.[15]

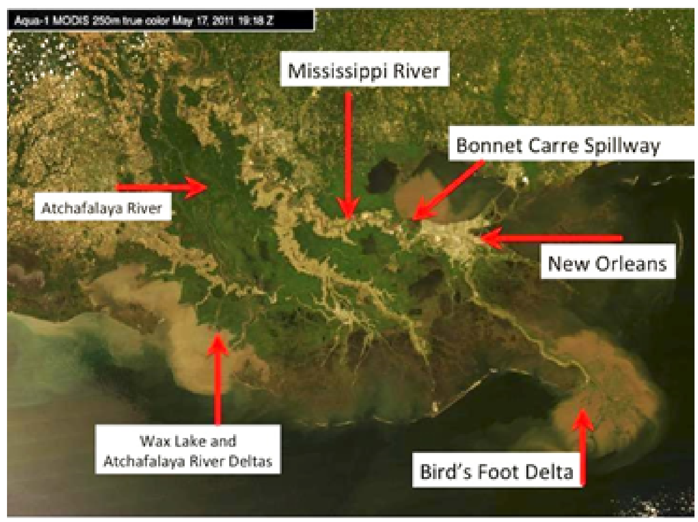

Fig. 1 NASA/MODIS Imagery of the Mississippi River Delta and its coastal zone, with key areas highlighted. Image date: May 17, 2011. Image credit: Louisiana State University Earth Scan Laboratory. www.esl.lsu.edu

STUDY SCOPE

A working group was convened to discuss and examine the influences of the Mississippi River and its delta on the ecology, oceanography, and economy of the Gulf of Mexico Large Marine Ecosystem. The study is concerned largely with modern time scales, which as defined here are having occurred during the last 100 years, and changes that are likely to occur over the next 50-100 years. This time scale covers most of the intensive post-industrial human impacts to the river system, and incorporates the reasonably foreseeable changes that could occur with climate change, continued environmental impacts, and planned restoration. Longer time scales will only be examined to the extent that they inform the focus time scale.

This group examined the following five critical questions:

1. How does the Mississippi River influence water column processes in the Gulf of Mexico? What material does the river deliver, over what area is this material delivered, and how is it reworked and redistributed over time? What are the impacts of Mississippi River water on living resources in the Gulf of Mexico?

2. What is the Mississippi River's influence on the seafloor in the Gulf of Mexico? What are the major benthic communities in the Gulf of Mexico? How do benthic habitats and substrates change from the shallow regions of the Gulf of Mexico to the deep ocean, and what are controls on these changes? How do the processes that control sediment metabolism, sediment reworking, and sedimentary geochemical cycles change from the shallow reaches of the Gulf of Mexico to the deep sea, and how do these processes change as the river's influence becomes increasingly distant?

3. What is the impact of the river on the estuarine reaches of the delta, and what is the impact of the delta on the coast?

4. What are the human influences on the ways that the Mississippi River and its delta influence the oceanography, ecology, and economy of the Gulf of Mexico?

5. What are the potential future impacts on the ways that the Mississippi River and its delta influence the oceanography, ecology, and economy of the Gulf of Mexico?

These questions are addressed through a synthesis-style process that examines existing data, publications and, where appropriate, numerical models. The influence of the Mississippi River and its delta on the oceanography of the Gulf of Mexico have been addressed by individual researchers and specific teams for decades. Such efforts include, but are not limited to: efforts to study the seasonal hypoxic zone; river/plume physical dynamics; the diversity of abundance of many species; fisheries production; the flux of nutrients, organic matter and contaminants; the impacts of major oil spills; and the ecological restoration of the Mississippi River Delta. Despite this intensity of research, there have been relatively few review efforts that have examined the impact of the river and its delta on the oceanography of the Gulf of Mexico. Many of the best reviews to date have examined the drivers of hypoxia[6], the role of large rivers and their deltas in general[2], specific issues related to river management and coastal restoration[16], syntheses in support of the offshore energy industry[17], general introductions to oceanography and ecology the Gulf of Mexico and the Mississippi River Delta[15], and the impacts of the BP/ Deepwater Horizon Oil Spill in 2010.[18] The goal of this effort is to provide a comprehensive, yet easily accessible analysis that can provide managers, decision makers, academics, and the interested public with the information that they need to understand how the largest river in the United States and its delta impact the ocean.

HOW DOES THE MISSISSIPPI RIVER INFLUENCE WATER COLUMN PROCESSES IN THE GULF OF MEXICO?

The Mississippi River and its distributary, the Atchafalaya, deliver large amounts of freshwater, sediment and nutrients to the northern Gulf of Mexico which have wide-ranging and far-reaching influence on the water column of the Gulf (Fig. 2). The plume of freshwater from the river extends 10,000 to 35,000 km^2 (3,800 to 14,500 mi^2).[4] Influenced by the amount of discharge from the river, winds, tides and the Gulf Loop Current, and its influence can regularly extend west to Matagorda Bay and east to Mobile Bay with eddies transporting plume water offshore.[4,5] The Mississippi River is also a source of sediment, trace metal, rare earth elements, nitrate from fertilizers and pesticides to the gulf, although the latter is generally below levels considered unsafe by drinking water standards.[19] Increases in nitrate from fertilizers have likely fueled an increase in harmful algal blooms in the gulf. In addition, the high influx of nutrients from the river stimulates primary productivity, that combined with intense water column stratification typically in the summer due to limited mixing between buoyant fresher surface waters and denser, saltier gulf water, leads to the development of a low-oxygen, hypoxic (<2 mg/L) area along the Louisiana and Texas continental shelf. Low oxygen waters can cause detrimental impacts and even mortality to many marine fish, but that many species can migrate away from the hypoxic zone.[6] However, the primary productivity that is stimulated by nutrients from the river fuels the "Fertile Fisheries Crescent," a 200 km (124 mile) band in the gulf that extends from the Alabama/Florida border to the Texas/Mexico border, where production and landing are among the highest in the nation.[20]

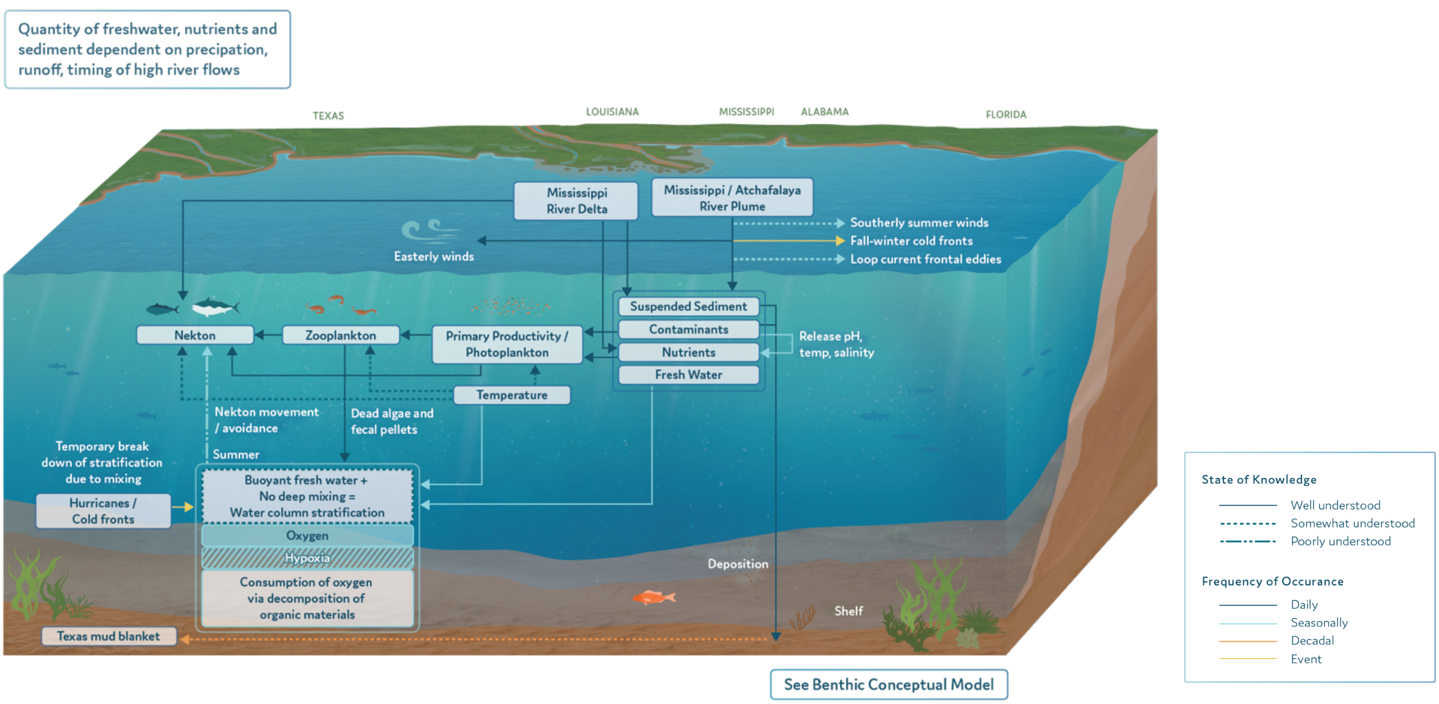

Fig. 2 Conceptual model of the influence of the Mississippi River and Delta on water column processes in the Gulf. Lines indicate links between key elements, along with the frequency of occurrence and strength of scientific knowledge.

WHAT IS THE MISSISSIPPI RIVER'S INFLUENCE ON THE SEAFLOOR IN THE GULF OF MEXICO?

The bottom-dwelling organisms make up the benthic communities of the Gulf of Mexico that extend from shallow regions near land to depths of more than 3,500 meters (11,400 feet). The primary influence of the Mississippi River on benthic communities in the Gulf of Mexico is governed by the deposition of mineral sediment from the river and the accumulation of organic material that is enhanced by river-influenced waters in the Gulf (Fig. 3). Benthic communities can be divided into hard and soft bottom communities. The river is a major source of mud to the Gulf seafloor, and this mud primarily forms the soft bottoms. The mineral sediment contributes to the physical structure of the bottom, both by providing habitats and potentially burying benthic organisms in high sedimentation areas. Organic material provides an important, but often irregular, food source to the benthos.[8] The river is also a source of contaminants to the deep waters of the Gulf. Since many contaminants attach to fine-grained particles, the distribution of these contaminates is dictated by the distribution of the Mississippi River plume. Sediment from the river also has the potential to slowly cap and bury contaminants that are introduced from the Deepwater Horizon oil spill and other similar events.

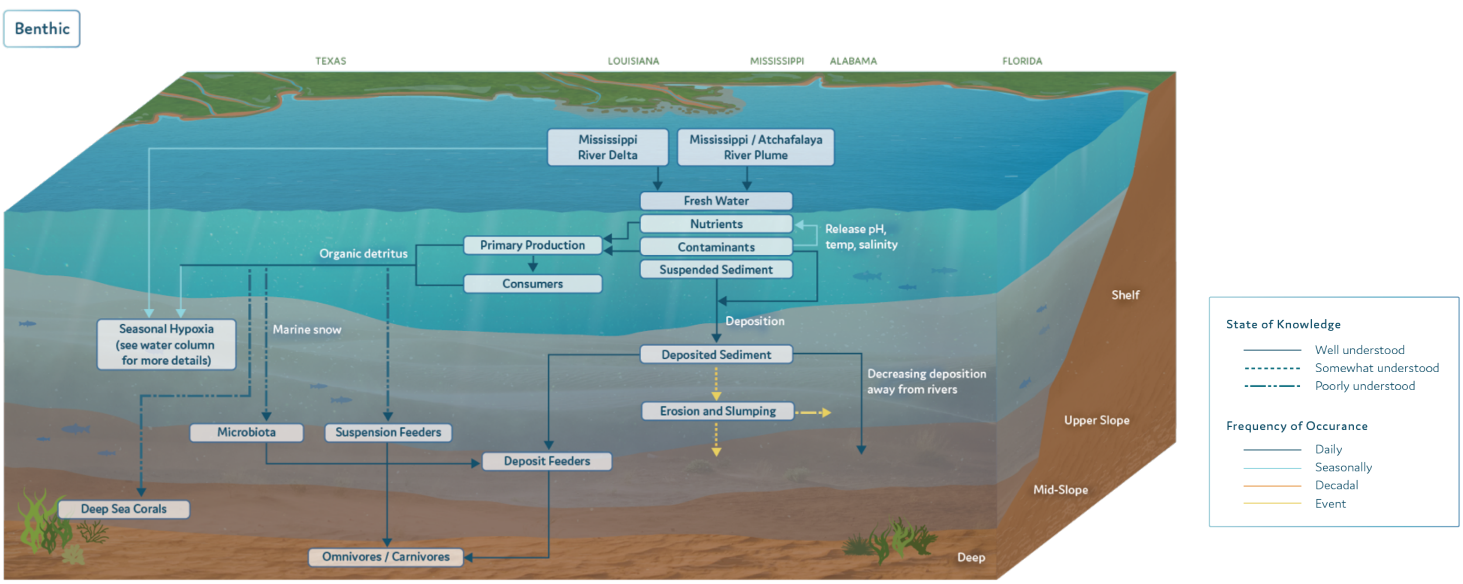

Fig. 3 Conceptual model of the influence of the Mississippi River and Delta on seafloor processes in the Gulf. Lines indicate links between key elements, along with the frequency of occurrence and strength of scientific knowledge.

WHAT IS THE IMPACTS OF THE RIVER ON THE ESTUARINE REACHES OF THE DELTA, AND WHAT IS THE IMPACTS OF THE DELTA ON THE COAST?

The deltaic estuaries of the Mississippi River were built and shaped over time by the river and the Gulf of Mexico. These estuaries serve as an important influence to the Gulf as sources of freshwater, sources and sinks of sediment and organic carbon and important spawning, growth and feeding habitat for various organisms that move between the estuaries and the Gulf (Fig. 4). Modifications to the river, including control structures, damming of distributaries and levees have largely reduced the amount of sediment and freshwater that flows into many of the delta's estuaries, but they are still an important source of freshwater to the Gulf of Mexico.[15] The Mississippi River Deltaic estuaries can serve as a sink for sediment in the few places where there is active land-building, such as the Atchafalaya Basin and parts of the Birdsfoot Delta, but in most of the delta's estuaries land loss is occurring which increases the sediment export from the estuaries to the Gulf.[11] The loss of coastal wetlands coupled with the primary production that occurs in the estuaries, likely make them a source of organic carbon to the Gulf.[12] Despite land loss, the delta's estuaries continue to support most of the Gulf's most important commercial and recreationally valuable fisheries.

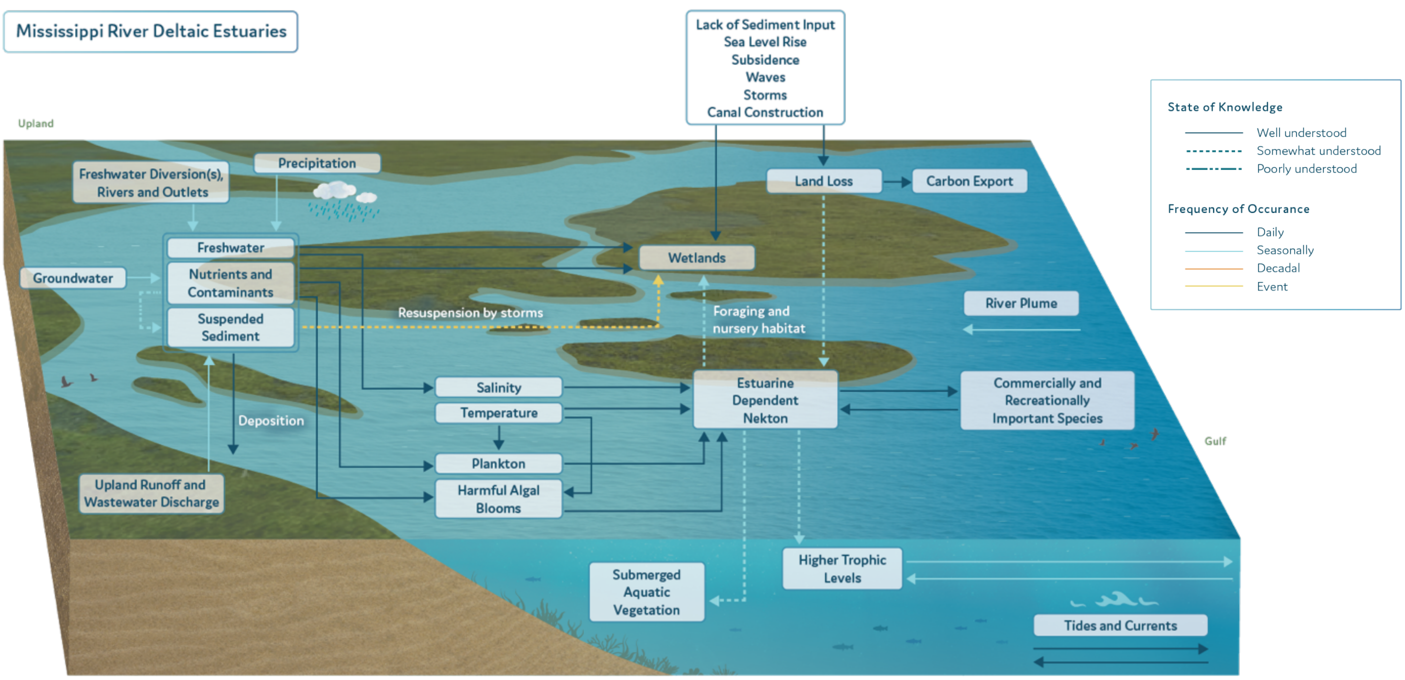

Fig. 4 Conceptual model of the influence of the Mississippi River Deltaic Estuaries on the Gulf. Lines indicate links between key elements, along with the frequency of occurrence and strength of scientificknowledge.

WHAT ARE THE HUMAN INFLUENCES ON THE WAYS THAT THE MISSISSIPPI RIVER AND ITS INFLUENCE THE OCEANOGRAPHY, ECOLOGY, AND ECONOMY OF THE GULF OF MEXICO?

Human changes to how the Mississippi River and Delta influence the Gulf of Mexico have been widespread and have had intended and unintended consequences. (Fig. 5) The construction of dams and locks on the Mississippi River and its tributaries for various purposes have reduced the amount of sediment carried by the river.[21] Levees and control structures constructed along the river have provided flood protection and navigation, important to river communities and much of the economy of South Louisiana, but have also cut off much of the delta from the river's sediment, contributing to wetland loss.[15] Agriculture and industry have flourished in the river's watershed and transport via the river provides for cheap export of produced-goods on the world market, but the increased in nutrients and contaminants in the river from agriculture runoff, fuel plankton blooms and the development of seasonal hypoxia on the continental shelf.[6] The oil and gas industry which is important to the economy of Louisiana and the nation. The delta is a hub of offshore oil and gas activity with extensive oil and gas facilities and infrastructure, importing large amounts of the U.S.'s oil from the Gulf of Mexico. However, dredging of canals for navigation and oil and gas and human-induced oil spills have also contributed to loss of the delta's wetlands. The loss of deltaic wetlands has reduced the storm protection benefits provided by the natural wetland landscape, leaving coastal communities and industry infrastructure more vulnerable to powerful storms.[15] Future impacts, including sea level rise, storms and even ecological restoration, will alter and shape the ways the Mississippi River and Delta influence the Gulf of Mexico.

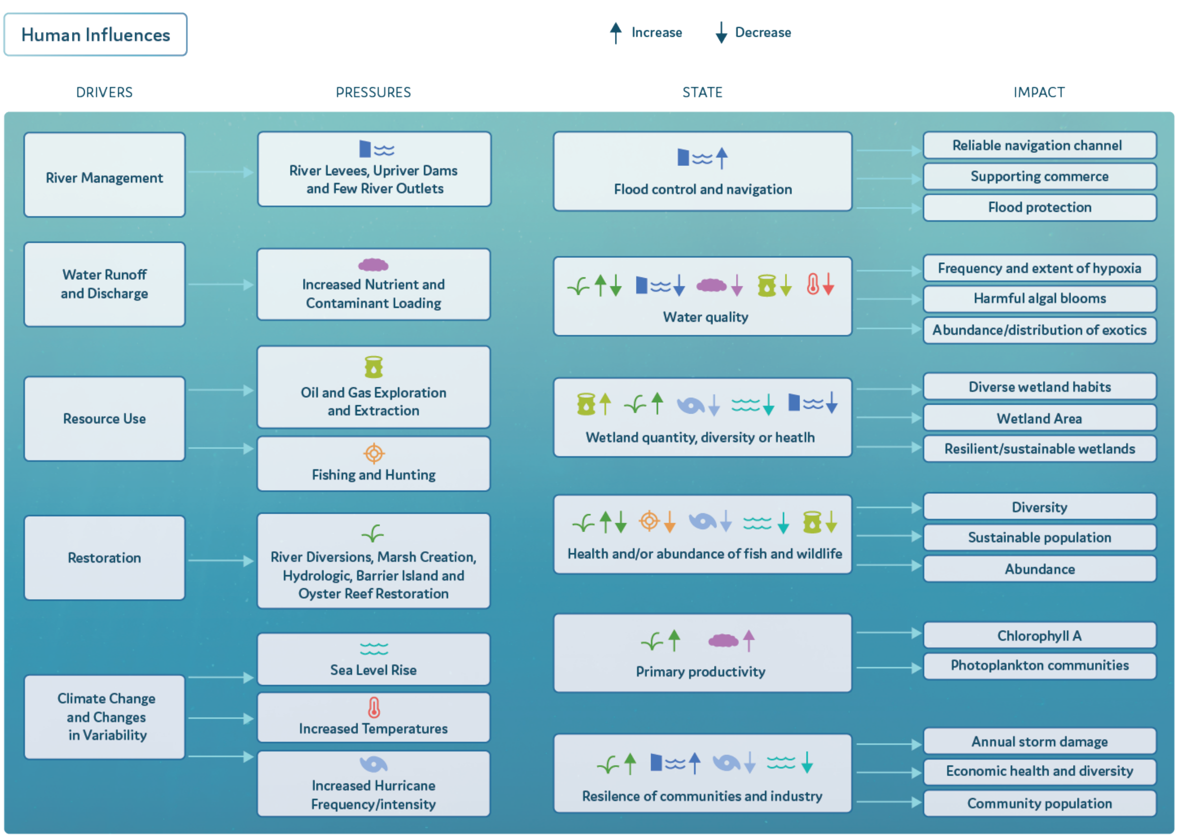

Fig. 5 Conceptual model of the human influences on the Mississippi River and its Delta on the Gulf. Lines indicate links between key elements and up and down arrow indicate increases or decreases in state.

RESEARCH GAPS IN THE UNDERSTANDING OF THE IMPACTS OF THE MISSISSIPPI RIVER AND ITS DELTA ON THE GULF OF MEXICO

Despite decades of research on river/ocean interactions many questions remain about the specific impacts of both the Mississippi River and its delta on oceanographic and ecological processes in the Gulf, and their cascading economic impacts. The working group examined research gaps in five major topic areas: conceptual gaps, modeling gaps, measurement gaps, gaps that could be filled by synthesis and gaps in research organizations.

- Conceptual gaps that need further research include biogeochemical cycles an environmental fluxes, the impacts of the Mississippi River on coastal circulation, the importance of ecosystem services and valued ecosystem components, and how human community interact with the interface between the Mississippi River, its delta and the Gulf of Mexico.

- Modeling gaps include a need for improved parameterization and calibration, improved boundary condition definition, model integration, and a fundamental understanding of river-ocean processes, improved decision support tools, and a need for improved spatial and temporal coverage/resolution.

- Measurement gaps include processes where improved measurement can lead to enhanced understanding (e.g. salinity dynamics, biogeochemical processes, river diversions), geographic regions that could be improved by further measurement (the eastern section of the Mississippi River and its delta, as well as the mouth of present-day and future distributaries), a need for improved baseline data, and a need to invest in emerging sensors.

- There is a pressing need for transdisciplinary synthesis that can bring together diverse knowledge from across scientific disciplines develop a new or improved understanding of the ways that the Mississippi River and its delta influence the Gulf of Mexico. Synthesis can address a range of issues ranging from air/sea/land interactions to the impacts of invasive species on the environment to the integration of the physical and social science in the river and delta influenced areas of the coastal zone. Synthesis is best done with highly collaborative, diverse, groups that span a range of academic backgrounds, professional levels, and experiences.

- This team also examined the role of research organizations that were best suited for Gulf-based work. While it was recognized that successful research can be done by a range of organizations, often government agencies are best at long-term monitoring and data collection, universities are best at hypothesis driven or experimental research, and that there is a developing role for private (both non-profit and for-profit) organizations in research. Finally, this team recognized the importance of involving managers into research at all stages in order to enhance restoration and protection efforts that are needed in the Gulf in the decades ahead.

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