Improving the Enabling Environments for Ecosystem-Based Coastal Restoration and Protection Through the Use of Ecological Modeling

Case Studies from the Mississippi River Delta and the Coastal Netherlands

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Executive Summary

This research culminates my time in the Johns Hopkins University Environmental Science and Policy Master's Program. Originally from Louisiana, I was in New Orleans for Hurricane Katrina in 2005, helped rehab oiled sea turtles after the 2010 BP spill in the Gulf of Mexico, and grew up enjoying the bayou at the Mississippi River Delta. I worked for three years in Washington, D.C. at the National Fish and Wildlife Foundation focusing on ecosystem projects in the Gulf of Mexico resulting from funds directed from the 2012 BP settlement. I began the Hopkins program in 2015, and nearly every class drew me back to issues in the Gulf. In May 2016, a renewable energy course led me to the Benelux region, where I first observed the palpable similarity between the Netherlands and Louisiana coastal systems. On a visit to the Dutch Sand Motor and Maeslant storm surge barrier, I became enthralled, and the topic of my research was clear.

Throughout the Capstone Project, I have lived in Paris, France, traveling often to the Netherlands for my research on the coastal systems involved. This project was monumental to the culmination of my studies, and I am more inspired than ever to continue doing what I can to help protect coastal communities and nature simultaneously, using newer ecosystem-based restoration approaches.

My research taught me a great deal about the two governance frameworks, and where breaks exist between a European, centralized policy and a U.S. bottom-up policy. I learned about ecological modeling and the corresponding research being conducted right now that will drive more solid data and thereby success. I have garnered a strong understanding of policy limitations as well as means of enhancing enabling environments. I also learned invaluable research, interview, and writing skills.

The knowledge I learned over this semester was unparalleled, and I am thankful for the opportunity to have met so many talented people in Louisiana and Europe and to have witnessed firsthand the research and innovation driving coastal projects. The biggest theme I learned from this project is a need for positive action to take place *now* in order to protect coastlines. I hope that others will capture the same sense of urgency from my work and that it might prove useful in helping to protect treasured ecosystems and communities.

Introduction

The Coastal Netherlands and U.S. Mississippi River Delta in Coastal Louisiana share a unique feature: both areas are low-lying river deltas, threatened by some of the highest land subsidence and eustatic sea-level rise rates in the world. The regions are at-risk from land loss, flooding, and storm surge and in need of coastal protection and restoration measures with an ecological component for long-term sustainability.[1] The best policy and decision-making should be informed by best available science and knowledge; however, this science may not advance at the same rate as policy setting. Modeling can be used for taking limited knowledge and extending it into enhanced current understanding as well as future predictions, making it a useful tool for this type of management and decision-making.

An enabling environment is a policy and decision-making framework for implementing management actions.[2] In the past, a surplus of physical models influenced enabling environments for hard engineering solutions to coastal problems, known as "gray infrastructure," including the levee/dyke systems. These engineered solutions can be ecologically harmful, costly to maintain, and are unsustainable in a changing world. Newer solutions may emphasize the use of ecosystem-based restoration and protection, coastal solutions that work with nature to develop results, but more modeling is needed to enhance these options.

While ecological modeling currently exists in each location, and the need for further modeling studies is considered, there is an absence of current literature on whether the modeling is and should be absorbed to effect change, and if so, how. These two locations will be compared to

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[1] Day Jr. et al., "Implications of Global Climatic Change and Energy Cost and Availability for the Restoration of the Mississippi Delta"; Temmerman et al., "Ecosystem-Based Coastal Defence in the Face of Global Change"; Morris et al., "Responses of Coastal Wetlands to Rising Sea Level."

[2] Thindwa, "Enabling Environment for Civil Society in CDD Projects."

provide results that may demonstrate coastal ecological modeling benefits to a policy realm. This is particularly important to evaluate as the northern Gulf Coast is critically threatened by land loss, and both areas face growing threats from rising sea levels, so receiving landscape-scale restoration effort, utilizing that effort, and funding for most effective outcomes requires first-rate decision-making and management.[3] Restoration approaches that enhance sustainable ecosystems and communities while reducing community vulnerability and risk, such as soft, nature-based or green infrastructure measures of management, referred to throughout this paper as ecosystem-based restoration (EBR), can support these multiple goals.

By researching the ways in which ecological modeling can help frame policy for ecosystem-based restoration, this study can help to enact that positive change and possibly contribute to ways to do so in the future. As such, it is important to think about the governance framework in each location as relates to coastal policy; uncover blockages that exist in implementing ecosystem-based restoration; find ways to improve its enabling environment; and finally to use this information to think about how new forms of ecological modeling can be applied. The study will investigate whether an increased use and understanding of coastal ecological modeling, versus a sole focus on coastal protection modeling, can help allow development of policy to enhance the enabling environments for ecosystem-based coastal restoration in the Netherlands and Mississippi River Delta.

[3] Rutger, Rotmans, and Loorbach, "The Transition in Dutch Water Management"; Day et al., "Pattern and Process of Land Loss in the Mississippi Delta."

Further Background

Historical Context of Two Systems

With complementary histories of flood events, hydraulic engineering, boosting port economies, and rising community structures, the Coastal Netherlands and Mississippi River Delta have many similarities; however, they sit on opposite sides of the Atlantic with different historical and current managerial contexts. Major differences occur largely in recent years, both in coastal policy decisions as well as natural occurrences. Current trends show the Netherlands coastline accreting sediment, fighting subsidence, and boosted by an army of scientists, researchers, and volunteers who are promoting policy that focuses on being proactive against disasters associated with rising sea levels, despite challenges in the project implementation stage.[4] The Louisiana coastline faces a different story, with very high rates of wetlands loss and vulnerability from sea-level rise and storm surge, exposing an acute need for action still in preliminary stages.[5]

Netherlands Coastal History:

The Netherlands is an innovative European country with a long history of flood protection and coastal engineering. The name of the country itself, "Nederland" is derived from the Dutch word "neder," meaning low, land. About one-fourth of the country is below sea level, and the Dutch must work to keep water levels low enough to protect from flooding while high enough to protect from subsidence, making flood protection a central Dutch way of life. The Rhine, Meuse, Scheldt, and Ems rivers all run through the Netherlands into the North Sea.[6] Due to ports and harbors in

[4] Bakker, *Ecology of Salt Marshes*; Rutger, Rotmans, and Loorbach, "The Transition in Dutch Water Management."
[5] Day et al., "Pattern and Process of Land Loss in the Mississippi Delta"; Day et al., "Restoration of the Mississippi Delta."
[6] Wesselink, et al., "Dutch dealings with the Delta."

the area, roughly 65 percent of the Netherlands' GNP is brought in from the coast. In addition, nine million people reside in and form the country's coastal communities.[7]

The history of Netherlands coastal engineering begins before the year 700 with the Romans, who built early structures called terpens, similar to hills, to live on should flooding occur. The first floodwalls, called dykes, and water channels, called sluices, connected the terpens for water control. Later, windmills were built to help pump water out of the city, which caused the land to sink and the beginning of subsidence in the country as manmade phenomena.[8] Low-lying areas were designed as polders, using dykes to enclose the land on all sides for protection, and canals were built for drainage. Water boards of local leadership were created as the early decision-makers for hydraulic engineering.[9]

An extreme flood event in 1953 prompted the advancement of new coastal management measures for the Netherlands. The flood was led by a devastating storm surge, which breached nearly 150 dykes and inundated the coastal Netherlands completely. With 1,800 deaths, thousands of refugees and great economic and ecological stress, the event led to the creation of the Delta Plan to reevaluate coastal policy.[10] Delta Works, a restoration and protection project originally designed in the 1930's, was reignited at this time to present new management schemes and complex hydraulic engineering including dams and barriers to prevent future floods. Since, higher dams, locks, and eventually storm surge barriers have been created through this plan.

More recently, since the environmental movement of the 1970's, the Dutch have largely moved from hard to soft measures of flood control, prioritizing natural systems and ecosystem services in

[7] Kabat et al., "Dutch Coasts in Transition."
[8] Vossestein, *The Dutch and Their Delta*, 21–23.
[9] Wesselink, et al., "Dutch dealings with the Delta."
[10] Herman Gerritsen, "What Happened in 1953? The Big Flood in the Netherlands in Retrospect."

their flood protection.[11] The Second Delta Committee was established in 2008 to help incorporate these tools for the future, and eventually, environmental coastal programs including Building with Nature and Ecoshape were activated for these types of projects.[12] Dutch flood control incorporates such ideas as the Maeslant barrier on the Nieuwe Waterweg – a unique and innovative giant storm surge barrier with the ability to move opened and closed; Room for the River – a project to give more "room" naturally to the river for flood events; and the Sand Motor – a pilot project to naturally move sand along the coast. While barriers to ecosystem-based restoration exist, by continuing to enact current planning efforts and research, the Dutch are moving forward on working with nature to protect their coast and build a sustainable future. Ways in which the Dutch work to achieve this are researched and then put into an ecological modeling context.

Mississippi River Delta Coastal History:

The coastal history surrounding the Mississippi River's southernmost delta can be strongly compared to the Dutch context. Here, Louisiana's Gulf Coast comprises 37% of the estuarine herbaceous marsh in the U.S. and is crucial as one of the nation's largest port systems; the largest commercial fishery in the lower 48 states; habitat for waterfowl, fish, and wildlife; storm defense for coastal communities; and more.[13] The Mississippi River flow rate is on average 600,000 cu ft/s (at New Orleans), and at its base is comprised of a complex system of wetlands.[14] Wetlands are the first line of armor against storm surge, but Louisiana is losing more shoreline than all other states in the continental U.S. combined, at a rate of 42.9 km^2 per year (1985-2010 average),[15] or as

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[11] "Remaking 'Nature': The Ecological Turn in Dutch Water Management."
[12] "How the Second Delta Committee Set the Agenda for Climate Adaptation Policy."
[13] Glick et al., "Potential Effects of Sea-Level Rise on Coastal Wetlands in Southeastern Louisiana."
[14] "USGS Scientific Investigations Map 3164: Land Area Change in Coastal Louisiana from 1932 to 2010."
[15] Bailey, Gramling, and Laska, "Complexities of Resilience"; Couvillion et al., "Forecasting the Effects of Coastal Protection and Restoration Projects on Wetland Morphology in Coastal Louisiana under Multiple Environmental Uncertainty Scenarios."

often quoted, about equivalent to a football field an hour. This predominantly began with the construction of levees at the start of engineering for flood protection as early as the 1700's and especially in 1874, when the first U.S. Levee Commission was created, eventually establishing a levees-only flood protection strategy for the Mississippi River Delta.[16]

Similarly to the Netherlands, a great flood increased attention on coastal protection policy. In 1927, flooding of the Mississippi River led to thousands of deaths, as well as changes for flood protection and social movements. Following the flood, the U.S. Army Corps of Engineers (USACE) continued to modify the river with gray infrastructure solutions as flood protection merged into national governance. The Flood Control Act of 1928 created the Mississippi River and Tributaries Project, which in addition to levees, allowed for the construction of large floodways, a spillway, cutoffs, outlets, reservoirs and more.[17] A stronger system of levees was constructed with the Flood Control Act of 1965. Concurrently, from the 1950's to 1970's, oil and gas companies entered and drilled nearly 10,000 miles of canals, further separating wetlands from the Mississippi River.[18] Several levees failed once more with Hurricane Katrina in 2005, again prompting more focus on flood protection, and creating the Coastal Protection and Restoration Authority and Southeast Louisiana Flood Protection Authority.

The levee system, oil and gas canals, plus additional impacts from damming up the river and forming navigation channels, combine to disconnect the river sediment supply and the delta. Sediment deposits from the Mississippi River first created the wetlands many years ago, allowing the land to experience vertical accretion and subsist.[19] With this high level of hydraulic

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[16] Barry John, *Rising Tide: The Great Mississippi Flood of 1927 and How It Changed America.*
[17] Kemp, Day, and Freeman, "Restoring the Sustainability of the Mississippi River Delta."
[18] Turner, "Wetland Loss in the Northern Gulf of Mexico."
[19] Day et al., "Pattern and Process of Land Loss in the Mississippi Delta"; Day et al., "Restoration of the Mississippi Delta"; Turner, "Wetland Loss in the Northern Gulf of Mexico"; Couvillion et al., "Forecasting the Effects of Coastal Protection and Restoration Projects on Wetland Morphology in Coastal Louisiana under Multiple Environmental Uncertainty Scenarios."

engineering cutting off their supply, the wetlands have since lost their land-building capacity. In addition to this, warming temperatures are leading to rising sea levels (SLR) due to thermal expansion and melting ice sheets and glaciers.[20] Today, the deltaic wetlands are disappearing because without sediment replenishment and freshwater supply, wetlands do not have strong enough vertical accretion rates to keep up with rising sea levels and are being engulfed by the sea.

Coastal policy is imperative and central to the core of Louisiana's future. Loss of wetlands destroys entire ecosystems and their services like flood protection and species habitat, threatening coastal communities, industries, and wildlife.[21] After the 2005 storms, changes in coastal policy were integral, and wetlands restoration was finally viewed as a critical component to reducing storm risk, as opposed to exclusively continuing to build gray infrastructure.[22] A state-led Coastal Master Plan (commonly referred to as The 50-Year Plan) was created with an updated plan in development for 2017. Each iteration of the plan encompasses more refined models and project prioritization. The plan is largely focused on enacting a newer concept of landscape-scale river diversions, which will work with nature to redirect the Mississippi River to its wetlands and tributaries and help them fight against SLR with improved sediment deposition and root growth.[23] Other projects include barrier island restoration, oyster reef building, terracing, and additional marsh restoration projects. While a majority of the funding will go toward these EBR strategies, the Master Plan also incorporates gray infrastructure, including levees, walls, floodgates, and pumps. Finally, smaller projects including raising home elevations, flood-proofing, and possible voluntary acquisition are also part of the plan.[24] The plan and its ecosystem options are designed to be carried out using adaptive management, in which projects are adjusted over time to account

[20] Michener et al., "Climate Change, Hurricanes and Tropical Storms, and Rising Sea Level in Coastal Wetlands."
[21] Couvillion et al., "Forecasting the Effects of Coastal Protection and Restoration Projects on Wetland Morphology in Coastal Louisiana under Multiple Environmental Uncertainty Scenarios"; Bailey, Gramling, and Laska, "Complexities of Resilience."
[22] Lopez, "The Multiple Lines of Defense Strategy to Sustain Coastal Louisiana."
[23] Glick et al., "Potential Effects of Sea-Level Rise on Coastal Wetlands in Southeastern Louisiana."
[24] "Louisiana's 2012 Coastal Master Plan.," 71–73.

for unforeseen changes in the natural landscape.[25] Coastal policy here can be slow moving, but it is critical that the Master Plan and sustainable protection be enacted properly and swiftly. This study will look at policy barriers and solutions, then frame them in a modeling context, in an effort to help this critically threatened region retain its coastline.

Governance Frameworks

Table 1. *Delineating the governance frameworks of the Netherlands and Mississippi River Delta.*

	Netherlands	**Mississippi River Delta**
High Level:	EU, River alliances	National/Federal, Congress, ACE
Mid Level:	Rijkswaterstaat, Several ministries	State, CPRA
Local:	Water boards, Provinces, Municipalities	Parish, Industry

Netherlands:

High Level: On the EU level internationally, legislation and regulation including mandates, international agreements, and a Water Framework Directive are enacted. This Water Framework Directive from 2000 gave EU member countries conservation targets to reach by the year 2015, which are now in a review stage.[26] In 2013, a Green Infrastructure Strategy was adopted by the European Commission to promote EBR solutions to general planning and development in the country.[27] There are also International River Basin Commissions in place for cross-border collaboration in the Rhine, Scheldt, Meuse, and Ems rivers.[28]

Mid Level: On the national level, Dutch leaders debate what these international goals mean for their country. This is where project decisions are largely made, contemplating flooding from the Coast and the North Sea, flooding from Germany and the Rhine, and other macro issues before

[25] "Louisiana's 2012 Coastal Master Plan."
[26] "Introduction to the New EU Water Framework Directive - Environment - European Commission."
[27] European Commission, Report of the Expert Group on the Interim Evaluation
[28] "Assessment and Recommendations Water Governance in the Netherlands Fit for the Future?"

sending them to regional bodies.[29] The Rijkswaterstaat, part of the Dutch Ministry of Infrastructure and the Environment, is largely associated with project planning and coastal protection. Several other ministries are also involved including the Ministry of Transport, Public Works and Water Management; Ministry of Agriculture, Nature and Food Quality (LNV); Ministry of Housing, Spatial Planning and the Environment (VROM); and Ministry of Economic Affairs.[30]

<u>Local:</u> At the regional level, there are 12 provinces involved in planning and supervising regional water authorities. Regional Water Authorities at the watershed level, called local water boards and with a total number of 24, cover maintaining infrastructure, managing projects, and controlling flooding and/or subsidence. They also hold significant decision-making power, as long as they are meeting targets for the country.[31] At the most local municipal level, there are an additional 408 municipalities that have some decision-making input, particularly in spatial planning.[32]

In all, coastal policy is at the forefront of the Netherland's political agenda. It begins with a large international policy vision, then translates to the federal level of what that vision means for the Netherlands and its particular set of issues, then turns to the water boards who implement desired projects in their watershed. One other policy level is the stakeholders, including industry, community leaders, and the general public. While they have some potential to steer the debate, these would not usually be considered an overly persuasive policy level.[33]

[29] NL Interviewee 2.
[30] Mulder, Hommes, and Horstman, "Implementation of Coastal Erosion Management in the Netherlands."
[31] NL Interviewee 2.
[32] "Assessment and Recommendations Water Governance in the Netherlands Fit for the Future?"
[33] NL Interviewee 2.

Mississippi River Delta:

The governance framework in the Mississippi River Delta is largely state-centric, with funding coming in from decisions made on a federal level, project decisions and executions made on a state level, and local leaders and industry playing a major role in the decision-making arena.

High Level: Coastal policy in the U.S. is framed on a federal level largely with The Army Corps of Engineers, a federal agency responsible for national water-related issues that manages the nation's flood risk, associated with levee maintenance. They report to the U.S. Congress, who can make broad legislative decisions. Federal statutes such as NEPA, the Endangered Species Act, and the Clean Water Act, are considered in coastal policy. In addition, much of the funding provided is federal, including money from The Coastal Wetlands Planning, Protection and Restoration Act (CWPPRA) (16 U.S.C. 3951) passed by Bush, G.W., that helps fund coastal wetlands restoration projects, and more recently from the Restore Act, which was passed by President Obama and provides a restoration trust fund in the U.S. Treasury based on OMB Guidance from the Clean Water Act.[34]

Mid Level: At the state level in Louisiana, the Coastal Protection and Restoration Authority (CPRA) is the main authority for coastal issues, tasked with the development of the long-term, 50-year Coastal Master Plan. On a funding level, the state was granted billions of dollars from a federal decision of BP settlement funds resulting from the 2010 Deepwater Horizon oil spill.

Local: At the parish or county level, officials can make decisions by application and status as a local coastal zone management program. Money from federal funds is allocated to parishes based

[34] *Resources and Ecosystems Sustainability, Tourist Opportunities, and Revived Economies of the Gulf Coast States Act of 2012 (RESTORE Act).*

on a formula that includes population size and miles of shoreline.[35] The state incentivizes cooperation with the Master Plan by offering matching funds for projects in parishes that help the Master Plan.

Finally, community opinion is influential as communities and community leaders and/or industry can be vocal when opposed to a project. The most considerable difference between the Mississippi Delta and the Netherlands in coastal policy is possibly the role that public opinion plays. In the Netherlands, industry and community leaders can steer but not make decisions, whereas in the Mississippi Delta industry and community leaders yield a great amount of power.

Also notable is that the two administrations share ideas and hold a good deal of collaboration and information sharing. An example of this on the national level is a Levee Safety Working Group developed between the USACE and the NL Rijkswaterstaat.

Ecosystem-Based Restoration

Ecosystem-based restoration is an addition to traditional gray infrastructure approaches to coastal protection and adaptation that uses natural coastal infrastructure to enhance the sustainability of an ecosystem while protecting its community from risk. By focusing on the ecosystem as a whole, EBR uses the goods and services naturally provided as multiple lines of defense in flood protection. Ecosystem-based approaches should maximize the sustainable benefit for all organisms, plants, and habitats in the project area; utilize both abiotic and biotic approaches[36]; be adaptive with a changing environment; and provide recognized ecosystem services to

[35] *Coastal Impact Assistance Program*.
[36] NL Interviewee 3.

communities, which include protection, food, livelihood, and intrinsic cultural values. The focus is on achieving combined goals by coupling protection of ecological and social systems.[37]

Netherlands:

In the Netherlands, the recent move toward ecosystem-based restoration approaches largely stemmed from an increased knowledge and care of the environmental degradation caused by some gray infrastructure. Historically the sediment rate was increased with groundwater extraction. After the Great Flood of 1953, Delta Works introduced bundles of classic gray infrastructure with the primary goal of flood protection. The dyke system was found to cause sediment to accumulate in riverbeds rather than reaching its wetlands and floodplains, causing overly high sedimentation in riverbeds and subsidence in the low-lying polders, with a need to continuously build higher and higher dykes.[38] This led to habitat loss, eutrophication, reduced flow, sediment disruptions,[39] increased erosion, and toxic algae blooms.[40] The latest import of EBR is seen by some as a measure to undo some of the environmental degradation caused by Delta Works in the 1950's.[41] Here, ecosystem-based restoration is most often referred to as "building with nature."[42]

Mississippi River Delta:

The Mississippi River Delta is a naturally complex and dynamic system. Sediment trapped throughout the 30,000 km^2 watershed of the Mississippi River is deposited behind water control structures along the River, influencing downstream conditions.[43] Human activities, such as clearing, agriculture, and damming, historically contributed to this.[44] After the Great Flood of

[37] Roy et al., "Living within Dynamic Social-Ecological Freshwater Systems."
[38] Wesselink, et al., "Dutch dealings with the Delta."
[39] van Wesenbeeck et al., "Damming Deltas."
[40] Verspagen et al., "Water management strategies against toxic Microcystis blooms in the Dutch delta."
[41] NL Interviewee 2.
[42] NL Interviewee 3.
[43] Coleman, Roberts, and Stone, "Mississippi River Delta."
[44] MRD Interviewee 4.

1927, persistently altered hydrology of the river at its delta with levees and other gray infrastructure was effective at preventing floods but held unintended consequences of disconnecting the river sediment and the delta, contributing to wetlands and habitat loss today. Ecosystem-based management first entered the scene as an alternative to single species management in fisheries, founded on the idea that the health of one species was dependent on the health of other species and of the system as a whole.[45] Today, its importance is largely related to reducing wetlands loss, with the CPRA primary metric as land building and reducing land loss.[46] There is consideration of the entire system to prevent against flooding and storm surge while also protecting wetlands, two goals with co-benefits. EBR has also been shown as more cost effective in the long run than continued costs of maintaining gray infrastructure.[47]

Ecosystem-based restoration has many definitions and thoughts. It can be referred to by different names by different important actors including "green infrastructure" (EPA, European Commission),[48] "integrated coastal management" (UNEP),[49] "living shorelines" (NOAA),[50] and more. There is also a spectrum for classifying these projects, as coastal projects may be hybrids with variable levels of both natural and gray infrastructure.

In all, the unintended environmental consequences of some gray infrastructure approaches are now well documented and range from impairing hydrodynamics and sediment budgets to threatening local economies, plant and animal life.[51] The EBR approach to restoration helps benefit plants,

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[45] MRD Interviewee 6.
[46] "Louisiana's 2012 Coastal Master Plan."
[47] Broekx et al., "Designing a Long-Term Flood Risk Management Plan for the Scheldt Estuary Using a Risk-Based Approach."
[48] US EPA, "What Is Green Infrastructure?"; "EUR-Lex - 52013DC0249 - EN - EUR-Lex."
[49] ":: UNEP :: Regional Seas Programme."
[50] "NOAA Guidance for Considering the Use of Living Shorelines."
[51] "Coastal Adaptation with Ecological Engineering."

animals, nature, people, industry, and everything in between, while remaining sustainable for dynamic coastal systems.[52]

Ecological Modeling

A conceptual model is built to look at and communicate a research question in its early stages. Next, quantitative models (QM) are those that use mathematical expressions in evaluating research questions and results. QM's can take many forms and complexities. Ecosystem models are complex QM's that incorporate different aspects of ecosystems to develop a greater understanding of the ecosystem in real life. They serve many purposes in understanding ecosystems including analyzing status and concepts, integrating large data sets, revealing trends, simulating processes, and making predictions.[53]

Modeling tools have improved greatly in the last century. In the early 20th century, models representing physical processes only were produced as actual build scale models. In the U.S., physical build scale models were the common approach used by engineers to design the levee system in Louisiana. Protection was designed with the use of a standard-project hurricane that any particular type of event was the one that would be analyzed. In the United States during World War II, physical coastal models were produced to support landing on beaches, improving their capacity. Similarly, in the Netherlands, scale models and qualitative assessments were used in dyke design. After the Flood of 1953, statistics were first involved in models used for Delta Works.[54]

[52] Broekx et al., "Designing a Long-Term Flood Risk Management Plan for the Scheldt Estuary Using a Risk-Based Approach."
[53] Lookingbill et al., "Chapter 9."
[54] Wesselink, et al., "Dutch dealings with the Delta."

In the 1970's, a transformation occurred in both locations. On the one hand, advances in field measuring capability were achieved and modeling began a process of reductionism matched with greater detail. At the same time, a global environmental movement began, as public opinion and policy regimes shifted toward environmental issues. In the 1980's and 90's, computers were able to integrate that knowledge of detail and concern for the environment, particularly using geochemistry, and physical build scale models did not need to be used as often. With a greater need for an understanding of ecosystems, computer models were used to model physical processes, such as hydrology and bathymetry, as well as ecological processes, such as primary and secondary production. Eventually, knowledge and validation of certain ecological processes were readily available and used.[55]

In the U.S., the first efforts to link ecological modeling to the restoration of coastal systems are contested. Some would say they began in the Everglades, and others that they date back to Louisiana and the Costanza Coastal Ecological Landscape Simulations Model (CELS).[56] Yet more might date them back to the Chesapeake Bay Estuarine models in 1983, when computers were first used to model the watershed.[57] In Louisiana, the 2007 Coastal Master Plan in Louisiana was largely conceptual, so the 2012 Coastal Master Plan developed a set of ecological modeling tools to help think about the outcomes of the Plan, the value of which was widely recognized.

In the Netherlands, ecological modeling for coastal systems was first attempted in 1977 in relation to the Oosterschelde Dam project, when a powerful movement was incited by environmentalists and fishermen to prevent the construction of a dam. Eventually, the government ceded and called for a feasibility study of a moveable storm surge barrier. A study called "Protecting an Estuary

[55] "Remaking 'Nature': The Ecological Turn in Dutch Water Management."
[56] Costanza, et al., "Modeling Coastal Landscape Dynamics."
[57] Keiner, ""Modeling Neptune's Garden."

from Floods – Policy Analysis of the Oosterschelde" (POLANO) was contracted by the government to a group named RAND, which ran ecosystem models to evaluate the impact of different projects on the Oosterschelde ecosystem. In place of the dam, the government built a moveable storm surge barrier to prevent a large amount of the major environmental degradation that the dam would have caused, first demonstrating the value of ecological modeling in a policy framework. Later, in 1989, an ecological calibration standard was created for ecosystem models, the General Method for Ecological Description, called AMOEBE's, which enhanced model capacity greatly.[58]

Today, ecological modeling is performed on many coastal projects in both locations. Ridge to reef approaches are considered in many locations to manage coral reef conservation using landscape-scale projects that focus on the ecosystem as a whole, with a wide array of modeling studies to link land and water systems.[59] In the Mississippi Delta and the Netherlands, ecological modeling is performed for deltaic systems, but there are also still many information gaps. Modeling ecosystems is an important tool to show the usefulness of EBR for many reasons including making predictions, simulating projects, influencing policy, evaluating science and more. This study will look at the way ecosystem models can be used to increase the enabling environment from a policy framework.

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[58] "Remaking 'Nature': The Ecological Turn in Dutch Water Management."
[59] "Ridges to Reef Fisheries."

Methods

Data collected in this research came from both quantitative and qualitative methods. Sources of information included a review of the literature, review of government technical reports, interviews with scientists and other experts, and project-level case study analysis.

This data was used to show the governance framework in each location and the policy blockages that presented themselves to form barriers in enacting EBR. The data was also used to present approaches for increasing enabling environments in each location. Case studies were utilized to help evaluate the results of the study with solid examples in EBR projects. The approaches used for synthesizing current knowledge and opinion are further described below.

MI. Literature-Based Approach

A review of the literature related to my topics was performed to determine the current state of knowledge as well as knowledge gaps. This helped reveal both blockages and enhancement approaches for EBR as found in interviews as well as to fill in the gaps.

MII. Interview Approach

Interviews were performed to evaluate expert opinion on the research performed. Interviewees were primarily scientists and other experts informed at the various governance levels. In Louisiana, key organizations and higher research institutes were scanned and approached to find contacts. Well-known authors, journalists, and engineers were also asked. In the Netherlands, key organizations and higher research institutes were scanned and approached for experts willing to provide information. Questions asked were adjusted for each location and individual (see Appendix). Interviews were a mean length of one hour and 11 people were interviewed in total.

Table 2. *Interviewees.*

Institute	Expertise	Location
1. Architecture Firm	Water Architect and Manager	New Orleans, Louisiana
2. Deltares	Researcher for Governance and Building with Nature	Delft, Netherlands
3. Deltares	Researcher and Advisor for Marine and Coastal Management	Delft, Netherlands
4. Deltares	Researcher and Advisor for Marine and Coastal Management	Delft, Netherlands
5. Leiden University	Researcher and Associate Professor	The Hague, Netherlands
6. Loyola University	Environmental Communication	New Orleans, Louisiana
7. LSU Sea Grant Program	Director and Professor	Baton Rouge, Louisiana
8. The Lens	Journalist	New Orleans, Louisiana
9. The Water Institute of the Gulf	Natural Systems Director	Baton Rouge, Louisiana
10. The Water Institute of the Gulf	Policy Research and General Counsel	Baton Rouge, Louisiana
11. The Water Institute of the Gulf	Scientist	Baton Rouge, Louisiana

MIII. Identification of Policy Blockages and Approaches to Enhance Enabling Environments with Sources of Information

Tables were created to summarize the literature and interviews, identify commonly raised topics, and carry out a gap analysis. Table 4 looked at the data presented in commonly raised blockages to ecosystem-based restoration and Table 5 looked at data presented in commonly raised approaches for enhancing enabling environments. Blockages and approaches were then listed and evaluated in a prioritized order for each location. Tables 4 and 5 are found in the Results Section, page 24 and 32 respectively.

MIV. Case Study Approach

A case study approach was employed to further analyze the results based on specific examples of EBR projects. Information for case studies was collected from literature, interviewees and site visits.

Table 3. *List of case studies, with each case encompassing one current EBR project in the Netherlands or Mississippi River Delta.*

Case Study:	Page Reference:
Room for the River (NL)	37-38
The Sand Motor (NL)	39-40
River Diversions (LA)	41-42
Barrier Island Restoration (LA)	43-44

Each of these major EBR approaches was analyzed for (1) a description and history of the project; (2) the policy framework of the project; (3) the blockages and approaches to enhance taken from the study results; and (4) modeling capacity. In describing these case studies, the potential of ecological modeling to enhance the enabling environments for EBR policy both previously and for the future was explored.

Gray infrastructure including levees in the Mississippi Delta and dykes in the Netherlands were also studied for comparison and use of physical models in their enabling environments.

MV. Modeling Uptake in Case Studies

Table 10 was created to directly discuss the correlation between modeling use and project status, in the absence of other factors, and to show by example some projects where modeling use directly linked to decision-making. Table 10 can be found in the Discussion section, page 45.

MVI. Linkages of Results

A final results table was created to incorporate all aspects of the study into answering the initial research questions and determining whether enabling environments could be improved through a greater use of ecological modeling studies. This data was used to discuss the study results from a solution framework and to then recommend a way forward. Table 11 can be found in the Discussion section, page 47.

Results

Overall Blockages Found to Inhibit Enabling Environments of Ecosystem-Based Restoration

Despite the proven ecosystem benefits of coastal ecosystem-based restoration, questions asked in both interviews and literature revealed that these projects are not easily implemented and faced blockages from respective policy frameworks. Because of this, on the global scale, very few landscape-scale projects have been implemented this way.

Table 4. *Relationship of the different sources of information in determining policy blockages for EBR, demonstrating cross-cultural trends and existing gaps in the literature.*

Blockages	**Interviewees**		**Literature**	
	NL	LA	NL	LA
1. Disparate and minimal actors	X (3)	X (2)	X	X
2. Lack of knowledge and awareness	X (2)	X (2)		X
3. Lack of funding	X (2)	X (2)	X	X
4. Diversity of societal interests		X (4)		
5. Engaging community opinion	X (1)	X (2)	X	
6. Scale		X (2)	X	X
7. Designed EBR projects not implemented as such	X (2)		X	

Blockages Found in the Netherlands:

Key Blockages

In prioritized order:

1. Disparate and minimal actors
2. Designed EBR projects not implemented as such
3. Lack of knowledge and awareness
4. Lack of funding
5. Engaging community opinion

In the Netherlands, a major blockage in enabling EBR was policy fragmentation, with disparate and minimal actors. With divided actors often influenced by local scale political needs and priorities, a challenge was presented.[60] In the Netherlands, the several different ministries involved in coastal planning were found to be discordant, further slowing possible EBR legislation. Each ministry was charged with working on different aspects of coastal and societal issues without Minister intervention, leading to a lack of responsibility by any one actor. The limited community support of EBR and resulting limited influence on Dutch politicians resulted in a blockage to adapt to these solutions.[61]

Further, in the Netherlands, projects designed as ecosystem-based (or nature-based) restoration were not always implemented as such.[62] An example was found in coastline management or sand nourishment projects, where the Dutch government nourishes the coastline to prevent it from sinking and allow it to accrete despite SLR.[63] Originally intended to combine sustainability with protection, in some nourishments aspects other than flood protection were not fulfilled in project execution.[64] Ideas that specific nourishments might be more expensive or take away from flood protection led to gray infrastructure being included in project implementation, and natural nourishments reduced.[65]

Lack of knowledge and awareness, due to limited knowledge-sharing, was a perceived blockage in both the public and political arena. A common conviction was held that aspects of natural programs can take away from flood protection, and wide uncertainty existed pertaining to some of the benefits as relates to flood protection.[66] On a global scale, the relative newness of EBR

[60] NL Interviewee 2; NL Interviewee 3.
[61] Mulder, Hommes, and Horstman, "Implementation of Coastal Erosion Management in the Netherlands"; "Eb En Vloed Wachten Op Niemand, Bouwstenen Voor de Deltacommissie | TU Delft Repositories."
[62] NL Interviewee 3.
[63] NL Interviewee 4.
[64] Mulder, Hommes, and Horstman, "Implementation of Coastal Erosion Management in the Netherlands"; Lubbeers et al., "Evaluatie Derde Kustnota."
[65] NL Interviewee 3.
[66] NL Interviewee 2; NL Interviewee 4.

approaches showed that not enough long-term studies currently exist.[67] Finally, the public was found to hold a general mindset that they were protected and not in need of updated coastal strategies, and only were put on guard after major flood events.[68]

Funding was cited as a problem in that EBR may be more expensive at launch than certain gray infrastructure projects, with lesser-known protection benefits.[69] A cost-benefit analysis was found difficult to perform for these projects as compared to gray infrastructure, particularly in quantifying externalities such as benefits in monetary terms.[70]

A final challenge was related to engaging community opinion. Public opinion could work both for and against EBR projects in the Netherlands. In Room for the River, community opinion was highly favorable and helped improve its enabling environment, then morphed into a permeating negative attitude toward giving land back to the sea.[71] Moving people, or "managed realignment," as part of a deepening project in the Zeeland Province received a great deal of pushback from the local community. People had experienced the Great Flood of 1953 and a long history of water battles and were fundamentally opposed to returning coastal land to the sea.[72] Several protests took place and the project is now headed to court. Projected to happen regardless, public opinion and litigation hindered this project, and could certainly have stalled its timeline.[73] This embedded attitude against giving valuable land back to the water was therefore influential in policy making.[74]

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[67] Temmerman et al., "Ecosystem-Based Coastal Defence in the Face of Global Change."
[68] Wesselink, et al., "Dutch dealings with the Delta."
[69] NL Interviewee 2; NL Interviewee 3.
[70] "Coastal Adaptation with Ecological Engineering."
[71] NL Interviewee 3.
[72] Wesselink, et al., "Dutch dealings with the Delta."
[73] NL Interviewee 3.
[74] Temmerman et al., "Ecosystem-Based Coastal Defence in the Face of Global Change."

Blockages Found in the Mississippi River Delta:

Key Blockages

In prioritized order:

1. Diversity of societal interests
2. Lack of knowledge and awareness
3. Engaging community opinion
4. Disparate and minimal actors
5. Scale
6. Lack of funding

In the Mississippi River Delta, where landscape-scale EBR projects were found primarily to be in an E&D phase, several challenges were cited as blockages to implementation. The most universally asserted challenge related to a diversity of interests and players in the area. Multiple sectors including the oil and gas industry, recreational and commercial fishing industry, environmental groups, coastal communities, and government, were cited as having an array of different aspirations for LA coastal policy. Coastal decisions were found unlikely to be supported by all actors, with a roadblock to EBR existing when resistance came about from any one of these groups.[75] As a result, short-term and long-term goals of projects were often obverse.[76] Blockages from big business were strong due to the wealth and power of those putting money into gray infrastructure projects, such as levees, seawalls, and other hard structural methods.[77] For instance, a lawsuit from the Southeast Louisiana Flood Protection Authority-East's (SLFPA-E) was presented but has been blocked against 97 oil and gas and pipeline companies for their original role in wetlands loss and need to remediate by filling in canals or mitigating.[78]

Another widely mentioned blockage in the Mississippi Delta related to lack of awareness and knowledge. An observed challenge found that when people were kept in the dark they believed

[75] MRD Interviewee 2; MRD Interviewee 3; MRD Interviewee 4; MRD Interviewee 6.
[76] MRD Interviewee 3.
[77] MRD Interviewee 2.
[78] "Petition-for-Damages-and-Injunctive-Relief."

their specific interest could be harmed and projects were not implemented.[79] Scientists and engineers did not always understand public demand, widening the gap between best available knowledge and the public and political spheres for restoration measures.[80] For example, a majority of people in a 2013 Coastal Louisiana study believed that wetlands loss should be addressed, but fewer than 60% of participants believed that wetlands restoration would reduce storm surge impact in their local community. This reduced perception directly correlated to lower levels of public trust in government.[81] Another example was following the BP oil spill, when lack of trust in the government led to a public overestimation of risk and dangers related to prolonged effects of the disaster.[82] Globally, a study in the Pacific Islands found that the ability of governments to advise communities was a major barrier to EBR, with a related consequence that the people in the region did not understand its benefits, and continued to favor gray infrastructure.[83]

Related to this lack of awareness and diversity of interests was a blockage of engaging community opinion in support of projects. Public opinion stood in the way when (1) an embedded history led people to disfavor a project; (2) policy leaders were swayed by their constituencies; or (3) there was perception that solid structures provide more flood protection. A further public perception was that EBR projects, even if enacted swiftly using best practices, would be ineffective due to sea-level rise.[84] Some experts also believed either not enough data existed or vulnerability would increase despite best EBR efforts.[85] The current rate of eustatic SLR was approximately 3 mm/yr. along the Gulf Coast, even greater than the increasing global rate of 1.8 mm/yr., and in

[79] MRD Interviewee 3.
[80] MRD Interviewee 4; Blind et al., "Chapter 2.4."
[81] Kim and Petrolia, "Public Perceptions of Wetland Restoration Benefits in Louisiana."
[82] Simon-Friedt et al., "Louisiana Residents' Self-Reported Lack of Information Following the Deepwater Horizon Oil Spill."
[83] Hills et al., "A Social and Ecological Imperative for Ecosystem-Based Adaptation to Climate Change in the Pacific Islands."
[84] MRD Interviewee 4.
[85] Young, "Restoring Coastal Louisiana Will Not Guarantee the Protection of Infrastructure from Storms: Policy Makers Should Also Plan for Strategic Relocation of Critical Infrastructure and Vulnerable Communities."

combination with high land subsidence rates of 10mm/year.[86] Another challenge is that EBR projects can include voluntary flooding of areas previously dry or changes that would affect economic interests.[87] Public opinion was found to have strong, embedded history due to a long history of resilience in the region.[88] Voluntary acquisition, as cited by the Coastal Master Plan, would not be easily implemented.

With disparate actors involved in flood protection policy, goals or initiatives could easily get crossed.[89] The CPRA was originally designed as a way to direct all Louisiana coastal dollars to one place and avoid fragmentation, but this blockage remained a long-standing challenge. The diversity of interests mentioned above is governed by different agencies with different plans, mandates, and priorities. While the Master Plan calls for coordination involving different stakeholders, research reveals an overall comprehensive governance framework still not yet in place.[90] An example on the federal level was that projects needed section 404 and section 10 permits, as well as a coastal use program under the state. These programs were all developed in a protective manner and focused heavily on gray infrastructure. Local authorities may continue to use gray infrastructure when the permitting process and its associated time and costs are already familiar. It may take additional time and costs to gain permits for EBR projects as they are newer to much of the Coast. A corresponding theory cited was the tragedy of the commons, when a locally elected government official with term limits protects his or her constituency by selecting the best short-term solution to evidence change, usually gray infrastructure.[91] The cumulative effect of individual acts together could create serious economic damage and a barrier to enacting

[86] Anderson et al., "Variable Response of Coastal Environments of the Northwestern Gulf of Mexico to Sea-Level Rise and Climate Change"; Yuill, Lavoie, and Reed, "Understanding Subsidence Processes in Coastal Louisiana."
[87] MRD Interviewee 6.
[88] Bailey, Gramling, and Laska, "Complexities of Resilience."
[89] MRD Interviewee 4.
[90] Jordan and Benson, "Governance and the Gulf of Mexico Coast."
[91] MRD Interviewee 2.

EBR, shared-benefit projects. Greater principles were found needed to be set forth in policy terms to increase enabling environments.[92]

Another challenge was the scale of the systems, assuming these projects would require maximum space.[93] This presented a problem in that a large extent of space between the coastline itself and people in the coastal community would be needed to perform EBR projects in general.[94] In Louisiana, an Entergy Corporation study identified over two trillion dollars worth of industrial infrastructure along the Gulf Coast within 70 miles from the coastline.[95] Projects were fragmented but needed to be viewed at a greater scale, as they would require unprecedented scale in terms of the large area at risk and the serious effort needed to accomplish EBR goals.[96]

A final blockage was funding and the cost of projects, which could elevate quite high. For example, costs found for river diversions included large expenses for construction methods, maintenance, operation, land ownership, and regulatory costs, as well as external costs like harm to fishing communities. Public funding was perceived to be disappearing that would protect the lower bird food of the river.[97] A Tulane study found that funding for coastal restoration would be short by at least 71 billion due to factors not previously considered including inflation, federal flood protection factors, and additional projects needed.[98] At the same time, funding from the BP settlement was available, with the primary challenge being how to be most proactive in leveraging that funding.

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[92] MRD Interviewee 4.
[93] MRD Interviewee 6.
[94] Temmerman et al., "Ecosystem-Based Coastal Defence in the Face of Global Change."
[95] MRD Interviewee 2.
[96] Jordan and Benson, "Governance and the Gulf of Mexico Coast."
[97] MRD Interviewee 2; MRD Interviewee 4.
[98] Mark S. Davis, John Driscoll, and Harry Vorhoff. "Financing the Future: Turning Coastal Restoration and Protection Plans Into Realities: The Cost of Comprehensive Coastal Restoration and Protection."

Comparison and Analysis:

An analysis of Table 4 demonstrated that similarities and trends in challenges for EBR existed in everything from policy fragmentation, having the most overall shared mentions, to the cost of projects and lack of awareness the second most, and finally engaging community opinion the next.

Noteworthy location-based differences in policy blockages included the different components of society in the Mississippi Delta, which was the highest cited problem here and not present in the Netherlands discussion. Engaging community opinion was also more heavily cited as a barrier in the Mississippi Delta. Both areas were found to have rooted and cultural positions against giving up land to the sea, but overall issues with the public and industry were more of a barrier in Louisiana than in the Netherlands, aligning with the bottom-up nature of the area and the large amount of industry and community groups present.

In the Netherlands, projects designed as ecosystem-based that did not go into practice as such were mentioned as a barrier not mentioned in the Mississippi Delta context. However, there are also fewer EBR projects at an implementation stage in the Mississippi Delta.

Finally, gap analysis demonstrated the lack of literature focused on the blockages of the diversity of societal interests and engaging community opinion in the Mississippi Delta. In the Netherlands, gaps in the research were much smaller and more literature was found related to policy blockages. Lack of awareness in the science of these projects could be further expounded upon in the literature there. Also in the Netherlands, scale was mentioned as a blockage in the literature but not by the experts interviewed.

Approaches Found for Increasing Enabling Environments of Ecosystem-Based Restoration

To overcome some of the blockages to implementation, much of this research was structured to find ideas for increasing the enabling environments of EBR. The data was pulled together to find the following results for each location and overall.

Table 5. *Demonstrating the relationship of the different sources of information in determining ideas of enhancing enabling environments for EBR, showing cross-cultural trends and differences as well as existing gaps in the literature.*

Approaches	Interviewees		Literature	
	NL	LA	NL	LA
1. Increased Knowledge and Knowledge-Sharing	X (2)	X (3)	X	X
2. Collaboration and Interaction	X (1)	X (2)		
3. Framing the Project	X (2)		X	
4. Leveraging Funding	X (2)			
5. No Alternative Solutions	X (1)			
6. Planning with Adaptive Management		X (1)	X	X
7. Understanding Societal Wants and Incentivizing		X (1)		X
8. Greater Transparency		X (1)		

Enhancing Enabling Environments in the Netherlands:

Key Approaches

In prioritized order:

1. Framing the Project
2. Increased Knowledge and Knowledge-Sharing
3. Leveraging Funding
4. Collaboration and Interaction
5. No Alternative Solutions

One idea cited for increasing enabling environments in the Netherlands was the importance of framing the project. If projects were framed solely for flood protection or were originally designed to be gray infrastructure, there was no objective to look at them in terms of benefits to nature or change them to be more ecosystem-based.[99] When projects were framed with broader objectives than exclusively flood protection, such as Room for the River and the Sand Engine, additional ecosystem goals were eventually fulfilled.[100]

Increased knowledge and knowledge-sharing were also found to increase enabling environments for EBR.[101] The Oosterschelde Dam project was an early example, when increased environmental awareness in the 1970's led to a movement that persuaded parliament to change their plans to reduce environmental harm.[102] The effect of increased environmental knowledge and awareness first became evident with this project. The importance of increased knowledge and utilizing that knowledge to correctly inform both public and government sectors is widely recognized, with an additional need for better organization, dissemination, and integration into the decision-making.[103]

With significant monies in the region dedicated to flood protection, another improvement mentioned was the importance of wisely leveraging funding dollars for nature and flood protection.[104] Another important approach was collaboration and interaction, which is being done with sand nourishment projects by involving nature organizations as project partners in an early stage, preventing any pushback or legal action from these groups.[105]

A final approach mentioned was when there were no alternative solutions in an area, and conventional approaches no longer worked. This was found with the increased costs being

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[99] NL Interviewee 3; Janssen, "Greening Flood Protection in the Netherlands."
[100] NL Interviewee 3.
[101] NL Interviewee 2; NL Interviewee 3.
[102] "Remaking 'Nature': The Ecological Turn in Dutch Water Management."
[103] Janssen, "Greening Flood Protection in the Netherlands."
[104] NL Interviewee 3.
[105] NL Interviewee 4.

discovered both literally and externally of gray infrastructure in the area.[106] However, this situation does not exist as often.

Enhancing Enabling Environments in the Mississippi River Delta:

Key Approaches

In prioritized order:

1. Increased Knowledge and Knowledge-Sharing
2. Collaboration and Interaction
3. Planning with Adaptive Management
4. Understanding Societal Wants and Incentivizing
5. Greater Transparency

In the Mississippi River Delta, several ideas arose for increasing enabling environments for EBR policy, starting with the approach of increased knowledge creation and sharing. There was a need for macro views of coastal Louisiana, rather than the common trend in reductionism for science, and to occasionally generalize, rather than properly replicating everything in the given timeframe and capacity.[107] At the start of talks for the Coastal Master Plan, several projects were brought to the state and there was a state level need to determine which projects to invest in using increased scientific knowledge.[108]

Collaboration and interaction were also found important, with a system needed in which all players may interact and incorporate ideas. Because of the bottom-up framework, greater coordination was needed between the various actors and stakeholders.[109] This could help to increase the use of public-private partnerships in coastal projects. Ideas were discussed including an industry task force to help protect the ecosystem and coastal industries at large by having

[106] NL Interviewee 3.
[107] MRD Interviewee 6.
[108] MRD Interviewee 4; MRD Interviewee 6; MRD Interviewee 7; Kim and Petrolia, "Public Perceptions of Wetland Restoration Benefits in Louisiana."
[109] MRD Interviewee 4.

separate groups join together as a single force to effect change.[110] Collaborating was seen as particularly important in project design, between project developers, biologists, modelers, and others to establish the best possible project and minimize negative impacts.

Because natural systems respond in different ways and are very complex, a need for adaptive management was highlighted for remaining open-minded and innovative in project designs. At times, the response of an ecosystem could not be what was predicted in planning. Adaptive management was found critical in showing a range of outcomes and emphasizing this range to decision-makers while allowing adjustments to be made that maximize the benefits of projects while minimizing any unintended impacts.[111] This tool was found critical to project success and was also a key component of the state's 50 year Master Plan for 2012.[112]

Another tool involved finding a better understanding of what people want.[113] The specific needs of different groups including housing, infrastructure, oil and gas, transportation, and others were important to consider.[114] With this was the idea of helping and incentivizing people on these EBR projects based on a greater understanding of those wants and needs.[115]

Greater transparency was also mentioned as an approach for helping with public awareness and getting public support for projects.[116]

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[110] MRD Interviewee 2.
[111] MRD Interviewee 3.
[112] "Louisiana's 2012 Coastal Master Plan."
[113] MRD Interviewee 6.
[114] Laska et al., "At Risk."
[115] MRD Interviewee 6.
[116] MRD Interviewee 3.

Comparison and Analysis:

Analysis of Table 5 showed primarily that ideas of increasing enabling environments for EBR were spread out and not often mentioned more than once, providing an array of useful policy tools for enhancing enabling environments. A prominent method was the idea of increased knowledge and knowledge-sharing, as the only tool mentioned by multiple interviewees in each location and by the literature in each location.

Differences in enhancement approaches for each place show that Mississippi Delta ideas were more focused on improving public opinion and industry desires toward these projects, demonstrating a prominent role of these forces as policy drivers. Framing the project was mentioned in the Netherlands and not the Mississippi Delta.

Gap analysis showed a need for further literature on improving transparency related to coastal policy in the Mississippi Delta. The analysis also demonstrated adaptive management as a strategy mentioned in EBR in the Netherlands, but not widely discussed by experts.

Case Study Analysis

Room for the River (NL)

Project Description and History

Room for the River is an ecosystem-based restoration project in the Netherlands, which, as the name entails, gives more "room" to the river for flooding occurrences, creating areas where the river can expand safely during high water levels as a natural solution to flooding. Its projects are in 30 locations throughout the Netherlands and use several methods including lowering the flood plain; lowering the river bed; building water retention or storage areas; lowering or building gyrones; depoldering and/or relocating dikes inward; and removing other obstacles.[117]

The Noordwaard is a specific example of a controversial yet successful Room for the River project worth analyzing. A 4,450 hectare polder was removed and the land opened. Where a dyke was still needed, it was built much lower and with willow trees planted alongside to block the wave action. The project is expected to not only aid in flood protection but to further do so by improving the Biesbosch wetlands.[118]

Policy Framework

The Noordward depoldering project was chosen by two regional steering committees, began in 2009, and has since been completed.[119] The project was led by the Rijkswaterstaat on the national level and partnered with the Province of North Brabant, City of Werkendam, and Rivierland Water Authority, thus encompassing many levels of governance in its design and implementation.

[117] "Ruimte Voor de Rivier."
[118] van der Deijl et al., "A Channel Sediment Budget for the 'Kleine Noordwaard' in the Biesbosch Area, the Netherlands."
[119] Ibid.

Enabling Environment

Table 6: *Room for the River policy blockages and approaches to enhance enabling environments (refer to Table 4 for blockages and Table 5 for approaches to enhance enabling environments.)*

Blockages:	2. Lack of knowledge and awareness – some perception that still not natural or would not be effective
	5. Engaging community opinion – fundamental disagreement to return land to sea in Noordward[120]
	6. Scale – more room to riverbeds, space away from coastal communities
Approaches to Enhance:	2. Collaboration and Interaction – policy fragmentation not an issue[121]
	3. Framing the Project
	4. Leveraging funding
	7. Understanding Societal Wants and Incentivizing – Noordward, financial incentivizes to move, kept land agriculturally useful
	8. Greater Transparency – esp. early years of Noordward project

Modeling Capacity – High

Modeling capacity for Room for the River is high and complex. For example, sedimentation has been modeled for the Noordward, and LIDAR data has been used to show sediment budgets.[122] Unfortunately, this study showed that even with the positive sediment accretion, the project is unlikely to keep up to SLR. VU University performs models including GLOFRIS for flood risk, GTSM for sea-level rise, and CaMa Flood for River flooding, with intent to combine the three approaches. Room for the River projects have been evaluated next to gray infrastructure and continued dyke enhancements to emphasize ecological and economic benefits.[123]

[120] de Groot and de Groot, "'Room for River' Measures and Public Visions in the Netherlands."
[121] NL Interviewee 3.
[122] van der Deijl et al., "A Channel Sediment Budget for the 'Kleine Noordwaard' in the Biesbosch Area, the Netherlands."
[123] Klijn, Buuren, and Rooij, "Flood-Risk Management Strategies for an Uncertain Future."

The Sand Motor and Sand Nourishments (NL)

Project Description and History

The Sand Motor, or Sand-Engine, is a large pilot nourishment project in The Hague area that created an artificial peninsula 2 km wide at the shore and lengthening 1 km into the sea. A large and unprecedented deposit of 21.5 Mm^3 of sand was placed in the main current's direction when the peninsula was built. The hope is that with such a large nourishment, the Dutch will not need to replenish the peninsula with sand for another 20 years, with just the one large deposit at the onset. Sand is projected to naturally move along the South Holland shore using long-shore currents and to protect the coastline against the sea. The project is a test case to see if this type of EBR project could be built elsewhere in the Netherlands or yonder.[124]

Smaller sand nourishment projects are also performed when the Dutch government manages the coastline to prevent it from sinking with sea-level rise by nourishing it with sand deposits.

Policy Framework

A joint approach from the Ministry of Transportation, Public Works, and Water Management and the South-Holland Province was used for this project, which began in 2007 with the idea of mega-nourishments. The project was completed in less than four years and did not have to go through regular measures of policy implementation as a test project. Three main policy actors were involved including the Rijkswaterstaat, the Directorate General Water – both part of Ministry of Transportation, Public Works, and Water Management – and Deltares, a research institute.

Smaller sand nourishment projects are conducted by the Dutch government and involve different nature organizations as partners.

[124] "The Sand Engine."

Enabling Environment

Table 7: *Sand Motor and sand nourishments policy blockages and approaches to enhance enabling environments (refer to Table 4 and 5.)*

Blockages:	2. Lack of knowledge and awareness – need for more knowledge on relationships with shoreline and effects on migratory bird populations[125]
	7. Designed EBR projects not implemented as such – the case in some sand nourishment coastline mgt. projects[126]
Approaches to Enhance:	3. Framing the Project – EBR principles framed starting with original designs of SM. Smaller nourishments partner with nature organizations.
	4. Leveraging funding – Sand Motor financial sources brought in from two policy domains – Province and Ministry[127]
	8. Greater Transparency – attempts to share knowledge

Modeling Capacity – Mid-level

The modeling capacity for the Sand Motor can be described as medium, with more studies needed. In early project stages, four designs were created by different actors and experts through the use of computer ecological modeling.[128] The first models were mostly physical and numerical to find that the project would result in a 10-20 m stretch of beach widening in 20 years.[129]

Since, detailed numerical modeling shows the project spreading sand to nearby coasts. It is still monitored intensely but while modeling exists, it is not yet linked to the engineering. Further, models are not yet involved with effects on recreation and associated costs to a community.

For smaller scale sand nourishment projects, ecological modeling is largely focused on one specific case study at the Ameland Island in the Wadden Sea, where one location was monitored for four years. More studies are needed on differences in morphology and species response to find the impact of these nourishments on ecology including birds, sand dunes, and shoreline.[130]

[125] Mulder, Hommes, and Horstman, "Implementation of Coastal Erosion Management in the Netherlands."
[126] NL Interviewee 3.
[127] Hermans, Cunningham, and Slinger, "Adaptive Co-Management and Learning."
[128] Janssen, "Greening Flood Protection in the Netherlands."
[129] Stive et al., "A New Alternative to Saving Our Beaches from Sea-Level Rise."
[130] NL Interviewee 4.

River Diversions (LA)

Project Description and History

River diversion projects aim to redirect the flow of sediment from the Mississippi River back to its delta and wetlands. The goal is to enhance sediment supply both directly through deposits and indirectly by enhancing root growth. If successful, these deposits will help to naturally regrow and protect wetlands, keeping them strengthened against sea-level rise. As wetlands are the first line of defense against storm surge and wave attenuation[131], this can be considered an EBR strategy. One example of a landscape-scale river diversion is at Mid-Barataria and is projected to deliver river water with 150 million tons of sediment into the Basin over a 50-year period.

Policy Framework

River diversion projects in Louisiana are the main focus and primary funding target of the state's Coastal Master Plan.[132] They are therefore decided upon on a state level and receive a large amount of funding from BP settlement dollars.

Enabling Environment

Table 8. *River diversions policy blockages and approaches to enhance enabling environments (refer to Table 4 and 5.)*

Blockages:	1. <u>Disparate and minimal actors</u>
	4. <u>Diversity of societal interests</u> – worries from fishermen, oil and gas companies, communities[133]
	5. <u>Engaging community opinion</u> – rooted public thoughts from the resilience of coastal communities found embedded in the area[134]
Approaches to Enhance:	3. <u>Framing the Project</u> – focus on total impact of diversions from original planning and design
	4. <u>Leveraging funding</u> – high costs predicted to be higher than planned, but large focus of coastal monies
	6. <u>Planning with Adaptive Management</u>

[131] Cobell et al., "Surge and Wave Modeling for the Louisiana 2012 Coastal Master Plan."
[132] "Louisiana's 2012 Coastal Master Plan."
[133] Gotham, "Coastal Restoration as Contested Terrain."
[134] Bailey, Gramling, and Laska, "Complexities of Resilience."

Modeling Capacity – High

River diversions have a high modeling capacity in Louisiana, which helps to show their importance in restoration in the area. The Caernarvon diversion, a small-scale diversion completed in 1991, has been modeled and found to produce a small effect on water quality and nutrient levels, suggesting much larger scale efforts would be needed for future river diversions to affect nutrient and sediment quality.[135] Another study finding a relationship between sediment accretion and sea-level rise in 2002 shows that even in medium scenarios of SLR, diversions would succeed in flood protection.[136] Several models are used to predict the growth rate of sediment and water and view this in conjunction with SLR scenarios through SLAMM.[137]

The Coastal Louisiana Ecosystem Assessment and Restoration program (CLEAR) is a framework for encapsulating ecological modeling strategies related to diversions in Louisiana.[138] This program incorporates information from monitoring, modeling, and research and can be seen to follow some early model including Costanza in 1990, Martin in 2000 and 2002, and Reyes in 2000.[139] Delft3D models are process models used for basin-wide decisions for river diversions.

Ecosystem models were highly involved in the state's Coastal Master Plan. These models were largely predictive and included such aspects as water movement, salinity dynamics, a wide range of vegetation species, and a wide range of fish and shellfish for birds and mammals.[140] In the future 2017 plan, a strong component of quantitative ecological modeling will be included.[141]

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135 Lane, Day, and Thibodeaux, "Water Quality Analysis of a Freshwater Diversion at Caernarvon, Louisiana."
136 Morris et al., "Responses of Coastal Wetlands to Rising Sea Level."
137 Kim et al., "Delta Progradation Driven by an Advancing Sediment Source."
138 MRD Interviewee 7.
139 Twilley et al., "Coastal Louisiana Ecosystem Assessment and Restoration Program: The Role of Ecosystem Forecasting in Evaluating Restoration Planning in the Mississippi River Deltaic Plain."
140 Nyman et al., "Likely Changes in Habitat Quality for Fish and Wildlife in Coastal Louisiana during the Next Fifty Years"; Visser et al., "A Computer Model to Forecast Wetland Vegetation Changes Resulting from Restoration and Protection in Coastal Louisiana."
141 "2017 Coastal Master Plan Model Improvement Plan."

Barrier Island Restoration (LA)

Project Description and History

Barrier islands in the Mississippi River Delta are low-elevation coastal landforms, separated from the mainland by an estuary or sound or by inlets from other islands, with a duo-benefit of protecting coastal communities from storm surge and protecting important natural resources. These islands help protect against waves attenuation and high salinities; create healthy marshes and habitat; and shield manmade navigable channels. In Louisiana, primary systems include Isles Dernieres, the Timbalier Islands, the Barataria shoreline, and the Chandeleur Islands. The Mississippi Delta barrier islands are disappearing with coastal erosion, compromising the important functions they serve.[142]

A barrier island restoration project is taking place at Barataria Bay, with a specific project underway at the Caminada Headland, a 14-mile beach, on the west. Two other projects have been completed in the area thus far by dredging sand and sediment offshore and moving it to the shoreline through a pump, then using earth-moving equipment to shape the sand and sediment. Planting is done to help rebuild the land naturally.

Policy Framework

Barrier Island projects at Barataria Bay are enacted under the Coastal Wetlands Planning, Protection and Restoration Act, and led by NOAA in consultation with the CPRA. The Coastal Impact Assistance Program (CIAP), the State, and the National Fish and Wildlife Foundation's (NFWF) Gulf Environmental Benefit Fund, resulting from the 2012 BP Settlement Agreement,

[142] Cobell et al., "Surge and Wave Modeling for the Louisiana 2012 Coastal Master Plan"; Kemp, Day, and Freeman, "Restoring the Sustainability of the Mississippi River Delta."

fund the Caminada project. Other barrier island projects are led by the CPRA on a state level and the DOI on a federal level.

Enabling Environment

Table 9. *Barrier Island Restoration policy blockages and approaches to enhance enabling environments (refer to Table 4 and 5.)*

Blockages:	4. Diversity of societal interests – may require removal of protective infrastructure or produce stronger zoning laws and changes in navigation channels
	5. Engaging community opinion – voluntary acquisition may be needed
Approaches to Enhance:	2. Collaboration and Interaction – wide variety of actors involved in projects
	4. Leveraging funding – projects are expensive in terms of their size[143], but funding available from Coastal Master Plan

Modeling Capacity – Mid-level

Barrier island restoration assessments are conducted through both the CWPRA program and Louisiana's Barrier Island Comprehensive Monitoring Program. Cross-shore and long-shore responses are monitored and X-beach models are used in evaluating response during storms. Landscape change models are also used from the CLEAR framework to look at scale, sediment, loss rates, and more.

Right now, it is too early to know the full impact of the Barataria project or model final results. It is evident that marsh is being built from aerial photographs.[144]

[143] Kemp, Day, and Freeman, "Restoring the Sustainability of the Mississippi River Delta."
[144] "Coastal Louisiana Ecosystem Assessment and Restoration Program: The Role of Ecosystem Forecasting in Evaluating Restoration Planning in the Mississippi River Deltaic Plain."

Discussion

Introduction

This discussion will evaluate the results of the study in relation to ecological modeling by first applying them to specific case studies. The results found for improving enabling environment will be evaluated both in terms of how they can solve the various policy barriers presented and in terms of how modeling can be used to do this. The question of whether increasing ecological modeling can enhance the enabling environment for EBR will be answered through each step and summarized in the conclusion. Limitations to modeling and recommendations for a way forward are also presented.

Interpretation of Findings

Table 10. *Evaluating the case studies for modeling use and level of project implementation.*

		Mississippi River Delta			**Netherlands**		
Ecosystem	System Type:	Delta			Delta		
	System Drivers:	SLR, sediment starvation, subsidence, flood events, hurricanes			SLR, subsidence, flood events		
	Trends:	Coastal erosion, wetlands loss, increased hurricane frequency and intensity, high projected rates of SLR, EBR project planning			Sediment accretion, high projected rates of SLR, EBR project implementation		
	Area:	~30,000 km2 area of Delta			~34,000 km2 as total land surface area of NL		
		River Diversions	Barrier Island Restoration	Not EBR: Levees	Room for the River	Sand Motor	Not EBR: Dykes
Modeling Level	Physical Models:			Available and simple			Available and simple
	Ecosystem Models:	Multiple large-scale and complex	Some available and smaller scale		Multiple large-scale and complex	Some available and smaller scale	
	Conceptual Models:	Several in design				Four used in design phase and project decision	
Project Status:		High level of funding approved, in E&D phase	Projects implemented and/or approved	Continue to rebuild stronger and higher after disasters	Several landscape-scale projects implemented and/or approved	Pilot project, implemented as test for future like projects	Moving away from continued maintenance and heightening

Table 10 demonstrates a direct correlation between project implementation status of EBR projects and ecological modeling and of gray infrastructure engineering and physical models.

Further analysis shows a high modeling component at many complexities and scales available for river diversion projects, which are currently in a funds-delegated, engineering and design phase. These projects are landscape-scale and have received the highest level of funding, attention, and planning in the Mississippi Delta. More modeling should continue to help with project planning and prioritization and assist the implementation phase. A high level of ecological modeling is also present for Room for the River, which is a similar, state-centric and landscape-scale plan with a large funding capacity currently in successful implementation phases.

Mid-level ecosystem model presence for Barrier Island restoration and the Sand Motor project are performed, as it is too early to know the full impact for these projects and many unknowns remain. Models were performed in planning phases but were not as involved in the engineering itself.

In both locations, high levels of physical models particularly in earlier history have led to and continue to influence further maintenance of dyke and levee structures. The notable difference is the considerable focus on levees and gray infrastructure engineering that still exists in the Mississippi Delta, while in the Netherlands the overall trend is moving against these structural hydraulic management schemes.

Increasing Enabling Environments For EBR with Ecosystem Models

Table 11. *Increasing enabling environments through the use of ecological modeling, with examples from case studies to relate all relevant results in answering the research question.*

Method for enhancing enabling environment →	**Responds to which limitations in enabling environments?** →	**Can ecological modeling be used?** →	**Examples found in case studies** →					**Where could this be increased?**				
			RFR	SM	RD	BI	GI	RFR	SM	RD	BI	+
1. Increased knowledge and knowledge-sharing	(1) Disparate and minimal actors (2) Lack of knowledge and awareness (5) Engaging community opinion (6) Scale	Increase modeling capacity and grow knowledge-base; make models public and readable; enhance info sharing										
2. Collaboration and interaction	(1) Disparate and minimal actors (2) Lack of knowledge and awareness (4) Diversity of societal interests (5) Engaging community opinion (7) Designed EBR projects not implemented as such	Shared knowledge-base to better define mutually beneficial goals										
3. Framing the project	(2) Lack of knowledge and awareness (5) Engaging community opinion (7) Designed EBR projects not implemented as such	Preliminary phase to establish likely outcomes in project framing										
4. Leveraging funding	(2) Lack of knowledge and awareness (3) Lack of funding (5) Engaging community opinion	Cost-benefit analysis; esp. in comparison to structural projects										
5. No alternative solutions		Show when gray infrastructure will not succeed in flood protection										
6. Planning with adaptive management	(1) Disparate and minimal actors (5) Engaging community opinion	Create many models with different inputs and conditions to help with adaptive management of project execution										
7. Understanding societal wants and incentivizing	(2) Lack of knowledge and awareness (3) Lack of funding (4) Diversity of societal interests (5) Engaging community opinion (7) Designed EBR projects not implemented as such	Run models to show how EBR will affect different stakeholders; where relocation needed										
8. Greater transparency	(1) Disparate and minimal actors (2) Lack of knowledge and awareness (5) Engaging community opinion	Increased justification of sound-science decision-making										

Table 11 is framed around the solution, showing the interrelated web of correlations in this study to demonstrate the use of ecosystem models in increasing enabling environments for EBR in the Mississippi River Delta and the Coastal Netherlands. The first column refers to Table 5 and approaches to enhance the enabling environment for EBR, the second column refers to Table 4 and the blockages, and the third column describes how modeling is or can be used. The fourth column is divided by case study to determine when modeling is being used, including (from left to right) Room for the River, the Sand Motor, River Diversions, and Barrier Island Restoration, then gray infrastructure. The final column is divided by case study to determine when modeling could be increased, including (from left to right) Room for the River, the Sand Motor, River Diversions, and Barrier Island Restoration, then looking at additional EBR projects (+).

Insights and Implications for Further Research

Increased Knowledge and Knowledge-Sharing

Increasing knowledge and knowledge-sharing to better inform coastal decision-making relates to most of the blockages found, including policy fragmentation, scale, lack of awareness, and engaging community opinion. With greater modeling, a complete picture of an area with greater system-wide understanding may be created. The limitation dealing with scale can be improved with greater knowledge because models allow an ability to look at the larger picture of how a project will play out by linking findings. Increased knowledge can also help show specific benefits or risks that will be important to different stakeholders. For all four case studies and additional EBR projects, more uncertainty models and models for post-implementation are still needed.[145]

[145] Ibid.

This, in turn, relates to the increase in knowledge-sharing when communicating science to managers or sharing data between scientists. Between scientists, an integration of models can help to further the knowledge base and link different components of deltaic systems. By creating a cross-disciplinary and compiled database for reference and understanding ecosystems, quantifying benefits, analyzing risk, and more, projects can be designed and generated correctly through the use of scientific knowledge. In the public and political sphere, modeling can be shared by translating results into layman's terms for non-experts and making the models public. The same database could be utilized as a tool for non-experts to reference readable models, with shared language and design. In addition to a database, this can be absorbed into the public and policy realm through communication tools like newsletters, conceptual diagrams, booklets, and other message sharing strategies.[146] Models can then be presented on websites, in stakeholder meetings, and at public forums. Conversely, greater knowledge from community stakeholders, who may be very familiar with the land, its trends, and its ecosystem, could be better incorporated into models to add to the knowledge base.[147] More information is needed from a knowledge perspective and more tools should be created to share and integrate that knowledge.

Collaboration and Interaction

Models can be utilized as a tool to better define mutually beneficial goals across different political and socioeconomic sectors. Collaboration has helped greatly with Room for the River, and in the case of the Noordward policy fragmentation was found to not be a barrier due to this successful collaboration. With the controversy of river diversions in LA, production and incorporation of further models are needed to help guide decision-making through collaboration.

[146] Carter et al., "The Challenge of Communicating Monitoring Results to Effect Change."
[147] Bethel et al., "Sci-TEK."

Framing the Project

Ecosystem models can help frame projects by working at initial project phases to assess land-building potential and flood protection of a project based on environmental and historical trends of the ecosystem as a whole. These tools can keep a project framed in an EBR context, but an increased modeling capacity and increased absorption of modeling results into the policy framework is needed. To communicate early knowledge to decision-makers, it is helpful to use translatable language such as visualizations and to synthesize the data needed for the specific policy goal.[148] The early initiation phases for all four of the EBR projects studied, as well as the engineering and design phase for the Noordward and sediment diversions, all used modeling to help frame projects. In the Coastal Master Plan, models were used in framing sediment diversion projects. This application could be improved for the Sand Motor, barrier island restoration, and smaller-scale EBR projects in early phases that do not yet have a good historical context.

Leveraging Funding

Modeling can be used to assist cost-benefit analyses of EBR projects and quantify ecosystem services using non-market valuation. There is difficulty in performing CBA for these projects including with assigning values to ecosystem functions and concern with the ethics of monetizing nature, providing an advantage to gray infrastructure which is much easier to analyze, with only structural influence.[149] Modeling tools can help determine the relationship between initial project costs and returns, particularly as compares to structural projects, to aid investment decisions both between projects and for a specific project in terms of whether or not it should proceed. Such analysis is currently being performed for many Room for the River projects to reveal project costs and benefits as compared to dyke raising. Models were also used in creating the State Coastal

[148] Carter et al., "The Challenge of Communicating Monitoring Results to Effect Change."
[149] "Coastal Adaptation with Ecological Engineering."

Master Plan for Louisiana to help justify the billions of dollars to be spent toward these projects, as well as determine which site locations to invest in. Increased modeling and research are needed both in evaluating costs for project selection and execution, investment decisions, and predicting EBR benefits as compared to gray infrastructure. CBA's performed for EBR that properly take into account all ecosystem services can help engage community opinion and policy leaders towards these projects. Integration of modeling from different deltaic systems can increase the capacity for assigning costs to ecosystem services and enhance future EBR achievement.

No Alternative Solutions

In the limited cases where there are no alternative solutions to EBR, models can evidence when gray infrastructure does not produce solutions or where EBR will work for purposes of flood control and ecosystem sustainability.

Planning with Adaptive Management

Adaptive management planning assures policymakers and the public that projects will be updated for changing needs of the environment. Modeling can be used to project many scenarios based on different rates of natural factors such as sea-level rise. It is impossible to account for every scenario, so models are translated into adaptive management by being run over a wide range of conditions as well as finding a range of outcomes, rather than a specific input and output. The more ranges accounted for at an initial stage, the greater projects will be able to adapt to different scenarios throughout their lifecycle based on foresight. River diversions in LA use adaptive management planning in their modeling. The range of uncertainty models could be enhanced for other EBR projects to add to adaptive management planning.[150]

Understanding Societal Wants and Incentivizing

Ecosystem models can be run to predict or simulate how EBR will affect components of ecosystems used by various stakeholders. They can then be communicated strategically to demonstrate various group needs and positive coastal effects related to that specific group.[151] Modeling can also show where the controversial practice of voluntary acquisition, involving moving people and communities, will be unavoidable in protecting the coast. This was looked at in Room for the River, though projects were ultimately implemented irrespective of societal wants. In river diversions, modeling can be better applied to predict what will happen under approaches desired by some industry fields for landscape-scale dredging by looking at dredging and river diversions next to each other in terms of benefits. In all, modeling at a greater capacity can help to look further at alternatives and make decisions that incorporate social desires.[152]

Greater Transparency

Increasing transparency responds to the blockages of policy fragmentation when work is not disclosed between different governance sectors; lack of awareness and engagement from an uninformed public; and negative public opinion when distrust in government prevails. Increased incorporation and sharing of ecosystem models including translating them into layman's terms can help to demonstrate informed decision-making by policy leaders and to garner trust. Modeling is used to increase transparency in the Sand Motor throughout the project life, and the public largely supports the project. In the example of the Noordward/greater Room for the River project,

[150] Twilley et al., "Coastal Louisiana Ecosystem Assessment and Restoration Program: The Role of Ecosystem Forecasting in Evaluating Restoration Planning in the Mississippi River Deltaic Plain."
[151] Carter et al., "The Challenge of Communicating Monitoring Results to Effect Change."
[152] MRD Interviewee 2.

transparency was evident at the start, and the project received a great deal of support at first. Some public support has wavered, particularly related to strategic realignment, and the government has continued the project with decreased transparency. If the Noordwaard shows continued success and the government is transparent with those findings and engaging the public, the public and other sectors will be more likely to support future depoldering projects. Here, models can be greater absorbed into the policy framework.

Limitations of Ecological Modeling

Modeling itself runs into limitations and blockages, so it is important to also think about the best use of modeling itself in applying it to these approaches. First, there is a tendency of modelers to want to zoom in, with very specific detail.[153] This creates a disconnect between research scientists who want to understand components in as much detail as possible and the need of decision-makers who want to zoom out with a large view and understand in a non-expert matter. Ecological models for EBR should be created in an approach that zooms out and looks at the larger process in order to help with absorption into the policy arena.

Next, models depend on input and questions requiring assumptions. Gathering info to model is complex with underdrawn conditions. Conditions constantly change, and to account for this a modeler must remember that since you cannot stay in a modeling phase forever, you have to understand projects may not play out as the original model predicted. Since models are predictive and not exact, the importance of adaptive management is evident for projects.[154] Running many models, many times, with different inputs and outputs, can help allow policies and investment

[153] MRD Interviewee 6.
[154] MRD Interviewee 4.

decisions to be set on modeling principles while minding an adaptive management understanding in scenario planning.[155]

Finally, there is a barrier related to costs for modeling, which can be quite high, and limited coastal funding dollars are not always leveraged toward greater research, particularly as models performed for gray infrastructure are often already available or less costly to produce. Even in 2016, hardware is still limited in terms of processing speed, and landscape-scale models can take weeks. When spatial scales get bigger, there is thus an incentive to simplify the model and produce results more quickly. Costs are high in enhancing access to high-level technology.

Conclusion

In conclusion, the role of ecological modeling, versus a sole focus on physical coastal protection modeling, is shown to enhance the enabling environment for ecosystem-based restoration. It was found that in both primary locations, ecological modeling is used and can be further used to address the blockages found in EBR implementation and to enhance the approaches found to increase its enabling environments. Based on study results, three ecological modeling recommendations for a way forward are proposed. These include (1) leveraging funding; (2) better integration and cross-disciplinary studies; and (3) better absorption to the policy framework.

Greater investment in ecological modeling is needed, as models are expensive to perform, but a greater modeling capacity is essential to enhancing enabling environments for EBR. Greater research is needed for leveraging funding using CBA's, increasing the knowledge base for project planning and design, and planning with adaptive management using models run with several different conditions or outputs. The continued need for greater and greater understanding of

[155] MRD Interviewee 3.

ecosystem benefits, services, risks, costs, and more has been well defined throughout this study. In Louisiana, the 2017 Coastal Master Plan will work on increasing modeling capacity, and in the Netherlands, Deltares is the largest delta research base in the world, but modeling costs can run high.[156] Increased funding should be redirected to research from the political arena as well as from industry and stakeholders.

Better integration is needed for ecological modeling performed on deltas in the Mississippi Delta, the Netherlands, and worldwide to best understand these natural systems. Integrated assessment and cross-disciplinary studies by scientists can also help when indicators for a phenomenon in one area are used to help to understand a phenomenon in another.[157] The wider the integration of different modeling levels and dimensions into comparable units that can be shared and applied within one system or even globally, the greater the knowledge base can continue to grow and be enforced. The idea of a worldwide collaboration or database with like-units for ecologically modeling deltas has been discussed and should continue to receive further attention for achievement.[158] Growing the knowledge through cross-disciplinary studies and research can help improve enabling environments for EBR across different deltaic systems.

Finally, better absorption of ecological modeling into policy is needed to enhance EBR enabling environments through their production. Absorbing modeling into policy has been shown to help decision-makers with the framing of the project, interaction with the public sphere, an increased understanding of societal wants and incentivizes, and greater transparency from the government. From scientists to the policy framework, it is important that models be communicated with non-experts in a translatable fashion for the target audience. Better absorption into policy helps with

[156] "2017 Coastal Master Plan Model Improvement Plan."
[157] Brouwer, Georgiou, and Turner, "Integrated Assessment and Sustainable Water and Wetland Management. A Review of Concepts and Methods."
[158] "Natural Processes in Delta Restoration: Application to the Mississippi Delta."

knowledge-sharing between departments (agencies, ministries, etc.) to account for policy fragmentation and associated perils, and knowledge-sharing between variously affected actors for engaging community opinion in support of projects. It is important to emphasize that science is not exact and models will never be one hundred percent precise but will show the best available knowledge and science. On the other side, from the policy framework to scientists, it is important that decision-makers communicate with modelers to address their specific needs. It may be challenging for a scientific researcher to decide on a model useful for a decision-maker, so decision-makers and resource managers should be involved in the direct planning for modeling.

Ecosystem-based restoration is a decisive way forward for coastal zones. This type of policy can help areas to remain proactive amid sea-level rise by caring for the environment in flood protection, decreasing costs of protecting communities, and restoring critical areas that are threatened or destroyed. Like much environmental policy, both scientific and policy blockages exist in implementing EBR. The increased use of ecological modeling, versus solely coastal protection modeling, in a greater, more integrated, and more absorbed approach can help both the Mississippi River Delta and the Netherlands move forward on important ecosystem-based restoration strategies to create a better, more sustainable future for their critical and cherished delta regions.

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References

Anderson, John B., Davin J. Wallace, Alexander R. Simms, Antonio B. Rodriguez, and Kristy T. Milliken. "Variable Response of Coastal Environments of the Northwestern Gulf of Mexico to Sea-Level Rise and Climate Change: Implications for Future Change." *Marine Geology*, 50th Anniversary Special Issue, 352 (June 1, 2014): 348–66. doi:10.1016/j.margeo.2013.12.008.

Bailey, Conner, Robert Gramling, and Shirley B. Laska. "Complexities of Resilience: Adaptation and Change within Human Communities of Coastal Louisiana." In *Perspectives on the Restoration of the Mississippi Delta*, edited by John W. Day, G. Paul Kemp, Angelina M. Freeman, and David P. Muth, 125–40. Estuaries of the World. Springer Netherlands, 2014. doi:10.1007/978-94-017-8733-8_9.

Bakker, Jan P. *Ecology of Salt Marshes: 40 Years of Research in the Wadden Sea*. Wadden Academy, 2014.

Barry John. *Rising Tide: The Great Mississippi Flood of 1927 and How It Changed America.* New York: Simon & Schuster, 1997.

Bethel, Matthew B., Lynn F. Brien, Michelle M. Esposito, Corey T. Miller, Honora S. Buras, Shirley B. Laska, Rosina Philippe, Kristina J. Peterson, and Carol Parsons Richards. "Sci-TEK: A GIS-Based Multidisciplinary Method for Incorporating Traditional Ecological Knowledge into Louisiana's Coastal Restoration Decision-Making Processes." *Journal of Coastal Research* 30, no. 5 (September 2014): 1081–99. doi:10.2112/JCOASTRES-D-13-00214.1.

Blind, Michiel W., Jens Christian Refsgaard, Ilke Borowski, and Willem J. De Lange. "Chapter 2.4:Narrowing the Science–Policy Gap – Experience from the Harmoni-CA Concerted Action." In *Chapter 2.4:Narrowing the Science–Policy Gap – Experience from the Harmoni-CA Concerted Action*, 181–99, 2009. http://pubs.rsc.org/en/content/chapter/bk9781847558619-00181/978-1-84755-861-9.

Broekx, Steven, Steven Smets, Inge Liekens, Dirk Bulckaen, and Leo De Nocker. "Designing a Long-Term Flood Risk Management Plan for the Scheldt Estuary Using a Risk-Based Approach." *Natural Hazards* 57, no. 2 (May 2011): 245–66. doi:10.1007/s11069-010-9610-x.

Brouwer, R., S. Georgiou, and R.k. Turner. "Integrated Assessment and Sustainable Water and Wetland Management. A Review of Concepts and Methods." *Integrated Assessment* 4, no. 3 (September 2003): 172–84.

Carter, Shawn L., Giselle Mora-Bourgeois, Todd R. Lookingbill, Tim JB Carruthers, and William C. Dennison. "The Challenge of Communicating Monitoring Results to Effect Change." In *The George Wright Forum*, 24:48–58, 2007. http://www.academia.edu/download/40115558/Carter_et_al_GWF_Paper.pdf.

Cheong, So-Min, Brian Silliman, Poh Poh Wong, Bregje van Wesenbeeck, Choong-Ki Kim, and Greg Guannel. "Coastal adaptation with ecological engineering." Nature climate change 3, no. 9 (2013): 787-791.

Coastal Impact Assistance Program. *TItle 43*. Vol. 1331. Accessed November 21, 2016. https://www.law.cornell.edu/uscode/text/43/1356a.

Coastal Protection and Restoration Authority. 2013. 2017 Coastal Master Plan: Model Improvement Plan. Version II (March 2014), prepared by The Water Institute of the Gulf. Baton Rouge, Louisiana: Coastal Protection and Restoration Authority, 52p.
Cobell, Zachary, Haihong Zhao, Hugh J. Roberts, F. Ryan Clark, and Shan Zou. "Surge and Wave Modeling for the Louisiana 2012 Coastal Master Plan." *Journal of Coastal Research*, July 1, 2013, 88–108. doi:10.2112/SI_67_7.
Coleman, James M., Harry H. Roberts, and Gregory W. Stone. "Mississippi River Delta: An Overview." *Journal of Coastal Research* 14, no. 3 (1998): 699–716.
Couvillion, Brady R., Gregory D. Steyer, Hongqing Wang, Holly J. Beck, and John M. Rybczyk. "Forecasting the Effects of Coastal Protection and Restoration Projects on Wetland Morphology in Coastal Louisiana under Multiple Environmental Uncertainty Scenarios." *Journal of Coastal Research*, July 1, 2013, 29–50. doi:10.2112/SI_67_3.
Costanza, Robert, Fred H. Sklar, and Mary L. White. "Modeling Coastal Landscape Dynamics." BioScience 40, no. 2 (1990): 91-107. doi:10.2307/1311342.
Day, John W., Donald F. Boesch, Ellis J. Clairain, G. Paul Kemp, Shirley B. Laska, William J. Mitsch, Kenneth Orth, et al. "Restoration of the Mississippi Delta: Lessons from Hurricanes Katrina and Rita." *Science* 315, no. 5819 (2007): 1679–84.
Day, John W., Louis D. Britsch, Suzanne R. Hawes, Gary P. Shaffer, Denise J. Reed, and Donald Cahoon. "Pattern and Process of Land Loss in the Mississippi Delta: A Spatial and Temporal Analysis of Wetland Habitat Change." *Estuaries* 23, no. 4 (2000): 425–38. doi:10.2307/1353136.
Day Jr., John W., John Barras, Ellis Clairain, James Johnston, Dubravko Justic, G. Paul Kemp, Jae-Young Ko, et al. "Implications of Global Climatic Change and Energy Cost and Availability for the Restoration of the Mississippi Delta." *Ecological Engineering*, Wetland creation, 24, no. 4 (April 5, 2005): 253–65. doi:10.1016/j.ecoleng.2004.11.015.
Deijl, Eveline C. van der, Marcel van der Perk, Wouter Zonneveld, Eelco Verschelling, and Hans Middelkoop. "A Channel Sediment Budget for the 'Kleine Noordwaard' in the Biesbosch Area, the Netherlands," 17:7489, 2015. http://adsabs.harvard.edu/abs/2015EGUGA..17.7489V.
Disco, Cornelis. "Remaking "nature": the ecological turn in Dutch water management." Science, Technology & Human Values 27, no. 2 (2002): 206-235.
"Eb En Vloed Wachten Op Niemand, Bouwstenen Voor de Deltacommissie | TU Delft Repositories." Accessed November 19, 2016. http://repository.tudelft.nl/islandora/object/uuid:cd34bde0-af8b-4e3c-b46a-a2a09c402f9d/?collection=research.
European Commission. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions on the Response to the Report of the Expert Group on the Interim Evaluation of the Seventh Framework Programme for Research, Technological Development and Demonstration Activities and to the Report of the Expert Group on the Interim Evaluation of the Risk-Sharing Finance Facility. Publications Office of the European Union, 2011.
Gerritsen, Herman. "What happened in 1953? The Big Flood in the Netherlands in retrospect." Philosophical Transactions of the Royal Society of London A: Mathematical, Physical and Engineering Sciences 363, no. 1831 (2005): 1271-1291.

Glick, Patty, Jonathan Clough, Amy Polaczyk, Brady Couvillion, and Brad Nunley. "Potential Effects of Sea-Level Rise on Coastal Wetlands in Southeastern Louisiana." *Journal of Coastal Research*, April 1, 2013, 211–33. doi:10.2112/SI63-0017.1.
Gotham, Kevin Fox. "Coastal Restoration as Contested Terrain: Climate Change and the Political Economy of Risk Reduction in Louisiana." *Sociological Forum* 31 (September 1, 2016): 787–806. doi:10.1111/socf.12273.
Groot, Mirjam de, and Wouter T. de Groot. "'Room for River' Measures and Public Visions in the Netherlands: A Survey on River Perceptions among Riverside Residents." *Water Resources Research* 45, no. 7 (July 1, 2009): W07403. doi:10.1029/2008WR007339.
Hermans, Leon M, ScottW Cunningham, and Jill H Slinger. "Adaptive Co-Management and Learning." In Water Co-Management, 266–91. CRC Press, 2013. http://dx.doi.org/10.1201/b14591-14.
Hills, T., T. J. B. Carruthers, S. Chape, and P. Donohoe. "A Social and Ecological Imperative for Ecosystem-Based Adaptation to Climate Change in the Pacific Islands." *Sustainability Science* 8, no. 3 (2013): 455–467.
"Introduction to the New EU Water Framework Directive - Environment - European Commission." Accessed November 29, 2016. http://ec.europa.eu/environment/water/water-framework/info/intro_en.htm.
Janssen, S. K. H. "Greening Flood Protection in the Netherlands : A Knowledge Arrangement Approach." Phd, Wageningen University, 2015. http://library.wur.nl/WebQuery/wurpubs/490484.
Jordan, Stephen, and William Benson. "Governance and the Gulf of Mexico Coast: How Are Current Policies Contributing to Sustainability?" *Sustainability* 5, no. 11 (November 7, 2013): 4688–4705. doi:10.3390/su5114688.
Kabat, Pavel, Louise O. Fresco, Marcel J. F. Stive, Cees P. Veerman, Jos S. L. J. van Alphen, Bart W. A. H. Parmet, Wilco Hazeleger, and Caroline A. Katsman. "Dutch Coasts in Transition." *Nature Geoscience* 2, no. 7 (July 2009): 450–52. doi:10.1038/ngeo572.
Keiner, Christine. "'Modeling Neptune's Garden: The Chesapeake Bay Hydraulic Model, 1965-1984' in The Machine in Neptune's Garden: Historical Studies on Technology and the Marine Environment, Ed. David van Keuren and Helen Rozwadowski (Science History Publications, 2004), 273-314." Accessed December 12, 2016. https://www.academia.edu/1369906/_Modeling_Neptune_s_Garden_The_Chesapeake_Bay_Hydraulic_Model_1965-1984_in_The_Machine_in_Neptune_s_Garden_Historical_Studies_on_Technology_and_the_Marine_Environment_ed._David_van_Keuren_and_Helen_Rozwadowski_Science_History_Publications_2004_273-314.
Kemp, G. Paul, John W. Day, and Angelina M. Freeman. "Restoring the Sustainability of the Mississippi River Delta." *Ecological Engineering*, Sustainable Restoration, 65 (April 2014): 131–46. doi:10.1016/j.ecoleng.2013.09.055.
Kim, Tae-Goun, and Daniel R. Petrolia. "Public Perceptions of Wetland Restoration Benefits in Louisiana." *ICES Journal of Marine Science / Journal Du Conseil* 70, no. 5 (August 2013): 1045–54.
Kim, Wonsuck, Albert Dai, Tetsuji Muto, and Gary Parker. "Delta Progradation Driven by an Advancing Sediment Source: Coupled Theory and Experiment Describing the Evolution of Elongated Deltas." *Water Resources Research* 45, no. 6 (June 1, 2009): W06428. doi:10.1029/2008WR007382.

Klijn, Frans, Michaël van Buuren, and Sabine A. M. van Rooij. "Flood-Risk Management Strategies for an Uncertain Future: Living with Rhine River Floods in the Netherlands?" *Ambio* 33, no. 3 (2004): 141–47.
Korbee, Dorien, Arthur P. J. Mol, and Jan P. M. Van Tatenhove. "Building with Nature in Marine Infrastructure: Toward an Innovative Project Arrangement in the Melbourne Channel Deepening Project." *Coastal Management* 42, no. 1 (February 1, 2014): 1–16. doi:10.1080/08920753.2013.863722.
Lane, Robert R., John W. Day, and Burnell Thibodeaux. "Water Quality Analysis of a Freshwater Diversion at Caernarvon, Louisiana." *Estuaries* 22, no. 2 (1999): 327–36. doi:10.2307/1352988.
Laska, Shirley, George Wooddell, Ronald Hagelman, Robert Gramlings, and Monica Teets Farris. "At Risk: The Human, Community and Infrastructure Resources of Coastal Louisiana." *Journal of Coastal Research*, 2005, 90–111.
Lookingbill, T, T. J. B. Carruthers, J. M. Testa, W. K. Nuttle, and G. Shenk. "Chapter 9: Environmental Models: Providing Synthesis, Analysis, Simulation, and Prediction." In *Integrating and Applying Science: A Handbook for Effective Coastal Ecosystem Assessment*, 133–50. Cambridge, MD: IAN Press, 2010. http://ian.umces.edu/press/books/publication/259/integrating_and_applying_science_a_handbook_for_effective_coastal_ecosystem_assessment_2010-05-10/.
Lopez, John A. "The Multiple Lines of Defense Strategy to Sustain Coastal Louisiana." *Journal of Coastal Research*, September 1, 2009, 186–97. doi:10.2112/SI54-020.1.
"Louisiana's 2012 Coastal Master Plan." *Coastal Protection and Restoration Authority*. Accessed June 22, 2016. https://issuu.com/coastalmasterplan/docs/coastal_master_plan-v2.
Lubbeers, B, J De Heer, J Groenendijk, M Van Bockel, M Blekemolen, J Lambeek, and R Steijn. "Evaluatie Derde Kustnota." *Twynstra Gudde & Alkyon, Amers- Foort, The Netherlands*, 2007.
Mark S. Davis, John Driscoll, and Harry Vorhoff. "Financing the Future: Turning Coastal Restoration and Protection Plans Into Realities: The Cost of Comprehensive Coastal Restoration and Protection" the first in an occasional series of white papers by the Tulane Institute on Water Resources Law & Policy. August 18, 2014.
Michener, William K., Elizabeth R. Blood, Keith L. Bildstein, Mark M. Brinson, and Leonard R. Gardner. "Climate Change, Hurricanes and Tropical Storms, and Rising Sea Level in Coastal Wetlands." *Ecological Applications* 7, no. 3 (1997): 770–801. doi:10.2307/2269434.
Morris, James T., P. V. Sundareshwar, Christopher T. Nietch, Björn Kjerfve, and D. R. Cahoon. "Responses of Coastal Wetlands to Rising Sea Level." *Ecology* 83, no. 10 (2002): 2869–77. doi:10.2307/3072022.
Mississippi River Delta Interviewee 2, October 13, 2016.
Mississippi River Delta Interviewee 3, October 21, 2016.
Mississippi River Delta Interviewee 4, October 20, 2016.
Mississippi River Delta Interviewee 6, October 18, 2016.
Mississippi River Delta Interviewee 7, October 27, 2016.
Mulder, Jan P. M., Saskia Hommes, and Erik M. Horstman. "Implementation of Coastal Erosion Management in the Netherlands." *Ocean & Coastal Management*, Concepts

and Science for Coastal Erosion Management (Conscience), 54, no. 12 (December 2011): 888–97. doi:10.1016/j.ocecoaman.2011.06.009.

Netherlands Interviewee 2, October 11, 2016.

Netherlands Interviewee 3, November 3, 2016.

Netherlands Interviewee 4, November 23, 2016.

"NOAA Guidance for Considering the Use of Living Shorelines." National Oceanic and Atmospheric Administration. U.S. Department of Commerce., 2015.

Nyman, J.a., D.m. Baltz, M.d. Kaller, P.l. Leberg, C. Parsons Richards, R.p. Romaire, and T.m. Soniat. "Likely Changes in Habitat Quality for Fish and Wildlife in Coastal Louisiana during the Next Fifty Years." *Journal of Coastal Research*, July 1, 2013, 60–74. doi:10.2112/SI_67_5.

Paola, Chris, Robert R. Twilley, Douglas A. Edmonds, Wonsuck Kim, David Mohrig, Gary Parker, Enrica Viparelli, and Vaughan R. Voller. "Natural processes in delta restoration: Application to the Mississippi Delta." Annual Review of Marine Science 3 (2011): 67-91.

"Petition-for-Damages-and-Injunctive-Relief.pdf." Accessed November 19, 2016. http://biotech.law.lsu.edu/blog/petition-for-damages-and-injunctive-relief.pdf.

Resources and Ecosystems Sustainability, Tourist Opportunities, and Revived Economies of the Gulf Coast States Act of 2012 (RESTORE Act). *33 U.S.C. 1323*. Vol. Public Law 112-141, 2012.

"Ridges to Reef Fisheries." *SNAPP*. Accessed December 12, 2016. http://snappartnership.net/groups/ridges-to-reef-fisheries/.

Roy, Eric D., Jay F. Martin, Elena G. Irwin, Joseph D. Conroy, and David A. Culver. "Living within Dynamic Social-Ecological Freshwater Systems: System Parameters and the Role of Ecological Engineering." *Ecological Engineering* 37, no. 11 (November 2011): 1661–72. doi:10.1016/j.ecoleng.2011.06.044.

"Ruimte Voor de Rivier." *Room for the River for a Safer and More Attractive River Landscape*. Accessed June 21, 2016. https://www.ruimtevoorderivier.nl/english/.

Rutger, Brugge, Jan Rotmans, and Derk Loorbach. "The Transition in Dutch Water Management." *Springer-Veriag 2005*, May 10, 2005.

Simon-Friedt, Bridget R., Jessi L. Howard, Mark J. Wilson, David Gauthe, Donald Bogen, Daniel Nguyen, Ericka Frahm, and Jeffrey K. Wickliffe. "Louisiana Residents' Self-Reported Lack of Information Following the Deepwater Horizon Oil Spill: Effects on Seafood Consumption and Risk Perception." *Journal of Environmental Management* 180 (September 15, 2016): 526–37. doi:10.1016/j.jenvman.2016.05.030.

Stive, Marcel J.F., Matthieu A. de Schipper, Arjen P. Luijendijk, Stefan G.J. Aarninkhof, Carola van Gelder-Maas, Jaap S.M. van Thiel de Vries, Sierd de Vries, Martijn Henriquez, Sarah Marx, and Roshanka Ranasinghe. "A New Alternative to Saving Our Beaches from Sea-Level Rise: The Sand Engine." *Journal of Coastal Research*, August 8, 2013, 1001–8. doi:10.2112/JCOASTRES-D-13-00070.1.

Temmerman, Stijn, Patrick Meire, Tjeerd J. Bouma, Peter M. J. Herman, Tom Ysebaert, and Huib J. De Vriend. "Ecosystem-Based Coastal Defence in the Face of Global Change." *Nature* 504, no. 7478 (December 5, 2013): 79–83. doi:10.1038/nature12859.

"The Sand Engine." *The Sand Engine*, 2016. http://www.dezandmotor.nl/en/.

Thindwa, Jeff. "Enabling Environment for Civil Society in CDD Projects." *Washington, DC: World Bank*, 2001.

Turner, R. E. "Wetland Loss in the Northern Gulf of Mexico: Multiple Working Hypotheses." *Estuaries* 20, no. 1 (1997): 1–13. doi:10.2307/1352716.
Twilley, Robert R., Brady R. Couvillion, Imtiaz Hossain, Carola Kaiser, Alaina B. Owens, Gregory D. Steyer, and Jenneke M. Visser. "Coastal Louisiana Ecosystem Assessment and Restoration Program: the role of ecosystem forecasting in evaluating restoration planning in the Mississippi River Deltaic Plain." In American Fisheries Society Symposium, vol. 64, pp. 000-000. 2008.
"UNEP :: Regional Seas Programme." Accessed December 14, 2016. http://www.unep.org/regionalseas/issues/management/mngt/default.asp.
US EPA, OW. "What Is Green Infrastructure?" Overviews and Factsheets. Accessed December 14, 2016. https://www.epa.gov/green-infrastructure/what-green-infrastructure.
"USGS Scientific Investigations Map 3164: Land Area Change in Coastal Louisiana from 1932 to 2010." Accessed November 29, 2016. http://pubs.usgs.gov/sim/3164/.
Verduijn, Simon H., Sander V. Meijerink, and Pieter Leroy. "How the Second Delta Committee set the agenda for climate adaptation policy: A Dutch case study on framing strategies for policy change." Water alternatives 5, no. 2 (2012): 469.
Visser, Jenneke M., Scott M. Duke-Sylvester, Jacoby Carter, and Whitney P. Broussard. "A Computer Model to Forecast Wetland Vegetation Changes Resulting from Restoration and Protection in Coastal Louisiana." *Journal of Coastal Research*, July 1, 2013, 51–59. doi:10.2112/SI_67_4.
Vossestein, Jacob. *The Dutch and Their Delta: Living Below Sea Level*. XPat Media, 2011.
"Verspagen, Jolanda MH, Jutta Passarge, Klaus D. Jöhnk, Petra M. Visser, Louis Peperzak, Paul Boers, Hendrikus J. Laanbroek, and Jef Huisman. "Water management strategies against toxic Microcystis blooms in the Dutch delta." Ecological applications 16, no. 1 (2006): 313-327.
"Water governance in the Netherlands: fit for the future?." Dutch Ministry of Infrastructure and the Environment Headquarters. 17 March 2014, The Hague, Netherlands.
Wesenbeeck, Bregje K. van, Jan P. M. Mulder, Marcel Marchand, Denise J. Reed, Mindert B. de Vries, Huib J. de Vriend, and Peter M. J. Herman. "Damming Deltas: A Practice of the Past? Towards Nature-Based Flood Defenses." *Estuarine, Coastal and Shelf Science* 140 (March 1, 2014): 1–6. doi:10.1016/j.ecss.2013.12.031.
Wesselink, Anna J., Wiebe E. Bijker, Huib J. De Vriend, and Maarten S. Krol. "Dutch dealings with the Delta." Nature+ Culture 2, no. 2 (2007): 188.
Young, Robert. "Restoring Coastal Louisiana Will Not Guarantee the Protection of Infrastructure from Storms: Policy Makers Should Also Plan for Strategic Relocation of Critical Infrastructure and Vulnerable Communities." Pardee Keynote Symposia: Reducing Vulnerability of Gulf Coast Communities to Hurricane Impacts and Sea-Level Rise: Are Large Scale Restoration and Engineering the Answer? The Geological Society of America (GSA), 2008.
Yuill, Brendan, Dawn Lavoie, and Denise J. Reed. "Understanding Subsidence Processes in Coastal Louisiana." *Journal of Coastal Research*, September 1, 2009, 23–36. doi:10.2112/SI54-012.1.

Yuill, Brendan, Dawn Lavoie, and Denise J. Reed. "Understanding Subsidence Processes in Coastal Louisiana." *Journal of Coastal Research*, September 1, 2009, 23–36. doi:10.2112/SI54-012.1.

Appendix

Interview Questions Basic Template

Interview Questions: Netherlands

1. What is your concept/definition of ecosystem-based restoration with some examples?
2. Can you tell me more about the enabling environments for implementation of ecosystem-based restoration in the Netherlands?
    a. Are projects decided upon more often by the EU or nationally? What is the overall process?
    b. How much does public opinion matter in project decisions?
    c. In order for me to best research and identify times when ecological modeling is brought in or cited, where might I look?
        i. E.g. in the US would look at hearing transcripts, witness testimonies, congressional reports, and committee reports related to U.S. coastal policy for the Gulf.
3. Can we go over a little bit about the range of ecosystem-based restoration approaches taking place and being proposed in the Netherlands, such as Room for the River, the Sand Motor, and coastline management? I will be organizing my paper using a case study approach based on projects.
4. What were some of the lessons learned in implementing these restoration approaches, including any scientific and policy blockages?
    a. How did you overcome those blockages?
    b. What is your opinion on the best means of overcoming policy obstacles for the future? Do you believe enhancing the focus on ecological modeling could help with that in the Netherlands, or back in the Mississippi Delta?
5. Now, looking at past coastal policy decisions and policymaking in the Netherlands, are there any distinct times that you know of when ecosystem-based models have helped expand enabling environments in past coastal policy?
6. To follow up on that, are there times that you know of when coastal policy has been set based on models that focus on protection and engineering, with an absence of ecological modeling?
    a. What kind of policy resulted from these times?
7. How do you believe that modeling methodologies influence, and are being used within, the relevant policy frameworks there?
8. Do you have any final thoughts or opinions ways in which mathematical and conceptual models may be able to overcome implementation challenges and enhance policy that provides for ecosystem-based restoration either here or back in the Mississippi River Delta?
    a. What do you think are the most important steps to achieving successful nature-based coastal restoration for the future?
9. Do you have any suggestions of other people that you recommend I speak with?

Interview Questions: Mississippi River Delta

1. What is your concept/definition of ecosystem-based restoration with some examples?
2. Can you tell me more about the enabling environments for implementation of ecosystem-based restoration in Louisiana?
    a. From what I understand, the money is primarily coming in from the BP suit and Restore Act, with the state making the most major decisions. What about some of the other players?
    b. How much does public opinion matter in project decisions?
    c. In order for me to best research and identify times when ecological modeling is brought in or cited, do you have any thoughts on additional places I might look? Right now, my plan is to look at hearing transcripts, witness testimonies, congressional reports, and committee reports related to U.S. coastal policy for the Gulf.
        i. Where might I look to find where modeling is brought in more on a state or local level? On a parish level?
3. Can we go over the range of ecosystem-based restoration approaches taking place and being proposed in the Mississippi River Delta, such as river sediment diversions, barrier island restoration, oyster reef building, terracing, and additional marsh restoration projects? I will be organizing my paper using a case study approach based on projects.
4. What were some of the lessons learned in implementing these restoration approaches, including any scientific and policy blockages?
    a. How did you overcome those blockages?
    b. What is your opinion on the best means of overcoming policy obstacles for the future? Do you believe enhancing the focus on ecological modeling could help with that in the Mississippi Delta?
5. Now, looking at past coastal policy decisions and policymaking in the Mississippi River Delta Region, are there any distinct times that you know of when ecosystem-based models have helped expand enabling environments in past coastal policy?
6. To follow up on that, are there times that you know of when coastal policy has been set based on models that focus on protection and engineering, with an absence of ecological modeling? It is my impression that this is generally the modeling methodology used by the Corps in building structures like levees.
    a. What kind of policy resulted from these instances?
7. How do you believe that modeling methodologies influence, and are being used within, the relevant policy frameworks there?
8. Do you have any final thoughts or opinions ways in which ecological mathematical and conceptual models may be able to overcome implementation challenges and enhance policy that provides for ecosystem-based restoration in the Mississippi River Delta?
    a. What do you think are the most important steps to achieving ecosystem-based coastal restoration for the future?
9. Do you have any suggestions of other people that you recommend I speak with?