ABSTRACT

Title of Dissertation: BUILDING FLOOD RESILIENCE IN SOCIAL-ECOLOGICAL SYSTEMS

Natalie L. Snider, Doctor of Philosophy, 2023

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Historic driving forces of economic development, continually growing population and expanding inequities, are already challenging the resilience of the social-ecological system (SES) on multiple fronts, including socially, economically and environmentally. Existing and increasing threats from climate change will exacerbate the challenges in managing for resilience. The dynamic nature, involvement of multiscale feedback mechanisms between the natural and social sub-systems, possible existence of multiple states of the social-ecological system and inability to ever gain full control or understanding make it a challenge for institutions and actors to define and manage the system boundaries, its components and feedbacks. This complexity requires a transdisciplinary approach that integrates those most impacted into building knowledge and solutions across the environmental, economic and social fields. Similarly, institutions managing these systems will need to develop new approaches and strategies to integrate social, ecological, economic and political aspects of the SES and expand the participation of individual actors in the system, including a redistribution of power to successfully achieve resilience outcomes.

The Social-Ecological Resilience Framework, proposed here, seeks to build resilience in the SES through purposeful interventions to maintain or change the forms, functions or both. This framework relates the key terms of sustainability, adaptation, transition and transformation, under the overall umbrella term of resilience. Within this framework, **resilience** is defined as the ability of the system to sustain, adapt, transition or transform in the face of acute or systemic change. Each subsequent term is then defined by the level of change in forms and functions: (1) **sustainable** maintains the same forms and functions, (2) **adaptation** changes the forms while maintain the functions, (3) **transition** changes the functions while maintaining the forms and (4) **transformation** changes both forms and functions. The framework can be used to manage the changes that society is experiencing in these systems.

Adaptive management and social learning are two examples of approaches for managing the SES under the overarching construct of the Social-Ecological Resilience Framework. Adaptive management, an iterative decision-making process to address uncertainties and adapt to future conditions, should be combined with social learning, a participatory process where knowledge, skills and values are gained or modified through social interactions and collective learning.

This dissertation demonstrates the framework and these approaches through five case studies focused on building resilience to flood impacts. Flooding is the costliest natural disaster in the world. However, the calculation of disasters costs typically only includes the cost of flood damages to infrastructure. But flooding is also putting a toll on society's ability to provide social services, maintain important social factors, such as community cohesion, impacting both physical and mental health, exacerbating inequities and deteriorating the environment and ecosystem services, all with significant costs.

In China's Sponge Cities Program, the key takeaway is that defining the SES, both geographically and in terms of important forms and functions relevant to achieving the resilience goals, should be identified early to be able to address any barriers to success. The key takeaway of the Coastal Structures case study is that roles and responsibilities need to be clearly defined for institutions and actors, by which they can collectively achieve both institutional goals of reducing the societal impacts of flooding and the actors' goals of reducing their own impacts to well-being. In the Honduras case study, the key takeaway is that building institutional support requires a redistribution of power dynamics to facilitate bottom-up approaches that can increase the utility of resilience actions to solving more than one social, ecological or economic problem within the SES. In Indonesia's case study, by identifying the key forms and functions for each resilience goal, the range of possible vulnerabilities can be better defined, and timelines of potential changes and strategies to safeguard that positive outcomes are achieved can be developed. And finally, in Louisiana, the key takeaway is that institutions should not be defining the future of the SES without all the key actors engaged or represented. Institutions should support building a common vision of a resilient future through an integrated adaptive management and social learning program.

The dissertation discusses a proposed Social-Ecological Resilience Framework (Chapter 1) to define key terms that integrates the notion of resilience, sustainability, adaptation, transition and transformation in relationship to each other and in relationship to the form and function of the

SES. Several case studies from around the world demonstrate various aspects of operationalizing the framework. Technical aspects of adaptive management are developed and applied to a case study in Louisiana (Chapter 2). Lastly, social learning is then integrated into adaptive management using the same case study (Chapter 3). Both of these two chapters discuss actions to build resilience in the SES at a localized scale.

Managing a social-ecological system (SES) can be an arduous task, and many institutions, such as governmental, non-profit, and research entities, may feel overwhelmed by the complexity and scope of this challenge. It's tempting to concentrate on a particular aspect of the system that seems more manageable or familiar. Nevertheless, without adopting a systems-thinking approach and examining the interactions within and beyond the SES, there is a risk of unintended and cascading consequences and missed opportunities to tackle multiple vulnerabilities collectively. Although this dissertation focuses on flood-related risks, the underlying themes and methodologies are relevant to any disaster, whether caused by nature or humans. Ultimately, our shared efforts to shape a more equitable, resilient, and sustainable world for present and future generations can benefit from these approaches.

BUILDING FLOOD RESILIENCE IN SOCIAL-ECOLOGICAL SYSTEMS

by

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Dissertation submitted to the Faculty of the Graduate School of the
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INTRODUCTION

C.S. Holling (1973) made foundational contributions to resilience theory. His work defined resilience as a "measure of the persistence of systems and of their ability to absorb change and disturbances and still maintain the same relationships between populations and state variables" (p14). He recognized resilience as a property of the system that can change over time, not an outcome to be achieved. Hollings with Carl Walters thus developed the adaptive management process to manage this uncertainty in natural systems towards resilience (Holling 1978; Walters & Hilborn, 1978; Holling & Meffe, 1996; Walters, 2007).

While Holling and Walters were leading resilience thinking in natural resource management, these concepts were also being developed in parallel in social science fields, such as psychology and economics (McCubbin, 2001; Kumpfer,1999). Individual resilience to adversity, such as an illness or a stress event, is commonly used as a character trait. The resilience of the economic system, such as the resilience of the dollar, is commonly used to evaluate how the financial system responds to shocks. The widespread emergence of resilience thinking into social science appears to have occurred simultaneously with the increased attention on the socio-ecological system (SES).

Socio-Ecological System

Socio-ecological systems consist of complex and dynamic interactions of a vast number of interdependent entities within the social and natural sub-systems (Young et al., 2006). The emergence of the SES construct addressed a growing need in the ecological field to embrace the importance of social capital and both the positive and negative feedbacks between the social and natural sub-systems. The ever-present reality of climate change impacts on the SES requires managing a system with rapidly changing baselines, increased levels of uncertainty and knowledge gaps about future conditions and the interactions and feedback loops between the natural and social sub-systems (Cammen et al., 2019; Fernandez-Llamazares et al., 2015). These are also complicated by population growth and growing inequalities. In addition, the SES and its interactions and feedbacks are not static over time and can change drastically, especially after an unexpected shock, which provides an additional challenge in capturing the dynamism of the system.

Within the Social-Ecological Resilience Framework, proposed here, resilience is defined as the ability of the system to sustain, adapt, transition or transform in the face of acute or systemic change. Each subsequent term is then defined by the level of change in forms and functions: (1) sustainable maintains the same forms and functions, (2) adaptation changes the forms while maintain the functions, (3) transition changes the functions while maintaining the forms and (4) transformation changes both forms and functions. Institutions and actors play a crucial role in shaping the behaviors and outcomes of social-ecological systems. Institutions can be defined as the formal or informal rules and organizations that structure human behavior and interactions between the social, economic and environmental systems (McGlynn et al., 2023; Kimmich et al., 2023). Actors are individuals or groups that participate within the social-ecological system and interact with each other and the environment (McGlynn et al., 2023; Kimmich et al., 2023).

Transdisciplinary approaches are extremely important in understanding the complex and dynamic system: its components, structure, functions and linkages between the natural and social subsystems. Transdisciplinary approaches for institutions integrate knowledge and methodologies from multiple disciplines, as well as actors and communities, to address complex problems in an inclusive and participatory way (Max Neef, 2005; Stokols et al., 2008). Institutions, working with a wide variety of research disciplines, should embrace the active participation of actors in management, allowing those most impacted to define their own future. Adaptive management, combined with social learning strategies, provides an approach that integrates social, ecological, economic and political aspects of the SES for more holistic management of our future.

Adaptive Management

Adaptive management (AM) is an iterative decision-making process to address heightened levels of uncertainty, thereby accounting for a variety of forces and processes at a landscape level that enable institutions and actors in the system to accommodate risks and reduce levels of uncertainty to achieve desired outcomes and goals (Holling, 1973; Holling, 1978; Williams & Brown, 2014; Williams et al., 2009; Canter & Atkinson, 2010; Stankey et al., 2005; Walters, 1986). The expanded use of AM beyond natural resource management is being explored to understand the uncertainty and stochasticity within actions taken to improve the resilience of socio-ecological systems (Waylen et al., 2019; Barnard & Elliot, 2015; Sterk et al., 2017).

Components of the AM process have been well defined in the literature with continuous feedbacks between the six key components of AM (assess, design, implement, monitor, synthesize and adapt) (Chades et al., 2017; Holling, 1978; McFadden et al., 2011; Walters & Holling, 1990; Williams, 2011; Williams & Brown, 2014). Developing an adaptive management program requires a framework by which to define the overarching goals, value components, hierarchical objectives, key management and research uncertainties, performance metrics, monitoring plans, data synthesis and adaptive management actions.

Adaptive management requires the commitment of the institution(s) to develop a governance structure that supports and funds the six steps of the process, iteratively. The most common failures to implement all six steps stem from the institutions, such as lack of coordination across institutions, desired certainty of actions and investments (ignoring uncertainties), risk-averse culture, lack of long-term perspective (working within political timeframes), fear of litigation, lack of long-term funding streams or commitments and lack of participatory processes for engaging actors (Lynch et al., 2022; Tribbia & Moser, 2008; Cammen et al., 2019; Keith et al., 2011; Glicksman & Page, 2022; McDonald & Styles, 2014; McDonald-Madden et al., 2010; Mulvaney et al., 2022; Stern & Dietz, 2008). Whereas established institutions may have more resource capacity to integrate adaptive management, they can also be mired in bureaucratic processes (McGlynn et al., 2023). These characteristics can be heavily embedded in the ethos of an older, established institution, such as the U.S. Army Corps of Engineers (USACE), whereas newly formed institutions, such as Louisiana’s Coastal Protection and Restoration Authority (CPRA), are more likely to have adaptive capacity characteristics and exhibit more adaptive governance.

The complexity of our socio-ecological system as it confronts climate change means that there is no one right perspective. There will be challenging decisions to be made which will come with very real trade-offs to components of the system, including individuals, communities or ecosystems (Berkes, 2017). Without collaborative governance, informed by adaptive management, co-production of knowledge and social learning, the ramifications of potential actions will not be fully understood and are destined to make poor decisions or result in unintended consequences.

Social Learning

Social learning has been an emerging approach to increasing the adaptive capacity for managing the socio-ecological system in a time of climate change (Kraker, 2017; Keen et al., 2005; Thi Hong Phuong et al., 2017; Ensor & Harvey, 2015; Haque et al., 2021). Social learning involves acquiring new or adjusting existing knowledge, skills and values through social interactions and collective action (Cundill et al., 2015; Lebel et al., 2006). Common understanding across diverse actors is achieved through dialogue and exchange of ideas, perspectives and experiences, in order to co-create and share knowledge about environmental and social challenges (Wiek et al., 2014). Through social learning, participants can gain a deeper understanding of the social-ecological system, identify potential solutions and trade-offs and develop new strategies for building resilience (Reed et al., 2010).

Particularly suitable for complex SESs with systemic uncertainty (Ison, 2010; Ensor & Harvey, 2015), social learning engages multiple actors with varying perspectives, values and knowledge to move forward collective action and increase adaptive capacity (Thi Hong Phuong et al., 2017). The benefits of social learning are an increased understanding amongst actors, relationship and trust building, developing a comfort with uncertainty, integrating experience-based knowledge and implementing collective actions (Cundill & Rodela, 2012; Kraker, 2017; Thi Hong Phuong et al., 2017). Thi Hong Phuong et al. (2017) noted that institutions, governance structures and legal frameworks are key catalysts to enabling social learning to greater adaptive and coping capacity to disasters and climate change impacts (Haque et al., 2021).

Flood Resilience

Humans need water and have an affinity for living near water. Throughout our history, societies have congregated near coasts and rivers. In developed countries, there is a high societal value on living near water. In developing countries, place attachment near water is closely tied to social networks and livelihoods. These waters provide the resources needed to survive and the economic opportunities that have fueled national and international economies. Critically, in pursuit of these benefits, society has a history of altering these systems in ways that have ultimately been detrimental to the environmental, economic and social landscape.

For millennia, society has been working to harness the dynamic natural river and coastal systems into static and controllable systems. These concepts of controlling waters and floods have resulted in degraded natural systems and systemic inequalities. Historic and continuing patterns of development and flood protection have diminished ecosystem services, often removing natural protections and, in the process, exacerbated flood risk.

As the costliest natural disasters in the world, the impacts of flooding typically only calculate the cost of flood damages to infrastructure (Rufat et al., 2023). Cascading impacts are rarely quantified across other aspects of the economic system or the environmental and social landscape, including accounting for 44% of all weather-related deaths globally (UNDRR, 2020).

The toll of flooding is multifaceted, affecting society's ability to provide social services, maintain community cohesion and impacting both physical and mental health. It also exacerbates inequalities and harms the environment and ecosystem services, all resulting in significant costs.

Climate change, bringing increasingly variable and extreme weather events and unprecedented sea level rise, is leading to an increase in the frequency and intensity of floods that threatens individuals, communities and ecosystems, specifically those on the front lines along the world's rivers and coasts. While climate mitigation efforts to reduce greenhouse gas emissions are critically important to prevent future catastrophic impacts, the effects of climate change are already being felt in coastal and river communities. Building resilience within a social-ecological system not only requires that societies mitigate greenhouse gas emissions through energy transitions and work to limit the scale of climate change, but also that current and future impacts are addressed without fully knowing how extensive those impacts will be based on our collective progress on climate mitigation. Impacts to human health and safety, homes, businesses and livelihoods are undermining local economies and personal well-being and causing a long-term decline in national GDPs around the world (IPCC, 2023).

Climate change also exacerbates the loss of habitats, biodiversity and ecosystem services, which further increases the risks for nearby built communities. For example, globally coastal wetland areas have declined by nearly 50% relative to pre-industrial levels as a result of warming, sea level rise, extreme climate events and other human impacts (Li et al., 2018). These environments provide a wide range of ecosystem services that are critical to climate resilience, such as risk reduction from storms and sea level rise, carbon sequestration, providing critical habitats for biodiversity, improving water quality and enhancing local fisheries production. While society typically focuses on infrastructure that is at risk from flooding, flooding also impacts more intangible forms and functions of the system such as livelihoods, mental and physical health, community cohesion, social networks, justice and equity, communications, sense of agency and overall well-being. This impending decline in social capital, such as networks, norms and trust, and natural capital, such as goods and services from nature, from flood impacts will further degrade the resilience of these social-ecological systems (Folke et al., 2005; Adger, 2000).

Problems associated with this loss of resilience are large and growing. Yet, in the midst of these historic and emerging threats, communities are still not adequately responding to flood risk signals. The arrangement of built and natural infrastructure on coastal and riverine landscapes does not reflect the real and growing risks in these systems. Some of the overarching reasons that the behavior of societies has not changed in the face of immense risks are a lack of information, barriers of existing public policies and financial structures, systematic inequality and structural racism, lack of capacity and coordination and beliefs and behaviors informed and driven by political ideologies, personal gain and presentism. The impact of climate change on future flood risks and vulnerabilities will likely expand social and economic injustices and reveal or exacerbate fragilities in the system (Redman, 2014; Bollettino et al., 2017).

Resilience research can help us to better understand the system and its components, as well as develop solutions to address the existing positive feedback loops. A holistic approach to the socio-ecological system will more effectively address this complex problem by engaging social scientists, ecologists, economists and other disciplines, as well individuals, communities and institutions across spatial and temporal scales to build resilience.

Building on Previous Research

This research builds on my previous studies conducted as lead researcher or as a co-author, including reports and scholarly publications (some under my previous legal name, Natalie S. Peyronnin). Relevant non-peer reviewed reports includes, “Sediment diversion operations working group: An overview of food web dynamics in a Louisiana estuary” (Rhode et al., 2019), “Comprehensive recommendations supporting the use of the multiple lines of defense strategy to sustain coastal Louisiana” (Lopez & Snider, 2008), “Building land in coastal Louisiana: Expert recommendations for operating a successful sediment diversion that balances ecosystem and community needs” (main report and supplemental information) (Peyronnin et al., 2016), and “Implementing nature-based flood protection: Principles and implementation guidance” (van Wesenbleck et al., 2017).

In 2013, I was lead author on a publication entitled, “Louisiana’s 2012 Coastal Master Plan: Overview of a science-based and publicly informed decision-making process” (Peyronnin et al., 2013). This study describes the resource constrained decision-making process to prioritize coastal resilience actions in Louisiana, supported by integrated, coastwide modeling and a decision-support tool, and informed by the public and key actors through a formalized advisory team (Peyronnin et al., 2013).

Through collaboration with physical scientists, I co-authored hydrodynamic modeling studies to explore how sediment diversions could mitigate the impacts of sea-level rise (White et al., 2019) and the potential for openings in the Mississippi River levee system to mitigate storm surge impacts on communities in the Barataria and Breton Basins (Hu et al., 2022). Additional synthesis research evaluating the central role that the Mississippi River plays in ecological resilience in the upper Gulf of Mexico (Kemp et al., 2016) and how bypassing sediment constraints in the upper Mississippi River could increase sediment available for restoration of coastal Louisiana through sediment diversions (Kemp et al., 2016).

In collaboration with social scientists, co-authors and I conducted a qualitative study using focus groups to explore the role of place attachment and risk perception related to an individual's intentions to mitigate their own personal flood risk (Lambert et al., 2021). This work was further supplemented with a quantitative study using surveys and protection motivation theory to access how place attachment, negative emotions and coping mechanisms relate to behavioral intentions to mitigate flood risk exposure, from disruptive behaviors, like moving out of one's community or state, changing jobs or elevating homes, to less disruptive behaviors, like public participation and voting (Holley et al., 2022).

Relevant to Chapter 1, I was lead author on a publication entitled, "Using Louisiana's Coastal History to Innovate its Coastal Future" that postulated a future where marshes that would inevitably be submerged by sea level could be transformed over time into protective oyster reefs, harkening back to the Great Barrier Reef of the Americas (GBRA) (Peyronnin & Condrey, 2017). This transformation of form and function was an impetus for the Social-Ecological Resilience Framework presented here.

Especially relevant to Chapters 2 and 3, I facilitated an interdisciplinary group of 12 core experts and 42 guest experts in monthly day-long meetings over 8 months to explore how operating a sediment diversion affects the complex interactions of the social-ecological system of southeast Louisiana. The goal was to discuss, deliberate and develop a variety of potential operation strategies that could be tested in models or field experiments (once constructed). The experts worked to optimize diversion operations for one isolated variable (such as basin geology, wetland health, specific fish and wildlife species or communities and user groups), and then identify operations strategies that aim to optimize across as many of those variables as possible. The work produced potential operational strategies for future consideration and modeling, as well as recommendations for future research (Peyronnin et al., 2017)

In addition, related to adaptive management, I co-authored a paper entitled, “Measuring success through outcome indicators for restoration efforts in Louisiana,” which outlines how non-profit organizations are using success criteria to prioritize ecosystem restoration projects for funding and implementation through advocacy (Kar et al., 2020). I also co-authored a chapter on adaptive management in the *International Guidelines on Natural and Nature-Based Features for Flood Risk Management* (de Looff et al., 2021).

This Research

My motivation for this dissertation is driven by the same passion that fuels my 20-year career in ecological and community resilience to flooding. After personally living through Hurricane Katrina, I am determined to do my part to deter any other community from going through that trauma. Having been an institutional decision maker and now working in advocacy, I know the importance that institutional form and function have on catalyzing the future of an SES – as they can either build flood resilience, embrace bottom-up approaches, increase adaptive capacity and build social justice, or they can perpetuate these negative states.

This research focuses on three approaches to building resilience: (1) I propose a Social-Ecological Resilience Framework to define key terms (resilience, sustainable, adaptation, transition and transformation) in relationship to each other and in relationship to the form and function of the SES, (2) I apply the technical components of adaptive management with a case study in coastal Louisiana through an interdisciplinary approach and (3) I expanded to a transdisciplinary approach by integrating social learning into adaptive management with the same case study.

Chapter 1 proposes a theoretical resilience framework by which the form and function of the SES are used to define the actions needed to sustain, adapt, transition or transform the SES with flood resilience case studies from around the world. I started by evaluated the existing literature on a heavily used lexicon of terms: resilience, sustainable, adaptation, transition and transformation. I then developed the Social-Ecological Resilience Framework, which defined the terms in relationship to each other and in relationship to the form and function of the SES, touching on both the positive and negative connotations of terms. I defined resilience as the ability of the system to sustain, adapt, transition or transform in the face of acute or systemic change. Sustainability is maintaining form and function, adaptation is changing form while maintaining function, transition is maintaining form while changing function, and transformation is changing both form and function. I applied the Social-Ecological Resilience Framework to various case studies to demonstrate its utility in providing a structure by which an SES can be evaluated and researched, level of change and effort needed can be clearly articulated and predictions on impacts to interactions with other key aspects of the SES can be better understood. The sustainable case study focuses on China's Sponge Cities Program with the goal to change the impact that flooding is having on a city's form and function, without changing the various forms and functions of social, environmental or economical components and relationships. The adaptation case study is not geographically bound, instead focusing on Coastal Structures with the goal of building resilience in this SES to reduce the social and economic damages from flooding and lessen the period of recovery by adapting the form (coastal structures) while maintaining all the functions of the community. The transition case study focuses on the function of institutions in building community resilience with the goal to change the functions of institutions from top-down to bottom-up to build community-driven resilience that maintains the form and functions of the community. The final case study on transformation evaluates the transformation of two SES systems as the Indonesian government moves the capital city from Jakarta to a new site, named Nusantara. The goal is to build a resilient city that embraces nature as a fundamental necessity in reducing vulnerabilities in the economic, social and environmental aspects of Nusantara, while improving resilience and reducing vulnerabilities in Jakarta. Finally, I propose steps to operationalize the Social-Ecological Resilience Framework, including defining the SES and its form and functions, setting resilience goals, developing possible interventions for maintaining or changing form, function or both, identification of barriers and limitations, measuring outcomes and learning and adapting. My hope is that this proposed framework for resilience can be tested in the future and will provide a path towards long-term climate resilience using approaches to sustain, adapt, transition and transform that define a new societal regime.

In Chapter 2, I describe the importance of adaptive management in managing the complexity and uncertainties of the social-ecological system (SES). The study seeks to identify enabling and inhibiting factors at the institution level for developing a robust adaptive management program, challenges and solutions to adaptive management in the regulatory setting applying to a case study on sediment diversions in coastal Louisiana. A sediment diversion is a structure of gates built into the Mississippi River levee system that can be opened and closed to allow river water, sediment and nutrients to flow into the degraded wetlands, mimicking the natural cycle of spring flooding, crevassing and distributary sub-delta formation and restoring coastal wetlands. My results found that community engagement, trust and transparency were the most inhibiting factors in developing a robust adaptive management program for the Coastal Protection and Restoration Authority (CPRA), the institution in charge of designing and constructing sediment diversions. Being a relatively newly formed institution (formed in 2006), adaptive management is enabled by the CPRA’s learning capacity which was strongest due to contextual factors of low institutional inertia and high political support. Process factors of management approach, role of science and cumulative effects and resource factors of sufficient funding were also enabling factors. Within the regulatory context, I also found adaptive management was inhibited by a variety of institutional barriers, including the application to project design, risk and uncertainty, institution risk aversion, front-loaded analysis and funding, lack of true experimentation, data synthesis and participatory processes. Finally, I used specific elements in the design of an adaptive management program on a case study for sediment diversions in coastal Louisiana. My research highlights the role of institutions in enabling adaptive management and the complexity of social and environmental aspects of the social ecological systems in developing an adaptive management framework.

In Chapter 3, I facilitated a social learning process around the adaptive management of sediment diversions. I initiated an approach for a social learning approach that brought together actors with a variety of viewpoints to mimic a participatory process that could be adopted by the institution, Coastal Protection and Restoration Authority. Aspects of social learning that I employed included selection of diverse participants, established collaboration rules to ensure respect and openness to others, power distribution, relationship and trust building and effective facilitation of discussions. With little to no knowledge or understanding of adaptive management by actors, I created an environment in which social learning could emerge. I utilized aspects of the adaptive management framework from Chapter 2. The social learning group built consensus on value components, a set of objectives, measures of success and monitoring and adaptative management actions. In addition, without direction from the facilitators, the social learning group requested to also develop a set of principles for the development of the adaptive management program by the CPRA. Unfortunately, it is unclear how the CPRA, as the lead institution, will embrace or integrate the recommendations and work of the social learning group, or recognize the merits of social learning and integrate its strategies and approaches to replicate this effort. Although I was not able to directly produce outcomes to the social-ecological system or the management of sediment diversions (due to the lack of institutional involvement), the study still resulted in positive learning outcomes for the participants, as evidenced by the social learning group's public comment letter. Although to date, planning for the construction of the sediment diversion has not been inclusive and fully transparent, my colleagues and I hope that the CPRA, as the institutional actor, will take the opportunity to use social learning and participatory processes as they establish an adaptive management program over the next 5 years to ensure inclusivity, transparency, knowledge co-creation and the integration of the social and natural subsystems of the coastal Louisiana SES.

In this dissertation, I present a Social-Ecological Resilience Framework, adaptive management, and social learning and by which institutions and actors can build towards ecological and community resilience to flooding. My work will help advance the integration of different disciplines and encourage the continued expansion of trans- and inter-disciplinary efforts to understand the interactions and feedbacks of the SES, how future uncertainties such as climate change, population growth and justice impact the SES and how management actions can increase positive economic, social and ecological outcomes.

Chapter 1: A resilience framework around the form and function of the Social-Ecological System: A means to better plan for sustaining, adapting, transitioning and transforming our systems to climate change

INTRODUCTION

Addressing the impacts of the climate crisis requires an understanding of what changes are needed within social-ecological systems (SES) and what level of effort that would require. At the very least, this must be based on an estimation of how those changes would affect key interactions with other aspects of the SES. The ambiguity and inconsistent use of terms, such as resilience, sustainable, adaptation, transition and transformation, from the literature across disciplines and in the public discourse has further complicated the planning, implementation and communication of social, economic and environmental actions needed to manage the impacts of climate change.

This chapter seeks to address this problem by proposing a planning framework by which to relate important concepts in this heavily used lexicon to each other. The Social-Ecological Resilience Framework (Figure 1.1) adopts a technical approach to define these terms and their relationship to the form and function of SESs. The framework is then applied to various case studies to demonstrate its utility in providing a structure by which an SES can be evaluated and researched, level of change and effort needed can be clearly articulated and predictions on impacts to interactions with other key aspects of the SES can be better understood.

A Complex System

Historic driving forces of economic development, continually growing population and expanding inequalities are already challenging the resilience of the social-ecological system (SES) on multiple fronts, including socially, economically and environmentally (Neumann et al., 2015; Leach et al., 2018). The existing and increasing threats from climate change will exacerbate the challenges in managing for resilience. The dynamic and complex nature, including the involvement of multiscale and nonlinear feedback mechanisms between the natural and social sub-systems and possible existence of multiple states of the SES (Colding & Barthel, 2019; Anderies et al., 2004; Nelson et al., 2022; Davidson, 2010), make it a challenge to actually define the system boundaries, its components and feedbacks (Fischer et al., 2015; Olsson et al., 2014). Researchers will never have full understanding of the SES and the system will remain partially unpredictable with critical uncertainties about the system function, structure and interrelationships, specifically around system shocks (Fischer et al., 2015; Preiser et al., 2018).

A transdisciplinary approach is most ideal to assess and improve the social-ecological system. Institutions, working with a wide variety of research disciplines, should embrace the active participation of actors into management, allowing those most impacted to define their own future and help develop a more systematic understanding. There is a lack of consistency and scattering of research across disciplines and at various scales (Amiezadeh et al., 2022). As with any multi-disciplinary effort, two-way dialogue on both the common discipline-specific classification frameworks, key theories and methodologies that may be implemented need to be properly communicated to each other and decision makers (Gardner et al., 2009; Olsson et al., 2014; Hughes et al., 2017; Quinlan et al., 2015). This reiterates the importance of having a Social-

Ecological Resilience Framework that can be implemented across disciplines, including ecology, social science and economics.

A Complexity of Terms

Resilience

The term resilience has well over 60 different definitions in the literature, undergoing fundamental evolution in meaning, and has expanded to a wide range of disciplines, including economics, engineering, ecological, social, health, psychology, community, business and technology (Bollettino et al., 2017; Olsson et al., 2014; Marchese et al., 2018; Walker et al., 2004; Rose, 2016; Sterk et al., 2017; Tengblad & Oudhuis, 2018; Amirzadeh et al., 2022; Quinlan et al., 2015; Martin-Breen & Anderies, 2011). Other key terms, such as sustainable, adaptation, transition and transformation, also have a wide range of definitions in the literature, many with overlapping meanings or relationships with the term resilience (Preiser et al., 2018; Folke et al., 2010; Walker et al., 2004; Smit et al., 1999; Vos, 2007). Most of these related yet abstract terms share some aspects of the definition, such as it is a property of the system, it pertains to form and function, it includes ecosystems and human systems and there is constant change in the system (Mcgreavy, 2016; Marchese et al., 2019; Martin-Breen & Anderies, 2011).

The original concept of resilience theory in natural resource management included defining it as the ability of systems to persist and maintain relationships between populations and state variables despite disturbances and changes (Holling, 1973). While ecologists focused on resilience that maintained the function, structure, identity and feedbacks of the environment (Walker et al., 2004), social scientists have moved from approaches of risk and vulnerability to approaches for social and cultural resilience as an overarching term to “overcoming adversity and adapting to one’s environment” (McCubbin, 2001; Kumpfer,1999). Other definitions use terminology such as “survive following collective trauma”, “adaptive capacity…to evolve”, and “maintain some desired system characteristics despite fluctuations in behavior” (Anderies et al., 2004; Barrios, 2014; Pooley & Cohen, 2010; Aburn et al., 2016). A resilient community has been defined as a community that takes intentional action to enhance the personal and collective capacity of its citizens and institutions (Berkes & Ross, 2013) or ability to “withstand external shocks to their social infrastructure” (Adger, 2000 (p.361). In addition, “cultural resilience” tends to have a lot of overlap with community resilience. Crane (2010) defined cultural resilience as the “ability to maintain livelihoods that satisfy both material and moral (normative) needs in the face of major stresses and shocks” (p.2). No matter the discipline or definition, resilience is not an end state and is variable over time (McCubbin, 2001; Hollings, 1973).

Social-ecological resilience combines the social, economic and environmental aspects of resilience in the dynamic, non-linear system and provides an approach to addressing hazards and vulnerabilities among multiple levels and spatial and temporal scales, along with uncertainties in system characteristics, relationships and the impacts of climate change (Tyler & Moench, 2012; Berkes, 2017; Ostrom, 2009). The ability for maintenance, renewal, re-organization and innovation, specifically in institutions and governance but across spatial and temporal scales—a characteristic referred to as panarchy—is key to resilience and requires a large number of disciplines and sectors (Siders, 2018; Folke, 2006; Walker et al., 2002; Walker et al., 2006).

Sustainable

Resilience is not interchangeable or easily merged with sustainability, but they do share some common characteristics, such as increased strategic competencies, such as identifying and managing risks, within a dynamic system (Basiago, 1995; Redman, 2014; Marchese et al., 2018; Martin-Breen & Anderies, 2011). Depending on the time scale and discipline, such as sociology, ecology, business or economics, sustainable can have widely varying definitions and authors have repeatedly called for the need for a consistent application (Brown et al., 1987; Basiago, 1995; Vos, 2007). Most simply, sustainable is maintaining some structure or function in a desirable manner (Martin-Breen & Anderies, 2011). Moore et al. (2017) found five key constructs to sustainable in social science literature, including time, continued delivery, behavior change, evolution and continued benefits. Environmental definitions stem from the Brundtland Report that focuses heavily on defining sustainability as a wide array of actions that would ensure resources meet the needs of future generations (WCED, 1987; IISD, 2020; Sverdrup & Sevnsson, 2002). In general, sustainability refers to something that can be maintained over time without causing harm or depletion to the environment, society or economy (UN, 2019; Berkes, 2003).

Adaptation

Adaptation is largely defined in the literature as the ability to adjust properties or characteristics of the natural or human system to become better suited to combat and manage the negative consequences of changing conditions, stressors or risks (Patt et al., 2010; Adger et al., 2009; Smit & Wandel, 2006). Some authors expand the definition to include taking advantage of the opportunities that arise from changing conditions to achieve more positive outcomes (Eakin et al., 2014; NRC, 2010; Smit & Wandel, 2006). In addition, adapt or adaptability is often used to refer to the capacity of the actors in the system to build resilience (Walker et al., 2006).

Transition

Transition has a wide variety of definitions in the literature depending on the discipline, but generally is described as a movement or shift in a function or service (Geels, 2019; Geels & Schot, 2007). More frequently used in technology or social sciences, transitions involve processes that include multiple actors and results in operating under new rules, practices or assumptions (Jerneck & Olsson, 2015). In the context of climate change, transitions are largely referenced in terms of an energy transition to mitigate greenhouse gas emissions and social transitions, especially in reference to technology (Shove, 2010; Smith & Stirling 2010; Rosenbloom et al., 2019). In environmental terms, transitions have historically been more likely to occur with the loss of function, such as ecosystem services (Sterk et al., 2017). However, transitions and transition management are growing in importance in the resilience space, especially when considering the socio-technology system that operates across the SES (Loorbach et al., 2010; Olsson & Jerneck, 2018; Smith & Stirling 2010).

Transformation

When the ecological, political, social or economic conditions of the SES are untenable, maintaining the current state or returning to a previous state may not be desirable and, in many cases, is not a viable option (Walker et al., 2004; Martin-Breen & Anderies, 2011). In these cases, transformation would provide a means to evolve into a new or novel state, a new way of living or a new community (Folke, 2006; Folke et al., 2016; Nelson et al., 2022). Transformation has been defined as “the capacity to create a fundamentally new system when ecological, economic, or social structures make the existing system untenable” (p.3) (Walker et al., 2004). Rapid regime shift transformations can be instantaneous and fast-paced, if triggered by conflict or exceeding a threshold (Crane, 2010; Pereira et al., 2018; Martin-Breen & Anderies, 2011), or can occur gradually along a continuum until a full transformation has occurred, known as incremental transformation (Pelling et al., 2015). Transformation does not have to occur on the entire system, but on specific aspects such as changes in mental models, institutions, structures and flows (Pereira et al., 2018). Small transformations at one level of panarchy can move and accumulate through the larger system, as well as just a specific component of the system may be transformed (Martin-Breen, 2011; Pelling et al., 2015). Transformations can be unexpected and unintended, specifically when there is a shock that ruptures or disjunctions the connections between social institutions, normative values and the practices of day-to-day life (Crane, 2010; O’Brien, 2012). Transformation, driven by human collective agency, can be positive in changing negative trajectories, addressing fragilities in the system, entering a period of renewal and re-organization and facilitating innovations within the system (Folke et al., 2016; Davidson, 2010; Pereira et al., 2018; Westley et al., 2013).

METHODS

I reviewed the literature on resilience, sustainability, adaptation, transition and transformation and developed a structure by which to assess a community, ecosystem or other aspect of the social-ecological system. This literature review spanned definitions and use of terms across disciplines including ecology, economics, social science, engineering, health, technology, etc. The Social-Ecological Resilience Framework was then utilized to evaluate various case studies.

The case studies were selected based on being well-documented, related to flood risk resilience, and provide geographic variability around the globe.

The development of the Social-Ecological Resilience Framework relies on thinking about the social-ecological system in terms of its form and its function. To properly assess each term and associated case studies, clear definitions of form and function are required, both from the perspective of both the social and natural sub-systems of the SES.

Form is defined as the physical, biological and social organization of the environment, including the built environment, that influences interactions between the different components. In ecological terms, form, also frequently referred to as structures, describes the physical and biological structure of the environment, including the spatial and temporal distribution of land, water, flora and fauna (Odum, 1962; Seppelt et al., 2012). In social terms, form refers to the cultural, economic and political structures that shape societal behavior, and can include individual characteristics (i.e., beliefs, life experiences, sense of purpose), social capital (i.e., agency, social networks, learning capability, leadership, sense of place, community competence), economic capital (i.e., innovative economy, economic development, diversity and fairness of distribution) and institutional characteristics (infrastructure and support services, engaged governance, information and communication) (Smit et al., 1999; McPhearson et al., 2016; Crooks et al., 2015). These attributes occur within a setting of the natural and built environment and the interactions between the two, thus could be referred to as the social-ecological form.

Function is defined as the processes and interactions that occur within the system to produce goods and services. Ecological function refers to the roles and activities of organisms, populations and communities within the SES that contribute to biotic and abiotic processes and ecosystem services (Bock & von Wahlert, 1965; Hooper et al., 2005; Garland et al., 2020). Social functions are used to explain how social phenomena (i.e., institutions, norms and practices) operate and contribute to social order, shaping societal norms, interactions and behavior (Folke et al., 2016; Berkes et al., 2003; Bodin et al., 2006). Examples of social functions include resource management practices, knowledge production, collective action and cultural preservation (Berkes, 2009; Galafassi et al., 2018; Folke et al., 2016; Olsson et al., 2014).

For the purposes of this paper, the case studies were restricted to the natural environment and communities experiencing the impacts from flooding across the world, although the application of the Resilience Framework could be utilized in any hazard, aspect or geography of the SES. Flood resilience was selected as the focus of these case studies both based on the expertise of the author and because flooding is a dynamic threat, with multiple pathways for risk, and highlights key interactions between the physical and environmental landscape with the social, economic and cultural landscape.

RESULTS

Social-Ecological Resilience Framework

The Social-Ecological Resilience Framework provides a means to define the terms commonly used in climate change planning (sustain, adapt, transition or transform) in relation to each other, all under the overarching term of resilience. These definitions are designed to function across multiple disciplines. Within this framework, **resilience is defined as the ability of the system to sustain, adapt, transition or transform in the face of acute or systemic change**. The level of change is defined by the change to form, function, both or neither, depending on the vulnerability to extreme disturbances or persistent stressors being imposed on the SES, the capacity and agency of the system and its actors, social networks and institutions to respond and the timescale by which interventions are being proposed (Smit & Wandel, 2006; Lebel et al., 2006; Berkes & Ross, 2013). This definition incorporates an integrated approach to social, economic and environmental aspects of the SES.

The broadness and reach of the term resilience makes it more difficult to define clearly and operationalize into research and action, especially across disciplines (Olsson et al., 2014; Martin-Breen & Anderies, 2011). However, the inclusiveness of the term, once collectively defined, can provide a holistic framework for understanding and be an asset to future planning and research. Figure 1.1 provides a graphical representation of the Social-Ecological Resilience Framework. The x-axis denotes an increasing change in function, while the y-axis denotes an increasing change in form. It is important to note here that although this graphic depicts positive outcomes, it could also be applied to depict negative outcomes (to be considered in Discussion section).

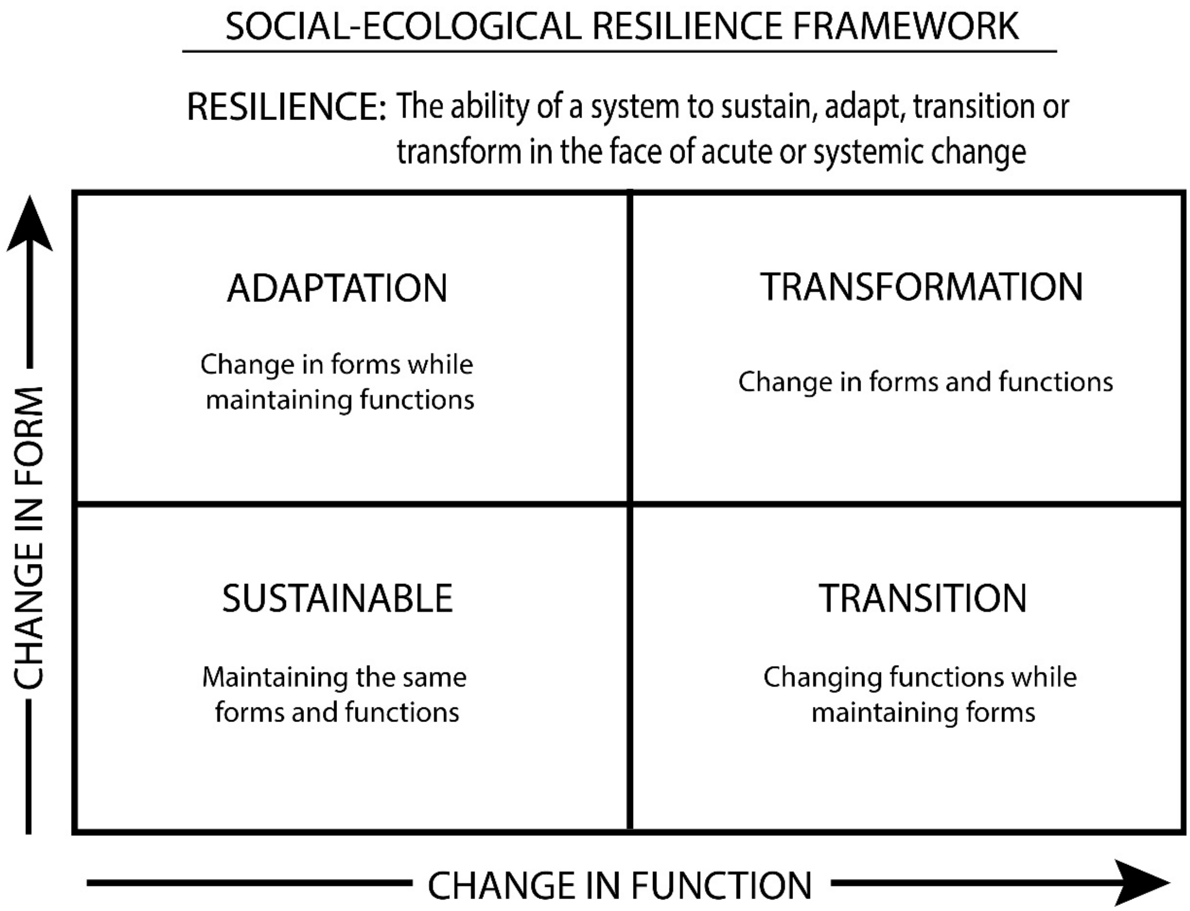

Figure 1.1: Social-Ecological Resilience Framework Denoting the Change in Form and Function of the SES in relationship to the terms sustainable, adaptation, transition and transformation.

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Sustainable

This chapter defines **sustainable as a system that maintains the same form and function**. In many instances, this is maintaining the status quo, or making small adjustments that do not change the overall form and function of the system. To maintain form and function in the context of sustainability means that a system, process or norm is able to continue to operate and provide benefits without degrading or damaging the natural resources, the social structures or the economic systems that support it.

The U.N. 2030 Agenda for Sustainable Development established 17 Sustainable Development Goals (SDG) and adopted an analytical framework for risk and resilience to effectively coordinate the actions to achieve the SDGs (UN, 2019). The Social-Ecological Resilience Framework is an effective mechanism for achieving the SDGs. The term sustainability, as used in the SDGs and widely in the literature, is rooted in maintaining the overall natural resource base. Due to this context, sustainability has been largely focused on how development occurs in relationship to the natural and social environment and has not fully embraced the essential multiscale feedback loops within the social-ecological system (Ostrom, 2009; Sachs et al., 2019). In order to achieve the SDGs, actions will have to span the full range of strategies and approaches, including sustaining, adapting, transitioning and transforming (Sachs et al., 2019). This paper does not seek to invalidate the common use of sustainability but proposes a more inclusive definition that better encompasses all aspects of the SES and is not directly tied to environmental outcomes above others.

Sustainable Case Study: China's Sponge Cities Program

China's Sponge City Program (SCP) provides case study for a sustainable approach to the urban social-ecological system. Rapid urbanization in China, from ~18% of the population in 1978 to ~60% in 2018 with continued growth projected, has resulted in increasing flooding, ecological deterioration, poor water quality and low quality of life (Li & Zhang, 2022; Jia et al., 2017). The majority of urban cities are vulnerable to flooding (641 of 657 cities), with 130 cities experiencing flooding almost annually, at an annual cost of US$14 – 28 billion in property damages (Jiang et al., 2018; Ma & Jiang, 2023).

The SCP was initiated in 2014 with 30 pilot cities and an investment of US$6.35 billion (Jia et al., 2017; Han et al., 2023). Based on that success and the recognition of water as China's most critical resource, SCP became a national priority, now covering all 657 cities with an investment of US$1.5 trillion (Han et al., 2023; Yin et al., 2022; Jiang et al., 2018). The SCP goals are to control urban floods, collect rainwater for reuse, improve water quality, restore ecosystems and ecosystem services, aesthetics and recreation (Jiang et al., 2017; Jia et al., 2017). The program is promoted as a paradigm shift from a reliance on traditional grey infrastructure to integrated grey-green-blue infrastructure with the target of absorbing or reusing 70% of the annual runoff volume for 80% of the developed urban area by 2030 (Jia et al., 2017; Jiang et al., 2018).

While having widespread successes, the SCP has also experienced challenges and barriers, especially in the initial years of implementation. The ambitious SCP takes a top-down approach to governance and implementation (Jiang et al., 2017), which has led to limited technical guidance that incorporates localized conditions and needs (Yin et al., 2022; Jia et al., 2017), a lack of local government capabilities and coordination across the multiple agencies and local jurisdictions (Li & Zhang, 2022; Jia et al., 2017), a lack of education and training (Jia et al., 2017; Jiang et al., 2017; Ma et al., 2020), an accelerated implementation timeline that resulted in hasty planning with a higher risk of poor design or results (Jiang et al., 2017; Ma et al., 2020), a lack of holistic, long-term planning (Ma et al., 2020), inconsistent construction of features (Ma et al., 2020), a lack of monitoring and learning networks (Jiang et al., 2017) and a lack of community engagement (Fu et al., 2022).

Some solutions have been implemented to address these barriers, such as "Sponge City Offices" that were created to facilitate coordination and the need for knowledge from multiple agencies and disciplines and improve city-to-city learning (Jia et al., 2017; Chan et al., 2022). Transdisciplinary research will provide the ability to co-create knowledge with actors and integrate traditional ecological and social knowledge (Yin et al., 2022; Jiang et al., 2017; Qi et al., 2020).

Public awareness has also increased over time (Ma et al., 2023; Jia et al., 2017; Luo et al., 2022; Zhu et al., 2022; Yin et al., 2022; Han et al., 2023; Zhang et al., 2023; Qi et al., 2020). There is some indication that the increase in knowledge and support for sponge city initiatives has increased since its inception in 2014 and initial calls for increased public engagement and education through media (Luo et al., 2022; Jia et al., 2017). Sponge city initiatives are common practice in the pilot cities with 71% understanding the concept, 60% willing to pay for additional features, and a general satisfaction with transportation and living conditions and local government (Luo et al., 2022; Zhang et al., 2023). Public discourse still exists around unrealistic expectations, specifically after low-frequency events, and a reluctance to accept trade-offs of prioritized actions (Yin et al., 2022; Qi et al., 2020), while others are working to improve outreach on flood risks and warning systems and encourage healthy water use habits (Li & Zhang, 2022).

The SCP is actively looking for drivers to increase financing including public and private investments, cost effectiveness and quantifications of environmental, social and economic benefits (Li & Zhang, 2022; Jia et al., 2017; Jiang et al., 2017). Policy and market tools that are being explored include public-private partnerships (PPP), environmental fines, tax incentives, regulatory restrictions, development charges, value-capture taxes and rainwater trading (Li & Zhang, 2022; Jia et al., 2017; Shi et al., 2023; Griffiths et al., 2020; Zha et al., 2021). Strengthening the financing for implementation and maintenance will need to address policy uncertainties, the implied risk in the SCP and the monetization of co-benefits (Li & Zhang, 2022; Jia et al., 2017). Ma et al. (2023) optimistically predicted a future where there is an increase in the benefits to society and the environment, while sustaining the economic benefits within an adequately secure range.

Urban water management systems are complex social-ecological systems (Jiang et al., 2018). This case study can provide some insights into how the additional evaluation under the Social-Ecological Resilience Framework could provide additional context. Defining the boundaries, scale and components (forms and functions) of the system can dictate the approach. Table 1.1 is a comparison of how a sustainable approach using the Social-Ecological Resilience Framework compares to the Sponge Cities Program.

Using the Social-Ecological Resilience Framework, the goal for this SES would be to change the impact that flooding is having on a city's form and function, without changing the various forms and functions of social, environmental or economical components and relationships. The SES using this framework would consider a watershed approach to evaluate the interactions of the hydrologic and ecological system with the built and social environment (Li & Zhang, 2022). The scale encompasses all aspects of the urban environment within the city. The form encompasses the structures of the urban city, including the built and natural environment and social structures, such as businesses and neighborhoods. The functions of the SES are also vast within an urban city, however this case study will focus on the functions, such as providing means to meet basic needs, generating income and asset accumulation, creating social and cultural identity, building and sustaining social networks and overall well-being. Thus, at the city scale, this is an example of a sustainable approach that is maintaining both form and function.

The goal of the Sponge City Program SES would be to maintain the same function with increased capacity of that function by adapting the form from grey infrastructure to an integrated blue-grey-green approach. The SCP SES uses the city boundaries and does not provide connectivity to the larger drainage basin (Griffiths et al., 2020). The scale focuses on the water management infrastructure. Examples of forms include pumping stations, retention ponds/parks, wetlands, drainage networks, green roofs, etc. Examples of functions include water regulation, flood mitigation, stormwater storage, water quality, etc. (Ma et al., 2020; Song, 2022). At this scale, this SES is an example of an adaptation approach that is changing form while maintaining function.

Table 1.1: Comparison of Aspects of the SES Between the Social-Ecological Resilience Framework and the Sponge City Program

Aspect of the SES	Social-Ecological Resilience Framework	Sponge City Program
SES Boundaries	Watershed Boundaries: The focus on this SES is on the interactions of the hydrologic system with the built environment. Based on the importance of the hydrologic connections, the boundaries should be defined with a watershed approach (Li & Zhang, 2022).	City Boundaries: The SCP lacks connectivity to the larger drainage basin outside of the city boundaries (Griffiths et al., 2020).
Scale	Urban City	Water Management Infrastructure
Form	Road and transport networks, housing, utilities, public spaces, businesses, municipal agencies, water infrastructure	Pumping stations, retention ponds/parks, wetlands, drainage networks, green roofs, etc.
Function	Overall well-being	Water regulation, flood mitigation, stormwater storage, water quality, etc. (Ma et al., 2020)
Goal	The goal of the SCP at this scale would be to change the impact that flooding is having on a city's form and function, without changing the various forms and functions of development and economic growth.	The goal of the SCP at this scale would be to maintain the same function but increase the capacity of that function by adapting the form from grey infrastructure to an integrated blue-grey-green approach.
Approach	Sustainable Approach	Adaptation Approach

Properly defining the SES and failure to integrate the social sub-system are very critical to defining the approaches and achieving the desired results. This case study demonstrates how two definitions can occur simultaneously at various levels in the panachy, or scalar levels of the system. By not including the larger SES of the urban city in the programs development, the Sponge City program ran into institutional failures mainly pertaining to the social system.

Yet the biggest consequences in not integrating the social system into flood risk management is the cascading failures that can occur when a disaster hits (Yuan et al., 2022; Fu et al., 2022). The city of Zhengzhou is a good example of the importance of properly defining the SES and capturing the interdependent complexity of the social system. Although Zhengzhou is a pilot

Sponge City, extreme events, such as the 1,000-year rainfall event in 2021, caused widespread flooding, affecting 14 million people, taking 398 lives, inundating 16 million hectares of crops and costing US$20 billion in direct economic losses (Chan et al., 2022; Fu et al., 2022; Guo et al., 2023). This event, like many others, and the resulting fatalities were not just caused by a natural disaster, but by human failures within the SES during a period of shock (Guo et al., 2023). These cascading failures included the lack of concern over seven red alerts, lack of closure of businesses, schools and transportation networks, lack of awareness of emergency procedures and missed rescues and failure of power and communication networks, leading to paralyzed payment systems and the inability to purchase essential needs (Guo et al., 2023; Fu et al., 2022). In this case, as in many others, these human failures are fatal (Guo et al., 2023). Integrating extreme events will likely require additional adaptation and transformation approaches.

The SCP has largely ignored the social effect and the interconnected social-ecological-technical systems (Fu et al., 2022; Luo et al., 2022). To build flood resilient cities, social resilience that provides knowledge, power and capacity to individuals and communities to take deliberate actions to build resilience is required (Fu et al., 2022). Co-creating knowledge occurs through transdisciplinary approaches with actors at the individual, community and institution level to create a shared understand (Fu et al., 2022; Jiang et al., 2018; Zhu et al., 2022). Power dynamics must be balanced within a participatory governance structure, with clear and transparent feedback mechanisms between government and residents (Luo et al., 2022). Institutions can support a more equal power balance with policies and actions that prioritize the public good and account for social and ecological impacts or benefits in new business models (Jiang et al., 2017).

New and expanded capacities, social learning and social constructs can support individual and collective actions (Jiang et al., 2018; Fu et al., 2022).

Within the SES, history and culture can play a role in defining existing form, function or interactions of the system and help identify areas of intervention. An ancient Chinese notion of "man can conquer nature", that was also a guiding philosophy of long-time leader Mao Zedong, and the deep-rooted history of traditional infrastructure continues to cause resistance and inertia from moving away from traditional approaches (Shapiro, 2001; Jia et al., 2017; Fu et al., 2022). Culturally significant ancient courtyards designed using ancient scientific thinking are examples of integrated drainage, nature and harvesting rainwater (Yin et al., 2022). These courtyards have been vastly replaced through rapid urbanization, but still offer a glimpse into how traditional culture can inform future actions (Yin et al., 2022). Ma et al. (2023) call for a modernization of the ancient concept of harmonious development of man and nature to build an ecological civilization.

Gated communities are also culturally significant and make up 80% of urban residences across 300,000 communities (Fu et al., 2022; Zhu et al., 2022). At one level of the panachy, building flood resilient gated communities can scale up to contribute to flood resilient cities (Fu et al., 2022). It is especially important to understand the role of gated communities within the SES, both as effective neighborhood level governance structures and implementers of community-based, bottom-up features (Fu et al., 2022; Zhu et al., 2022). Specifically, leadership structures in gated communities can contribute to investments in resilience measures, increase the uptake of policies and programs, such as flood insurance, increase community engagement and awareness and conduct resilience mapping that includes risks to specific properties and the interdependent systems (transportation, energy, communications, etc.) (Fu et al., 2022; Han et al., 2023).

There is also a strong history of development and economic growth with acceptance of significant damage to the environment (Jiang et al., 2018). Although a more integrated approach is now being implemented, and an integrated ecosystem services framework for development decision making being considered, the political and economic drivers are still very strong, and the SCP is not fully integrated into the development of the city itself (Ma & Jiang, 2023; Ma et al., 2020). Institutions have enduring self-reinforcing feedback mechanisms that create resistance to change from past methods and implement a new approach (Jiang et al., 2017; Fu et al., 2022). This is evident in the New Urbanization Plan (NUP) goals to promote the orderly conversion of rural migrants into urban residents, optimize the patterns of urbanization, enhance the sustainability of cities and promote the urban-rural integration (Chu, 2020). The NUP acknowledges that optimizing a pattern of urbanization has negative effects on already deteriorating environments and that rural-urban transition will leave vacant land for large-scale agricultural production (Chu, 2020), thus causing further loss of watershed capacity. A major failing in policy is that there are no clear connections in how the NUP and SCP should interact and support each other. In addition, there is no clear integration with other initiatives and plans in China, including land use plans, smart cities, eco-cities and low-carbon cities (Jiang et al., 2018; Jin et al., 2022).

Although the Sponge Cities Program has begun to rectify many of its initial failures, the deficiencies in flood risk management could have been minimized or avoided with proper assessment of the SES and the goals it was aiming to achieve. This case study demonstrates the importance of defining the appropriate SES boundaries in the context of the overall resilience goals, both geographically and the boundaries of linkages and feedbacks, specifically in the social sub-system. It also is important to integrate history and culture into defining the system, its forms functions and interactions, as well as help identify areas of intervention.

At the institutional level, the SES should be governed by a participatory governance structure that encourages the collaboration between interconnected and overlapping jurisdictional and mission boundaries of multiple agencies and policy-making bodies, while also accounting for political realities in each country (Yin et al., 2022; Jiang et al., 2017; Jiang et al., 2018). A coordinated institutional framework is needed to capture the intersections of social, ecological and economic forms and functions, support feedback structures to build capacity for social learning, innovation and adaptive management, develop and implement enabling policies and provide resources and capacity (Jiang et al., 2017; Jiang et al., 2018).

Adaptation

Adaptation is defined as a change in system form while maintaining its function. Adaptation is a process of adjustment to new or changing conditions in order to maintain function, even if the appearance or behavior of an aspect changes. Martin-Breen and Anderies (2011) reiterated this definition describing a system where the functions are maintained while the structure may not be.

Adaptation Case Study – Coastal Structures

Coastal residents around the world are experiencing an increase in flood risk due to climate change and have a growing personal responsibility to mitigate their own risk (Snel et al., 2021; Hemmati et al., 2021). Today, over 1.6 billion people and their homes and businesses, are vulnerable to flooding, with 90% from poorer countries (World Bank, 2016; IPCC, 2023). As the overall coastal population continues to grow, some residents and communities are looking for ways to build resilience to these impacts either in place or somewhere new. This case study investigates building resilience of residential, public and commercial structures, either through the actions of an individual property owner or through collective community actions.

The form of this SES is narrowly defined as residential, public and commercial structures in flood-prone coastal areas. Residential structures provide functions such as providing a home (shelter), raising a family, part of their identity, a sense of belonging and safety and contributing to overall health and well-being (Greer & Trainor, 2021; Rolfe et al., 2020; World Bank, 2016). Public structures provide social services to the community (education, health care, municipal, recreational, etc.). Commercial structures provide goods and services that support livelihoods, economic prosperity and social resilience (Hudson et al., 2022). The key actors in this SES are the individual homeowners, community leadership and business owners, and can all behave differently in driving or obstructing the mitigation of risks (Hudson et al., 2022; Hegger et al., 2017; Javeline & Kijewski-Correa, 2019). The institutions are government agencies and international aid organizations that provide funding at the property or community level. The goal of building resilience in this SES is to reduce the social and economic damages from flooding and lessen the period of recovery by adapting the form (coastal structures) while maintaining all the functions of the structures and the community, as a whole (M.V. & Philip, 2022).

The resilience measures available can be categorized as technical, financial or behavioral (Snel et al., 2021). This case study focuses on a handful of technical resilience measures considered adaptation approaches and entail changing the form of a coastal structure but not its function. Other technical measures (i.e., floodproofing and rainwater harvest), as well as financial measures (except disinvestment), such as insurance and disaster funding, and behavioral measures, such as risk awareness, emergency planning and evacuations, would be considered a sustainable approach (maintain form and function) and are not covered here (Snel et al., 2021; Mannucci et al., 2022).

Technical adaptation actions include various building typologies that are being implemented today as adaptation actions, including amphibious structures, floating structures or elevating a structure (Mannucci et al., 2022; Archer et al., 2022; English et al., 2017; Proverbs & Lamond, 2017). By integrating current and future flood risks, architects and engineers can consciously design structures that coexist with water, thereby reducing the damages to the property and increasing the ability for the property to remain occupied during and after a disaster (Archer et al., 2022, M.V. & Philip, 2022; Zarekarizi et al., 2020; Felicioni et al., 2020). Disinvestment is also included as a financial adaptation action. Property or business owners may decide to sell property in more flood-prone areas and public entities may decide to disinvest and not rebuild public infrastructure. Relocation from high-risk areas has occurred in an ad-hoc manner although more attention is being paid to assisted community relocation (Schwaller & BenDor, 2021).

In the last century, there has been a shift across the globe away from traditional housing design, such as slab-on-grade instead of pilings in floodplains in the U.S., as well as using local materials, such as replacing bamboo with concrete in Vietnam (Tuan et al., 2015). Culturally significant housing, specifically as practiced for centuries, is important to consider and can increase resilience, such as vernacular housing in Nepal which uses localized technology and resources (Gautam et al., 2016), terps or dwelling mounds in the Netherlands (Proverbs & Lamond, 2017) or traditional stilt or raised homes in Thailand and the U.S. (Proverbs & Lamond, 2017). At the same time, some vernacular housing may not be more resilient in the face of climate change, such as the "Assam-type" in India, which is proposed to be replaced with amphibious bamboo-based hybrid foundations (Das & Mukhopadhyay, 2018). Embracing new technologies can help preserve the cultural and architectural significance of a community, such as amphibious housing in New Orleans (English, 2009). However, existing policies can also restrict the implementation of new resilient technologies. For examples, structures in a Vietnam village were unable to be updated due the town's ancient preservation policy (Nguyen et al., 2021).

The ecological sub-system role is focused on hydrological conditions that lead to flood events that, in general, are well monitored and researched. It is also proven that taking structural adaptation actions, such as elevating structures on stilts or pilings, flood-proofing and more innovative approaches like amphibious housing, can reduce flood damages and lessen recovery times (English, 2009; Archer et al., 2022, M.V. & Philip, 2022; Zarekarizi et al., 2020; Felicioni et al., 2020). The uptake of adaptation measures for coastal structures, however, is largely driven by the economic and social sub-systems of the SES, indicating a need for extensive research on these sub-systems (Hemmati et al., 2021; Greer & Trainor, 2021).

One question that arises is who is responsible for providing flood risk solutions? While many residents' perspective is that governmental bodies are responsible for flood risk management (Snel et al., 2021; Nguyen et al., 2021; IWRA, 2020), there is a shifting of responsibility from government to homeowners, who are reluctant to accept this responsibility (Hegger et al., 2017; Snel et al., 2021; Greer &Trainor, 2021). This shift is occurring due to (a) increasing risks requiring all actors to engage, (b) a lack of resources, (c) beneficiaries of risk reduction, (d) rising physical and mental health impacts to the individual, (d) conflicting timescales and (e) private property rights, where ultimately the homeowner is the sole decision maker (Snel et al., 2021; Hegger et al., 2017; Valois et al., 2020a). Market drivers, such as real estate development and markets, pass on flood risks to unknowing and uninformed buyers, and growing insurance crisis, such as in Louisiana and Florida, are greatly impacting residents ability to maintain coverage (Ubert, 2017). If homeowners feel responsible for their own flood risk, they are more likely to be informed with data provided by the government, insurance and others (Snel et al., 2021; Hemmati et al., 2021).

Like market drivers, economic conditions need to support the implementation of adaptation measures. Housing is often the largest investment asset for individuals (Greer & Trainor, 2021) and contributes to generational wealth (UCS, 2018). Poverty-related barriers are significant, specifically in flood-prone slums and dilapidated housing (Nguyen et al., 2021; Tikul, 2015). Flooding can also exacerbate the fight against poverty. Individuals suffer from evacuation, temporary housing and recovery expenses while also paying mortgage and taxes (UCS, 2018) which can cause a downward slide into poverty (Tuan et al., 2015; Nguyen et al., 2021). In addition, low-income and marginalized communities are more likely to be experiencing physical and mental health issues from the trauma of flood disasters and recovery, which have their own costs (Snel et al., 2021; Valois et al., 2020b). Although these inequities should be addressed with policies and financial aid, wealth is not a direct indicator on whether a homeowner will implement adaptation actions (Zou et al., 2020; Greer & Trainor, 2021).

Implementing adaptation actions has a strong return on investment for the property owner and some communities, such as in the UK, who have demonstrated a high willingness to pay to protect property, psychologic benefits and intangibles (sentimental assets, health impacts, etc.) (Owusu et al., 2015; Joseph et al., 2015). Yet it has not resulted in widespread adoption, especially before a flood event, due to market failures, lack of information and other social and cultural factors (Tuan et al., 2015; Javeline & Kijewski-Correa, 2019; Golz et al., 2015). Residents in North Carolina felt absolved of their responsibility to implement adaptation actions by simply following building codes and purchasing insurance (Javeline & Kijewski-Correa, 2019), while residents in the UK wanted to build resilience into recovery efforts but were restricted to the original, pre-flood condition by the insurance provider (Snel et al., 2021). A majority of residents surveyed in the Netherlands were more willing to pay to elevate their home than insurance if it meant risk elimination (Botzen et al., 2013). Market drivers, such as risk-based insurance costs and real estate markets informed by data such as flood disclosure and Flood Factor, are growing incentives to implement adaptation actions, not purchase or move away from flood-prone areas (Hegger et al., 2017; Tompkins et al., 2010). Similarly, businesses, understudied on this topic, are less likely than households to take adaptation actions or contribute to collective flood risk management, specifically small and medium sized businesses (Hudson et al., 2022). While there isn't research on the motivations of businesses, without timely recovery of housing, businesses and the local economy suffer from a shortage of labor and a lack of consumer and tax base (Greer & Trainor 2021; UCS, 2018).

Higher risk perception and those with a historical experience with flooding are more positively linked to the implementation of adaptation actions; however, this isn't always the case and there are other key variables to consider (Valois et al., 2020a; Schwaller & BenDor 2021; Holley et al., 2022). Various studies have described elements of a homeowner's decision making, including costs, ease of installation, information about risks and solutions, effect on home value, loss of life or property, timing and fit of financial aid and attractiveness (Zou et al., 2020; Greer & Trainor, 2021; Schwaller & BenDor, 2021). Additional drivers of decision making revolve around norms and behaviors (Hemmati et al., 2021). Place attachment, community cohesion and coping mechanisms are just a few examples of the social capital that is important in this SES.

A strong behavioral norm, specifically in developed countries, is the place attachment and value that society places on living or vacationing on the coast for overall well-being (M.V. & Philip, 2002). In developing nations, place attachment could be closely tied to social networks and livelihoods that are dependent on the coast. Holley et al.'s (2022) study in Louisiana found that strong place attachment motivated initiatives to build resilience, such as home elevation, but when coupled with negative associative emotions, was more likely to motivate relocation behaviors than those with weaker place attachment. The study also indicated demographic variances, such as non-whites and political liberals were positively related to elevating one's home or business, in addition to perceived self-efficacy (Holley et al., 2022). Strong community cohesion can lead to the lack of preparation, as the psychological barrier puts heavier emphasis on external support from neighbors and government (Nguyen et al., 2021). Flood risk is seen as a collective community problem and those not at risk are expected to assist those that are (Snel et al., 2021). Although flooding can cause a loss of security, community cohesion and essential lifelines, the survival and rebuilding process can build stronger social networks and sense of place and restore community cohesion (Sen et al., 2021; Hallegatte et al., 2019). Coping mechanisms, specifically those informed by inherent knowledge passed down through generations, can help manage repetitive shocks (Nguyen et al., 2021; Lambert et al., 2021; Davidson, 2010). In a study of south Louisiana, risk perception did not indicate adaptation actions, possibly because of the coping mechanisms that have developed over multiple flood disasters (Holley et al., 2022; Lambert et al., 2021). In other communities, flooding will be a relatively new occurrence; therefore, individuals and the community will need to increase their learning capacity in a short period of time to cope.

Low-income and marginalized communities are impacted more by the same disaster simply because they have fewer assets and financial savings, are more vulnerable to education and health impacts and need additional time and capacity to recover (World Bank, 2016). Low-income households have less capacity and social capital to implement adaptation measures (Nguyen et al., 2021). There are challenges to some solutions, like elevated homes, for the elderly and disabled (Sameen, 2018). Ramps and elevators have to be integrated into the design and costs, such as was done after Hurricane Katrina (Evans-Cowley & Gough, 2009; Erdman et al., 2017). The ad-hoc nature of relocation has also been disproportionate as individuals who have the means (wealth, access, power, etc.) for out-migration moves once a threshold is crossed, while more socially vulnerable populations (marginalized, impoverished, elderly) are left behind in high-risk areas (Habans, 2019; Hobor et al., 2014; Schwaller & BenDor, 2021).

Institutions should modify or design existing or future policies with social and economic factors in mind to build flood resilience and equity. Institutions are expected to provide assistance before, during and after the flood event (Snel et al., 2020). Flood mitigation policies should consider stronger linkages to the individual actors, participatory process for planning and implementation and key social factors to increase acceptance by the community, prevent negative socioeconomic consequences and avoid administrative burdens (learning, compliance and psychological costs) on individuals (Hemmati et al., 2021; Suykens et al., 2019; Greer & Trainor, 2021). Greer and Trainor (2021) found that homeowners overwhelmingly thought that recovery policies were complex, constantly changing and repetitive, burdened with paperwork and lacked trust and common goals between the institution and the individual.

Awareness is still a top priority for policy and public entities to enhance risk knowledge and reduce the reluctancy for adaptation actions (Valois et al., 2020a; Bichard et al., 2012; Bichard & Kazmierczak, 2012) while also ensuring that new development does not increase flood risks on existing structures (Snel et al., 2020). Financial aid is another strong driver for recovery and resilience although temporary housing can actually slow the permanent housing recovery (Greer & Trainor, 2021). Institutions need to ensure that the timing and the fit of the aid program has the appropriate organizational capacity, is meeting the needs of the household and is designed to be efficient and effective (Greer & Trainor, 2021). Most importantly, governments and insurers should integrate resilience into rebuilding of structures (Zurich, 2013). Regulatory, market drivers and economic incentives have also been shown to be effective motivators for action (Zou et al., 2020; Valois et al., 2020a; Suykens et al., 2019; Dawson, 2011). Because of the vicious cycle between poverty and flooding, any disaster risk policies should conduct analysis and design to fully integrate equity (World Bank, 2016; Nguyen et al., 2021).

Ultimately, both institutions and actors serve existing functions in this SES however they are either not aware of their roles and responsibilities or not fulfilling them. Institutions should ensure easily accessible and timely financial support, increase flood risk awareness, provide knowledge and technical support for adaptation solutions, enact supportive policies, such as requiring insurance to build back with resilience and not just back the way it was, and new development accounts for flood risk, and utilize equitable participatory processes to alleviate barriers and increase social acceptance. Actors are responsible for knowing their own risks and solutions available, be willing to pay or seek financial aid, be active participants in engagement processes, use market drivers such as insurance and flood risk disclosure within the real estate market, and support collective agency through accepting new norms and behaviors.

As in all levels of SES, communities are dynamic and the actors are regularly shifting roles, interests and alliances in an attempt to build long-term adaptive capacity (Porter et al., 2014). Thus, longitudinal studies are needed to help understand the progressive decision making of households and businesses to taking adaptation actions (Nguyen et al., 2021 Schwaller & BenDor, 2021). To support changing the form of this SES while not losing its functions for the community, institutions and actors must understand the assets available, the ability to organize and act independently or collectively, the learning capability, the flexibility to change, the sociocognitive constructs and the agency for change to a more resilient future (Cinner & Barners, 2019).

Transition

Transition is defined as a change in system function while maintaining its form. Tompkins (2010) described transitions as “major long-term changes in the ways societal functions are fulfilled” (p.628). Research on transitions, specifically to climate change impacts, have focused on how the socio-technology transitions can lead to new social practices (Smith & Sterling, 2010), the transition of livelihoods (Ellis, 2000) and the transition to equitable practices (Sen et al., 2021). Another common reference is to the energy transition needed to decarbonize and limit the extent of climate change impacts. In this instance, the form of the energy delivering systems and the use of energy by actors in the system are being maintained while the functions of fossil fuels, wind and solar within the system are being modified.

To promote transitions, and considering they are fundamentally political, it is necessary to implement policy changes and allocate a significant amount of social revenue (Meadowcraft, 2011). Societal transitions tend to arise from a combination of concurrent changes, including alterations in technology, user behavior, regulation, industrial networks, infrastructure, symbolic meanings and culture (Tompkins, 2010). Geels and Schot (2007) propose core components of transitions include: the early stages of change (involving the accumulation of niche activities), technological add-ons (where niche activities are integrated with existing technologies to overcome obstacles) and hybridization (when the new technology supplants the old and is adopted on a wider scale). These elements are influenced not only broader social changes, but also by the actions of specific actors and political agendas, which may be transparent or concealed (Smith & Sterling, 2008; Geels & Schot, 2007)

Transition Case Study: Community-Driven Resilience

The historic driving force of economic development has been a key factor in the formalization of most modern institutions providing goods and services. These often overly bureaucratic institutions have legally embedded regulations and policies (Wiering et al., 2017). The global environmentalism movement in the 1970s led to the creation and modification of new and existing institutions driven to protect the environment (Wiering et al., 2017).). Social movements, such as environmental and climate justice, are continuing to bring changes within institutions. Through these changes, there is a growing recognition that resilience cannot be met unless the historic driving force of economic development are balanced with environmental and social needs (Sachs et al., 2019; IPCC, 2018).

Institutions play a key role in building resilience or the perpetuation of vulnerabilities to flood disasters, specifically governance institutions, non-profit organizations and legal systems, such as property rights (Oberlack, 2017). Practices of institutional power and institutional knowledge making are intimately involved in the manifestation of resilience and vulnerability (Barrios, 2014). Governance institutions are generally top-down organizations, where regulations and policies are developed and imposed on communities. Institutions have entrenched processes, are slow to adapt to changing conditions and have reinforced path dependencies (Wiering et al., 2017; Oberlack, 2017). When dealing with life-threatening disasters, institutions can be hesitant to make major changes and can fall into many institutional traps, such as overreliance on technical or single-discipline experts, centralized management and resources, vested interests, mistrust, temporal planning horizons and fragmented organizational structures (Lebel et al., 2011; Oberlack, 2017).

Affected actors in this SES lack power in the decision-making process of institutions, specifically in developing and informal regions of the world and where the socio-political climate is fragile or violent (Peters et al., 2022). A widespread call for participatory governance demonstrates that the best resilience outcomes are achieved when the planning and implementation of resilience actions are community-driven (Peters et al., 2022; Paul et al., 2018; Fung, 2015). Participatory or community-driven governance should build effectiveness, legitimacy and social justice by embracing time, trust-building and interdependence, but faces many challenges including political tensions, financial power and sustained engagement (Fung, 2015; Ansell & Gash, 2007; Matin et al., 2018). A redistribution of power within the decision-making process involves active coordination among actors at all stages of governance, from defining the problem to developing solutions, implementation and monitoring. Institutions should provide pathways to integrate new learning, indigenous knowledge, citizen science and innovative technologies by embracing time, trust and interdependence (Paul et al., 2018; Choudhury, 2021).

Communities are never static or bound and in a constant state of transformation (Barrios, 2014). Defining not only the boundaries of the system, but the boundaries of each level of panarchy is challenging. When assessing a community in the SES, it is important to acknowledge that community boundaries may not be static, especially before, during and after a disaster and the boundaries may be different for different institutions (Olsson et al., 2014). For instance, for the Federal Emergency Management Agency (FEMA), geographic boundaries before Hurricane Katrina were more constricted than after when survivors expanded beyond the boundaries of the city limits, or the greater coastal disaster area, to nationally and even worldwide. Whereas local institutions were not concerned in tracking relocated residents but with managing the residents that remained. Thus, community boundaries should not be assumed to be municipal boundaries and are more appropriately set by shared cultural context, shared relationships or shared futures.

Catastrophic shocks to a community can result in novel communities, new social relations and networks, changing boundaries and new forms and functions within the SES when thresholds are exceeded (Yu et al., 2017). While the occasional shock can be traumatic, it can also increase long-term resilience outcomes by providing social memory, increasing adaptive capacity and presenting the social norm for collective action (Yu et al., 2017; Davidson, 2010). Pre-trauma capacities are not necessarily going to help with the realities of post-disaster communities (Barrios, 2014). Community resilience builds social capacity that allows the community to evolve to systemic or acute changes in the social, economic or environmental landscape (Chandra et al., 2011; Berkes & Ross, 2013; Adger, 2000; Clark-Ginsberg et al., 2020). Moore et al. (2013) identified exemplary practices across the world that are essential elements of community resilience, including community education, community empowerment, practice, social networks, physical security and economic security.

The form of this SES are communities vulnerable to fluvial, pluvial or coastal flooding. The form encompasses the structures of the community, including the built and natural environment and social structures, such as social networks and households. The key actors in this SES are community members and institutions that govern the regulatory, funding and policy climate. The functions of the SES are vast within a community; however, this case study will focus on the institutional function of governance over disaster recovery and resilience planning and implementation and the actors' agency. The goal of building flood resilience is to change the functions of institutions from top-down to bottom-up to build community-driven resilience that maintains the form and functions of the community.

Barrios (2009a; 2009b; 2014; 2017) conducted an ethnographic study three years after Hurricane Mitch impacted the impoverished city of Choluteca in southern Honduras in October 1998. This study illustrates the importance of the relationships between institutions and actors to drive social and flood resilience outcomes in the SES.

Two new resettlement communities, Limon de la Cerca and Marcelino Champagnat, were constructed to remove residents from flood-prone areas in Choluteca through different political and social relations between institutions, specifically governments and international aid organizations and actors, the affected population (Barrios, 2014). Pre-hurricane, these communities were not distinct entities with residents migrating in from 22 similar working-class neighborhoods in Choluteca. Institutions leading the resettlement in Limon used a top-down approach, whereas Marcelino was influenced by an active network of grassroot organizers to connect institutions and funding to community members (Lizarralde & Boucher, 2004; Barrios, 2009a; 2009b; 2014; 2017). Power redistribution occurred for the residents of Marcelino, driven by acts of resistance, rejection of international aid proposals and the agency of grassroots leaders, while Limon residents were not provided power in decision making, evidenced by the rejection of residential requests based on institutional policies (cost-benefit login) or institution knowledge making (which ignored the socio-environmental context) (Lizarralde & Boucher, 2004).

Power redistribution in this case was not easy or institutionally-led. Government institutions can be bureaucratic, at best, and, at their worst, incorporate primary mechanisms of corruption and clientelism to influence political behavior and increase political tensions between institutions and residents. It was the agency of Marcelino residents that organized and protested and, ultimately, a demonstration turned violent resulted in institutions providing more decision-making power and adaptive capacity to Marcelino.

Housing in Limon was inadequately sized for multi-generational families, construction materials and design was unsafe from future storm events, infrastructure networks (sewer, water and electricity) were unfinished and unreliable and parcels were randomly distributed causing the separation of family and friends with cascading impacts (such as loss of child care, support systems, etc.) (Barrios, 2014; Lizarralde & Boucher, 2004). Housing in Marcelino, by contrast, had larger floorplans, larger plots to support cultural practices (small animal husbandry, gardening) and allowed separation for latrines, constructed to be resistant to storm damages, included functioning infrastructure networks and supported social networks in selecting parcels (Barrios, 2014).

The functions of the institutions in this SES have drastic effects on the community flood resilience outcomes. Institutions resettling Limon used top-down approaches designed without the local and environmental context in mind. Marcelino was developed with vertical and horizontal connections between institutions and community residents that incorporated the local and cultural context, trust, collaboration between government and aid organizations and affected residents and redistribution of power in decision making (Barrios, 2009a; 2009b; 2014).

Marcelino is more resilient to the next storm than Limon. However, by changing the functional role of institutions, Marcelino was also able to achieve other social resilience outcomes that were not observed in Limon, such as resilience to future overcrowding and poverty, limited crime and street gang activity and overall well-being (Barrios, 2014; Lizarralde & Boucher, 2004). In contrast, Limon's outcomes include structurally unsound housing, violent activity from street gangs, limited access to water and electricity, reduced sanitation, greater emigration and uneasy, mistrusting and insecure population (Barrios, 2014; Barrios, 2017; Griffiths et al., 2020). Limon residents are no more resilient to floods than before Hurricane Mitch, have additional vulnerabilities to other social stressors and the social fragmentation can make them more vulnerable to social and environmental stressors.

The functions that the institutions and actors played within the SES made a difference in achieving long-term resilience outcomes to multiple stressors the community was facing. Limon was institutionally driven with top-down approaches that had an overreliance on institutional power, knowledge and policies, such as using cost-benefit analysis justifications and complicated by corruption in political leadership. Institutions failed to consider the local context or cultural norms and actors lacked power and agency to influence decision-making and propose different solutions. Marcelino's resettlement was actor-driven. The bottom-up approach was fueled by an active network of grassroot organizers. Initial institutional resistance and corruption was met with organized rejection of political leadership and a forced redistribution of power. The individual and collective agency was able to ensure that the local context and cultural norms were integrated into the final designs.

Although not institutionally led, this case study demonstrates the need to be intentional in changing and modifying the functions of flood risk institutions to participatory or community-driven governance. Community-driven resilience planning and implementation should build and nurture social relations between the actors and the institutions. Changing the function of institutions from top-down to bottom-up and redistribution of power can maintain the form of the community by accounting for the social, economic and cultural context within the localized SES framework and produce a wider range of social, economic and environmental resilient outcomes. Ultimately, institutions can empower and support communities to define their own resilient futures.

Transformation

Transformation is defined as a change to both system form and function. Transformation occurs where an undesirable state of the existing ecological, economic or social landscape has been achieved and there is no pathway or it is extremely difficult to alter the state to a more desirable outcome (Walker et al., 2004; Folke, 2006). Transformation is necessary when systemic challenges or conflicts between sub-systems of the SES cannot be addressed with incremental change (Olsson & Jerneck, 2018). At some point, it may be necessary to define an entirely new state of the SES.

Transformative space is needed to explore these more complex and transdisciplinary research approaches (Pereira et al., 2018). Transformation can be planned or unplanned, accelerated or gradual. Transformation can come with cascading, unknown and unintended changes to other aspects or interactions with the SES. Transformation must include a change in power dynamics that can be fueled by new values and meanings or relationships between agents and networks (Leach et al., 2018).

Transformation Case Study: Capital City of Indonesia

The capital city of Indonesia, Jakarta, is a deltaic mega-city with over 13 million people in an extremely dense urbanized landscape (UNRISD, 2020). Being situated on a delta has provided a vast array of economic development opportunities that have resulted in Jakarta being the center of government, finance, tourism, culture and politics (Azhar et al., 2020; Azmy, 2021). But being on a delta also brings multiple flood hazards, which have all had repetitive, independent and compounding impacts on the capital city, including sea level rise (and high subsidence), tropical events, monsoon season and river flooding (Budiyono et al., 2016; UNRISD, 2020; Brinkman & Hartman, 2008). From 2005 to 2019, Jakarta experienced chronic annual flooding with fatalities in 10 of 15 years (UNRISD, 2020) and risks are predicted to increase by 180% by 2030 (Budiyono et al., 2016). The decision to move the capital city was not made just because of the flood risks, which will entirely submerge 40% of the city by 2050, but a combination of natural disasters, overpopulation, traffic congestion, relieve land subsidence, environmental degradation and pollution (Shimamura & Mizunoya, 2020; Brinkman & Hartman, 2008).

The new site has very low risk of natural disasters and social conflicts and sufficient natural resources to sustain the new city (Azhar et al., 2020; Azmy, 2021). Prioritizing nature-based solutions and renaturalization with multi-functional design while integrating social justice can build resilience and provide positive environmental, social and economic benefits (Heryati & Koestoer, 2022). Trade-offs will have to be made throughout the process. An initial trade-off that has some opposition is the loss of tropical forests to construct the new city. Deep societal debate and engagement of residents is required as the greatest obstacles to success are not technical or financial, but social and political (Garschagen et al., 2018; Padawangi & Douglass, 2015).

The government's goal of "A Global City for All" aims to provide comfort, welfare, education, health care, fair and equitable participation and distribution of economic equality (Simarmata et al., 2023; Azmy, 2021). Eight principles of the relocation provide for balancing nature and equity with economic development to build a resilient city. As defined by the New National Capital City or Ibu Kota Negara (IKN), the principles are (1) design accounting to natural conditions (75% green area and 100% residents within 10 minute walk to green space), (2) Bhinneka Tunggal Ika (local wisdom, social and community services and inclusive design for locals and immigrants), (3) connected, active and easily accessible (80% public transport, strategic airports), (4) low carbon emissions (100% renewable for IKN, net zero by 2045), (5) circular and resilient (10% land for food production, 60% of all waste is recycled, 100% wastewater treatment), (6) safe and affordable (fair housing, 10 best global cities), (7) convenience and efficiency through technology (100% digital connection, smart city) and (8) economic opportunity for all (0% poverty) (IKN, 2023).

Figure 1.2: Conceptual Visions of Nusantara (Source: IKN, ikn.go.is, 2023)

This vision of a utopia (see Figure 1.2 has growing concerns surrounding how these goals and principles will be achieved. Others have noted that the government's true agenda is economic development (Ishenda & Guoqing, 2019; Azmy, 2021). With the majority of the $33 billion investment needed to be secured from private sources, there are concerns that economic development will ultimately proceed environmental and social needs. A state-centered approach has provided autonomy that allows the state to make decisions that are in the best interest of the society (Azmy, 2021). However, state autonomy can also allow the government to carry out their own agenda or act as agents of capitalists that does not necessarily reflect the interests of society (van Voorst et al., 2016; Azmy, 2021). Some have called for regulatory laws to dictate how the transformation would occur (Azmy, 2021). In 2019, surveys indicated disapproval with moving the capital and for the use of state funding to do so (Azmy, 2021; Azhar et al., 2020), while an analysis of Twitter data indicated 56% positive sentiment (Sutoyo & Almaarif, 2020). Public participation is minimal in a planning process some have called authoritarian, both for the residents of Jakarta and the indigenous and migrant villages around the hundreds of thousands of hectares of ancient tropical forests that will become the new capital (Padawangi & Douglass, 2015; Azmy, 2021; Shimamura & Mizunoya, 2020).

Although parts of Jakarta will be lost to rising seas, it will still be a functioning city and require purposeful investment and planning to build resilience (Shimamura & Mizunoya, 2020). Unlike Nusantara, there are no overarching resilience goals for Jakarta. Currently, there is less than 10% green space, but as residents and businesses move, infrastructure will be abandoned and can be given back to nature to improve the well-being of the remaining residents (UNRISD, 2020). In addition, formal housing that is abandoned, like governmental green buildings, can be refurbished for businesses and residents currently in high-risk areas or the slums (kampungs) of the city (UNRISD, 2020; Hidayat et al., 2020).

The government's deliberate decision to move the capital city over the next 10 years is a directional transformation, as it will be designed, planned and constructed purposefully (O'Brien, 2012). This planned transformation will change the forms and functions of an ancient tropical forest with associated villages, into an urban metropolis. The transformation of Nusantara will also be challenged with prioritization and tradeoffs on very ambitious resilience goals, especially with a lack of secured funding for full implementation. By contrast, Jakarta is likely to experience a gradual and largely unplanned transformation both with the movement of social and economic capital to Nusantara and the growing flood threats within the city. Even when purposefully planned, the innumerable changes to the forms and functions, and their relationships within the SES, of both Jakarta and the new capital Nusantara, will carry deep uncertainty and unintended consequences (UNRISD, 2020). Transformational resilience could result in changes to norms, values, beliefs, power distribution, rules and practices (Moore et al., 2014). Social justice is an essential component of transformation (UNRISD, 2020). The unknowns are where those transformational changes will result in either positive or negative resilience outcomes for a wide range of social, economic and environmental factors. Planners for the future city have a massive undertaking to achieve. How the government uses resources and engages society to transforms both cities will determine if they can address the existing problems of Jakarta and truly build a resilient city.

This case study actually addresses two social-ecological systems, Jakarta and Nusantara. Management of Jakarta's SES would entail a variety of actions that would either maintain or change the form or function. Therefore, resilience will be built through sustaining, adapting, transitioning and transforming different aspects of the SES. The Nusantara's SES is currently tropical forests with small indigenous and migrant villages, thus an example of transformation by changing the forms and functions of the SES. The goal of this SES would be to build a resilient city that embraces nature as a fundamental necessity in reducing vulnerabilities in the economic, social and environmental aspects of the SES.

Without understanding the SES, and in-depth thinking about the range of possible future states that would occur with changes to various forms and functions, the transformations could increase inequities and perpetuate negative states. Some have called on regulatory laws that could dictate how the transformation would occur, ensuring things like social justice and participatory processes, are at the forefront.

This SES case study highlights the opportunity to transform the capital city with its planning relocation to Nusantara to not only build flood resilience, but to address multiple vulnerabilities that exist in the SES. Transformational changes towards resilience can change all aspects of the SES and it is impossible to predict all the ways that this transformation would change the various forms and functions of both cities. This complexity makes it especially challenging to plan for all the cascading changes that will occur. A large transdisciplinary approach, with participatory governance, is needed if the goals for Nusantara are going to be fulfilled.

Operationalizing the Social-Ecological Resilience Framework

Implementation of the Social-Ecological Resilience Framework would require multiple steps and the capacity and collective agency of the individual actors and institutions to assess through a participatory and transdisciplinary process (Lebel et al., 2006; Berkes & Ross, 2013; Westley et al., 2013).

The first, and most important step, is to set resilience goals for the SES through a participatory process. It is essential to have an alliance or network of actors involved in this process which will give collective agency to ensure desired outcomes are achieved with collective action and learning (see Chapter 3 for example application) (Walker et al., 2002; Anderies et al., 2004; Lebel et al., 2006; Westley et al., 2013). Goal setting will have to be balanced between short-term needs and long-term goals and consider the values and priorities of all actors involved (Westley et al., 2013). Goals and defining the desired state of the SES, specifically in terms of human well-being, social equity and ecological diversity, are needed in order to operationalize in practice, provide transparency on priorities, conflicting goals and trade-offs and measure our progress toward resilience (Walker et al., 2002; Lebel et al., 2006; Olsson & Jerneck, 2018;

Smith & Sterling, 2010; Nelson et al., 2022). A commonly used context for setting resilience goals is to ask the question: "Resilience of what to what?" (Meerow et al., 2015; Carpenter et al., 2001; Walker et al., 2002) and "for whom?" (Lebel et al., 2006; Brown, 2013). A similar construct can be used to ensure resilience goals address issues of equity by asking "of what?" and "between whom?" and considering distributional, procedural and recognitional equity (Leach et al., 2018; Olsson & Jerneck, 2018). Nelson et al. (2022) suggest two key considerations to define the 'how', equity in process, and the 'what', equity in outcome.

The second step in applying the framework is defining the social-ecological system of interest, which is highly complex as well as locally specific, and will include the exchange with external drivers (Smit et al., 1999; Preiser et al., 2018). Planners, decision makers and actors should develop a common conceptual model and mental models to identify the key systematic components of importance and their relationships and interactions to each other (aka, multiscalar feedback loops) as well as the threats from climate change, while acknowledging the complexity, assumptions and uncertainties in both causality and future conditions (Preiser et al., 2018; Walker et al., 2002; Walker et al., 2006). Cause-and-effect mechanisms are non-linear and difficult to know or predict (Folke et al., 2016; Colding & Barthel, 2019; Beisbroek et al., 2017). In addition, the signals of change can have varying interpretations across the system (Moser & Ekstrom, 2010). As individual actors or institutions can have varying knowledge, experience or agendas, it requires a shared understanding of the SES (Smith & Sterling, 2010; Amirzadeh et al., 2022). Impact assessment and system dynamics models, systems-thinking approaches and scenario planning are advancing and can provide relevant scientific information on the ecological, economic and social landscape and anticipated shifts or changes, with probability distributions (Smit et al., 1999; Preiser et al., 2018; Walker et al., 2002; Elsawah et al., 2017; Constanza, 2014; Levin et al., 2012). Multiple disturbances can occur simultaneously, affecting different or overlapping aspects of the system. It will also be important to distinguish between process disturbances affecting functions and structural disturbances affecting the form or both (Abbott et al., 2023). Transdisciplinary experts, including local and traditional knowledge, should be used to ensure all relevant aspects of the SES are being considered and there is an understanding of key uncertainties and unpredictability. Frameworks for defining the SES and its economic, environmental and social components are available in the literature (Binder et al., 2013; Fischer et al., 2015; Frey, 2017; Berrouet et al., 2018; Ostrom, 2009; Tengblad & Oudhuis, 2018; Preiser et al., 2018; Anderies et al., 2004; Collins et al., 2010; Colding & Barthel, 2019).

Resilience goals should be evaluated in terms of the level of change required and to what aspect of the SES in terms of its form and/or function. Studies of the SES to date are typically focused on the overall form and functions and system dynamics, as opposed to individual layers or components which are more likely to be the unit of change and have ignored key influences of the system, such as political, historical and cultural context (Cote & Nightingale, 2012).

Decision makers and actors should then develop a diversity of interventions, pathways, policies and actions to address the direct changes to form and/or function of the system to build resilience, as well as secondary actions, including management rules and social rules, that may be needed, based on changes to interactions within the SES (Smith & Sterling, 2010; Chiaravolloti et al., 2021). Potential solutions should address the collective goals, embrace innovation and technology and be feasible across the actors, institutions and systems (Moser &

Ekstrom, 2010). Solutions should include identifying new institutions and arrangements among existing institutions (Smith & Sterling, 2010; Olsson et al., 2004). Consider multiple simultaneous approaches that allow for variability and redundancy as key attributes of a resilient system (Martin-Breen & Anderies, 2011; Walker & Salt, 2012; Walker et al., 2006).

An assessment of interventions should expose limitations and barriers to implementing resilience actions and identify strategies and resources needed to minimize or eliminate them (Moser & Ekstrom, 2010; Kates et al., 2012). Limits and barriers to resilience include resource availability, leadership and decision making, communication and information, values and beliefs and uncertainties over actions and accountability (Moser & Ekstrom, 2010; Tompkins, 2010).

Across disciplines, learning and ensuring a flow of information and knowledge is crucial for the expansion of understanding and adjusting our ability to manage complex systems effectively (Walker et al., 2006). It is necessary to expand our knowledge of systems beyond just understanding their structures, but also to consider their interactions and multiscale feedbacks, surprises arising from uncertainties and unpredictability and residual risks and vulnerabilities (Olsson et al., 2004; Nelson et al., 2022; Davidson, 2010). Many methodologies exist to learn, adapt and reduce uncertainties over time, such as adaptive management, commonly used in natural resource management (Holling, 1973) and transition management, commonly used in business and technology (Smith & Sterling, 2010; Park et al., 2012). These methodologies can be supported through power structures, such as adaptive governance or adaptive co-management, which link the various actors and institutions for sharing and transferring power and knowledge through self-organization or purposeful design (Olsson et al., 2004; Meadowcraft, 2011; Nelson et al., 2022; Park et al., 2012).

Learning and adapting the SES is supported through the measurement of resilience based on shared resilience goals. Measurements can include a mixture of qualitative and/or quantitative analytics, such as report cards, metrics or indices, network mapping and tools (Bollettino et al., 2017; Janssen et al., 2006; Nelson et al. 2022). Some indicators for resilience have been developed (NASEM, 2019; Sterling et al., 2017; Sharifi, 2016); however, there are definite gaps in our ability to measure the system, including a lack of indicators for intangible metrics (e.g., social networks, motivations), indicators can be very context or location specific, data availability at the scale appropriate, ignoring harder to measure factors and missing indicators for gradual change or early warning sign indicators (Janssen et al., 2006; Bollettino et al., 2017; Folke, 2016; Quinlan et al., 2015). However, developed measurements should feedback in system dynamic models of both intentional and unintentional changes in the system and span all relevant aspects of the SES, including economics, engineering, society, ecology and technology (Quinlan et al., 2015).

DISCUSSION

Key Takeaways from Case Studies

Although the Sponge Cities Program has begun to rectify many of its initial failures, the deficiencies in flood risk management could have been minimized or avoided with proper assessment of the SES and the goals it was aiming to achieve. This case study demonstrates the importance of defining the appropriate SES boundaries in the context of the overall resilience goals – both geographically and the boundaries of linkages and feedbacks, specifically in the social sub-system. It also is important to integrate history and culture into defining the system, its forms functions and interactions as well as help identify areas of intervention.

The key takeaways from the Coastal Structures case study are that institutions and actors both have existing roles and functions in adapting the form of coastal structures, but they don't always know what their role is or how to accomplish it. Institutions shifting responsibility to actors must be accompanied with institutional support and participatory processes to remove barriers for actors to gain agency and co-create solutions. By defining each within the SES, they can collectively achieve the institutional goals of reducing societal impacts of flooding and the actors' goals of reducing their own impacts to well-being and maintaining their community.

For the transition case study in Honduras, although the forms in this system did change, the driving force in building resilience outcomes was the change in function of the institutions. Marcelino was not an institutionally led bottom-up approach. The collective agency of actors forced a transition in the function of the institutions. Therefore, institutions that can redistribute power and transition from top-down to bottom-up can increase resilience, not just to floods but to other social, environmental and economic stressors.

And the case study from Indonesia demonstrates that no matter which city, transformation is a massive and complex undertaking. The government should transition its functioning as state-centered to a transdisciplinary approach that involves participatory processes. A transdisciplinary approach allows for the government and interdisciplinary researchers to co-create these future visions with those impacted by those decisions – and can help integrate social norms and behaviors that may need to change to build resilience. The driving forces of economic development have to be balanced with the environmental and social needs. As demonstrated again by this case study, the greatest obstacles to resilience of the SES are not technical or financial but social and political. How the Indonesian government uses resources, prioritizes resilience goals, and engages society to transform both cities will determine if they can address the on-going problems of Jakarta and truly build a resilient city in Nusantara.

Using the Social-Ecological Resilience Framework

Climate change will bring extensive changes to existing SESs, both in how well societies mitigate greenhouse gas emissions to reduce the burden of the most drastic impacts and how impacts are managed or mismanaged (IPCC, 2023). Planning for these levels of change will include tensions between trying to sustain or adapt the current SES and making more drastic and long-term changes to the function of the SES. Depending on how the challenge is interpreted and shaped by the broader social, economic and political forces, it can lead to different approaches to maintain critical functions for the short-term versus the long-term resilience of the SES (Smith & Sterling, 2010; Smit & Wandel, 2006). Presentism, or a bias towards the needs of the present, is favored in democratic processes, such as in regulatory requirements, which provides a challenge for managing climate-impacted SESs that need a long-term viewpoint to address the deep-rooted causes and provide for future generations (Vos, 2007; Pelling et al., 2015). Political forces, such as pressing issues, uncertainties and complexity in approaches, established interests, and changing leadership, can impede actions, specifically for long-term outcomes (Meadowcraft, 2011). The short-sighted nature of political forces may be more socially acceptable, but it is also a “pathway to potentially catastrophic systems collapse” (p.11) (Pelling & Manuel-Navarrete, 2011), “paving the way for a new order” (p.506) (Handmer & Dovers, 1996). Ultimately, decision makers should use the Social-Ecological Resilience Framework to plan for the near-term stressors while simultaneously anticipating and building capacity to address long-term and more transformative change.

Decision makers, informed by other actors in the system, will have to make difficult decisions about which institutions will govern and which system components get prioritized (Smith & Sterling, 2010; Biggs et al., 2015). Prioritization of actions will result in trade-offs with winners and losers (Biggs et al., 2015; O’Brien, 2012). Movement towards resilience will require that some structures or functions are lost or fractured and resources depleted (Shove, 2010; Walker et al., 2006), while new or re-arranged actors, institutions or networks are developed (Smith & Sterling, 2010; Olsson et al., 2004). Institutions play an integral role in building resilience yet are challenged with the dichotomy between stable and flexible (Beunen et al., 2017). Stable institutions can provide consistency, fairness and accountability while also reinforcing existing unsustainable approaches, while flexible institutions can provide learning and innovation while also being subject to quick changes from political or cultural desires/presentism (Beunen et al., 2017).

Equity in social outcomes must be carefully considered in any resilience actions, specifically to ensure that actions are not exacerbating existing inequalities in the system (Biggs et al., 2015). Leach et al. (2018) noted that the SDG’s focus on sustainability in inefficient in achieving equity goals since it fails to incorporate critical interactions where equity and sustainability are both outcomes and drivers under a systemic framework. Through the resilience literature, specifically in the natural sciences, equity and social difference is often overlooked and left to economic drivers to determine (Vos, 2007; Nelson et al., 2022; Olsson & Jerneck, 2018; Shove, 2010). Ulibarri et al. (2022) found that equity is insufficiently considered in policy tools for adaptation and transformation in the academic literature, recommending policy tools that both support transformational change and marginalized groups. Equity in process and equity in outcome also have to consider the temporal scale by which equity will be improved or achieved (Nelson et al., 2022). How will the equity landscape change over time with and without actions, and how does that interact with other aspects of the SES In some cases, resilience actions to build equity could result in negative outcomes to the environment; however, the lack of equity is also interfering with environmental protections (Nelson et al., 2022).

Like any overarching policy framework, resilience is fraught with power dynamics that can be key drivers but hidden or ignored within resilience research, and often viewed as externalities (Cote & Nightingale, 2012; Smith & Sterling, 2010). If designed correctly, resilience research can be extremely powerful due to the knowledge co-production of a vast diversity of experts, individuals and institutions that bring together discipline-specific knowledge, traditional ecological (indigenous) knowledge and life experiences in a heterogeneous process. This co-production of knowledge will not only expose underlying drivers of the system, such as cultural, political or ethical motivations, but can also be used to shift power dynamics (Cote & Nightingale, 2012). Ultimately, the drastic and fast-paced changes due to global warming will require us to face a future of trade-offs, where the increased resilience of one component (such as a species or livelihood) can lead to a reduced resilience in another. Without transparency on the power dynamics and inclusion in knowledge co-production, these trade-offs are likely to lead to additional social and economic inequalities (Davoudi et al., 2012; Smith & Sterling, 2010).

Negative Outcomes of Resilience

In theory, all of these terms and definitions are neutral and do not indicate a positive or negative outcome. In practice, these terms are quite often taken with a positive connotation, specifically when it comes to social and environmental outcomes. This section explores how these terms could be used to prolong or exacerbate negative outcomes.

Resilience, often defined as the ability to withstand change, can lead to systems that perpetuate negative outcomes or an undesirable state (Walker et al., 2002). For an individual, this could include an unwillingness or inability to address risks being faced, such as individuals who experience repetitive flooding that results in negative outcomes to wealth, health and their environment (Tengbald & Oudius, 2018). Poverty is often used as an example of a highly resilient state (Martin-Breen & Anderies, 2011; Cinner & Barnes, 2019). Economic structures, such as deregulated and profit-oriented economies, can be resilient in the face of change, but lead to the lack of accounting of externalities to natural resources and inequalities in social outcomes in the SES (Leach et al., 2018). Institutions and actors are less likely to undertake changes when the historical economic and social investments are higher, and increased complexity over time exponentially increases the likelihood of negative outcomes (Davidson, 2010).

The inverse of the Social-Ecological Resilience Framework (Figure 1.3) defines unsustainable approaches, maladaptation, setback transition or failed transformation as all changes in the form and/or function of the SES that result in unintended or negative consequences to society, economy or environment or fail to reduce the targeted vulnerability (Smit et al., 1999; Ford et al., 2019). These results can be from purposeful actions or inaction. The inability to act or "wait and see" approach can indicate a lack of ability to envision a different and better world or the knowledge of actions to achieve it. This same inability to rethink the form and function of institutions, actors and social interactions is credited with the collapse of many past societies, such as the Mayans (Constanza, 2014).

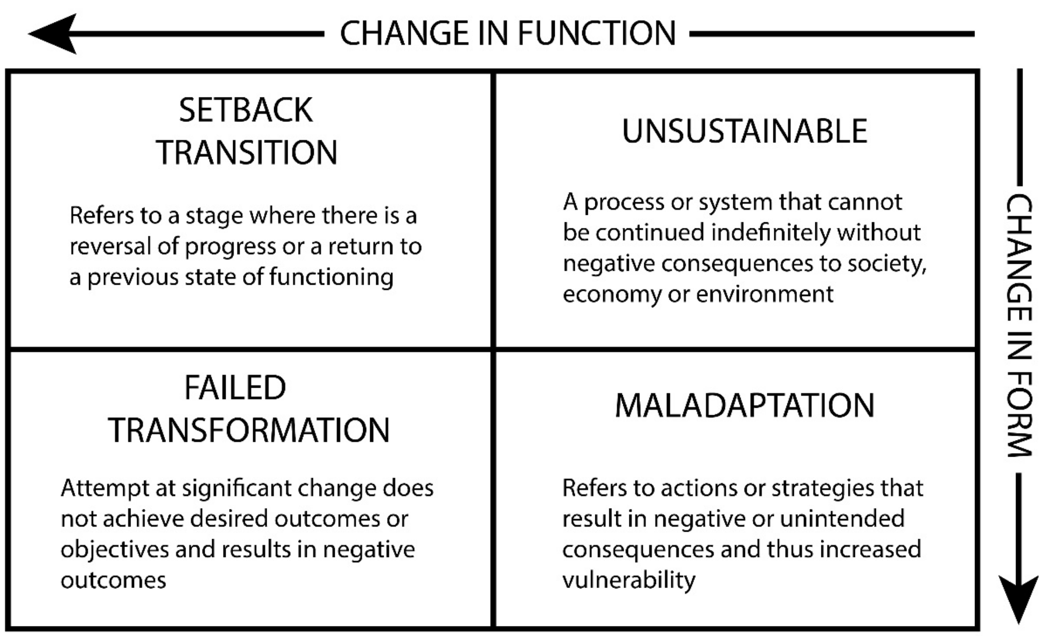

Figure 1.3: Negative Outcomes for the Social-Ecological Resilience Framework (Definition sources: WCED, 1987; Ford et al., 2019; Gunderson & Hollings, 2002; Folke et al., 2016)

Some processes and behaviors are self-reinforcing and entrenched in the SES, while others are more fluid and flexible (Loorbach, 2010; Shove, 2010; O'Brien, 2012). Societal functions can get locked in, allowing only incremental modifications to occur, especially where institutions, actors, technology and resources are interconnected and mutually enforced (Loorbach, 2010; Moore et al., 2014). Technology, institutions and markets can perpetuate and reinforce mechanisms that are not resilient, while being influenced by social behaviors (Smith & Sterling, 2010). Limited diversity in economic actors and centralized power can restrict the willingness to change the current state of the SES (Olsson & Jerneck, 2018; Pelling & Manuel-Navarrete, 2011). Political structures and ideas also perpetuate systems that may have positive outcomes for the economic or technology sector but negative outcomes for the social or environmental sector (Brown, 2013; O'Brien, 2012). Election cycles, large and variable issues of constituent concern, specialized interests and uncertainties around action and inaction limit the political sector from contributing to building more positive outcomes across sectors (Meadowcraft, 2011; O'Brien, 2012).

The scale of the SES being researched can also impact the ability for change (Moore et al., 2014). Smaller scale, or individual, level can be more resistant to change due to personal interactions and networks (Jerneck & Olsson, 2015). The lack of knowledge and understanding of the SES, and the various scales operating, can undermine resilience efforts. Causal mechanisms must expand beyond the ecological and further the understanding of the interdependent relationships between governance, actors and sectors (Beisbroek et al., 2017). Lastly, mismanagement of resources, or lack thereof, can lead to the collapse of aspects of the SES, which may be masked temporarily by technology (Smith & Sterling, 2010).

CONCLUSION

As Costanza (2014) points out, our society is both ecologically unsustainable and no longer contributing net benefits to overall human well-being. The status quo has now been called into question and our future relies on harnessing and dissecting the complexity in resilience, rather than trying to eliminate it and reject change (Shove, 2010; Ostrom, 2009). Radical reformulation of world views, inclusive forms of governance and societal innovations are needed to truly build a resilient future (Shove, 2010; Smith & Sterling, 2010; Pelling & Manuel-Navarrete, 2011). As society works towards long-term transformation, approaches to sustain, adapt and transition will grow and help define the new societal regime.

Across disciplines, resilience is one of the most significant constructs for the advancement of science, policy, technology and equitable solutions. The Social-Ecological Resilience Framework developed here provides a common language across disciplines and logical consistency by which to apply these terms in relation to each other, all under the overarching term of resilience, to plan interventions in the SES. The conceptual nature of the framework will require additional transdisciplinary research to develop additional understandings and applications. There is much work to do to operationalize the Social-Ecological Resilience Framework, specifically to ensure cross-pollination of disciplines, methodologies and terminologies. Researchers and practitioners need to explore new ways of studying and engaging with the SES to address pressing resilience challenges. With continued exploration, the Social-Ecological Resilience Framework can bring about intentional change, encourage experimentation and motivate innovation.

Chapter 2: Technical framework for adaptively managing a sediment diversions in Louisiana

INTRODUCTION

Climate change impacts on the social-ecological system (SES) will require that actions be taken even in the face of uncertainty. Adaptive management provides a means by which to manage and reduce those uncertainties thereby accounting for a variety of social, ecological and economic forces and processes that enable institutions and actors in the system to accommodate risks and achieve desired outcomes and goals. As a well-established methodology, the use of adaptive management is expanding beyond just natural resource management to managing the complexity of the socio-ecological system. The interdependence of the social and natural system, as well as the changes brought on by climate change, lead to knowledge uncertainties in the future conditions of the SES, as well as the response to any proposed human interventions. Large-scale ecosystem restoration can have complex impacts on both the natural and social sub-systems, requiring adaptive management to achieve multiple environmental and social outcomes.

This chapter proposes elements for the design of an adaptive management program to operate a large-scale diversion of Mississippi River sediment in Louisiana to re-establish the deltaic processes of land-building, while also affecting communities and natural resource users. The study seeks to identify enabling and inhibiting factors at the institutional level for developing a robust adaptive management program, challenges and solutions to adaptive management in the regulatory setting and application to this Louisiana case study.

Adaptive Management in Socio-Ecological Systems

Adaptive management (AM) is an iterative decision-making process, first proposed by C.S. Holling (1973; 1978), that has been advanced for decades in natural resource management with various and widely ranging definitions and utility. AM is a methodology to address inherent levels of uncertainty in natural resource management, thereby accounting for a variety of forces and processes at a landscape level that enable managers and actors to accommodate risks and reduce levels of uncertainty in predicting and achieving desired results from management actions (Williams & Brown, 2014; Williams et al., 2009; Canter & Atkinson, 2010; Stankey et al., 2005, Walters 1986). AM emphasizes "learning while doing" in the face of uncertainty and risk, often through experimentation, active learning, and Actor engagement (Williams & Brown, 2014; Williams et al., 2009; Canter & Atkinson, 2010; Stankey et al., 2005). As an iterative process, AM when implemented appropriately requires effective and flexible governance to adapt to new information or conditions while considering the social and political context for decision making (Folke et al., 2005; Stringer et al., 2006). With the ever-present reality of climate change, management of rapidly changing baselines and unprecedented levels of uncertainty and risk, successful implementation of AM, along with adaptive governance, is now more important than ever to increase the efficacy of our actions (Williams & Brown, 2014; Williams et al., 2009; Canter & Atkinson, 2010; Stankey et al., 2005; Folke et al., 2005; Cammen et al., 2019).

The expanded use of AM beyond natural resource management is being explored to understand the uncertainty and stochasticity within actions taken to improve the resilience of socio-ecological systems (SES) (Waylen et al., 2019; Barnard & Elliot, 2015; Sterk et al., 2017). The ever-present reality of climate change impacts to the SES requires managing a system with rapidly changing baselines and increased levels of uncertainty and risk about future conditions and processes (Cammen et al., 2019; Fernandez-Llamazares et al., 2015). While current modeling capabilities and scientific data are available to reasonably predict some of these changes, there are other aspects of the ecosystem and the communities in the SES that are much more complex and harder to predict (Preiser et al., 2018; Walker et al., 2002; Walker et al., 2006; Smit et al., 1999). Specifically, interactions among and between the various aspects of the ecological and social landscape currently, and in a future with climate change effects, are not well studied or understood (Tyre & Michaels, 2011; Elsawah et al., 2017; Constanza, 2014; Levin et al., 2012; Barra, 2020).

These never-before-seen levels of uncertainty and risk in environmental science predictions pose challenges to the planning and implementation of natural resource protection and management, including the regulatory and permitting decision-making processes that typically rely on a reasonable estimation of future conditions (Glicksman & Page, 2022; McDonald & Styles, 2014; Keith et al., 2011; Lynch et al., 2022; Tribbia & Moser, 2008; Cammen et al., 2019). The utilization of AM will be critical in order for future management plans to be successful in such conditions. In particular, large projects that influence the natural environment at a landscape scale in complex ways, such as water resource projects, can benefit from the use of adaptive management strategies as a way to adjust actions based on the environmental and social conditions being experienced at any given point in time (Thom et al., 2016; Smith, 2010). However, implementation has become the downfall for many AM programs and continues to be seen as risky in the eyes of some decision makers and regulatory agencies due to the ambiguity involved with the definition of management goals and objectives and potential legal challenges to natural resource management plans (Gunderson, 2015; Glicksman & Page, 2022; McDonald & Styles, 2014; Keith et al., 2011).

Even with extensive analysis, substantial uncertainties will remain in the ability to predict the outcomes and impacts of major actions such as large-scale ecosystem restoration, specifically when compounded by the uncertainties of climate change. This poses real challenges to decision-making processes, specifically surrounding regulations and permitting, which typical rely on a reasonable estimation of future conditions (Glicksman & Page, 2022; McDonald & Styles, 2014; Keith et al., 2011). The level of uncertainty in predicting outcomes and impacts has repeatedly been used as a basis for regulatory legal challenges to environmental review and permitting such as under the National Environmental Policy Act (NEPA) in the U.S. (Craig & Ruhl, 2014; Glicksman & Page, 2022).

Components of the AM process have been well-defined in the literature and various graphics employed to illustrate the flow of its implementation (Chades et al., 2017; Holling, 1978; McFadden et al., 2011; Walters & Holling, 1990; Williams, 2011; Williams & Brown, 2014). Figure 2.1 illustrates the fluid, continuous and iterative nature of how the six key components of AM (assess, design, implement, monitor, synthesize and adapt) interact iteratively within a project lifespan.

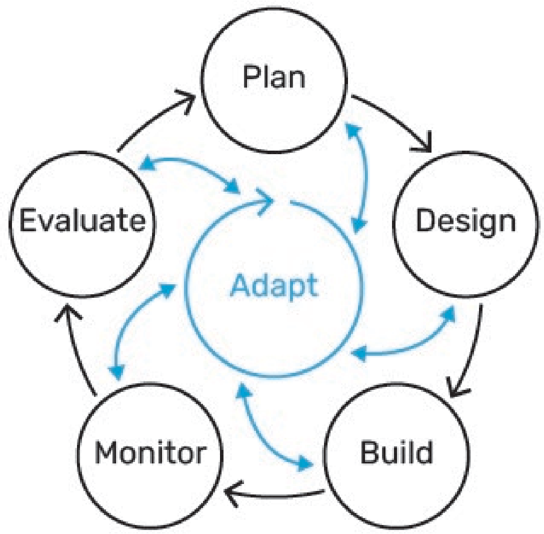

Figure 2.1: Conceptual process flow model of the six key components of adaptive management. The central component, adapt, emphasizes the point that informed feedback at any stage can be iteratively applied to promote adaptation (or change) anywhere in the sequence of plan, design, build, monitor, and evaluate to optimize the project (Modified from Greig et al., 2013; King et al., 2021)

The AM Framework

During the project planning phase of the AM cycle, decision makers should also develop the adaptive management framework. Many of the components of project planning are similar to the critical components of the framework, such as defining objectives, measuring performance metrics and monitoring plans. Adaptive management can take it further by developing a structured decision-making process that identifies and reduces uncertainties, establishes benchmarks and triggers and identifies future adaptive actions (Williams & Brown, 2014; Williams et al., 2009; Walters, 1986).

Every project or management action will have one or more goals it is trying to achieve. While the goals are broad and non-specific, management objectives are narrow, specific, concrete and measurable (Schultz & Nie, 2012). Objectives need to be measurable for two purposes: first, so decision makers can track and report on progress toward their objectives; second, so decision makers can adjust their actions to respond to the conditions that emerge as a result of implementing those interventions (Williams et al., 2009; Schultz & Nie, 2012). In general, the more complex and large-scale the project, the more diverse and extensive objectives it will have, especially those projects that address complex issues of the socio-ecological system (Bosomworth et al., 2017; Susskind et al., 2010).

With multiple objectives, it may be necessary to prioritize those objectives within an objective hierarchy. An objective hierarchy can provide a structured way for AM to prioritize objectives based on institutional and actors' values and interests and demonstrate the relationships between various objectives (Mulvaney et al., 2022; Roux & Foxcroft, 2011; Kingsford et al., 2011). An objective hierarchy will display multiple levels or tiers of objectives for the project, with increasing specificity, organized by the causal relationships depicted in the project's conceptual model (Roux & Foxcroft, 2011; Kingsford et al., 2011). Relationships can be represented based on their prioritization, level of precision or sequence of consideration in time (Roux & Foxcroft, 2011; Kingsford et al., 2011). For instance, high level objectives in a hierarchy may reflect a combination of conditions that are broadly aspirational or not directly measurable, while sub-objectives lower in the hierarchy correspond to conditions and performance metrics that are directly measurable. Similarly, an objectives hierarchy may represent the varying levels of importance of management objectives to decision makers in a way that recognizes the varying values of actors and mandates of institutions as defined by the statutory and regulatory responsibilities (Mulvaney, 2022; Roux & Foxcroft, 2011; Kingsford et al., 2011).

Uncertainties in planning, modeling and design generally increase with project scale and complexity. Climate change and its impacts adds not only changing conditions but another layer of uncertainty to future conditions and project performance. In any given SES, the universe of uncertainties is too vast to address, thus prioritization of uncertainties is necessary. In the context of an adaptive management program, an important distinction for prioritization is the difference between research uncertainties and management uncertainties (Nelitz et al., 2006; Marmorek et al., 2019). A research uncertainty relates to specific processes, patterns and relationships in the natural or social landscape that are not clearly understood but not directly impacted by management actions (Nelitz et al., 2006; Marmorek et al., 2019). The most important research uncertainties may be linked to management uncertainties to better understand the SES, but research uncertainties are not reduced through the active manipulation and adjustment of management actions. A management uncertainty implies the use of management actions, coupled with monitoring and analysis, to reduce the uncertainty and learn about whether an action is having its intended effect on the SES (McDonald-Madden et al., 2010; Nelitz et al., 2006; Marmorek et al., 2019). Management uncertainties are directly tied to the objectives of the project and anticipated outcomes. Management uncertainties are used to prioritize limited resources available for monitoring (Nelitz et al., 2006; Marmorek et al., 2019; McDonald-Madden et al., 2010).

An integral component of AM is the use of performance measures to track progress towards meeting management goals and objectives (Hijuelos & Reed, 2013; Kurtz et al., 2001). When monitored over time, performance measures inform managers as to whether intended results are being achieved or if additional action is needed to fulfill program expectations (Kurtz et al., 2001). Monitoring a wide variety of performance measures may be needed to fully evaluate achievement of project objectives. Different types of monitoring may be required for different purposes. These types of monitoring and their associated performance measures were considered: baseline status monitoring, implementation monitoring, effectiveness and validation monitoring (Roni et al., 2013; Nelitz et al., 2006). The other critical framework components not covered here include setting benchmarks and triggers and developing the monitoring plan.

Success of Adaptative Management

Although the theory and design of adaptive management have been well-documented in the literature, its practical implementation has been much less so. Several authors have examined the successes and failures, opportunities and challenges that have faced adaptive management programs around the world (Fernandez-Gimenez et al., 2019; Greig et al., 2013; Childs et al., 2013; Burns et al., 2015; Allen & Gunderson, 2011; Medema et al., 2008). There are concerns that adaptive management is often regarded just as process for "adapting as you go", trail and error, or contingency planning, as opposed to being a more rigorous and systematic process for testing hypotheses and reducing uncertainties over time to learn about which actions will best achieve the various objectives for the management intervention. When applied rigorously, AM is an approach for designing and implementing management actions to maximize learning about critical uncertainties that affect decisions while simultaneously adjusting actions to meet multiple objectives. Furthermore, in the case of restoration of degraded ecosystems and climate change, even with uncertainties, the risk of socio-environmental harm from no action may exceed the risk of harm from management actions (Peyronnin et al., 2013).

A key to Holling's concept of adaptive management, or active adaptive management, is a focus on hypothesis-testing and experimentation to bring restoration and ecological science into natural resource management and decision making (Holling, 1973; 1978; Zedler, 2017; Walters, 1986). However, there are very few examples of active adaptive management being fully implemented and, instead, there is a reliance on passive adaptive management, where critical steps in the process are missing (Kingsford et al., 2011). Passive adaptive management approaches are constrained by social, political or economic realities that lead to a lack of scientific rigor and absence of data synthesis and assessment essential to incorporate learning.

Social, economic and political constraints can derail science needed to support AM. With limited funding, monitoring budgets are often cut due to poor communication of the benefits, an absence of assessment and synthesis and, in general, ill-planned and misguided monitoring. (McDonald-Madden et al., 2010; Nichols & Williams, 2006). Monitoring programs need to demonstrate their value to decision makers and the public, specifically in achieving ecosystem services and socio-economic outcomes, to build the political support for sustained long-term funding (Nichols & Williams, 2006). Only with long-term funding can science be employed to truly evaluate restoration outcomes, specifically for ecosystem functionality that can take decades to establish.

Case Study: Sediment Diversions in Louisiana

The Louisiana coast is one of the most rapidly changing river deltas in the world (Kolker et al., 2018; Syvitski et al., 2009). Louisiana and the adjacent north coast of the Gulf of Mexico is a dynamic environment, influenced by many natural and anthropogenic processes. Persistent geomorphic forces and extreme events, such as winds, tides, currents and hurricanes, influence the deposition and erosion of materials along the shoreline (Kemp et al., 2014; Kemp et al., 2016). Human activities that resulted in levees, flood control structures and navigation channels have altered the area and changed the natural patterns of deposition and erosion, as well as salinity levels (Edmonds et al., 2023; Kemp et al., 2014; Meselhe et al., 2021; Das et al., 2012). The disruption of sediment supply by levees in addition to surface and subsurface resource extraction has exacerbated the land loss rates (Edmonds et al., 2023). Overall, these processes are interacting in a way that has led to significant land losses in recent years across the Louisiana coast, which are projected to be even more significant in the face of sea level rise and an increasing severity of storm surges (Couvillion et al., 2017; CPRA 2023). The Mississippi River Deltaic Plain is also a highly valued ecosystem which supports a variety of fish and wildlife species in nearshore, estuarine and wetland habitats (Nyman et al., 2013; Peyronnin et al., 2017; Fox et al., 2007). The Delta and these ecosystem components are more broadly valued since they support a commercial seafood industry and recreational and subsistence fisheries, which are significant contributors to the local economy and culture (Colten & Hemmerling, 2014; Loftin et al., 2011; McCall & Greaves, 2022; Barra, 2020).

Since the 1720s, anthropogenic modifications to this system, specifically the construction of a levee system which became federally managed after the flood of 1927, has resulted in the reduction of a distributary network of channels and subdeltas that deposited sediment across a vast area of the coastal landscape to build and sustain land (Kesel, 2003; Chatry & Chew, 1985; Viosca, 1927; Xu et al., 2019). The federal levee system ended any breaches or overtopping that had previously occurred during flood events and ultimately ended any of the natural functioning and flooding of the Mississippi River, severing the river from its delta and floodplain (Kemp et al., 2014; Boesch et al., 1994). The predicted result of this action, as noted by Engineer E.L.

Corthell in National Geographic (1897), is the "subsidence of the Gulf delta lands below the level of the sea and their gradual abandonment due to this cause." As predicted and exacerbated by human activities, there has been a collapse of expansive deltaic wetland complexes resulting in the loss of approximately 5,200 km^2 of land (Couvillion, 2017; Boesch et al.,1994; Kesel, 1989; Edmonds et al., 2023).

In an unstructured way, the management of the Mississippi River and its largest distributary, the Atchafalaya River, demonstrate a long-term experiment in river management. Although both rivers have levee systems, the Mississippi River levees are immediately adjacent to the riverbank, whereas the Atchafalaya River levees are located 20 miles apart, allowing the river to remain connected to a portion of its floodplain (Twilley et al., 2019). Decades of field tests and modeling have shown that the influx of freshwater, sediment and nutrients to the coastal landscape will continue to build and sustain vibrant, productive ecosystems (White et al., 2023; Xu et al., 2019; Twilley et al., 2019; Meselhe et al., 2012; Dean et al., 2014; Meselhe et al., 2021; Allison & Meselhe, 2010). Sediment diversions are, in a sense, adaptive corrective actions to the long-established levee system to reestablish the natural processes that built land in coastal Louisiana.

Sediment diversions are arguably one of the most effective ecosystem restoration actions to combat land loss and climate change impacts, such as sea level rise (CPRA, 2023; Peyronnin et al., 2013). A diversion is a structure of gates that can be opened and closed that are built into the levee system to allow river water, sediment and nutrients to flow into the degraded wetlands, mimicking the natural cycle of spring flooding, crevassing and distributary sub-delta formation

(USACE, 2022a; Lopez et al., 2014a; Lopez et al., 2014b; Yuill et al., 2016). Diversions are predicted to provide significant benefits to the deltaic complex, including the fish and wildlife that depend upon it and the estuarine complex it sustains, and in turn improving the overall health of the Gulf and forestalling the gradual abandonment of areas of the coast to the Gulf of Mexico (Gagliano et al., 1970; Gagliano et al., 1975; Paola et al., 2011; Peyronnin et al., 2017). The changes to the forms and functions of the ecosystem will have cascading impacts on the interrelationship with natural resource users and communities in the estuary. Restoring the river and ecosystem to a more natural state will result in negative impacts to specific species of fish and wildlife, as well as the associated natural resource user groups, that have benefited from an artificially created estuary over the past decades (USACE, 2022a; Peyronnin et al., 2017). However, without the diversions, the negative impacts the coastal ecosystem, food web and social landscape could be far worse, and result in collapse (Cowan et al., 2008). Individuals and communities are already being lost and under increasing risks that will result in substantial outmigration and loss of economic opportunities (Hobor et al., 2014; Habans, 2019).

Sediment diversions have been proposed as a foundational solution to the coastal land loss issue for decades (Gagliano et al., 1970; Gagliano et al., 1975; Boesch et al., 1994; Day et al., 2007). The first reports of coastal land loss from the 1970s made recommendations for the construction of diversions and subdeltas (Gagliano et al., 1970; Tripp & Herz, 1988). Not only does Louisiana have a long history of recognizing that utilizing the land-building capacity of the river with diversions is the key to sustaining functional coastal wetlands, the state of Louisiana has also identified numerous user groups and uncertainties that need to be addressed (Gunter, 1953; Dugas & Perret, 1975; McCall & Greaves, 2022; Barra, 2020; Loftin et al., 2011, Posadas &

Posadas, 2017; Yuill et al., 2014; Lopez et al., 2014a; Lopez et al., 2014b). The 1993 CWPPRA Restoration Plan stated that *"studies [on future sediment diversion projects] must determine the upper limit to the amount of water and sediment which can be diverted from the Mississippi River system without significantly affecting navigation channel maintenance, municipal and industrial water supplies, and other aspects of human activity, such as commercial and recreational fishing."* (CWPPRA, 1993)

The Coastal Protection and Restoration Authority of Louisiana (CPRA) is the sponsor for Mid-Barataria Sediment Diversion, the U.S. Army Corps of Engineers (USACE), New Orleans District, which is the lead permitting federal institution, and the project is being funded by the Natural Resource Damage Assessment (NRDA) trustees, with NOAA as the lead federal institution. A Record of Decision on the Final Environmental Impact Statement was completed in December 2022 (USACE, 2022b). In February 2023, NOAA released a Record of Decision to fund the estimated $2.26 billion project through the Deepwater Horizon Oil Spill NRDA designated funding for restoration of wetlands, coastal and nearshore habitats in the Barataria Basin, which suffered the greatest injuries from the historic oil spill (LaTIG, 2023).

Figure 2.2: Location of the Mid-Barataria sediment diversion (Peyronnin et al., 2017)

This case study focuses on the operation and adaptive management of the Mid-Barataria sediment diversion, one of the largest individual ecosystem restoration projects in the world. This diversion, set to begin construction in 2023, will deliver a maximum of 2,125 m^3s^{-1} of fresh water, along with nutrients and 275 million tons of sediment, to Barataria Basin (Figure 2.2) to restore and maintain approximately 55 km^2 of land and re-establish the natural deltaic processes of the Mississippi River (USACE, 2022a). These wetlands will provide positive flood risk reduction benefits to adjacent communities. These habitats will have positive impacts to the overall food web productivity and many specific species of fish and wildlife, including alligators, migratory birds, crabs, white shrimp and some finfish. The tradeoffs include elevated water levels that could impact basin-side communities leading to impacts to housing, public services and community cohesion, significant impacts to oysters and brown shrimp populations, resulting in impacts to livelihoods and fishing infrastructure for subsistence and commercial fishers and significant impacts to the bottlenose dolphin population (USACE, 2022a). To address these negative impacts, the project costs include a $360 million Mitigation and Stewardship Measures Plan.

The over 16,000-page final Environmental Impact Statement (EIS) documents extensive scientific analyses, data collection and computational and physical modeling, officially conducted from 2016-2022, is backed by decades of scientific support (USACE, 2022a; Xu et al., 2019). Projected environmental changes were evaluated using the Delft3D Basinwide Model Version 3 (Meselhe et al., 2021), while surveys, geotechnical analysis and FLOW-3D were used to support reaching 60% engineering and design (USACE, 2022a). To support the computational effort, a scaled-down physical model of the lower Mississippi River was created at the Louisiana State University Center for River Studies in Baton Rouge and a physical model of the conveyance channel (1/65 to size) was developed in Boston by Alden Research Labs (Figure 2.3). The project affects on fish and wildlife species, including federally protected species, were evaluated using ten Habitat Suitability Models (HSIs) and recent literature (USACE, 2022a). Socio-economic analysis was completed to include economic impacts of construction, impacts tied to coastal land loss, storm surge and tidal flooding, effects on commercial, recreational and subsistence fishing, tourism, population and migration, land use and property values, tax revenues, public services, cultural resources, environmental justice (EJ) and community cohesion (USACE, 2022a).

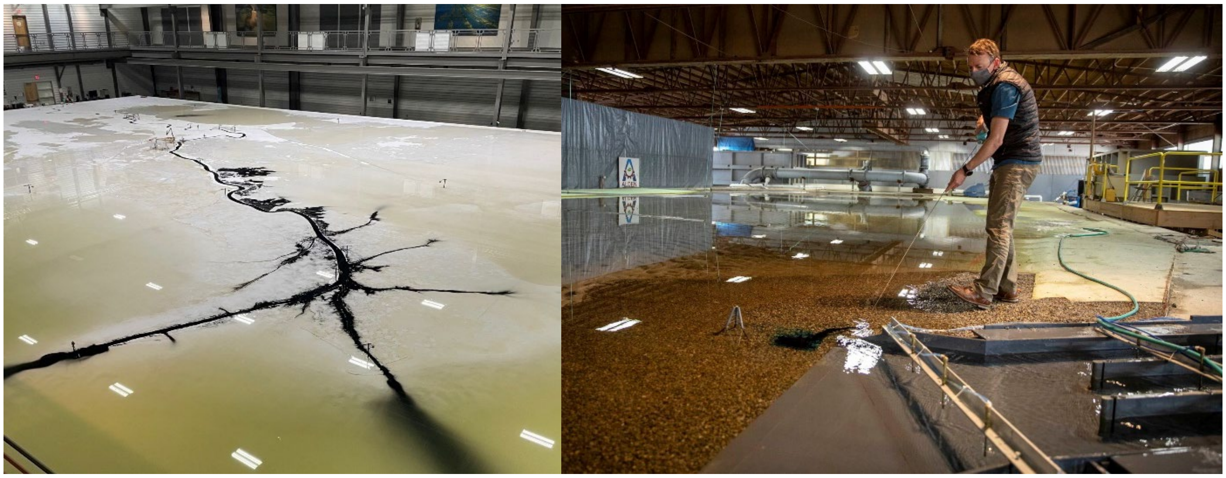

Figure 2.3: Small-scale physical models. On left, Lower Mississippi River model at the LSU Center for River Studies in Baton Rouge (Image Credit: author); On right, model of conveyance channel and Mississippi River interactions at Alden Research Labs in Boston (Image Credit: Robin Lubbock/WBUR)

Proposed operations for the diversion are simplified in the final EIS to aid the evaluation and modeling process as they provide consistency, reduce computational costs, and allow easy comparison between alternatives in the final EIS to better account for cause-effect relationships (Peyronnin et al., 2017). The operations are designed to increase the sediment diverted as flow in the main channel increases. The diversion would be opened when channel flow reached 12,742 m^3s^{-1} and operated proportionally until the diversion reached full capacity of 2,125 m^3s^{-1} when the Mississippi River flow reached 28,316 m^3s^{-1} (USACE, 2022a; Meselhe et al., 2021).

There are various and significant uncertainties that affect the ability to assess the project's impacts and understand how best to operate it. There has been extensive discourse among conflicting actors and decision makers, as well (Peyronnin et al., 2017; Jarreau et al., 2015; McCall & Greaves, 2022; Yuill et al., 2014; Barra, 2020). Foremost, there is seasonal and annual variation in the availability of freshwater flow and sediment available for diversion from the Mississippi River affecting the spatial and temporal creation of wetlands (Meselhe et al., 2021; Wang et al., 2014; Elsey-Quirk et al., 2019). Scientists have an inexact understanding about how changes in flow and sediment will affect deltaic formation, wetland habitats, salinity levels, vegetation establishment, as well as fish and wildlife species in the Barataria Basin and the social implications of those impacts to natural resources users and communities (McCall & Greaves, 2022; Das et al., 2012; Barra, 2020). These changes in the ecosystem will have the potential to affect the social and economic benefits that the estuary currently provides to local communities (Colten & Hemmerling, 2014; McCall & Greaves, 2022; Barra, 2020; USACE, 2022a). Furthermore, there is uncertainty in the rate of acceleration of sea level rise and increase in intense storm surge during the second half of the century and beyond, which has the potential to affect several environmental, social and economic components of the project, as it depends on reductions in greenhouse gas emissions (Boesch & Snider, 2024, *in press*). Lastly, the final EIS does not include a complete set of environmental, economic or social management objectives that should be considered while operating and evaluating the performance of the sediment diversion which are best defined collectively with actors.

To acknowledge these uncertainties, and ideally reduce critical ones over time, the CPRA has proposed to develop and use an Operations and Adaptive Management (AM) plan for operating the sediment diversion (USACE, 2022a; TWIG, 2013a). This plan is expected to provide the flexibility for responding to emerging conditions as knowledge about the system and operations of the diversion improves over time. An AM plan at this project scale is expected to sit within the context of Adaptive Management within the state's Master Plan, *Louisiana's Comprehensive Master Plan for a Sustainable Coast* (CPRA, 2023).

An Operation and Adaptive Management Plan needs to define the objectives the project is hoping to achieve, when and why the diversion structure will be opened and closed to achieve objectives; what factors will be considered; what monitoring is required; what governance and decision-making structures will be used to oversee these decisions; and what role actors will play in the decision-making process. Defining the operation and adaptive management plan, and the strategies to be included in it, is an iterative process that will need to incorporate modeling, data collection and analysis, best professional judgement from experts in their field and input from actors, people directly and indirectly affected and the public.

The objectives of this chapter are to assess how the CPRA can further develop the Operation and Adaptive Management Plan (AM Plan). It is anticipated that the AM Plan will be implemented over the next five years while the sediment diversion project is being constructed. This case study demonstrates the need for understanding the enabling conditions for effective AM, clear definition of management objectives, an analysis and prioritization of uncertainties impacting those objectives, and identification of clear performance metrics to monitor success or identify areas of concern over the long term.

METHODS

I led the work conducted in this chapter, but was supported by my co-authors, Marc Nelitz (ESSA Technologies), Rachel Rhode (Environmental Defense Fund) and Grace Tucker (Environmental Defense Fund). My co-authors and I conducted a review of the enabling and inhibiting factors for the implementation of AM was conducted for the institution managing sediment diversions, Louisiana's Coastal Protection and Restoration Authority (CPRA), drawing upon input provided from five key decision makers in the CPRA in the context for the Mid-Barataria Sediment Diversion project. The hierarchy of factors developed by the National Commission on Science for Sustainable Forestry (Greig et al 2013) was used to evaluate the enabling characteristics of the CPRA, including: (1) historical context, (2) trust and commitment, (3) leadership and vision, (4) executive direction and support, (5) problem definition, (6) communication, (7) mindset (around uncertainty and risk), (8) community involvement, (9) planning, (10) funding, (11) staff training and capacity, (12) knowledge flow and interpretation and (13) integration of AM science. The CPRA's learning capability was also accessed through 24 characteristics including contextual factors, process factors and resource factors (Murray & Marmorek, 2001).

In addition, I organized and facilitated a day-long workshop with 24 legal and adaptive management[1] experts from government, academia, non-governmental organizations and the private sector to identify key barriers for the inclusion of robust adaptive management into the NEPA process. The experts identified key challenges and developed solution pathways that can allow increased flexibility in the National Environmental Policy Act (NEPA) process without threatening the environmental protections provided by NEPA, specifically in the way that NEPA views future conditions. NEPA is structured with a deterministic view of the future that is challenging when faced with future climate conditions (Cammen et al., 2019; McDonald & Styles, 2014; Glicksman & Page, 2022). The workshop utilized large-scale case studies

[1] Nick Aumen, Eric Biber, Ted Boling, Ellie Brown, Steve Cochran, Michael Drummond, Deborah Freeman, Robert Glicksman, Barry Gold, Doria Gordon, Daniel Large, Tim Male, Jim McElfish, Jr., Gib Own, David Peterson, Denise Reed, Ramona Schreiber, Greg Steyer, Ron Thom, Ted Toombs, Jessica Wilkinson, and Ken Williams

(sediment diversion in Louisiana and sage-grouse habitat exchange in Nevada) to explore and identify multifaceted approaches to address these challenges, specifically (1) legal challenges surrounding the incorporation and implementation of adaptive management in the NEPA process, (2) solutions for future/proposed management plans to take into account the dynamic and uncertain environmental condition and still satisfy the requirements and relatively rigid constraints of environmental policy and legislation such as NEPA, (3) case studies to explore integrated solution pathways for including adaptive management and research uncertainty in a large-scale projects and (4) proposals to add flexibility in NEPA requirements and processes without hindering the environmental protection it provides.

With the foundational elements laid, an adaptive management framework was then used to design a representative program for a sediment diversion in Louisiana. The adaptive management framework included defining management objectives from stated goals, identifying relevant performance metrics and evaluating key uncertainties. From this information, a monitoring plan can be developed and implemented to support long-term operations and adaptive management of a sediment diversion.

The goals of a sediment diversion were pre-defined by the State of Louisiana in *Louisiana's Comprehensive Master Plan for a Sustainable Coast*. Programmatically, these five goals are to (1) reduce economic damages from storm surge flooding, (2) restore natural processes, (3) maintain wide variety of coastal habitats, (4) sustain Louisiana's unique cultural heritage, and (5) support the economic drivers of a Working Coast (CPRA, 2023). The purpose and need statement for a sediment diversion as defined in the draft Environmental Impact Statement for the Mid-Barataria Sediment Diversion is "to divert up to 75,000 cubic feet per second (cfs) of sediment-laden water from the Mississippi River to re-connect and re-establish the natural or deltaic sediment deposition process between the Mississippi River and the Barataria Basin to deliver sediment, freshwater and nutrients to reduce land loss and sustain wetlands" (USACE, 2022a). Sediment diversions will have multiple, complex impacts (both positive and negative) to the socio-ecological systems; thus, the project needs to consider multiple objectives of varying variables and at varying spatial and temporal scales.

I, with support from my co-authors, led a working group (hereon referred to as MRD workgroup[2]) of twelve physical and social scientists and policy experts associated with the Restore the Mississippi River Delta Coalition (MRD) using best professional judgement to develop potential management objectives that would demonstrate how the sediment diversion project would contribute to the State's programmatic goals. The MRD workgroup used an iterative process of prioritizing objectives through a hierarchy as an essential guide for adaptive management to inform the weighting and trade-offs among different outcomes for decision makers and actors, guide an evaluation of the effectiveness of management actions, and clarify science priorities for the purposes of decision making (e.g., clarifying management uncertainties, learning strategies and monitoring needs). The MRD workgroup defined their importance (low, medium, high) to achieving the outcomes, as well as the anticipated time scale over which the objectives would be most relevant, defined as an early warning period (EW, 0-3 years), a near-term period (NT, 4-10 years), and a long-term period (LT, >10 years).

Decision making in the face of uncertainties is broadly recognized as a fundamental requirement

[2] Alisha Renfro, Denise Reed, Jessie Ritter, Steve Cochran, Maura Wood, Corey Miller, Erik Johnson, Theryn Henkel, Emily Vuxton, John Lopez, Estelle Robichaux and David Muth

to the application of AM (Walters & Holling, 1990; Williams & Brown, 2014). If there is no uncertainty, decision makers would have perfect clarity about the effectiveness of an action or outcomes from their choices, thus AM is not necessary. Responses to climatic-, societal- and environmental-driven changes in conditions are complex, dynamic and unpredictable (Yuill et al., 2014; Lynch et al., 2022; Zedler, 2017). Detecting cause-effect relationships, while maneuvering around the noise and variation in the system, is especially difficult (Lynch et al., 2022; Murray & Marmorek, 2001; Holling (ed.), 1978; Sit & Taylor,1998). Increasing clarity around which uncertainties are most critical to achieving performance and avoiding undesirable consequences is necessary for an effective AM program.

As AM is driven by reducing uncertainties, the MRD workgroup then proceeded to conduct a series of workshops to define key uncertainties in the operations and adaptive management of a sediment diversion. Although not inclusive of all uncertainties, an extensive list of potential uncertainties associated with the project was developed. For each uncertainty, a learning strategy worksheet was completed with a series of questions including: (1) what are the management actions affected by this uncertainty?; (2) what are the endpoints or valued components affected by the related management actions?; (3) what is the primary management objective supported by the management actions?; and (4) what is it about the link between the management actions and endpoints that one is uncertain about? These questions represent how the uncertainty could be resolved to distinguish between management uncertainty (resolved through operations and AM of the project) or a research uncertainty (resolved through some other learning strategy) (Nelitz et al., 2006; Marmorek et al., 2019). This distinction allows decision makers to focus on those uncertainties that are most relevant to the success of the project. Priorities were assigned based on the expert judgement of the MRD workgroup around the relative uncertainty involved and the perceived importance of resolving the uncertainty to federal and state agencies. This was also informed by the priorities represented in the objectives hierarchy (Nichols & Williams, 2006).

At a series of workshops with scientists and policy experts, supported by a literature review, the objectives were further defined to their associated performance measures that would be monitored at each level of the hierarchy to facilitate evaluation of project success. This process identified a broad initial suite of candidate performance measures that could potentially be used for monitoring various management objectives. The identified performance measures were subsequentially screened based on criteria modified slightly from those that have been commonly used (Kurtz et al., 2001; Stalberg et al., 2009; Kershner et al., 2011; Hijuelos & Reed, 2013; Martone et al., 2016; Meselhe et al., 2022) to narrow down the longer list of performance measures to a core set that are considered most meaningful, reliable, and practical for long-term monitoring. Candidate performance measures were evaluated and rated (high/medium/low or yes/no) based on seven characteristics defined by Atkinson et al. (2004) (Table 2.1).

Table 2.1: Evaluation Characteristics used to screen candidate performance measures.

Evaluation Characteristic	Definition
Scientifically Valid	Legitimate and recognized evaluation method
Management Relevance	Relevant to policy and management issues, with a clear cause and effect relationship, and reflect management/actor concerns
Monitoring Cost	Cost effective data collection/analysis at required spatial and temporal scales for long term monitoring
Data Collection Feasibility	Technically feasible from the perspective of required staff skills, equipment, manpower, logistics, timing, duration, etc.
Signal-to-noise-ratio	Sensitive to change and occur within a narrow range of natural process variability such that it has a relatively high signal-to-noise ratio.
Baseline Data Available	Historical supporting data with sufficient spatial and time series coverage is available to allow for comparisons and setting benchmarks/triggers
Identified Benchmark/ Trigger	Relate to existing benchmarking/trigger approaches, with identified reference points and targets of concern.

Higher level objectives in the hierarchy may reflect a combination of conditions that are not directly measurable, but sub-objectives lower in the hierarchy correspond to performance metrics that could be directly measurable. Performance metrics are quantitative and qualitative criteria, based on anticipated physical, biological or social responses, to evaluate the success of the sediment diversion project in achieving the project's objectives (Hijuelos & Reed, 2013; Kingsford et al., 2011). These metrics will provide long-term information on how well the project achieved its intended outcomes but could also provide insight into any unintended outcomes, whether positive or negative.

When selecting relevant performance metrics, the following should be considered: scientific validity (SV), management relevance (MR), monitoring cost (MC), data collection feasibility (DCF), signal-to-noise ratio (STNR), baseline data available (BDA) and identified benchmarks or triggers (IBT) (see Table 2.1) (Kurtz et al., 2001; Kershner et al., 2011; Martone et al., 2016). In addition to the seven characteristics described in Table 2.1, the performance metrics were also evaluated for the underlying methods, the method of data collection, remote sensing (RS), monitoring (M) or model-based (MB), and the timeframe, spatial scale and frequency in which data collection will be needed. Where available, some preliminary understanding of when this data was already being collected and is available was included.

RESULTS

Enabling and inhibiting factors for adaptive management

The importance of the adaptive management (AM) program requires adequate capacity at the institutional level to fully implement AM. The evaluation of enabling and inhibiting institutional factors found that the strongest factors for enabling AM at the CPRA were funding and planning. The CPRA's most inhibiting factors were community involvement and trust in how AM is conducted. The CPRA's learning capacity was strongest due to contextual factors of low institutional inertia and high political support; process factors of management approach, role of science and cumulative effects; and resource factors of sufficient funding. The CPRA's five weakest learning capacities included responsiveness to unexpected events (contextual), clarity of management goals, insufficient frequency of analysis and lack of integration of traditional/local knowledge (process) and level of AM experience (resource).

This analysis resulted in the identification of multiple opportunities and challenges for the CPRA in implementing a robust adaptive management program. Opportunities included funding availability and commitment to monitoring, acknowledgment of uncertainty and importance of AM for sediment diversions, good reporting and data transparency and an interest in more effective adaptive governance structures. Some of the challenges include low understanding of

AM processes, lack of multiple objectives in decision making, actors fear of uncertainty ("experimenting with my future"), limited transparency on decision making and the length of time horizons needed to access the full effect of actions.

Adaptive management and regulatory requirements

Some challenges and potential solutions identified through this effort to increase the enabling factors at agencies and within NEPA include the following:

- Applicability to project: AM is not appropriate for every project. *Solution*: Managers should evaluate applicability upfront. Specifically, AM is applicable where (1) there are relevant uncertainties in the outcomes of management actions, (2) the project is controllable, allowing for future modifications in management actions and (3) there is a low risk of irreversible harm to the environment (Damgaard, 2002).
- Risk and uncertainty: Managers want to maintain the status quo or seek certainty in outcomes; thus, they underrepresent uncertainties and predictive futures. Planners' lack of ability to integrate shifting baselines and observe every aspect of the system and differences between intended management impacts and the actual results of management actions complicate compliance. *Solution:* Agencies should normalize uncertainty through established processes to integrate into decision-making, such as scenario planning and use AM processes to make decisions over time with imperfect information. Agencies should use AM to synthesize past actions and compare predicted and actual outcomes (Lynch et al., 2022; Tribbia & Moser, 2008; Cammen et al., 2019; Keith et al., 2011).
- Institutional risk aversion: Agencies also seek certainty in their actions due to investments (financial or personnel) or being "litigation-proof." Litigation can lead to

time delays, cost increases and political ramifications. *Solution*: Institutions should embrace examples that change the management paradigm to save both time and money and provide better outcomes (Glicksman & Page, 2022; McDonald & Styles, 2014; Keith et al., 2011). A case law review found that most AM in NEPA passed judicial challenges if it included (1) monitoring protocols, (2) thresholds for subsequent actions and (3) adaptive/mitigation actions that could be taken (Glicksman & Page, 2022).

- <u>Front-loaded analysis and funding</u>: Long-term funding steams for AM, monitoring and adaptive measures are not common; therefore, agencies tend to front-load their analysis with a culture of build it and walk away. *Solution:* Mandating AM monitoring, thresholds and adaptive actions in enforceable regulatory documents could reduce the complexity of the upfront analysis, reduce upfront mitigation, as well as secure the long-term funding needed leading to better outcomes (McDonald-Madden et al., 2010). An institution-wide AM contingency fund could provide funding as needed without having to set aside funding for each individual project.
- <u>Lack of true experimentation:</u> Most AM programs lack true experimental design, hypotheses, and results in a rigorous scientific manner to facilitate learning and identify cause-effect relationships. *Solution*: Use hypothesis-based treatments, empirical management or staged-scale restoration to experiment and scale the best solutions (e.g., Glen Canyon Dam, CWPPRA Demonstration Oyster Reef Restoration) (Susskind et al., 2010; McDonald & Styles, 2014; Keith et al. 2011).
- <u>Data synthesis:</u> Synthesizing monitoring data relative to the project objectives is the most common step which stops the AM 6-step process (Design, Implement, Monitor, Synthesize, Adjust, Assess). Assessment of multiple restoration projects found no or

inadequate evaluations of success. *Solution*: Design and fund synthesis process at the on-set, including recruitment of independent researchers to conduct the analysis. (Tribbia & Moser, 2008)

- Participatory process: AM frequency lacks clear leadership and a transparent and inclusive process for actors. Distrust can lead to failure of AM plans. *Solution*: Buy-in from leadership is essential for long-term implementation and funding. Although the process may seem complex, it is rooted in traditional ecological knowledge (TEK) which resource users understand. Incorporating TEK with academic science to inform decisions can increase buy-in with key actors (Mulvaney et al., 2022; Stern & Dietz, 2008).

Adaptive management framework for sediment diversion

Objectives and Objectives Hierarchy

An objectives hierarchy was developed for the Mid-Barataria Sediment Diversion (Figure 2.4) that reflects perceived priorities of objectives by the federal and state agencies responsible for the project and actors and local governments directly affected by the project. Management objectives with a high importance were denoted as being directly or closely related to the purpose and need of the project and goals of the Coastal Master Plan. Objectives with medium importance were denoted as being fundamentally important to the regulatory approval of the project and could reflect a legal mandate that will need to be considered or potential legal or political risk to the project if the objective was not achieved. Objectives of low importance were denoted as having a legal mandate that they be considered for regulatory approval of the project, but do not carry as significant a litigation or political risk as medium priority objectives. *Note: The Coastal Master Plan goal to support the unique cultural heritage is considered programmatic to the coastal* *resilience program and is not a specific to management outcomes of the Mid-Barataria Sediment Diversion, has broad relevance and are affected mostly by other factors beyond the influence of the project.*

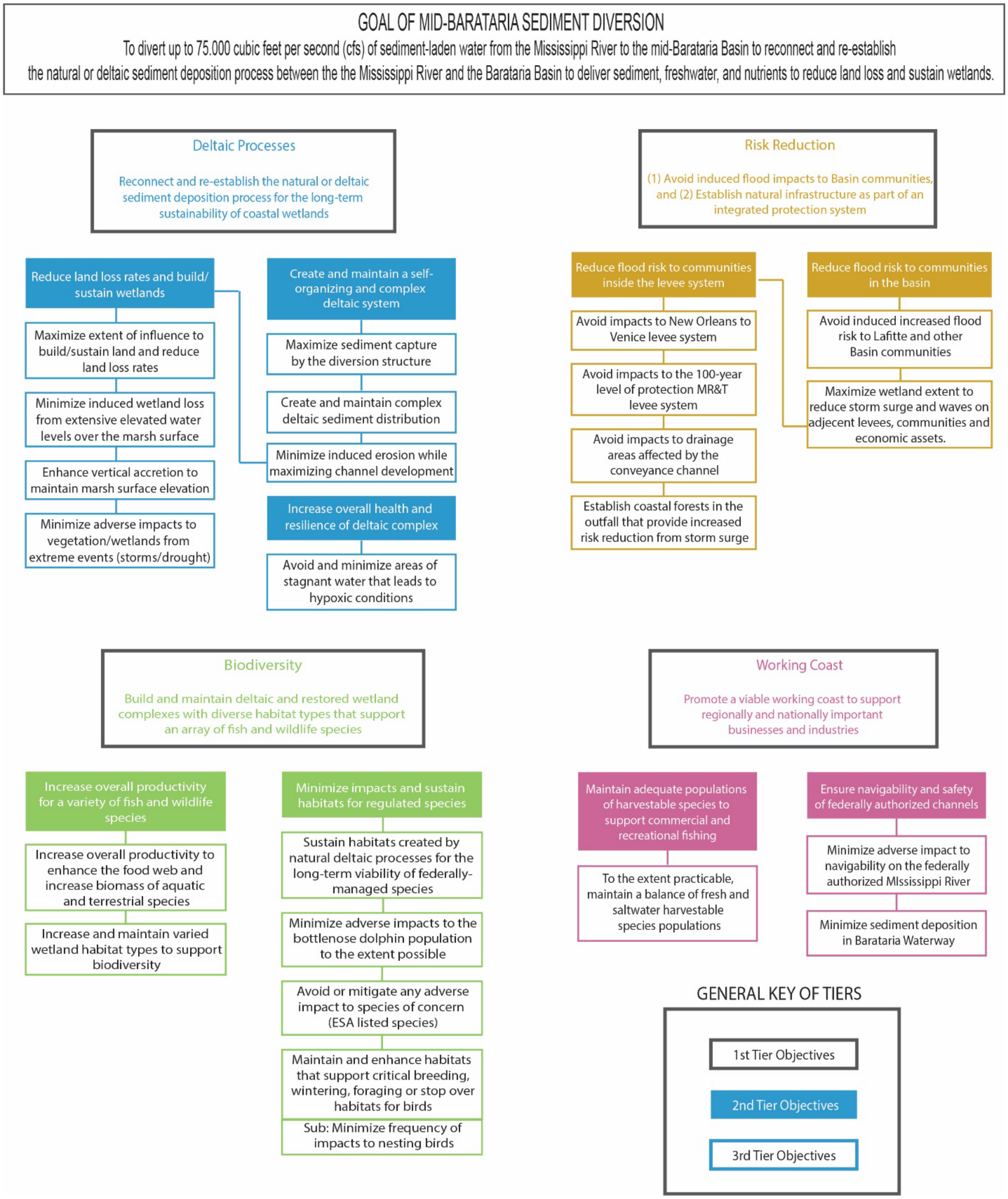

Figure 2.4: Proposed Objective Hierarchy for the adaptive management program of the Mid-Barataria sediment diversion

Timing of Objectives

This objectives hierarchy also presents management objectives based on the anticipated timing under which they are most important or relevant to consider. For instance, given the dynamic nature of the Barataria Basin ecosystem and the long-term fluvial geomorphic forcings of the diversion, the objectives in the first few years of the project could be different than the long-term objectives (Table 2.2). In initial years, the diversion will need to carve out distributary channels to meet the objective of creating and maintaining complex deltaic sediment distribution (Yuill et al., 2016; Twilley et al., 2019; White et al., 2023), so this objective will be more important in early years (to ensure no back-up flooding) and the near-term. Once established, the distributary network is unlikely to change significantly so this objective becomes less important (although still relevant) in the long-term.

Early-warning objectives considered that operations will begin gradually in the first few years, while evaluations of the diversion structure integrity and experimentation with the movement of water and sediment into the basin are conducted. Many of these objectives, such as the impact on the existing levee systems or currents in the river will be monitored or inspected regularly in the first few years to identify any issues of concern that would require adaptation. Many of these objectives, if found to be satisfactorily achieved, will be lower in importance in later years.

Near-term objectives consider that diversion operations will increase to capacity over the 4 to 10-year period. The focus will shift from the structure and its components in the immediate vicinity to basin-wide objectives. As the diversion operations increase over time, monitoring will reduce uncertainties in the interactions with some objectives, such as avoiding induced increased flood risk to communities in the Barataria Basin or impacts to species identified in the EIS (e.g., bottlenose dolphins).

Some objectives, specifically those directly related to the goals of the project, will be important across of the lifespan of the project. Long-term objectives consider the 50-year time horizon of the project and the overall goals of the diversion (i.e., building and sustaining land, enhancing vertical accretion and maximizing sediment capture). Other objectives may not be of high importance until the later years of the projects. For instance, establishing coastal forests in the outfall of the diversion for increased flood risk reduction cannot occur until later years when the diversion has built a delta platform.

This research considers that many uncertainties around the objectives will be better understood or resolved over time, and therefore will be either more or less important at varying times in the adaptive management program. Objectives may change in priority over time as uncertainties, such as those around climate change and the response of resource species, play out. For instance, at year 10, data should be available to inform if and how a sediment diversion affects bottlenose dolphin populations. However, if climate and other environmental conditions change in the future, these objectives could change in importance. This prioritization of objectives over time would also influence the monitoring priorities in any given year.

Table 2.2: Proposed time periods of importance for a subset of potential objectives. Early warning (EW) refers to the first few years of operation (years 0-4). Near-term (NT) refers to years 4-10 and long-term (LT) refers to the full 50-year lifespan of the project. An extended Table 2.2 is included in the Supplemental Information, but these are not considered inclusive of all relevant objectives.

Objective	Early Warning (EW)	Near-Term (NT)	Long-Term (LT)
Avoid induced increased flood risk to Lafitte and other Basin communities.	High	High	Medium
Minimize induced erosion while maximizing channel development.	High		
Minimize induced wetland loss from extensive elevated water levels over the marsh surface.	High	High	
Minimize adverse impact to navigability on the federally authorized Mississippi River.	Medium	Low	Low
Minimize adverse impacts to bottlenose dolphin populations to the extent practicable and consistent with the purpose of the project.	Medium	Low	
Avoid or minimize areas of stagnant water that could lead to hypoxic conditions.	Low	Low	Low
Create and maintain complex deltaic sediment distribution.		High	High
To the extent practicable, maintain a balance of fresh and saltwater harvestable species populations.		Medium	Medium
Minimize sediment deposition in the federally authorized Barataria Waterway.		Low	Low
Increase and maintain varied wetland habitats to support biodiversity.			Medium
Increase primary productivity to enhance the food web and increase biomass of aquatic and terrestrial species.			Medium
Provide conditions that support the establishment of coastal forests in the outfall area to increase protection from storm surge.			Low

Uncertainties

The social-ecological system of coastal Louisiana has extensive uncertainties in functions, interactions and future conditions. It important to distinguish management uncertainties from research uncertainties, as identified in an AM program. Not all uncertainties have the same importance to decision making even though there are many unknowns that scientists would like to investigate. Reducing a research uncertainty can lead to better knowledge about the components and their interactions within a socio-ecological system (e.g., the vulnerability of a particular fish species to climate impacts) (Nelitz et al., 2006). However, focusing on management uncertainties can lead to either, confirming that current management actions are appropriate, or lead to a change in management actions that better satisfies one or more of the objectives (e.g., the effect of changes in the timing and magnitude of freshwater inputs on salinity in the Barataria Basin) (Nelitz et al., 2006; Marmorek et al., 2019; Das et al., 2017; Peyronnin et al., 2017; McDonald-Madden et al., 2010). Appropriately designed conceptual and mathematical or computer models, with explicit assumptions and limitations, can help decision makers understand the relationships of components of the system, the sensitivity of outcomes to various uncertainties, test scenarios and plan robust project features.

A management uncertainty may evaluate or test how the timing and magnitude of operations affect population levels for key fish species of recreation and commercial importance. Associated research uncertainties would include how carbon fluxes affect the food web, changes to vulnerable life stages, the composition of trophic levels and changes to predator/prey interactions. Resolving or reducing these research uncertainties are not directly tied to the objectives or to operation of the sediment diversion. However, if the level of change in these research questions led to a reduction in fish populations, then it is impacting the management uncertainty and could change operational strategies. This distinction allows monitoring plans, with limited budgets, to focus on the uncertainties that are most relevant to objectives and ultimately the success of the project.

Some examples of management uncertainties are included in Table 2.3 and research uncertainties in Table 2.4 (a longer, yet not exhaustive, list is included as Table 2.3 and Table 2.4 in

Supplemental Information). Each uncertainty was analyzed to determine if it was a research uncertainty or a management uncertainty by determining the connection to management objectives. Each uncertainty was also evaluated for its level to indicate a priority in the science and monitoring program, a level of expected importance for various federal and state agencies and the primary learning strategy that could be employed to experiment or test various strategies or adapt to unexpected outcomes.

Table 2.3: Illustrative list of relevant management uncertainties, including level of uncertainty, the perceived institutional importance of the uncertainty and the primary learning strategy (or adaptive actions) that could be taken. An extended Table 2.3 is included in the Supplemental Information, but these are not considered inclusive of all relevant management uncertainties.

Management Uncertainties	**Level of Uncertainty**	**Institutional Importance**	**Primary Learning Strategy**
Does the timing and magnitude of operations affect food web dynamics (community composition of lower trophic levels and cascading effects through the upper trophic levels)?	High	High	Operations
How will the timing and magnitude of operations affect the habitat use, distribution and abundance for bottlenose dolphin in Barataria Bay?	High	High	Operations
What operational strategy most effectively limits unnecessary erosion during channel development?	High	High	Operations
How does residence time, which varies based on operation strategies, affect overall water quality and how can nutrient retention enhancement devices (NREDs) be used?	High	High	Operations NREDs*
How do variations in operations affect fish population levels (specifically harvestable stock) for key commercial and recreational species?	Medium	High	Operations
How do operations affect water levels (duration and depth) and across what extent could lead induced wetland loss?	Medium	High	Operations
How will the diversion affect the flood risk of adjacent communities?	Low	High	Operations Levees
How will base flows be needed seasonally to prevent saltwater intrusion leading to freshwater marsh collapse?	Medium	High	Operations
How can sediment trapping efficacy be affected by sediment retention enhancement devices (SREDs)?	Low	Medium	Operations SREDs**

**NREDs are Nutrient Retention Enhancement Devices that can be installed in the outfall area.*

***SREDs are Sediment Retention Enhancement Devices that can be installed in the outfall area.*

Table 2.4: Illustrative list of relevant research uncertainties, including level of uncertainty and the perceived institutional importance of the uncertainty. An extended Table 2.4 is included in the Supplemental Information, but these are not considered inclusive of all relevant research uncertainties.

Research Uncertainties	Level of Uncertainty	Institutional Importance
How does additional carbon influx affect food web productivity?	High	High
What are the changes to the composition/structure of trophic levels and how will it affect predator/prey interactions?	High	High
What are the near and long-term socio-economic effects of the project?	High	High
How do different vegetation species handle flood stress?	Medium	High
What is the rate of relative sea level rise and how does it affect delta development?	Medium	High
How much and where will sediment deposition on oyster leases affect productivity?	Low	High
What is the fate of nutrients and other contaminants in the basin?	High	Medium
Where and how much of each habitat type will be created over time?	Medium	Medium
How do changes in environment conditions affect population dynamics (growth/mortality/ reproduction) at vulnerable life-stages for populations of harvestable fish species?	High	Medium
How is river discharge (and extreme events) going to change seasonally and over time considering climate change?	High	Low

Performance Metrics

Table 4 provides a snapshot of some key potential performance measures (see Supplemental Information for an extended table) that could be used to monitor the project's success in meeting its objectives. The performance measures included in Table 2.5 are in no way exhaustive or complete. They represent a rapid assessment of some potential indicators based on my knowledge of the system and literature on resilience indicators (Sharifi, 2016; Bollettino et al., 2017; Martone et al., 2016; Sterling et al., 2017). Extensive and in-depth interdisciplinary work would need to be completed to synthesize the latest information on indicators, data collection methodology and data availability.

Table 2.5: Examples of performance metrics tied to objectives from Figure 2.4. Evaluated by performance metrics criteria scientific valid (SV), management relevance (MR), monitoring cost (MC), data collection feasibility (DCF), signal-to-noise ratio (STNR) and baseline data available (BDA). (Key – High (H), Medium (M), Low (L)).

3rd Tier Objectives	**Key Performance Measures (PMs)**	**PM Selection Criteria****					
		SV	**MR**	**MC**	**DCF**	**STNR**	**BDA**
Maximize extent of influence to build and reduce land loss rates	Rate of change of land area	H	H	M	H	H-L (spatially variable)	Y
Minimize induced wetland loss from extensive elevated water levels over the marsh surface	Duration and depth of inundation of wetland vegetation species	H	H	M	H	H-L (spatially variable)	Y
Enhance vertical accretion to maintain marsh surface elevation	Surface elevation	H	H	L	H	H-L (spatially variable)	Y
Minimize impacts to vegetation/wetlands from extreme events, including storms and droughts	Salinity thresholds (with duration) for freshwater marshes	H	H	L	H	H-L (spatially variable)	Y
Maximize sediment capture by the diversion structure	Sediment/water ratio; Total sediment captured (by particle size)	H	H	L	H	H	N
Minimize induced erosion while maximizing channel development	Geomorphology change	H	M	M	H	H	N
Minimize areas of stagnant water; Hypoxic conditions	Dissolved oxygen and retention times	H	H	H	H	M-L (spatially variable)	Y
Avoid impacts to the 100-year level of protection on the MR&T levee system	Federal levee integrity; Safety inspection ratings	H	H	L	H	H-L (spatially variable)	Y
Avoid induced increased flood risk to Lafitte and other Basin communities	Induced water level variation	H	H	M	H	M-L (spatially variable)	Y
Increase overall productivity to the food web and increase biomass of aquatic and terrestrial species	Primary productivity	M	M	M	H	M-L (spatially variable)	N
Minimize adverse impacts to bottlenose dolphin populations to the extent practicable and consistent with the purpose of the project	Number and cause of unusual mortality events (UMEs)	M	H	L	H	M	Y
To the extent practicable, maintain a balance of fresh and saltwater harvestable species populations	Stock assessments; species biomass; total commercial market value; landings by species, catch per unit effort; number of fishing licenses	M	M	L	H	L	Y

This process will focus the monitoring on metrics that are most meaningful, reliable and practical for long-term and systematic monitoring. Some examples of potential natural and social indicators are included in Table 2.5 (see also Supplemental Information).

Benchmarks and Monitoring

Additional critical framework components not covered in this study include setting benchmarks and triggers and developing the monitoring plan. Benchmarks represent clearly specified values for a performance metric (as quantified by one or more supporting indicators) against which its status can be compared over locations and time periods of interest (Landres et al., 1999). If explicitly desired goals or outcomes are identified at the outset, along with a monitoring plan to identify progress towards those goals, then benchmarks can be used as a signal to indicate positive progress or a trigger can indicate reaching a specific point where course corrections or alternative management actions may be required (Schultz & Nie, 2012).

DISCUSSION

Addressing inhibiting conditions

This analysis resulted in the identification of multiple enabling and inhibiting factors for the Coastal Protection and Restoration Authority (CPRA) in implementing a robust adaptive management program. As CPRA was formed only in 2006, adaptive management is enabled by the institution's learning capacity which was strongest due to contextual factors of low institutional inertia and high political support. Process factors of management approach, role of science and cumulative effects and resource factors of sufficient funding were also enabling factors. Community involvement and relevant factors, such as trust and transparency, are one of the most inhibiting factors to successful adaptive management of the Mid-Barataria Sediment

Diversion. Participatory governance is one way to improve community involvement in decision making (Luo et al., 2022; Peters et al., 2022; Paul et al., 2018; Fung, 2015). The concept of governance in the context of managing common pool resources emerged in the 1990s (Gardner et al., 1990). Although there are several definitions, one view of governance involves the dimensions of authority, decision making, and accountability: "*who has power, who makes decisions, how other players make their voice heard and how account is rendered*" (Institute on Governance, 2023). The term "adaptive governance" has been used in the context of AM which encourages a consideration of the need for organizational and institutional flexibility to cope with uncertainty and change (Folke et al., 2005). Some further assert that AM requires both adaptive and participatory governance to be successful (Gunderson & Light, 2006; Folke et al., 2005; Vob & Bornemann, 2011; Waylen et al., 2019; Stringer et al., 2006).

Evidence from other large-scale AM programs across North America[3] illustrate that rigorous AM requires a successful organizational and governance structure to provide clarity around who will be involved and describe the roles and responsibilities of individuals and organizations within that structure (Smith, 2020; Gunderson, 2015; Marmorek et al., 2019). Each of these programs has clear executive authority but a unique structure for policy, management and technical support. Governance at the policy level involves a focused committee or group with diverse perspectives that typically requires consensus or a strong majority for decision making (Smith, 2020; Gunderson, 2015; Marmorek et al., 2019). Governance at the management level tends to include consistent Actor perspectives and input and governance at the technical level includes some independent scientific review (Littles et al., 2022; Susskind et al., 2010;

[3] These programs included: (1) U.S. Columbia Basin Fish and Wildlife Program, (2) Trinity River Restoration Program, (3) Glen Canyon Dam Adaptive Management Program and (4) Platte River Recovery Implementation Program.

Marmorek et al., 2006).

Another most inhibiting factor for the Mid-Barataria Sediment Diversion was trust in how adaptive management science is conducted. Rigorous AM is an approach for designing and implementing management actions to maximize learning about critical uncertainties that affect decisions while simultaneously striving to meet multiple management objectives. A variety of resources are available to support practitioners in the conduct of AM (e.g., Bormann et al., 1994; Sit & Taylor, 1998; Stankey et al., 2005; Allan & Stankey, 2009). Put in simple terms, it can be described as a six-step process with three distinct phases of action: planning, learning and doing (Holling, 1973; Holling (ed.), 1978; Walters & Hilborn, 1978; Walker, 1986; Williams & Brown, 2014). The process for conducting AM can be further articulated by the elements that underlie each of these six steps as identified by leading practitioners from across North America (Marmorek et al., 2006). Some key elements to consider as building blocks for the CPRA to improve their enabling conditions for AM include: (1) identify multiple management objectives within a hierarchy; (2) articulate the governance structure and decision-making process including roles and responsibilities for other agencies, actors and independent scientists; and (3) improve data management, transparency and decision-support tools.

Meeting regulatory requirements

One additional element defined by Marmorek et al. (2006) involves meeting regulatory requirements. As an important regulatory checkpoint in the U.S., the NEPA process is designed to disclose environmental harm due to a human intervention (Glicksman & Page, 2022). The complexity of the Mid-Barataria Sediment Diversion and the restoration of the hydrology, geology and biology of the natural deltaic system cannot occur without environmental harm which leads to discourse among actors (Barra, 2020; McCall & Greaves, 2022; Peyronnin et al., 2017; Jarreau et al., 2015; Yuill et al., 2014). As a result of Mississippi River levees and other human factors, saltwater intrusion and land loss have increased, creating open water habitat where once there were wetlands (Kemp et al., 2014; Boesch et al., 1994; Day et al., 2007). This has allowed certain species to migrate into areas that they otherwise would not have inhabited (Kemp et al., 2014). Saltwater species such as oysters, brown shrimp and bottlenose dolphins had access to move further north into the Basin as land is lost and sea levels rise, expanding their ideal salinity habitat range (White et al., 2018; Hornsby et al., 2017; Peyronnin et al., 2017). But this system of decline, if the course is not changed, will eventually lead to ecological collapse (Cowan et al., 2008; Kemp et al., 2014; Day et al. 2007; Peyronnin et al., 2017).

In this context, adaptive management is seeking to manage and recreate the processes that build the deltaic system to begin with. The complex interactions of positive and negative effects of the Mid-Barataria Sediment Diversion will play out over time; however, the final EIS has to make some predictions based on best available science today (USACE, 2022a). There is an inevitable tension between the final EIS needing to provide clarity and precision around the environmental, social and economic impacts of the project and the AM Plan needing to test and evaluate a range of actions or alternatives to identify which will best achieve intended objectives over time. An institutional culture of risk aversion can lead to a reduced emphasis on the AM program.

Adaptive management framework

The Mid-Barataria Sediment Diversion will be one of the largest individual ecosystem restoration projects in the world and will fundamentally change how a whole estuarine basin functions (USACE, 2022a; CPRA, 2023). But reconnecting the Mississippi River to its floodplain is not as simple as just letting nature take it course. Although geologically developed over the last 7,000 years, the Louisiana coast has been dramatically altered by society in a mere 150 years (Gagliano et al., 1970; Gagliano et al., 1973; Boesch et al., 1994; Day et al., 2007; Kemp et al., 2014; Edmonds et al., 2023). Human society and its institutions must now operate within this complex socio-ecological system. For complex projects such as sediment diversions, this will require balancing multiple objectives to meet both the ecological needs of the system and the needs of society.

One of the institutional weaknesses was the lack of clarity of management goals. CPRA has only defined one objective for the Mid-Barataria Sediment Diversion – to build and sustain land. However, a project the size of the sediment diversions will have various effects on multiple aspects of the SES. The lack of multiple objectives was the impetus for the work in Chapters 2 and 3 which used Coastal Master Plan goals that span the ecological and social systems.

Developing an adaptive management framework is essential to make informed decisions on a monthly, or even daily, basis on operating the diversion. Engagement of actors and transparency in the objectives of the project, the hierarchy of those objectives and the scientific and management uncertainties are essential to the decision-making process. Performance metrics are key to understanding if the desired outcomes are being achieved, and if not, what adaptive actions need to be taken. Additional steps in the framework not taken here include setting benchmarks and triggers and developing and implementing the monitoring plan.

With regard to the objective hierarchy, future work will involve identifying performance measures that can be monitored to help evaluate whether the project is successfully meeting the desires of decision makers over time, synthesizing that data and providing learning to decision-makers. With regard to the management uncertainties, more detailed work will be required to translate the priority management uncertainties into more specific focal questions and testable hypotheses that can then guide the design of an effectiveness monitoring program and evaluation of data that emerges as the project becomes operational. In the process of identifying performance measures and clarifying more detailed monitoring needs given the information presented here, it will likely result in slight modifications of objectives and additional refinements to the list of uncertainties presented above.

The performance metrics will inform a robust monitoring plan that prioritizes the allocation of financial, human and material resources. Some performance metrics will be deemed more essential and receive greater funding, while others are only funded under specific conditions. For example, a tertiary objective of "minimize adverse impacts to bottlenose dolphin populations to the extent practicable and consistent with the purpose of the project" is directly tied to a legal mandate affecting the project. The performance metric for this objective could be the number and cause of unusual mortality events (UMEs) compared to the baseline statistical likelihood of occurrence. As seven criteria (aka benchmarks) for a UME are already established by the National Oceanic and Atmospheric Administration, diversion operators would work with NOAA to identify when the thresholds have been crossed and a UME has been declared (NOAA, 2023). This declaration will not necessarily trigger a change in operations, but will trigger additional monitoring and research into the causation of the UME. It is important that any threshold has a clear cause-effect relationship with diversion operations before changes in management actions are taken (Preiser et al., 2018; Walker et al., 2002; Walker et al., 2006). This is especially important if the effect was likely to occur due to external conditions with or without the diversion. If, and when, the diversion operations are directly tied to a threshold being crossed, diversion operators would work with NOAA to modify operations or thresholds for the performance metrics and possibly add additional performance metrics to better understand the cause-effect relationship in order to avoid future diversion-caused UMEs.

For the Mid-Barataria Sediment Diversion, there has been extensive discourse centered around the near-term impacts on bottlenose dolphins, brown shrimp and oysters that could impact management actions, such as operational regimes (USACE, 2022a; Loftin et al., 2011; Thomas et al., 2022; Barra, 2020; McCall & Greaves, 2022; Fox et al., 2007; Nyman et al., 2013; Posadas & Posadas, 2017). However, although modeling predictions provide some insight into the impacts, the scale of these impacts is still highly uncertain, based on the assumptions and limitations in the model. For instance, the Barataria Bay bottlenose dolphin population's survival rate is projected to decline, with some studies projecting functional extinction and others predicting a decline of 15.3% to 62.7%, with a mean reduction in survivorship of 34% (Thomas et al., 2022; Garrison et al., 2020, McClain et al., 2020; USACE, 2022a). However, there are substantial uncertainties in the projections of future salinity conditions based on the interactions of climate change impacts and diversion operation into the future, as well as the relationship between low salinity exposure and dolphin migration away from low-salinity habitats (Hornsby et al., 2017; Wells et al., 2017; White et al., 2018).

Another uncertainty concerns the temporal and spatial extent of elevated water levels on the marsh surface causing vegetation and wetland loss (Peyronnin et al., 2017; Snedden et al., 2007). This uncertainty bears importance to the primary management objectives of minimizing induced wetland loss from extensive elevated water levels on the marsh surface and avoiding induced increased flood risk to Lafitte and other Basin communities. Changing operations would alleviate any excessively elevated water levels thereby reducing the potential for loss of vegetation and wetlands. Other related uncertainties are more scientific in nature, such as the spatial extent of each wetland habitat type created by the diversion. There is not a direct objective to prioritize one habitat type over another or to create a specific amount of one type of habitat, so the extent of each habitat type would not change a manager's decisions on how diversions are operated. However, over time, this research uncertainty will influence other management uncertainties, such as the extent of base flow needed to maintain freshwater marsh and prevent its collapse from seasonal saltwater intrusion. If more freshwater marsh is created, then more base flow may be needed over time to ensure the sustainability of that marsh. This indicates the importance of a robust research and development program alongside the adaptive management monitoring program to provide the latest and best available science to the decision-making process.

Over the next five years, as the first sediment diversion is constructed, the adaptive management program should be further developed in collaboration with actors, to build transparency in data and decision making and provide an effective participatory governance structure. This diversion will be a model for future planned sediment diversions included in the 2023 Coastal Master Plan (CPRA, 2023). It should also be understood that all of these critical elements of an adaptive management framework are operating within a complex and dynamic socio-ecological system that will require flexibility over time and a regular reevaluation.

Sediment diversions are just one example of how adaptive management can help define and manage a complex socio-ecological system. Future conditions of coastal systems present uncertainties due to the dynamics of riverine and marine processes, vulnerability to extreme tropical events and sea-level rise resulting from climate change and evolving human reliance on the natural resources and ecosystem services of the coast (Fujitani et al., 2017; Gregory, 2006). Managing such complex and interconnected socio-economic systems is inherently difficult (Colding & Barthel, 2019; Anderies et al., 2004; Nelson et al., 2022). Future uncertainties, as well as existing data and knowledge gaps, can limit the ability to predict the functions and response to management actions of both the natural and social systems (Anderies et al., 2004; Nelson et al., 2022; Davidson, 2010). Specifically, interactions among and between the various aspects of the hydrodynamic, morphologic, ecological, economic and social landscape, currently and in the future, of a dynamic and ever-changing environment such as a delta can become increasingly variable. This increased uncertainty in outcomes reduces levels of certainty in making resilience action decisions. Taking action cannot be frozen by these uncertainties but has to understand and deal with them. Adaptive management is a unique management tool that can be modified and adapted over time based on the changing conditions experienced, best available science and collective desired outcomes of actors.

CONCLUSIONS

This interdisciplinary research identified institutional enabling and inhibiting factors, as well as regulatory challenges, that can be used to develop strategies to improve and overcome barriers. It also demonstrates the importance of developing multiple objectives for large complex resilience project. Multiple objectives can build consensus around desired outcomes, assess outcomes across the SES, provide a structure to understand key uncertainties which will inform future work on developing the monitoring plan and provides transparency and communication around expected outcomes. Instiutionalizing the adaptive management program, incorporating social learning or other participatory processes, and establishing learning as a foundational element will not only inform the operations of the Mid-Barataria Sediment Diversion but provide learning for future diversions and programmatic management of the coastal SES.

Across the world, the impacts and uncertainties of climate change are forcing decision makers to look for alternative management structures. The use of adaptive management outside of natural resource management is growing and has the ability to better manage the complex socio-ecological system over time than traditional management. Climate change and its impacts are occurring at rapid speed requiring more flexibility and adaptation in management. In addition, the trade-offs of various actions that may cause a complicated mix of environmental and social benefits and harm at the same time, requires multiple objectives, transparent decision making and robust science support for AM. This adaptive management framework takes a holistic approach to identify needs and desired outcomes across the social and ecological landscape, prioritize those outcomes and provide structure methodologies for addressing uncertainties while still making decisions in the present day.

To thoroughly understand the socio-ecological system requires a deep dive into the components, processes and feedbacks of the natural and social subsystems and indicators of resilience that are measurable over time. Without this approach, decision makers will likely waste limited funding and design inappropriate policies that at best do not fully address the problem, but more likely will not change the trajectory of resilience or, at its worst, can decrease the resilience of a community or region. By using adaptive management of the SES, a decision maker can better understand the functioning and structure of the entire socio-ecological system and how components are linked and connected, thus increasing efficiency and effectiveness. The approach enables improved coordination among governing institutions and engagement of communities and actors and the ability to increase resilience and reduce the risk of shocks to the system (Mulvaney et al., 2022). By integrating adaptive management and governance, decision makers can reduce uncertainties of future conditions and increase the efficacy of their actions and policies.

Chapter 3: Social learning as a tool to co-create adaptive management for sediment diversions in Louisiana

INTRODUCTION

Adaptive management is expanding beyond just natural resource management to managing a dynamic socio-ecological system (SES), adding complexity to an already complicated process for actors to understand. Social learning through effective actor engagement can provide a process by which experience-based knowledge and preferences of actors are integrated into an adaptive management (AM) program.

Significant discourse, mired in historical coastal management, exists around diversions of Mississippi River sediments, a large-scale ecosystem restoration approach in coastal Louisiana. A repetitive theme from the literature reflects the lack of inclusion in decision making around the decisions to implement such diversions (Lipsman, 2020; Barra, 2020; Hemmerling et al., 2020; Domingue, 2022a; Lipsman, 2019; Ko et al., 2017). This paper describes a social learning approach with divergent actors focused on the operations and adaptive management of diversions, and not debating whether or not to construct a diversion. This paper reports on the efforts of a social learning group to build consensus on value components, objectives, measures of success and monitoring, adaptative management actions and principles for governance.

Social learning

Social learning has been an emerging approach to increasing the adaptive capacity for managing the socio-ecological system, particularly in a time of climate change (Kraker, 2017; Keen et al., 2005; Thi Hong Phuong et al., 2017; Ensor & Harvey, 2015; Haque et al., 2021). Reed et al.

(2010) defines social learning as a change in understanding that goes beyond the individual and occurs through social interactions to benefit the greater social-ecological system. Social learning involves acquiring new or adjusting existing knowledge, skills and values through social interactions and collective action (Cundill et al., 2015; Lebel et al., 2006). Common understanding across diverse actors is achieved through dialogue and exchange of ideas, perspectives and experiences, in order to co-create and share knowledge about environmental and social challenges (Macintyre et al., 2018). Through social learning, participants can gain a deeper understanding of the social-ecological system, identify potential solutions and trade-offs and develop new strategies for building resilience (Reed et al., 2010).

Particularly suitable for complex SESs with systemic uncertainty (Ison et al., 2010; Ensor & Harvey, 2015), social learning engages multiple actors with varying perspectives, values and knowledge to move forward collective action and increase adaptive capacity (Thi Hong Phuong et al., 2017). The benefits of social learning are an increased understanding amongst actors, relationship and trust building, developing a comfort with uncertainty, integrating experience-based knowledge and implementing collective actions (Cundill & Rodela, 2012; Kraker, 2017; Thi Hong Phuong et al., 2017). Thi Hong Phuong et al. (2017) noted that institutions, governance structures and legal frameworks are key catalysts to enabling social learning to greater adaptive and coping capacity to disasters and climate change impacts (Haque et al., 2021).

Social learning must be accompanied by efforts to address power imbalances and foster equitable participation, particularly among marginalized and underrepresented groups (Armitage et al., 2008; Haque et al., 2021). Power dynamics and social relationships shape the process and outcomes of knowledge co-creation. Social learning is not a neutral or objective process, but rather is shaped by unequal power relations, diverse interests and competing values among participants (Pahl-Wostl et al., 2023). Institutional arrangements must promote learning and collaboration with effective structured decision making, such as adaptive management (Armitage et al., 2008).

Social learning can be especially useful where misinformation, mistrust of data or divergent perspectives are held (Beers et al., 2016; Reed et. al., 2010). In these cases, decision makers should not only define the desired outcomes for the socio-ecological system, but also define learning outcomes for actors (Kraker, 2017; Ensor & Harvey, 2015). Kraker's (2017) review of literature with defined learning outcomes found that local and regional cases experienced shared understanding and ownership, reduced conflict, increased communications, increased trust and adoption of new practices, while all national cases failed largely due to the rigor of policy windows for change (Pahl-Wostl et al., 2023).

Social learning approaches can help an individual and/or community to make quick decisions about response and recovery after a flood event. Many areas have a strong social memory of previous flood events or of information handed down through generations, increasing their coping abilities (Hemmerling et al., 2019; Haque et al., 2021). Community processes, like collective problem-solving and community competence, are especially important to prevent the community or institutions from building back the same way it was before and, instead, embracing resilience measures that leave the community more resilient to future storms than they were before (Ensor & Harvey, 2015; Hegger et al. 2017; Tompkins et al. 2010). Institutional processes, specifically those of government agencies and NGOs, can also greatly affect the ability to build resilience as part of the recovery, specifically by providing the infrastructure, supportive services, information and communication needed to effectively engage storm survivors in a participatory process (Haque et al., 2021; Thi Hong Phuong et al., 2017).

Cundill and Rodela (2012) make a distinction between adaptive management guided by experimentation and social learning guided by negotiations and dialogue. However, others have pointed to the need to integrate social learning with adaptive management (Ensor & Harvey, 2015; Armitage et al., 2008). Learning is foundational to both approaches, using monitoring, feedback loops, synthesis and reflection and adjusting actions (Chaffin et al., 2014). Combining the theories and practices of adaptive management with social learning can foster a culture where actors are encouraged to experiment and innovate, learn from successes or failures and adapt to changing circumstances (Ensor & Harvey, 2015; Armitage et al., 2008). Social learning through effective actor engagement is an essential component of an adaptive management (AM) program, through inclusive decision making, trainings, capacity-building and opportunities for cross-sectoral and cross-cultural dialogue (McGinnis et al., 2014).

Public discourse over sediment diversions

The Lower Mississippi River has a long history of human interventions, including river management for navigation and flood control and subsurface resource extractions, that has resulted in the loss of approximately 5,200 km^2 of Louisiana's coastal natural defenses and an increase in flood risk vulnerabilities (Couvillion, 2017; CPRA, 2023, Edmonds et al., 2023). The continued land loss crisis is resulting in substantial outmigration of residents, lost economic opportunities and a degrading ecosystem that will continue without long-term changes to the

SES (Habans, 2019; Hobor et al., 2014). Advocates and academics began to question the river management approach in the 1970s, when the consequences of detaching the river from Louisiana's coastal wetlands was documented by scientists and recommendations were made to reconnect the Mississippi River to the delta through flow diversions and creation of subdeltas (Gagliano et al., 1970; Gagliano et al., 1973; Tripp & Herz, 1988; Haedicke, 2017). This sentiment grew and expanded to the public, especially after Hurricanes Katrina and Rita in 2005, when there was a rapid increase in community understanding of the importance of the coastal landscape to protecting communities from tropical storms (Haedicke, 2017). These disasters catalyzed decades of previous advocacy work into policies, including the formation of the Coastal Protection and Restoration Authority (CPRA), which collocated flood protection and restoration efforts into one state institution, and the establishment of a regularly updated Coastal Master Plan (Haedicke, 2017; Barra, 2020). At the core of the Coastal Master Plans (2007; 2012; 2017; 2023) are projects to reconnect the Mississippi River back to its coastal wetlands through sediment diversions. Although each of the four Coastal Master Plans were unanimously approved by the Louisiana Legislature and generally have high support from the public, sediment diversions continue to be very contentious, specifically among fishers and local residents (Lipsman, 2019; Haedicke, 2017; Lipsman, 2020; Boesch, 2020).

Sediment diversions are the most ambitious projects of the Coastal Master Plan, while being potentially the most effective and efficient at providing long-term coastal ecosystems (Lipsman, 2019; CPRA, 2023). A diversion is a controlled structure of functional gates built into the Mississippi River levee system to allow fresh water, sediment and nutrients to flow into the degraded wetlands, mimicking the natural cycle of riverine flooding, crevassing and distributary sub-delta formation (CPRA, 2023; USACE, 2022; Kolker et al., 2018; Twilley et al., 2019). As the size and scale of the land loss crisis grew, the flow capacity of planned diversions also increased, from 140 m^3s^{-1} in 1993 (CWPPRA, 1993) to 2,100 m^3s^{-1} in Louisiana's 2023 Coastal Master Plan (CPRA, 2023). Initially, the flow capacity of planned diversions was constrained to not significantly adversely impact any of the numerous user groups, including navigation, municipal and industrial water supplies, coastal residents and commercial and recreational fishing (CWPPRA, 1993; Fox et al., 2007). However, through multiple iterations of coastal planning, the flow capacity of diversions was increased to meet the scale of the land loss problem and address future climate change impacts, thus significant changes to ecological and social resources became unavoidable (CWPPRA, 1993; Reed & Wilson, 2014; CPRA, 2012; CPRA, 2017; Peyronnin et al., 2017).

In 2023, the State of Louisiana will begin construction of the first 2,100 m^3s^{-1} sediment diversion, the Mid-Barataria Sediment Diversion (MBSD), which was permitted in December 2022 and funded in February 2023 (USACE, 2022b; LaTIG, 2023). The estimated $2.26B project would be one of the largest individual ecosystem restoration projects in the world (CPRA, 2022). Once constructed, it is predicted to have significant benefits, as well as some adverse impacts to the ecosystem and user groups (USACE, 2022). The MBSD benefits include delivering an estimated 275 million tons of sediment to build and sustain approximately 55 km^2 of wetlands in a productive and healthy estuarine ecosystem over 50 years, which would also reduce flood risk for communities (USACE, 2022; CPRA, 2023). This increase in fresh water, nutrients and sediment will lead to positive impacts to overall food web productivity and on many species of fish and wildlife, such as ducks, alligators, crabs, migratory birds, white shrimp and some species of finfish (Peyronnin et al., 2017; USACE, 2022; Rhode et al., 2019). The adverse impacts include elevated water levels experienced by basin-side communities, and significant impacts to oysters, brown shrimp and the Barataria Bay Estuarine System (BBES) dolphin population (USACE, 2022; Peyronnin et al., 2017; Loftin et al., 2011; Hornsby et al., 2017; Thomas et al., 2022; McClain et al. 2020; Nyman et al., 2013; White et al., 2018). Subsistence, recreational and commercial fishers in the region, specifically oyster fishers and shrimpers, could experience impacts to their livelihoods and fishing infrastructure (USACE, 2022; Posadas & Posadas, 2017; Colten & Hemmerling, 2014; Loftin et al., 2011; McCall & Greaves, 2022; Barra, 2020). Communities in the basin could experience impacts to housing, public services and community cohesion (USACE, 2022; McCall & Greaves, 2022; Barra, 2020).

The public discourse over sediment diversions is not new and the mistrust among some members of the public, specifically coastal residents and fishers, is the result of historical and ongoing coastal management and racial injustice (Barra, 2020; Kang, 2022; Phillips & Soederberg, 2023; Nost, 2022; McCall & Greaves, 2022). Rooted historic racial practices of the deep south still shape communities and interactions in the influence area of the diversion, including Grand Bayou, a Native-American community, and Ironton, a Freedman's community (Barra, 2023; Barra, 2020; Nost, 2022). Across all coastal frontline communities, no matter descent (Creole, Cajun, Native Americans, Isleños, Croatian, Vietnamese, Laotian, Cambodian, Chinese, Latin American, Black or Euro-American), there are generational and cultural connections to the land (place attachment), a strong social network developed around fisheries, a reliance on sustenance (subsidence?) and barter systems for goods and services and collective coping capacities to disasters (Barra, 2023; McCall & Greaves, 2022). Also, across these communities there are a high number of residents vulnerable to falling below the poverty line with the next disaster (Hemmerling, 2018; McCall & Greaves, 2022).

In 1926 and 1927, the US Army Corps of Engineers, claiming necessary actions for flood control, constructed the Bohemia Spillway and purposefully cut the levee during emergency flood response on the eastern side of the Mississippi River (McCall & Greaves, 2022; Barra, 2020; Boesch, 2020). Both actions resulted in flooding predominantly Black farmland and homes forcing the displacement of African-American landowners, who saw these actions as a land grab for mineral rights and being sacrificed for other white, affluent communities (Barra, 2020; McCall & Greaves, 2022). Additional floodways constructed over future decades followed a similar pattern as marginalized communities lacked power to hold on to their land (Barra, 2020). The Caernarvon freshwater diversion, a smaller version of the planned sediment diversions, was constructed in 1991 with the purpose of increasing oyster production in Breton Basin with support from the oyster industry (Wilson, 2005; Rogers, 2003). Once operational, the Caernarvon diversion flow was increased beyond what some perceived as an agreement between the state institution and the oyster industry, resulting in widespread impacts to oyster farms (Wilson, 2005; Barra, 2020; Costa, 2018). Resulting failed lawsuits, reparation negotiations and the initial break in trust over operations (whether perceived or actual) have led to decades of mistrust and strained relationships between fishers and coastal managers (Barra, 2020; Wilson, 2005; Lipsman, 2019; Costa, 2018). Black oyster fishers had an especially difficult time with the impacts of Caernarvon, as they were already battling the distribution of leases to larger, white businesses in an effort to become economically independent (Barra, 2020; Kang, 2022; Barra, 2023). Similarly, Vietnamese-American and Cambodian-American fishers have been mostly excluded from oyster farming, but found a home in shrimping, making up 40% of the state's commercial shrimp fleet (Kang, 2022).

A history of forced migration of marginalized communities and impacts to fisheries resources in the name of flood protection or coastal restoration has led to the intense discourse over sediment diversions (Barra, 2020; Domingue, 2022a; Barra, 2023; Rogers, 2003). Key points of contention are the impacts to fisheries and associated livelihoods, the impact and potential loss of residences and private property (some harkening back to land grabs) and the resulting economic and cultural impact from both (Lipsman, 2020; Domingue, 2022a; Haedicke, 2017; McCall & Greaves, 2022). Social capital that is embedded in the community, cultural traditions, place attachment and sustenance living are all of high importance to coastal residents (Domingue, 2022a; McCall & Greaves, 2022).

Overwhelmingly, studies reported fishers and coastal residents with feelings of frustration from exclusion from the process (Lipsman, 2020; Barra, 2020; Hemmerling et al., 2020; Domingue, 2022a; Lipsman, 2019; Ko et al., 2017). Exclusion and lack of common understanding have not been institutionalized for existing freshwater diversions, much less planned sediment diversions (Ko et al, 2017). Language is a barrier for the Vietnamese-American and Cambodian-American fishers, who are viewed as "resilient refugees" who have the community network, coping mechanisms and institutions to adapt to new conditions (Kang, 2022). Similarly, Black coastal communities have strong traditions of self-reliance and autonomy, and still other communities have been termed "inherently resilient" (Colten et al., 2012).

The opposition to the diversions is also charged by the history of disasters for frontline communities and industries, such as fisheries (Barra, 2020; Barra, 2023; Kang, 2022; McCall & Greaves, 2022; Nost, 2022). Sediment diversions are seen as another assault in a long line of disasters that have drastically impacted these communities, from Hurricane Katrina and subsequent hurricanes, to the petroleum extraction industry and the Deepwater Horizon Oil Spill, to the 2019 Mississippi River flood (Kang, 2022). Efforts by those opposing diversions have been ineffective in disrupting the political momentum of diversions, leading to pessimism and a general belief that the ability for change is minimal (Lipsman, 2020; Domingue, 2022a). Lipsman (2020) describes a powerful coalition of institutions, centered around the CPRA, that are advancing sediment diversions and limiting the voices of dissent. Domingue (2022b) refers to the social construct of the “bigger picture” or shared common good allowing dismissal of frontline community concerns. This results in a widely held belief that seafood and coastal communities are a low-priority interest in the state restoration planning (Barra, 2023).

Operations and adaptive management

The Mid-Barataria Sediment Diversion (MBSD) project includes a $360 million Mitigation and Stewardship Plan to implement mitigation actions that address the adverse impacts to fishers and coastal residents as identified in the final Environmental Impact Statement (EIS) (USACE, 2022). These efforts will provide some economic and resource relief in the near-term. In the long-term, outcomes are occurring in a dynamic socio-ecological system in Southeast Louisiana, where a project of this scope and scale has complex and unclear interactions within and among the natural and social sub-systems. Model predictions today cannot fully provide the expectation management needed for real-world decisions by residences or fishing industry (Peyronnin et al., 2017; Nost, 2022). The standardization of operational scenarios used in the final EIS that allowed for simplified decision making and reduced computational costs lacks certainty in the spatial and temporal timing of impacts, as well as the magnitude (Peyronnin et al., 2017). A robust adaptive management program is essential, supported by an extensive monitoring system, to adjust operations initially and over time based on the drivers (i.e., riverine or basin conditions), ecosystem response and social change to ensure goals are achieved, impacts are minimized and unintended or unforeseen consequences are addressed (Peyronnin et al., 2017).

Science is fundamental to an adaptive management program. Institutions tend to prioritize and give more recognition to evidence-based knowledge over experience-based knowledge (Hemmerling et al., 2020; Domingue, 2022b; McCall & Greaves, 2022; Lipsman, 2019). There is a concerted effort by many to integrate experience-based knowledge into ongoing decision making around large resilience efforts around the country (McCall & Greaves, 2022; Lipsman, 2019; Ensor & Harvey, 2015). However, much of the ecological literature continues to focus on the incorporation of traditional ecological knowledge, whereas the social science literature does not restrict the value of experience-based knowledge to just ecological knowledge (Berkes et al., 2000; Franco & Luiselli, 2014; Fernandez-Llamazares et al., 2015; Domingue, 2022a; Hemmerling et al., 2020; Lipsman, 2020). The lack of integration of experience-based knowledge can be seen as a form of institutional racism (Barra, 2020) and perpetuates the marginalization of communities (Domingue, 2021; Nost, 2022; McCall & Greaves, 2022). Authentic inclusion by institutional actors can lead to improved social and ecological outcomes, including social justice and learning outcomes (Lipsman, 2020; Hemmerling et al., 2020).

Hemmerling et al. (2020) recently used a competency group of local knowledge providers and technical experts to create a new predictive model, demonstrating the ability to integrate local knowledge into even the most technical aspects of science.

Actors, specifically fishers and coastal residents, have a strong interdependence with the coastal landscape and are deeply engaged on the problem of coastal land loss and the solutions proposed (Kang, 2022; McCall & Greaves, 2022). Yet, the governance structures lack inclusivity and transparency (Lipsman, 2020; Barra, 2020; Hemmerling et al., 2020; Domingue, 2022a; Lipsman, 2019; Ko et al., 2017). Actor engagement and participatory processes are consistently referenced as weaknesses or reasons for failure of adaptive management (Allen & Gunderson, 2011; Deitch et al., 2021; Bond et al., 2015) and achieving the desired outcomes (Kraker, 2017; Pahl-Wostl, 2007). Social learning and participatory approaches can add time and complexity to the situation, especially if decision makers are struggling with strong discourse, oppositional science or a lack of consensus.

The objectives of this chapter are to provide information by which institutions can integrate social learning approaches with key actors, especially those of historically excluded and marginalized communities, into adaptive management programs. The case study on sediment diversions in Louisiana demonstrates a social learning approach that could be replicated and adopted by institutions to build consensus among divergent actors, integrate experience-based knowledge and build support for management actions.

METHODS

I reviewed the literature on social learning approaches to increase participation in adaptive management or as used within a social-ecological system context. There are a variety of existing approaches and new ones emerging as the field expands (Ensor & Harvey, 2015). With that knowledge, I planned a social learning approach to bring together actors with a variety of viewpoints to mimic a participatory process that could be adopted by the CPRA. Aspects of social learning that I employed included selection of diverse participants, established collaboration rules to ensure respect and openness to others, power distribution and relationship and trust building (each in-person meeting began with a family-style dinner) and effective facilitation of discussions (Ensor & Harvey, 2015; Armitage et al., 2008; Ernst, 2019). Important facilitation must be independent, honest and able to manage power imbalances (Ernst, 2019). With little to no knowledge or understanding of adaptive management by actors, I created an environment by which social learning could emerge. My co-authors and I utilized aspects of the adaptive management framework (see Chapter 2) including defining objectives from stated goals, identifying relevant value components, selecting key performance metrics and monitoring and describing potential adaptive management actions.

Beginning in September 2019, I facilitated a social learning approach with key actors in Plaquemines and St. Bernard Parishes, Louisiana. Participants had a reliance on the coastal ecosystem in Barataria Basin for their homes or livelihoods, thus having a direct stake in how sediment diversions will be operated. In this study, volunteer participants were selected based on their backgrounds, livelihoods and reliance on the coastal landscape for some aspect of their well-being. The membership included some diversity in sex and race, including representation of the African-American and Vietnamese-American fishing communities. The viewpoints were also diverse with mixed positions on sediment diversion – some who supported, some who opposed and others were still unsure. However, all participants had little knowledge of adaptive management and how it would be used for operational decision making. The group agreed not to debate the merits or consequences of building a sediment diversion. Instead, the social learning group assumed that it will be constructed and will need to be operated under an adaptive management program.

Over six 1.5 to 2 hour meetings, held both in person with family-style dinners and virtually after March 2020, the voluntary participants, referred to as the social learning group[4], learned about key aspects of an adaptive management program and deliberated and discussed amongst themselves their priorities. Participants, facilitated by Snider and Wood, developed a list of value components, objectives, measures of success and key management actions of an adaptive management program. Without direction from the facilitators, the social learning group requested to also develop a set of principles for the development of the AM program by the State of Louisiana.

A Value Component is a "component" that matters most to the human communities of interest and serves as a focus for decision making and monitoring. In general, there are a variety of factors to consider for each value component, including whether they are (1) directly or indirectly related to human health and well-being, (2) directly or indirectly related to ecological health, (3) culturally important, (4) economically valuable, (5) directly or indirectly related to a food source,

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(6) related to an inherent existence value, (7) sensitive to human disturbance and/or (8) influential to decision making. Value components can serve as a critical guide for developing management objectives.

While value components are broad and non-specific, management objectives are narrow, specific, concrete and measurable. Objectives are concise statements about "what matters." They come from the value components and relate to the basic interests or concerns of actors. Clear and measurable objectives can help ensure that the various actors understand and agree on the intended overall outcomes. This is especially important on large, multipurpose projects that affect many actors such as sediment diversions. Clear management objectives reveal differing or even conflicting expectations regarding outcomes early during planning. Planners can then reduce misunderstanding and anticipate changes to monitoring and evaluation that may be warranted.

Performance metrics (or measures of success) and monitoring are key components of an adaptive management plan. Objectives may have one or more performance metrics that allow both managers and actors to evaluate the progress toward intended outcomes, identify any unintended impacts and implement adaptive actions.

An adaptive management plan should identify the potential management actions or decisions that need to be considered over time. Adaptive management actions are pre-determined ways for project managers to implement changes that improve the project's ability to meet its objectives. These management actions are anticipated in the context of the Mid-Barataria Sediment

Diversion and would be expected to support the broad project goals and more specific management objectives.

The group developed the components of the AM program by full consensus. The results of this effort were shared in a consensus recommendation letter signed by all participants and submitted to Louisiana's Coastal Protection and Restoration Authority in October 2020 and to the U.S. Army Corps of Engineers as part of the public comment period on the Draft Environmental Impact Statement in spring 2021.

RESULTS

Value components

In coastal Louisiana, the value components are grounded in the overarching Coastal Master Plan (CMP) goals. Programmatically, these five goals are to (1) reduce economic damages from storm surge flooding, (2) restore natural processes, (3) maintain a wide variety of coastal habitats, (4) sustain Louisiana's unique cultural heritage and (5) support the economic drivers of a Working Coast (CPRA, 2023). The Mid-Barataria Sediment Diversion contributes to each one of these goals to varying degrees. The social learning group used the goals as guideposts to identify and define value components and provided a determination of their anticipated level of importance for the sediment diversion project. The social learning group wrote about the process:

> *"We generated a list of Value Components in response to the question: 'What do we fundamentally want to enhance and/or protect through adaptive management of the operations of a sediment diversion?' We scored these components as being of high, medium high, or medium importance. Although not all of us agreed on the specific*

priority level of each value component, we did have agreement on the general level of importance."

Table 3.1: Value components and their level of importance defined by the social learning group, based on five overarching goals established by the Coastal Master Plan (CPRA, 2023).

CMP Goal	Value Component	Importance
Flood Protection: Reduce economic losses from storm surge-based flooding to residential, public, industrial and commercial infrastructure	Protection of communities and infrastructure	High
Natural Processes: Promote a sustainable coastal ecosystem by harnessing the natural processes of the system	Building and sustaining wetlands	High
	Reduce land loss	
Coastal Habitats: Provide habitats suitable to support an array of commercial and recreational activities coastwide	Sustainable estuaries	High
	Habitat protection and viability	Medium-High
	Support recreational fishing	Medium
Cultural Heritage: Sustain the unique cultural heritage by protecting historic properties and traditional living cultures and their ties and relationships to the natural environment	Generational fishing	High
	Mixed cultures and languages	Medium-High
	Barter system	Medium
	Cultural heritage, reputation and identity	Medium
	Community cohesion and uniqueness	Medium
Working Coast: Promote a viable working coast to support regionally and nationally important businesses and industries	Seafood industry and production	Medium-High
	National/state economy (economic engine of the Mississippi River)	Medium-High
	Employment and livelihoods	Medium-High
	Tourism	Medium

Table 3.1 describes the value components with their relative importance to the Mid-Barataria Sediment Diversion project as defined by the social learning group. A component of highest importance is directly or closely related to the goals of the project or of highest importance to

actors. Medium-high importance indicates a value that may be indirectly related to the project, but still a priority for actors. Components of medium importance were not as directly impacted by the project itself, but important on a programmatic level, as opposed to a project level, since they have broad relevance.

Objectives

We (Snider and Wood) facilitated a process to assist the social learning group in their development and discussions around objectives. Participants were asked to complete the following sentence: I/we want operations of a sediment diversion TO (WHAT)…FOR (WHAT). After numerous objectives were developed, the group came to consensus on these objectives as the most critical to the operation and adaptive management of a diversion (see Table 3.2). Objectives can vary in importance based on the desired outcomes of the project as well as timing (i.e., early warning, near-term or long-term objectives). Although not undertaken in this study, additional work could be completed to prioritize objectives into an objective hierarchy and across different time periods of the project.

Table 3.2: Objectives developed by the social learning group relevant to Louisiana's Coastal Master Plan Goals. Conducted by asking, "We/I want the operations of the sediment diversion to (what)…for (what).

TO (WHAT)	FOR (WHAT)	Final Objective
Maximize sediment deposits	Ecosystem health	To maximize sediment deposition for the health of the ecosystem
Minimize economic impacts	Fishing communities	To minimize impacts to economic development for fishing communities
Build and sustain land	Surge protection	To build and sustain land for surge protection
Assist fishing communities	Future existence	To assist fishing communities for future existence
Grow/sustain estuaries	Ecosystems and communities	To grow/sustain estuaries for the existence of the ecosystem and to sustain communities
Control operations	Estuary production	To control operation for maintaining estuary production
Maintain an estuarine gradient	Multiple habitats	To maintain an estuarine gradient for multiple habitats
Sustain estuaries	Economic opportunities and long-term jobs	To sustain estuaries for economic opportunities and long-term jobs
Monitor impacts	Mitigation and environmental justice	To monitor impacts for mitigation and environmental justice
Utilize outfall management	Sediment capture and retention	To utilize outfall management for more effective sediment capture and retention

Measures of success and monitoring

To demonstrate the decades of experience-based knowledge within the social learning group, the facilitators (Snider and Wood) asked the participants to define measures of success and potential types of monitoring that could be done for two of the objectives they defined (see Table 3.3). As the social learning group was voluntary, the effort to make a complete performance metric and monitoring plan was outside of the scope, however through development of the adaptive monitoring plan was outside of the scope, however through development of the adaptive management program by the institution, the experience-based knowledge could be integrated with evidence-based knowledge through a transdisciplinary approach.

Table 3.3: Measures of success and potential types of monitoring for two objectives developed by the social learning group.

Objective	Measure of Success	Type of Monitoring
To maximize sediment deposition for the health of the ecosystem	• More land for more fisheries • Sustain and build as much as we can • A better working coast • A range of habitats are provided • Living with the river's natural cycle	• Area of deposition • Submerged aquatic vegetation and emergent vegetation • Amount of sediment deposited • Marsh loss/gain • Marsh health
To minimize impacts to economic development for fishing communities	• Communities and culture intact • More licenses available/in use (inshore and offshore) • Predictable operation outcomes and future conditions are understood • More habitat for fisheries • Other economic opportunities are available outside of fishing • Front-end education of fishers and contingency plans to help ease anxiety • New fisheries and species targeted • Subsidies and other economic support are in place • Price of shrimp is stabilized • Trust and inclusion between decision makers and actors, specifically fishers	• # of licenses • # of launches • Size of boats • Size of catches and locations • Catch limits/regulation changes • # of community support programs established/used • Salinity • Marsh loss/gain • Marsh health • Vegetation/habitat types • Weather/climate change • Timing of year • Economic indicators (tax base, industry)

Adaptive management actions

The social learning group identified potential adaptive management actions worthy of consideration in the AM plan for the MBSD (see Table 3.4). Core management actions or decisions are directly related to the operations of the project. Supplementary management actions are additional measures that may accompany the project and support progress towards achieving the desired management objectives. Supportive management actions would not directly result in an on-the-ground management action but would indirectly support better decision making.

Table 3.4: Adaptive management actions categorized into core, supplemental and supportive actions or decisions.

Type of Action	Adaptive Management Action
Core Management Actions or Decisions	Operations • Timing and magnitude of diversion (flow / sediment / nutrients) through operation of gates and conveyance structures • Emergency shut-off of diversion when needed Maintenance • Maintenance of the diversion gates and conveyance structures Communications • Communication protocols related to operations and impacts of diversion on downstream users (e.g., notification to recreational harvesters to remove fishing gear, such as crab traps, if in outfall area)
Supplemental Management Actions/Decisions	Outfall Management • Dredging to control sediment accumulation, maintain access and navigation • Construction of barrier islands, channels, ridges to divert water and sediment and protect sensitive areas • Nutrient retention devices to prevent algae blooms River Management • Dredging to keep navigation channels open and prevent shoaling (upstream and downstream of diversion on Mississippi River and in Barataria Basin) Risk Management • Modifications to existing river and storm surge levees as needed Mitigation • Fish and wildlife habitat mitigation projects • Other mitigation, such as for community impacts
Supportive Management Actions/Decisions	Science Actions • Changes in monitoring (i.e., what is collected and at what frequency) • Other science studies to better understand effects and changing conditions Governance • An organizational structure and process to solicit input from the relevant agencies, the public and actors on project operations, emerging issues and the evolving state of knowledge

Principles for governance of adaptive management

The governance structure for an AM program is essential to determine who will be involved in the decision-making process and how. This can be critical for actors. The social learning group developed 12 principles that were recommended that CPRA adopt for inclusion in the adaptive management program and governance structure: (1) inclusion, (2) transparency with open and honest dialogue, (3) legally defined, (4) trust, (5) clear decision-making authority, (6) integrate traditional ecological knowledge, (7) let science lead, (8) results, (9) information sharing, (10) expectation management, (11) effective communication and (12) gradual operations.

Inclusion (1) and transparency with open and honest dialogue (2) are the two principles that focus on the need to define a specific role for actors and build two-way communication with a wide variety of viewpoints. The group was especially interested in participating in open and honest discussions on the decision-making process and the science and data being used in planning and how to build timely transparency with the public. The social learning group recommended the inclusion of the "*fishing community (broken into industry groups), landowners, parish leaders/coastal zone management, elected officials, community liaison(s) to capture cultural, historical and tribal issues, industry representations (oil and gas, navigation) and external scientists."* The group acknowledged that the AM program could not engage with every interested party as that would make the governance structure unmanageable. The group explored ideas for how to resolve this issue, such as "*community, fisheries, industry and technical advisory groups could be formed that nominate an individual to represent them on the diversion governance board."*

The discussions of trust (3), legally defined (4) and clear decision-making authority (5) were contentious, based on a history of mistrust, legal challenges and exclusion from decision making. Participants described experiences with two existing small freshwater diversions in which promises or legal responsibilities were not upheld and trust was broken, with few attempts to remedy.

"*Trust goes both ways and if it's broken, then it is lost. There needs to be acceptance of the uncertainty involved in operations and each responsible party needs to hold up their end of the bargain in order for trust to be maintained.*"

An essential component of building trust for the group was a legal charter with roles and responsibilities, a defined decision-making process and clear authority for final decisions with the CPRA. However, the group would like a legal mechanism to challenge the final decisions. "*For instance, we discussed providing a collective veto power with full consensus of all of the members of the governance group.*" Later in the letter, the group also identified a potential contingency fund, with clear scientific criteria to qualify, that could help build trust and ease anxiety over future uncertainties.

Integrate traditional ecological knowledge (6), let science lead (7) and results (8) are three principles that revolve around the science and outcomes. The group wrote "*A framework that incorporates physical, biological, social and traditional ecological sciences must be the basis for decision making -- not politics.*" The focus should be on making forward progress and getting results by optimizing the multiple objectives to *"achieve a healthy and viable estuary*." The group further recommended integrating TEK into ongoing monitoring, data collection and modeling, as well as including representation of TEK as members of any technical advisory committees.

The next set of principles revolves around communications, including information sharing (9), expectation management (10) and effective communication (11). Participants discussed the ongoing frustrations, specifically with fishers, of not knowing. The uncertainty around what to expect to happen to their livelihoods and industry is causing unease and anxiety. This was particularly fueled at the time of discussion as the Environmental Impact Statement was being developed and detailed modeling was occurring, but the agencies were not releasing information publicly and there was perceived inequity of access to the information by specific interest groups (Nost, 2022). As stated by the group, "*At this time, access to specific modeling results or data is not equal among all interested parties. Sharing information widely, as well as making model results and data understandable to the public, will help to bring parties together."* The group went on to say, "D*ecision makers should be clear about the expected outcomes and uncertainties involved*."

Finally, the social learning group recommended gradual operations (12). The group discussed that changes in the estuary could occur either quickly or gradually over time based on the operations. Trade-offs were discussed, but ultimately the group came to consensus that the "*diversion should begin operating gradually over time to allow the ecology and businesses to adapt gradually. Traditional ecological knowledge from fishers and others in the basin could be used to provide feedback as operations increase over time."*

DISCUSSION

Peyronnin et al. (2017), recognizing the growing discourse and the political momentum to drive sediment diversions forward, turned to discussions of balancing ecosystem and social needs within the operations and adaptive management program. Ultimately, no significant impacts will occur in the Barataria Basin until at the earliest 2028 when the diversion has completed construction and is fully operational. As Peyronnin et al. (2017) also noted, the current model predictions of impacts are based on standardizing and simplified operational strategies needed for efficient modeling, assuming consistent operational triggers from Year 0 to Year 50. This is unrealistic under real-world conditions and operations will have to be responsive to changes in conditions in the basin and river. The discourse may not wane after construction, as decision making shifts to questions of when to operate, how long to operate and how much flow will be made on an annual, monthly or even daily basis. Anticipating a shift in discourse from debates about whether or not to construct to how to operate a diversion is an opportunity to ensure local voices are included in the decision making of adaptive management (Lipsman, 2020).

The number and types of actors can be extremely diverse and conflicting (Stringer et al., 2006). In the present study, volunteer participants were selected based on their backgrounds, livelihoods and reliance on the coastal landscape for some aspect of their well-being. The social learning included some diversity, including representation of the African-American and Vietnamese-American fishing communities; however, future groups could be expanded. Participants had mixed positions on sediment diversion – some who supported, some who opposed and others who were still unsure. Through the dialogue of the social learning approach, the group was able to better understand the concerns of different positions and gather more details about how sediment diversions will impact other actors in their community. As stated by the social learning group collectively, "*Through open dialogue, we were able to better understand each other's perspectives and build consensus on key aspects of adaptive management*."

The value component exercise was the first step in building consensus. Just as experienced with this social learning group, other studies have also found that the aspects of the social-ecological system that are valued by the actors are the same or very similar (Stringer et al., 2006). Starting with values helped the individuals to get to know each other and provided a common understanding that assisted with the difficult conversations that would occur later. Multiple times the group was able to return to this common understanding as a way to find compromises since ultimately all participants wanted to see their common values protected. The group reiterated this importance in their consensus letter.

> "*We like the linkage of objectives to components of the coastal system that we value the most. These steps are very important to build widespread buy-in for the plan, and we predict that actors will want to be involved in some way early in the process. We encourage you to reach out to community members who can help bring a wide array of actors to participate productively."*

One of the difficult decisions was coming to agreement on a set of robust objectives. This is especially important on large, multipurpose projects that affect many actors such as sediment diversions. Clear management objectives reveal differing or even conflicting expectations regarding outcomes early during planning (Williams et al., 2009; Schultz & Nie, 2012; Bosomworth et al., 2017; Susskind et al., 2010). Planners can then reduce misunderstanding and anticipate changes to objectives, monitoring and evaluation that may be warranted. The social learning group was able to develop objectives that addressed the values they hold in the coastal landscape. They wrote,

> "*For us, generating multiple objectives to achieve desired outcomes helped each of us see where objectives fit together, overlapped, or even conflicted. This offers opportunities to*

resolve conflicts early on and fosters agreement by all parties on multiple objectives for operation of a sediment diversion."

The measures of success and monitoring exercise provides an avenue for the incorporation of traditional ecological knowledge. As is evident from the results, the participants collectively have a deep knowledge of the coastal system, both the wetland landscape and the communities and people who depend on it. It is apparent that measures of success for the group went beyond the ecological outcomes and included economic, social and health outcomes, such as keeping communities and culture intact, economic opportunities for fishers and education and contingency plans to ease anxiety. This demonstrates that the social learning group was providing experience-based knowledge, not just TEK focused on ecology.

> *"We want to know when and how decisions are being made and what to expect as a sediment diversion begins operation. We understand how measures of success, monitoring, and selection of management actions can enhance project success over time. We recommend that regular evaluation of the performance of the project include a public component so that coastal actors can stay informed and aware as operations progress."*

There is also a clear difference in terminology between experience-based knowledge and evidence-based knowledge. The group rejected using the term "performance metrics" as technical jargon, instead using "measures of success". The monitoring plan would not be operational based on the types of monitoring provided by the group, as more is needed regarding the technical data collection; however, the social learning group was able to provide the substance of what is important for them to monitor over time and report on in the future. These measures of success and types of monitoring can be further expanded by researchers to incorporate into an operational monitoring plan.

The adaptive management actions developed by the social learning group was inclusive of a wide range of options that would be available to decision makers. The group categorized these actions into operations, maintenance, communications, outfall management, river management, risk management, mitigation, science and governance. Just as with the measures of success, the social learning group demonstrated the ability to think beyond just operations into actions important to them, such as communication protocols and mitigation for fisheries and community impacts.

Finally, as mentioned previously, the social learning group requested to expand the framework discussions to include development of a set of principles for the AM program. This demonstrated a unity in the group that had formed over many months. The group developed a wide range of recommendations for governance that they also summed up as (1) *"lead with our values,"* (2) *"involve us earlier,"* (3) *"include an easily-accessed public component"* and (4) *"communicate, communicate, communicate!"*

CONCLUSIONS

Social learning and adaptive management are both crucial aspects of managing the social-ecological system, which emphasizes dynamic interactions between human societies and the natural environment. In this case, the social learning approach was not undertaken by the decision-making institution, and it is unclear how the results of this work have been integrated into the ongoing development of the adaptive management program by the CPRA. A lack of support in the institutional context is a common factor for why social learning is not more effective in adaptive management (Kraker, 2017; Mulvaney et al., 2022). This lack of institution support can also increase the lack of trust and transparency between decision makers and actors, two essential components when managing resilience in any social-ecological system (Ko et al., 2017; Greig et al., 2013; Childs et al., 2013; Burns et al., 2015; Allen & Gunderson, 2011; Medema et al., 2008). Although to date, planning for the construction of the sediment diversion has not been inclusive and fully transparent, the CPRA, as the institutional actor, has an opportunity to use social learning and participatory processes as they establish an adaptive management program to benefit all the actors in the SES. Embracing social learning can lead to an increase in adaptive capacity for all actors, which is essential for the future of coastal Louisiana (Thi Hong Phuong et al., 2017).

The present study brought together a diverse set of actors, representing those opposed, supportive and unsure about sediment diversions, and all with little knowledge of adaptive management, to explore components of an adaptive management program through a social learning approach. The process demonstrated the utility in investing the time and effort into bringing divergent actors to the table on long-term operations and maintenance of the diversions. As written by the social learning group themselves,

> *"Given that our personal opinions about sediment diversions vary widely, finding ourselves in agreement on the hopeful possibilities of adaptive management of operation of sediment diversions is both unexpected and exciting.* ***We believe that a robust adaptive***

***management plan for operations of the Mid-Barataria Sediment Diversion is absolutely necessary**.”*

Without the involvement of the institution, this case study could not directly produce outcomes to the social-ecological system or the management of sediment diversions; however, the study did produce learning outcomes, as evidenced by the social learning group’s public comment letter.

Although resource intensive, formalizing social learning into participatory processes of the adaptive management program by the decision-making authority should ultimately lead to more robust social and environmental outcomes for the social-ecological system, encountering fewer conflicts and a greater chance of success in achieving the desired outcomes from collective actions, as well as achieving the learning outcomes amongst actors.

FINAL THOUGHTS

Managing the SES is challenging…daunting even. It is easy for institutions, including governmental, non-profit and research entities, to become overwhelmed by the scale and complexity of managing a social-ecological system. It is easier to focus on one aspect of the system where more is known or controllable. However, without systems thinking and exploring the interactions within and external to the SES, society will continue to suffer from unintended and cascading impacts, as well as missing opportunities to address multiple vulnerabilities with our collective actions.

Let's take a quick look at the case studies discussed in this dissertation. The first 3 case studies below provide some answers to the questions - who, why and how. The remaining two case studies will be discussed in terms of the where and when.

In Louisiana, sediment diversions will fundamentally change the estuary on which so many actors are dependent. However, the majority of the science and research that has been conducted over the past few decades has focused on the biophysical or ecological system. Social science research on sediment diversions has been sparse, with a slight uptick just in the past few years. In addition, the planning for diversions has excluded affected actors from decision making and science, lacked transparency and been fraught with mistrust. Both the lack of social science research and the lack of participatory processes results in institutions that are ill-prepared to appropriately address social discourse. Top-down approaches and powerful coalitions have succeeded in moving diversions forward to construction starting this year and are anticipated to be operational in five years, despite concerns by some of social impacts (Lipsman, 2020). The discourse is expected to shift, but not wane, from whether or not sediment diversions are built but to how they are operated. The operations and adaptive management of diversions offers an opportunity for the institution to expand its approaches to incorporate social learning, inclusion and transparency and redistribute power.

One thing that almost all actors of the system can agree on is that the coastal Louisiana SES is currently in a degrading state. The coastal landscape and natural resources are degrading, community cohesion and social networks are degrading, the economy and individual wealth are degrading and inequalities are degrading. Ultimately, management of this degrading SES will likely require drastic changes, such as sediment diversions and massive relocation, in order to provide a more resilient future state for both actors and institutions. The key here is that institutions should not be defining the future for all actors without everyone engaged or represented. Institutions should support building a common vision of a resilient future where the actors see their place in the SES, even if it requires changes in the forms and functions of the actors.

This intersection of institutional and actor roles is reiterated in the case study on Coastal Structures. This case study demonstrates that everyone has a role to play in building resilience, but they do not always know what that role is or how to accomplish it. There is an ongoing shift in responsibility from institutions to mostly unknowing property owners for building resilience to individual structures. The property owners, as actors, do not necessarily know or believe their role and responsibility. When they do, they often meet barriers to acting, such as financial, technical, bureaucratic, etc. And the shift in roles does not absolve institutions from their responsibilities to support the individual actors. Institutions should provide flood risk information, information on resilience solutions, supportive policies and regulations and funding and technical capacity, especially in low-income and marginalized communities. Institutions should engage in participatory processes to evaluate and alleviate current barriers to adapting coastal structures, including an overly bureaucratic and complex process to receive funding support. Institutions should work with economic drivers, such as insurance, real estate markets and economic incentives to do their part in building back with resilience solutions integrated. Working together, institutions and actors should clearly define their roles and responsibilities, identify interactions between the two, identify barriers to each succeeding in their role and co-create solutions to overcome those barriers. By defining each within the SES, they can achieve both institutional goals of reducing the societal impacts of flooding and the actors' goals of reducing their own impacts to well-being and maintaining their community.

Identifying the roles and responsibilities of institutions and actors should be followed by a reallocation of the power dynamics as our transition case study on Community-Driven Resilience demonstrated. The tale of two cities highlights the different outcomes that occurred from a top-down approach and a bottom-up approach. In addition to increased flood resilience, Marcelino was also able to achieve other social resilience outcomes that were not observed in Limon, such as resilience to future overcrowding and poverty, limited crime and street gang activity and overall well-being (Barrios, 2014; Barrios, 2009a; Lizarralde & Boucher, 2004). This bottom-up approach was achieved in spite of the institutional resistance due to the determination and agency of the impacted residents. While it is beneficial to have an active and engaged constituency, it should not be a requirement for institutions to develop more participatory or community-driven governance. In fact, institutions should help to build an active and engaged constituency by redistributing power in the decision-making process. In addition, resilience to floods crosses multiple institutions and jurisdictional boundaries. Emergency management, housing authorities, insurance, transportation departments, community development, environmental quality, health and hospitals, education and natural resources are just a few examples of institutions that all have different mandates but play a role in flood resilience. These institutions largely work independently and with very little collaboration to manage one specific aspect or component of the system. The future will require new institutional structures and adaptive governance to facilitate the effective integration of these various mandates, a redistribution of the power dynamics and new approaches, including social learning and participatory governance. By doing so, institutions can increase their utility by solving more than one social, ecological or economic problem within the SES with one or one set of resilience actions.

Where do we draw the boundaries of the SES? That is really hard to say, as one can imagine it quickly expanding to unmanageable levels. A lot of times, decision makers let mandates, resources, expertise, time, risk aversion and other factors restrict their boundaries. I propose a different approach, that is, to use well-defined and holistic goals to guide the inclusion or exclusion of aspects of the SES. For this, let's look at the sustainable case study in China's Sponge Cities Program (SCP). Geographically, the SCP is restricted to inside of the urban city boundaries. This is ignoring that a major external driver is the hydrologic connectivity of the watershed. Expanding the geographic boundaries to a watershed approach opens the door for more solutions, such as natural infrastructure upriver that can contribute to the city's overall flood resilience goals. Boundaries are not just geographic; they also need to be defined across linkages and feedbacks in the system. The SCP initiated with an accelerated schedule that did not take into account the limited capabilities in local government, a lack of long-term planning, a lack of learning networks and a lack of community engagement that led to poor planning and design, inability to meet expected outcomes and discourse from the public. If the SCP had accessed the institutional and social capital available to implement on the desired timeline and the importance of their relationship to SCP success, they would have seen the deficiencies in the SCP and been able to address with additional support or adjust the timeline to ensure the positive outcomes were achieved. The SES boundaries, therefore, should evaluate and include all social or institutional capacities specifically tied to successfully reaching the goals of the resilience actions.

Finally, a key question when implementing the Social-Ecological Resilience Framework is when. When do we sustain the SES, and when do we decide to switch to adaptation, transition or transformation? This is a question that Indonesia faced, after years of trying to sustain Jakarta as it was and then deciding that it was time for transformation. This gradual shift usually occurs when the economic costs get too high. In general, societal change and changes in norms, behaviors and attitudes are slow. Over time, consistent flooding, such as now occurs annually in Jakarta, can erode at the social network with the growing costs to the individuals, institutions and economies to the point that it will eventually lead to a change in direction. However, shocks, such as episodic flood disaster, can result in rapid change in how actors, institutions and the system itself. In most places in the world, the science of flood risk analysis is fairly robust and easily acquired; therefore, we have a general understanding of the various scenarios and the type and scale of flood impacts that could occur to a specific SES. We can easily predict what this impact would mean to infrastructure or the environment; however, there is far less data available to predict the potential changes to social components and their interactions across the SES. Although the SES can always respond in unpredictable ways, we at least have good estimations of the types of responses that could happen. Using the Social-Ecological Resilience Framework, we would want to define the various forms and functions of the key attributes and interactions of the SES. Then, each form and function would be assessed for its vulnerability and possible shifts. For instance, the new capital city, Nusurtara, has a goal of being a green city with urban parks (SES form) that provide nature within a 10-minute walk for every resident for recreation and health and to provide flood risk reduction (SES functions). This is a lofty goal that is vulnerable to pressure on space for economic development, lack of funding to construct and maintain, limitations with the 10-year implementation timeline, and poor planning and design that fail to meet desired outcomes. The consequences of these actions would be a decrease in well-being and an increase in flood risk. To prevent these outcomes, advocates have called for regulations to be put in place to dictate how development will happen to meet the goals. By identifying the key forms and functions for each goal, we can better identify their range of possible vulnerabilities and the timelines of potential changes and develop strategies to safeguard that positive outcomes are achieved.

Social-ecological systems are dynamic and complex, characterized by multiple feedback loops, non-linear relationships and uncertainties, which makes them difficult to understand and manage. SES research aims to understand the dynamics and to develop effective management strategies to support the resilience of the SES. The Social-Ecological Resilience Framework proposes a structure by which to evaluate and manage these systems; however, there is an immense amount of research needed to operationalize this framework, both across disciplines and through trans- and inter-disciplinary studies. I propose that the following are key areas of the needed research:

1. Understanding the dynamics of the SES: SES research needs to investigate the interactions between social and ecological systems and the feedback loops that exist between them. This includes studying systems thinking and mental models, in addition to computational models, for the impacts of social and ecological changes on each other and how these changes affect the overall system. Research should also focus on identifying the key drivers of change in the SES, such as climate change, population growth, inequities and technological innovation.
2. Developing tools and methods for SES management: Research is needed to develop effective tools and methods for SES management that can help decision makers to navigate the complexity of these systems. There are growing efforts to model the SES and develop relationships between the natural and social sub-systems. Computer and mental models can simulate the dynamics of the SES, identifying indicators that can be used to monitor the health of the system and developing decision-making frameworks that can help to prioritize actions in the face of uncertainty.
3. Integrate experience-based knowledge: This knowledge can provide valuable insights into the dynamics of social-ecological systems and how they can be managed for resilience. Research is needed to explore ways to integrate experience-based knowledge into evidence-based knowledge to develop more holistic approaches to SES management.
4. Understanding the role of institutions, actors and governance in the SES: Governance plays a critical role in the management of social-ecological systems. Research is needed to understand how governance structures and processes affect the dynamics of the SES

and how they can be improved to support sustainable resource use and ecosystem services. This includes exploring the role of institutions and actors, policy and regulatory interventions and funding in SES management and how they can be designed to promote resilient outcomes.

5. Assessing the effectiveness of participatory approaches: Participatory approaches, such as adaptive management and social learning, are increasingly important to the management of the SES. Research is needed to assess the adoption of these approaches, to evaluate the effectiveness of different participatory approaches and to identify the conditions under which they are most effective.
6. Monitoring the global impacts of SES changes: SESs are subject to a range of global changes, including climate change, energy transitions, population growth, expanding inequities and innovation. Research is needed to understand the impacts of these changes on SESs and to develop strategies to support the resilience of these systems. This includes monitoring the success of actions to sustain, adapt, transition or transform and the overall health of SESs in the face of these challenges.

Finally, although the focus of this dissertation was on the risks caused by flooding, these themes and approaches could be applied to any disaster, whether natural or human-made, in our collective fight to shape a better, more equitable and more resilient world for ourselves and future generations.

Appendices

Extended Table 2.2. Proposed time periods of importance for each objective. Early warning (EW) refers to the first few years of operation (years 0-4). Near-term (NT) refers to years 4-10 and long-term (LT) refers to the full 50-year lifespan of the project.

Objective	EW	NT	LT
Avoid impacts to the 100-year level of protection on the MR&T levee system.	High	Medium	Medium
Avoid impacts to the New Orleans to Venice levee system.	High	Medium	Medium
Avoid induced increased flood risk to Lafitte and other Basin communities.	High	High	Medium
Avoid impacts to drainage in areas affected by the conveyance channel.	High	Low	Low
Minimize induced erosion while maximizing channel development.	High		
Minimize induced wetland loss from elevated water levels over the marsh.	High	High	
Minimize impacts to navigability on the federally authorized Mississippi River.	Medium	Low	Low
Minimize adverse impacts to bottlenose dolphin populations to the extent practicable and consistent with the purpose of the project.	Medium	Low	
Avoid or mitigate any adverse impacts to species of concern (sea turtles, manatees, Gulf or pallid sturgeon and other species defined in the EIS).	Medium	Low	
Avoid or minimize areas of stagnant water that could lead to hypoxic conditions.	Low	Low	Low
Create and maintain complex deltaic sediment distribution.		High	High
Maximize sediment capture by the diversion structure.		High	High
Enhance vertical accretion to maintain marsh surface elevation.		High	High
Maximize extent of influence to build/sustain land and reduce land loss rates.		High	High
Restore wetlands and ecological function that was injured in the DWH oil spill.		High	High
Increase wetland health by inputs of freshwater, sediment and nutrients.		High	High
Maintain a balance of fresh and saltwater harvestable species populations.		Medium	Medium
Maximize nutrient uptake in vegetation and soils for wetland health and water quality.		Medium	Medium
Minimize the frequency of impacts to nesting birds.		Low	
Minimize sediment deposition in the federally authorized Barataria Waterway.		Low	Low
Maximize wetland extent to reduce storm surge and waves on adjacent protection systems, communities and economic assets.			High
Minimize adverse impacts to vegetation/wetlands from extreme events			Medium
Increase and maintain varied wetland habitats to support biodiversity.			Medium
Sustain habitats for the long-term viability of federally-managed species.			Medium
Increase primary productivity to enhance the food web and increase biomass			Medium
Maintain and enhance the habitats that support critical habitats for birds.			Low
Reduce river stages in New Orleans and the use of the Bonnet Carre Spillway			Low
Support the establishment of coastal forests in the outfall area for risk reduction.			Low

Extended Table 2.3. The management uncertainties discussed, level of uncertainty, the perceived institutional importance of the uncertainty and the adaptive actions that could be taken. This is not an inclusive list.

Management Uncertainties	Level of Uncertainty	Institutional Importance	Primary Learning Strategy
Do the timing and magnitude of operations affect food web dynamics, specifically the community composition of lower trophic levels and does that have cascading effects through the upper trophic levels?	High	High	Operations
How will the timing and magnitude of operations affect the health, behavior, reproduction and habitat use/range change for bottlenose dolphin in Barataria Bay? How will this affect their distribution and abundance?	High	High	Operations
What operational strategy (i.e., gradual/non-gradual opening, increasing capacity over time) most effectively limits unnecessary erosion during channel development?	High	High	Operations
How does residence time, which varies based on operation strategies, affect overall water quality and how can nutrient retention enhancement devices (NREDs) be used?	High	High	Operations NREDs
How can we maximize the development of a highly functioning and diverse deltaic landscape through the timing/magnitude of operations and the use of outfall management activities?	High	High	Operations
How do variations in the timing and magnitude of operations affect fish population levels (specifically harvestable stock) for key commercial and recreational species?	Medium	High	Operations
How do various operations affect water levels (duration and depth) and across what extent based on seasonality that could lead to increased flood risk and induced wetland loss?	Medium	High	Operations
How will extreme riverine flood events affect the structural integrity of the diversion?	Low	High	Maintenance
How will the diversion increase or decrease the flood risk (from the diversion itself or storm/rain events) of adjacent communities behind the levees?	Low	High	Operations, Levees
How do the timing and magnitude of operations affect the estuarine recovery time for salinity and temperature?	Low	High	Operations
How do the frequency and timing of flooding affect long-term nesting success rates need for population stability and dynamics over time for ground-nesting birds/alligators?	Medium	Medium	Operations
How will base flows be needed seasonally to prevent saltwater intrusion to fresh marsh causing collapse?	Medium	High	Operations
Assuming a sediment retention goal is set, are we achieving the trapping efficacy desired and how can sediment retention enhancement devices (SREDs) be used for sediment capture?	Low	Medium	Operations SREDs
How will the diversion increase or decrease the flood risk (from the diversion itself or storm/rain events) of adjacent basin-side communities?	Medium	Medium	Operations

Extended Table 2.4. The research uncertainties discussed, level of uncertainty and the perceived institutional importance of the uncertainty. Not an inclusive list.

Research Uncertainties	Level of Uncertainty	Institutional Importance
How does additional carbon influx affect food web productivity?	High	High
What are the changes to the composition/structure of trophic levels and how will it affect predator/prey interactions?	High	High
What are the near and long-term socio-economic effects of the project?	High	High
How much marsh is restored/sustained and during what timeframe?	High	High
How would DHH closures due to HABs change over time?	Medium	High
How do different vegetation species handle flood stress?	Medium	High
What is the rate of RSLR and how does it affect delta development?	Medium	High
How much and where will sediment deposition on oyster leases affect productivity?	Low	High
How will the diversion affect shoaling and the overall dredging budget of the river/waterway?	Low	High
How to maximize sediment/water ratio captured by the diversion seasonally and over time?	Low	High
What is the fate of nutrients and other contaminants in the basin?	High	Medium
How does the input of sediment, freshwater and nutrients affect the above and below ground biomass of plants?	Medium	Medium
How will different distributions of marsh types affect biodiversity?	Medium	Medium
Where and how much of each habitat type will be created over time?	Medium	Medium
How will sediment load in the river change seasonally and over time considering climate change impact upstream?	Medium	Medium
How much turbidity and flocculation will be experienced in the system?	Medium	Medium
How will the addition of sediment, nutrients and freshwater change the soil characteristics and composition?	Medium	Medium
How will the diversion intake affect cross-current and boat safety in the Mississippi River?	Low	Medium
How do changes in environment conditions affect population dynamics (growth/mortality/reproduction) at vulnerable life-stages for populations of harvestable fish species?	High	Medium
How is river discharge (and extreme events) going to change seasonally and over time considering climate change?	High	Low
What is the timeframe by which land-building and salinity stabilization will promote the establishment of coastal forests?	High	Low
How does the timing and magnitude of operations affect the establishment and permanence of SAV beds?	Medium	Low
What is the economic impact for increased recreational opportunities and businesses (ecotourism, charters, bird watching)?	Medium	Low
Can the new delta provide protection for the levee system and reduce maintenance costs?	Medium	Low
What is the effect of storm surge on deltaic wetland development and structure?	Medium	Low
How will the delta building affect access for commercial and recreational users over time?	Low	Low
What is the distribution and fate of fine and coarse sediments?	Medium	High

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