Knowledge System Innovation for Resilient Coastal Cities

by

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ABSTRACT

Cities are in need of radical knowledge system innovations and designs in the age of the Anthropocene. Cities are complex sites of interactions across social, ecological, and technological dimensions. Cities are also experiencing rapidly changing and intractable environmental conditions. Given uncertain and incomplete knowledge of both future environmental conditions and the outcomes of urban resilience efforts, today's knowledge systems are unequipped to generate the knowledge and wisdom needed to act. As such, cities must modernize the knowledge infrastructure underpinning today's complex urban systems. The principal objective of this dissertation is to make the case for, and guide, the vital knowledge system innovations that coastal cities need in order to build more resilient urban futures. Chapter 2 demonstrates the use of knowledge systems analysis as a tool to stress-test and upgrade the Federal Emergency Management Agency flood mapping knowledge system that drives flood resilience planning and decision-making in New York City. In Chapter 3, a conceptual framework is constructed for the design and analysis of knowledge co-production by integrating concepts across the co-production and urban social-ecological-technological systems literatures. In Chapter 4, the conceptual framework is used to analyze two case studies of knowledge co-production in the Miami Metropolitan Area to better inform decisions for how and when to employ co-production as a tool to achieve sustainability and resilience outcomes. In Chapter 5, six propositions are presented – derived from a synthesis of the literature and the three empirical cases – that knowledge professionals can employ to create, facilitate, and scale up knowledge system innovations: flatten knowledge hierarchies; create plural and positive visions of the future; construct knowledge co-production to achieve desired

outcomes; acknowledge and anticipate the influence of power and authority; build anticipatory capacities to act under deep uncertainty; and identify and invest in knowledge innovations. While these six propositions apply to the context of coastal cities and flood resilience, most can also be useful to facilitate knowledge innovations to adapt to other complex and intractable environmental problems. Cities must move swiftly to create and catalyze knowledge system innovations given the scale of climate impacts and rapidly changing environmental conditions.

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LIST OF ABBREVIATIONS

100RC	100 Resilient Cities
AEP	Annual Exceedance Probability
BFE	Base Flood Elevation
BWFIRA	Biggert-Waters Flood Insurance Reform Act
CEO	Chief Executive Officer
Compact	Southeast Florida Regional Climate Change Compact
DAPP	Dynamic Adaptive Policy Pathways
DEM	Digital Elevation Model
DFE	Design Flood Elevation
District	South Florida Water Management District
EOTR	Eyes on the Rise
EPA	Environmental Protection Agency
FCI	Florida Climate Institute
FIU	Florida International University
GDP	Gross Domestic Product
GIS	Geographical Information Systems
IDF	Intensity-Duration-Frequency
ISC	Institute for Sustainable Communities
IPCC	International Panel on Climate Change
KES	Knowledge and Ecological System
KSS	Knowledge and Social System
KTS	Knowledge and Technological System

LiDAR	LIght Detection and Ranging
LOMR	Letter of Map Revision
MMA	Miami Metropolitan Area
NYC	New York City
NFIP	National Flood Insurance Program
NGO	Non-governmental Organization
NOAA	National Oceanic and Atmospheric Administration
NYPCC	New York Panel on Climate Change
PMR	Physical Map Revision
P-FIRM	Preliminary Flood Insurance Rate Map
RCAP	Regional Climate Action Plan
SES	Social-Ecological Systems
SETS-FKC	SETS Framework of Knowledge Co-Production
SFHA	Special Flood Hazard Area
SLR	Sea Level Rise
SLSC	Sea Level Solutions Center
STS	Science and Technology Studies
Tech WG	Technical Ad Hoc Work Group
TNC	The Nature Conservancy
UREx SRN	Urban Resilience to Extreme Events Sustainability Research Network
USACE	United States Army Corps of Engineers

CHAPTER 1

INTRODUCTION

1. Overview

Cities are complex sites of interactions across social, ecological, and technological dimensions (Bixler et al., 2019; McPhearson, Haase, et al., 2016). Cities are also experiencing rapidly changing and intractable environmental conditions including extreme weather events (Helmrich & Chester, 2020; McPhillips et al., 2018; T. R. Miller et al., 2018; T. A. Muñoz-Erickson et al., 2017; Rockström et al., 2009; Steffen et al., 2018). Given our uncertain and incomplete knowledge of both future conditions and the outcomes of resilience efforts (Crow, 2007; Hall et al., 2019; Marchau et al., 2019), today's knowledge systems are unequipped to generate the knowledge and wisdom we need to act and build more equitable, inclusive and resilient urban futures (Fazey et al., 2020; Feagan et al., 2019; T. A. Muñoz-Erickson et al., 2017). We are in desperate need of new and radical knowledge system designs (Fazey et al., 2020; Feagan et al., 2019) to bring knowledge systems up to date in the age of the Anthropocene – the present human-dominated geological epoch (Crutzen, 2002; Steffen et al., 2018). Not only are we going to need physical infrastructure innovations (Chester et al., 2020; Helmrich & Chester, 2020), but we will also need to upgrade the knowledge infrastructure (Markolf et al., 2018; T. R. Miller et al., 2018) underpinning modern cities' social, ecological, and technological systems (SETS). The more institutional, organizational, and knowledge innovations we conduct, the better prepared we will be as a society to meet these challenges in the face of our inescapable limits to knowledge (Crow, 2007). We must move swiftly to create and scale up knowledge innovations given the scale of and rapidly changing environmental conditions due to climate change (Fazey et al., 2020; Steffen et al., 2018). This dissertation study presents significant conceptual and empirical work to build a coherent framework and a set of propositions for the design, creation, and promotion of knowledge innovation for building more equitable, inclusive, and resilient coastal cities in the age of the Anthropocene.

Knowledge systems consist of both structures and functions. The structures include knowledge (what we know and don't know), actors (people and organizations), epistemologies (how we know what we know), and values (what we consider as important). The functions of knowledge systems include the generation, validation, sharing, and applying of knowledge claims. Taken together, a knowledge system is the network of actors and institutions, and their social and institutional practices of creating, validating, sharing, and using knowledge claims in order to advance specific policies, decision, and action (Miller & Muñoz-Erickson, 2018).

Knowledge co-production – a concept that gets explored in depth in this dissertation – is a specific form of knowledge system innovation. It is often described in the sustainability science literature as processes that bring together diverse groups, in frequent and iterative interactions, to create new knowledge and practices (Jagannathan et al., 2019; Mach et al., 2019; Wyborn et al., 2019). While knowledge co-production shows great promise as a tool to achieve many sustainability and resilience goals (Bremer & Meisch, 2017; Norström et al., 2020), many scholars have recently argued that knowledge co-production may not be the silver bullet to achieve all of its theoretical outcomes such as strengthening communities, deepening knowledge, utilization of knowledge in decision-making, catalyzing action, and transforming systems (Jagannathan et al., 2019; Lemos et al., 2018; Mach et al., 2019; Turnhout et al., 2020). Very little empirical work has been done to explore the conditions and contexts under which knowledge co-production is successful in achieving these outcomes (Jagannathan et al., 2019; Wyborn et al., 2019). This dissertation aims to help close that gap.

In the following sections, I summarize the objectives and research questions (Section 2), discuss the major contributions of each chapter of the dissertation (Section 3), and provide a review of key literature to set the conceptual foundation for the rest of the chapters (Section 4).

2. Objectives & research questions

The principal objective of this dissertation is to argue for and guide the knowledge system innovations necessary to build more equitable, inclusive, and resilient coastal cities. As such, I have sought out to accomplish several sub-objectives. The objectives, organized by chapters, include to:

1. Demonstrate the value of knowledge systems analysis as a tool to stress-test and upgrade knowledge systems that underpin coastal resilience planning and decision-making (Chapter 2).
2. Create a conceptual framework for the design and analysis of knowledge co-production initiatives by integrating concepts across the sustainability science, public administration, science and technology studies, and urban social-ecological-technological systems literatures (Chapter 3).
3. Apply the new conceptual framework to analyze several empirical case studies of knowledge co-production initiatives to better inform decisions for how and when to employ co-production as a tool for achieving its theory-based

outcomes – outcomes that are often associated with knowledge innovation for resilience and sustainability. (Chapter 4).

4. Propose several strategies – derived from a synthesis of the literature and my empirical case studies – that knowledge professionals can employ to create, facilitate, support, and scale up the knowledge system innovations we need to build more equitable, inclusive and resilient coastal cities (Chapter 5).

Objectives one through three above enable me to meet objective four. Taken together, this dissertation advances both the theory and practice of knowledge innovation for urban resilience – especially in coastal cities threatened by increasing sea levels and persistent floods (Ghanbari et al., 2020; Stephane Hallegatte et al., 2013; Sweet et al., 2017). In order to accomplish the abovementioned objectives, I ask in each chapter of this dissertation:

1. How can knowledge system analysis be used to stress-test and identify challenges with coastal flood risk mapping to promote innovation? (Chapter 2)
2. How do knowledge co-production initiatives shape and how are they shaped by their broader social, ecological, and technological systems? (Chapter 3)
3. How and in what ways has knowledge co-production worked – or not – to achieve its theoretical outcomes in the highly politicized urban context of a flood-prone coastal metropolitan area fighting for its future? (Chapter 4)
4. What knowledge system innovations are needed to build more equitable, inclusive, and resilient cities in the age of the Anthropocene? (Chapter 5)

This dissertation culminates in Chapter 5 with a set of propositions – to be used by knowledge professionals (Miller & Muñoz-Erickson, 2018) – to promote and scale up knowledge innovation for building more equitable, inclusive, and resilient coastal cities.

3. Intellectual contributions and broader merits

This dissertation makes several important intellectual contributions to the knowledge systems and co-production literatures. It also serves as a guide to design and implement knowledge co-production to build more resilient cities in practice. In Chapter 2, I demonstrate the value of knowledge systems analysis as a tool to stress-test and identify weaknesses in knowledge systems in order to upgrade or redesign them. While this Chapter serves as an example to scholars to apply knowledge systems analysis to other problems, it also specifically shows why the FEMA Flood Insurance Rate Map (FIRM) knowledge system is outdated and untenable – it is not designed for the non-stationary climate and contested urban politics of the Anthropocene. I offer practical suggestions that floodplain managers, city officials, and FEMA administrators can consider in order to upgrade this system. I also make suggestions for the design of a new system to augment or replace it.

In Chapter 3, I look closely at knowledge co-production as a specific form of knowledge system innovation, and then create a new conceptual model for knowledge co-production using a SETS lens. I integrate the literature on urban social-ecological-technological systems with the literature streams on co-production to create the SETS Framework of Knowledge Co-production (SETS-FKC). This framework serves to help scholars better conceptualize the couplings across the various social, ecological, and technological system domains in which knowledge co-production initiatives are situated.

The framework shows how knowledge co-production both shapes, and is shaped by its larger social, ecological, and technological systems contexts. As a result, this framework can be used to more deliberately explore such interactions as the role of power and authority of external actors influencing knowledge co-production processes and outcomes. While some scholars have attempted to link the social dimension of SETS to knowledge co-production, few have attempted to couple the material dimensions with knowledge co-production. As such, the SETS-FKC's main intellectual contribution is explicitly showing how the material dimensions (e.g., ecological and technological systems) both shape and are shaped by knowledge co-production. I demonstrate how to apply this framework to specific cases of knowledge co-production for resilience action in Chapter 4. I explore, in detail, the role that power, expertise, and visions all had on the process of co-producing new knowledge and the success of its outcomes. I suggest that this framework can be useful to knowledge professionals to anticipate and plan for the inevitable interactions between a knowledge co-production initiative and the unique SETS context in which it is dynamically arranged. As mentioned in Section 1, more empirical work is needed to explore the role of power, authority, and unique SETS contexts in driving the outcomes of knowledge co-production processes (Lemos et al., 2018; C. A. Miller & Wyborn, 2018; Turnhout et al., 2020; Wyborn et al., 2019). In Chapter 4, I conduct two empirical case studies in the low-lying coastal metropolis of Miami – using an ethnographic approach – to help fill this gap in the literature. While helping to fill this particular gap in the knowledge co-production literature, Chapter 4 also provides two rich case studies to identify what knowledge system innovations are needed to build more equitable, inclusive, and resilient coastal cities.

In Chapter 5, I synthesize across my two Miami case studies, the New York City case study, and the broader literature on knowledge systems, co-production, SETS, and decision-making under deep uncertainty to identify key themes for knowledge system innovation for building resilient coastal cities. I present six propositions for what we need to create and scale up the knowledge systems of the future. While the propositions are not individually ground-breaking in the scholarly literature, together, they present a coherent approach for knowledge professionals to create, facilitate, promote, and scale-up the knowledge innovations we need to build more equitable, inclusive, and resilient coastal cities. These were developed specifically for low-lying coastal cities like New York City and Miami, but the lessons and propositions can be readily applied to upgrade and redesign knowledge systems for addressing other intractable environmental and sustainability challenges. In my final chapter, Chapter 6, I offer some concluding remarks and discuss my intellectual agenda that has emerged from the insights gained during this dissertation.

3. Theoretical background and justification

This dissertation does not include an overarching literature review that encompasses all of the core literature for each chapter. Instead, I have provided a review of the relevant literature and justification integrated within each specific chapter. Chapter 2 provides a detailed review of the literature on knowledge systems and knowledge systems analysis prior to presenting the knowledge systems analysis of FEMA flood maps. Chapter 3 provides a rich overview and synthesis on the co-production literature from science and technology studies, public administration, and sustainability science while also integrating the literature on urban social-ecological-technological systems prior to develop the SETS-FKC. Chapter 4 further reviews the knowledge co-production literature – identifying key gaps in the literature – while also providing a rich overview of the literature on flood risk and sea level rise. Chapter 4 also provides a detailed profile – based in the peer-reviewed literature – of the Miami Metropolitan Area (MMA). Chapter 5 uses the concepts developed in previous chapters and introduces new literature on deep uncertainty. However, what is missing from these chapters is a detailed overview of the concept of resilience as well as a theoretical justification for my argument that we need more inclusive knowledge systems to advance urban resilience and sustainability goals. As these two concepts are central to every chapter of my dissertation, and hasn't been described in detail elsewhere, I review and define resilience in Section 3.1 and inclusive knowledge systems in Section 3.2 below.

3.1. Resilience

The concept of resilience originates from the Latin words *resilare*, to leap backwards, and *resilio* meaning to bounce back (Cretney, 2014; Meerow et al., 2016). The term has been used across a myriad of academic disciplines and comprehensive reviews can be found in Cretney (2014), MacKinnon & Derickson (2012) and Meerow et al. (2016). Table 1.1 highlights key papers and definitions across various literature streams such as cognitive psychology, engineering, physics, disaster risk management, geography, urban planning, global environmental change, ecology, social-ecological systems, management, economics, and development. The term has a long history in fields like psychology which have defined resilience as "a dynamic developmental process encompassing the attainment of positive adaptation within the context of significant threat, severe adversity, or trauma" (Cicchetti, 2010, p. 145). In engineering and physics, the term is generally related to the ability of the system to bounce back from a disturbance or to avoid accidents or breaking down altogether (Gordon, 1978; Hollnagel, Woods, & Leveson, 2007).

In a similar vein, in management and economics the term generally refers to recover from a shock or disruption (Hill et al., 2008; Vale, 2014). The United Nations Office for Disaster Risk Reduction defines resilience as,

> The ability of a system, community, or society exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner including through the preservation and restoration of its essential basic structures and functions (UNISDR, 2018).

The first usage of the term resilience in the ecology literature was by Holling (1973) who coined resilience as “a measure of the persistence of systems and of their ability to absorb change and disturbance and still maintain the same relationships between populations or state variables” (p.14).

Table 1.1

Definitions of Resilience from Various Natural and Social Science Disciplines

Author(s)	Type	Definition	Field
Hollnagel et al. (2007)	Engineering resilience	The ability in difficult conditions to stay within the safe envelope and avoid accidents	Engineering
Gordon (1978)	Resilience	The ability to store energy and deflect elasticity under a load without breaking or being deformed	Physics
Holling (1973)	Ecological resilience	A measure of the persistence of systems and of their ability to absorb change and disturbance and still maintain the same relationships between populations or state variables.	Ecology
Walker et al. (2004)	Social-ecological systems resilience	The capacity of a system to absorb disturbance and reorganize while undergoing change so as to still retain essentially the same function, structure, identity, and feedbacks.	Social-Ecological Systems; Ecology
Adger (2000)	Social resilience	The ability of groups or communities to cope with external stresses and disturbances as a result of social, political, and environmental change.	Social sciences
UNISDR (2018)	Community resilience	Ability of a system, community, or society exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner including through the preservation and restoration of its essential basic structures and functions	Disaster Risk Reduction
Nelson, Adger, & Brown (2007)	Resilience	The amount of change a system can undergo and still retain the same function and structure while maintaining options to develop.	Geography; Social Sciences
Meerow et al. (2016)	Urban Resilience	Urban resilience refers to the ability of an urban system—and all its constituent socio-ecological and socio-technical networks across temporal and spatial scales—to maintain or rapidly return to desired functions in the face of a disturbance, to adapt to change, and to quickly transform systems that limit current or future adaptive capacity.	Geography; Urban Planning
Comfort et al. (2010)	Urban resilience	The capacity of a social system to proactively adapt to and recover from disturbances that are perceived within the system to fall outside the range of normal and expected disturbances"	Disaster Risk Management
Cicchetti (2010)	Psychological resilience	A dynamic developmental process encompassing the attainment of positive adaptation within the context of significant threat, severe adversity, or trauma	Psychology; Cognitive Science

Vale (2014)	Organizational Resilience	A measure of an organization's ability to recover from a disruption to a headquarters or to some key element in a supply chain and to return to 'business as usual'	Management
Hill et al. (2008)	Resilience	The ability of a region to recover successfully from shocks to its economy	Economics; Development

Holling (1996) further elaborated on the concept of ecological resilience by contrasting it with what he calls engineering resilience (Pimm, 1984). Instead of thinking of resilience as maintaining the stability of one state of an ecosystem in the face of disturbances – engineering resilience – Holling (1996) argued for a concept called ecological resilience which focuses more on persistence, change, and unpredictability where instabilities can transform a system state into another state. Ecological resilience was the inspiration for the development of what has been come to be known as resilience thinking as first referred to as such by Folke et al. (2010) in the social-ecological systems (SES) literature. Resilience thinking is a collection of ideas including the adaptive cycle (Carpenter et al., 2001; Gunderson & Holling, 2002) and panarchy (Gunderson & Holling, 2002) to illustrate the process of social-ecological system change and resilience to perturbations or disturbances. The concept of resilience has advanced rapidly in response to criticisms from social scientists and geographers about its undertheorized social dimension of SES change; particularly its lack of incorporation of the role of power, politics, and agency in SES (Brown, 2014; Cote & Nightingale, 2012; Davidson, 2010a; MacKinnon & Derickson, 2012; Olsson et al., 2015; Smith & Stirling, 2010). In response to these criticisms, Walker et al. (2004) developed the ideas of adaptability and transformability and incorporated these ideas into a definition of resilience that explicitly embraced system change, "the capacity of a system to absorb disturbance and reorganize while undergoing change so as to still retain essentially the same function, structure, identity, and feedbacks" (p.2). Walker et al.'s (2004) definition is now widely cited throughout the SES and resilience literature.

Social scientists' critiques have not only lead to a reconceptualization of the term, but social scientists also began framing their own conceptualizations of resilience in SES. Adger (2000) was one of the first social scientists to examine the applicability of ecosystem resilience to understanding social resilience. Adger's (2000) seminal article defines social resilience as "the ability of groups or communities to cope with external stresses and disturbances as a result of social, political, and environmental change" (p. 347). To address issues of power and authority in the resilience concept, Harris, Chu, and Ziervogel (2017) advance a new resilience framing coined 'negotiated resilience', which explicitly focuses on deliberation, equity, justice, and inclusive practices in determining resilience for whom, what, where and why (L. M. Harris et al., 2017; Meerow & Newell, 2019).

The social and institutional dynamics are even more apparent in urban social-ecological systems. As such, geography and urban planning scholars have built on the debates regarding resilience to formulate their own resilience framing for urban systems. For instance, Meerow et al. (2016) defines urban resilience as:

> The ability of an urban system—and all its constituent socio- ecological and socio-technical networks across temporal and spatial scales—to maintain or rapidly return to desired functions in the face of a disturbance, to adapt to change, and to quickly transform systems that limit current or future adaptive capacity (p.39)

I adopt the above definition of urban resilience for this dissertation. This definition focuses attention on the need to anticipate, adapt, and transform urban systems that limit adaptive capacity. Specifically, this dissertation draws attention to existing knowledge systems that limit a city's adaptive capacity and the knowledge system innovations needed to build resilience. While prior studies have explored the role of urban knowledge systems in inhibiting or building adaptive capacities (T. A. Muñoz-Erickson, 2014b; T. A. Muñoz-Erickson et al., 2017), few have explored the role of urban knowledge systems in building the resilience of coastal cities – like New York and Miami (Rosenzweig et al., 2019; Rozance et al., 2019; Solecki & Rosenzweig, 2014). This dissertation helps to fill these critical gaps in the resilience and knowledge systems literatures.

3.2. Inclusive Knowledge Systems for Equitable and Resilient Cities

Inclusive knowledge systems may (1) improve our understanding of complex urban system dynamics (Olazabal et al., 2018) and (2) produce resilience outcomes that serve a larger representation of society (Norström et al., 2020). Norström et al. (2020, p. 5) claim that, under the right conditions, research has shown that both our understanding of problems and sustainability outcomes are enhanced by including various dimensions of diversity (e.g., gender, ethnicity, age and nationality) in knowledge production processes. For instance, Olazabal et al. (2018) find – by analyzing Fuzzy Cognitive Maps of diverse stakeholder's systems understandings – that there are no 'super-stakeholders' with a comprehensive understanding of all components and their interactions in a particular system. Instead, by integrating knowledge from a diversity of stakeholders, new knowledge about system interactions emerge. Such knowledge could "have never been gained through individual system perspectives alone" (Olazabal et al., 2018, p. 52).

Over the past decade, many sustainability scholars have joined in the calls for new knowledge system designs that are more inclusive of diverse actors and knowledge to find pathways toward more resilient and equitable cities (Cornell et al., 2013; Fazey et al., 2020; Feagan et al., 2019; Leach et al., 2010; Ramsey et al., 2019). One group of scholars asks: What would new designs actually look like? Fazey et al. (2020) brought together 340 researchers and practitioners to reflect on current knowledge systems and envision the knowledge systems we need to deal with today's sustainability and resilience challenges. Table 1.2 presents a selection of their findings.

Table 1.2

Current and Envisioned Knowledge System Characteristics

Current Knowledge Systems	Envisioned Knowledge Systems
Knowledge-focused	Wisdom-focused
Narrowly informed	Broadly informed
Elitist, exploitative and exclusive	Inclusive
Outcomes for a few	Outcomes for all (equitable)
Science for science	Science for all
Global knowledge	Local knowledge

Note. This table is adapted from Fazey et al. (2020)

Most importantly, Fazey et al. (2020) and other scholars suggest that there is a need to not just generate more knowledge about resilience and sustainability challenges, but instead to strengthen society's ability to know how to put that knowledge into action. In other words, we need to shift from generating more knowledge to generating more wisdom (practical knowledge about how to act). Cornell et al. (2013) argue that one way to do this is to 'open-up' knowledge systems so that scientists and societal actors work together in new spaces of knowledge co-production to unite new ways of producing and using knowledge to achieve improved sustainability and resilience outcomes. Democratic knowledge production processes – such as those proposed by Cornell et al. (2013) – are more likely to generate an enriched understanding of the complex ecological, political, and technical aspects of sustainability challenges and guide action (Norström et al., 2020; Olazabal et al., 2018).

Wijsman and Feagan (2019) argue that knowledge-making practices are closely tied with struggles for social justice, equity, and resilience in the city. Knowledge systems designed today tend to be those that support "existing ways of doing things, reinforcing existing social, economic and political forms of power and thus limiting emergence of more creative ways of working with global challenges" (Fazey et al., 2020, p. 9). Studies of resilience efforts and current knowledge systems corroborate this claim that current systems tend to reinforce and reproduce existing power relations and produce resilience outcomes that tend to favor privileged elites (Anguelovski et al., 2016; L. M. Harris et al., 2018; Wakefield, 2019; Wijsman & Feagan, 2019). In order to achieve more equitable outcomes, there is a need to shift knowledge systems away from elitist, exploitative, and exclusive designs to more egalitarian ones that empower rather than exploit participants (Fazey et al., 2020; Leach et al., 2010). To move from resilience for a few, to resilience for all will require new forms of integrating a plurality of actors in knowledge-making and decision-making processes (Anguelovski et al., 2016; L. M. Harris et al., 2018). Cornell et al. (2013) argue for a 'knowledge democracy' in which knowledge systems include a plurality of actors in socially situated knowledge arenas to develop a common vision, integrate their knowledge, implement actions collectively, and learn from their experiences to tackle societal problems.

Given these calls for creating more inclusive knowledge systems, this dissertation looks carefully at existing knowledge systems (Chapter 2) and deliberate knowledge co-production initiatives (Chapter 4) to explore how various knowledge production designs have closed-down or opened-up knowledge systems (Leach et al., 2010) to include various actors, types of knowledge, expertise, and visions. Six propositions are presented in Chapter 5 that help guide knowledge professionals in designing knowledge systems – with an emphasis on inclusive knowledge systems – by synthesizing lessons from my three empirical case studies and the literature. As such, this dissertation contributes to the burgeoning scholarship on how to open-up knowledge systems to be more inclusive of diverse forms of knowledge in order to build more equitable and resilient urban futures.

CHAPTER 2

PRODUCING AND COMMUNICATING FLOOD RISK: A KNOWLEDGE SYSTEM ANALYSIS OF FEMA FLOOD MAPS IN NEW YORK CITY

Copywrite disclaimer: Chapter 2 of this dissertation appears as Chapter 5 of the book *Resilient Urban Futures* with minor modifications (Hobbins et al., 2021). Figure numbers have been adjusted to reflect their location in the dissertation and follow the same format as the rest of the manuscript. Section numbers have been added to help the reader navigate the dissertation as well. In order to preserve the integrity of the original chapter, an addendum (Section 4) has been added after the conclusion to add additional insights pertinent to the dissertation that was not previously published. Both co-authors have given their consent to include this publication in the dissertation. Springer has also given consent to present the book chapter here. The full citation of the earlier version is provided below.

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1. Introduction

The burgeoning development of coastal cities coupled with increasing exposure to sea level rise and extreme weather events has exacerbated the vulnerability of coastal communities and infrastructure to floods. One trillion dollars in United States' coastal assets are currently vulnerable to coastal floods, and sea level rise threatens to expose 13 million people to flooding by 2100 (Reidmiller et al., 2018). Extreme events like

Superstorm Sandy have revealed the inadequacies of how we calculate, map, and use knowledge about flood risks. National studies have shown that 25% of Federal Emergency Management Agency (FEMA) flood claims lay outside of the FEMA 100-year flood zone (Blessing et al., 2017). Several studies report that population growth, gross domestic product (GDP), and climate change have all led to significant changes in flood exposure, and estimate that 41 million people—rather than the 13 million people shown in FEMA flood maps—live within the 100-year floodplain (Wing et al., 2018). It is clear that an upgrade, or even a rethinking, is urgently needed in how the U.S. maps and communicates risks of coastal floods.

In this chapter, we use the knowledge systems analysis framework as a lens to understand the social and technological challenges associated with coastal flood risk analysis, doing so with the objective of informing strategies and innovations needed to overcome those inadequacies. We refer to knowledge systems as the organizational practices and routines that produce, validate and review, communicate, and use knowledge relevant to policy and decision-making (Miller & Muñoz-Erickson, 2018; Muñoz-Erickson et al., 2017). Specifically, we conduct a knowledge system analysis of FEMA Flood Insurance Rate Maps (FIRMs) in New York City (NYC)—the largest coastal city of the Urban Resilience to Extremes Sustainability Research Network—to shed light on the social innovations required to make flood risk mapping work better for homeowners, businesses, and cities given our rapidly changing climate and urban landscapes. Cities are interested in improving their understanding of what are perceived to be the "true" or "real" risks of floods, so as to make and inform good decisions. What counts as a good estimate of such risks, however, is constructed through the design of a knowledge system that ratifies certain ideas and methods over others. Through this case study, we demonstrate the value of knowledge systems analysis as a method to stress-test and identify weaknesses and blind-spots that warrant attention. This analysis informs potential solutions to upgrade or redesign that system in support of building resilient cities.

1.1. The National Flood Insurance Program

The principal flood risk knowledge system in the U.S. is the FIRM produced by FEMA's National Flood Insurance Program (NFIP). FIRMs are also known simply as FEMA flood maps. The NFIP is responsible for generating knowledge about flood risk within defined zones, which in turn affects decisions about where and how homeowners and businesses build and the flood insurance rates they pay. The NFIP was created by the National Flood Insurance Act of 1968 and made federal flood insurance available for the first time (Michel-Kerjan, 2010). The Flood Disaster Protection Act of 1973 made the purchase of flood insurance mandatory for those living within the boundaries of high-risk zones—the 100-year flood zone as defined by the NFIP (Michel-Kerjan, 2010). The initial intent of the program was to provide immediate disaster relief to homeowners after experiencing a flood so they could get back on their feet and move out of the flood zone, ultimately reducing flood risk. Paradoxically, the NFIP instead disincentivized homeowners from moving out of flood-prone areas by shifting the costs to rebuild from the individual to society through heavily subsidized federal flood insurance (Platt, 1999). Burby (2006) calls this phenomenon the "safe development paradox." Unreliable flood maps (as discussed in this chapter) make this issue even worse when homes in high risk flood zones are not properly identified and are therefore not required to carry federal flood insurance. As a result, the NFIP does not collect enough insurance premiums to cover its flood claims and has had to rely on tens of billions in government bailouts to remain afloat. Simply put, the NFIP system is “broke and broken” (Walsh, 2017).

There have been several notable reforms to attempt to fix the NFIP. The 1994 Reform Act required FEMA to update its FIRMs every five years, though this policy has not been implemented diligently due to stressed budgets, limited administrative staffing, and appeals processes. The 2009 Department of Homeland Security Appropriations Act required FEMA to modernize flood maps by digitizing hand-drawn maps and updating FIRMs to reflect more recent historical climate data. The digitized maps were to be made publicly available through the FEMA Flood Map Service Center. The 2012 Biggert-Waters Flood Insurance Reform Act (BWFIRA) authorized FEMA to update the FIRM to include the best available scientific data regarding future intensities and frequencies of hurricanes, sea level change, precipitation, and storm surge (Grannis, 2012). The BWFIRA attempted to raise insurance rates to reflect a property’s “true” risk of flooding once a new flood map or update is produced—effectively eliminating the grandfathering process that was federally subsidizing risky properties with taxpayer money. The grandfathering process prevents owners of homes built before a map update from having to pay the full rate required by a new update. Instead, premiums increase over five years by just 20% per year. There was considerable backlash by flood insurance holders to the BWFIRA primarily due to the discontinuation of grandfathering. This political battle resulted in two additional bills which rolled back key provisions in the BWFIRA. The Consolidated Appropriations Act of 2014 prohibited FEMA from implementing Section 207 of the BWFIRA, which directed FEMA to use insurance rates commensurate with their full risk after a FIRM update. The 2014 Homeowner Flood Insurance Affordability Act restored the practice of grandfathering.

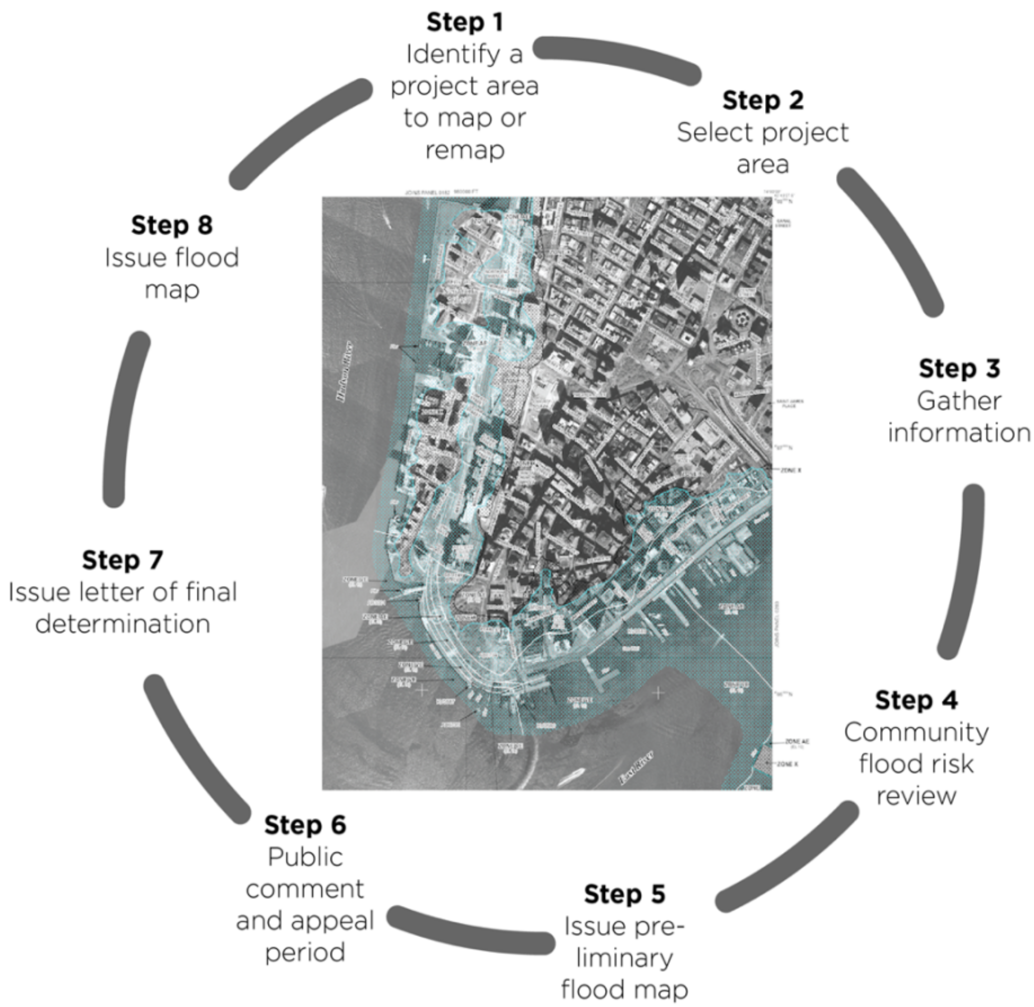
1.2. Flood Insurance Rate Maps as a knowledge system

Flood zones are demarcated by FEMA through a highly routinized process. Professional engineers use hydrodynamic modeling to calculate the expected height (i.e., base flood elevation or BFE) and location of floods by waterbodies such as rivers and oceans; the models do not consider floods from infrastructure failures, pluvial floods, or groundwater sources. For inland areas, flood zones and BFE are determined by modeling the overflow of water from streams that have exceeded their capacity during intense precipitation events (i.e., fluvial floods). In coastal areas, flood zones and the BFE are determined by several parameters: current sea level, wave setup, normal high tide, storm surge, and wave effects. Both fluvial and coastal flood modeling utilize Digital Elevation Models (DEM)—typically derived from LiDAR (LIght Detection and Ranging) data—for determining the elevation profiles of the study area. The Special Flood Hazard Area (SFHA)—for both inland and coastal areas—is defined as the area exposed to a 1% annual exceedance probability (AEP) of experiencing a flood in any given year. This area is often referred to interchangeably by its return period—the amount of time between floods of a certain size. A flood with T year return period will have a 1/T probability of occurring in any given year (Lin et al., 2012; McPhillips et al., 2018). As such, the return period for an AEP of 1% would be 100 years and the storm would be called a 100-year storm. The 100-year storm standard was selected as a compromise between two competing values: minimizing loss of life by restricting development in floodplains, and keeping floodplains open for economic and urban development (Federal Emergency

Management Agency, 2019b). The AEP is determined using statistical frequency analysis of past storms using historical weather data for fluvial floods, and synthetic storms (created from historical storm surge and tidal records, coastline profiles, and simulated laws of physics) for coastal floods (Sobel, 2014). The SFHA determines the areas where flood insurance is required and where to enforce floodplain regulations. In addition to the SFHA, flood maps include the areas exposed to a 0.2% AEP storm (i.e., 500-year flood) for reference only. The teal- and black-dotted zones on a FIRM demarcate the 100-year and 500-year flood zones respectively (see Figure 2.1). A common criticism of this system is that flood risk for a property is often misconstrued as binary—a property is either in a flood zone or out of it (Kousky, 2018). The 500-year flood zone line on flood maps creates this false sense of security on the other side of that line. To make matters worse, FEMA's terminology of a 100-year or 500-year flood zone is also misinterpreted by those who are actually aware that they are in one of those flood zones. For those living in a 100-year flood zone, the message received is that their property will only flood once in 100 years when, in reality, FEMA is trying to communicate that the risk is a 1% probability of flooding every year (Federal Emergency Management Agency, 2017). For instance, over the course of a 30-year mortgage, a property has a 26% chance of flooding. However, as shown throughout this chapter, that is not the "real" risk either.

Figure 2.1

The Process for Creating a Federal Emergency Management Agency (FEMA) Flood Map



Note. The current regulatory FEMA Flood Insurance Rate Map for lower Manhattan is shown in the center of the figure. Adapted from (Federal Emergency Management Agency, 2019b). Lower Manhattan FIRM courtesy of the FEMA Flood Map Service Center (Federal Emergency Management Agency, n.d.).

FEMA flood maps are the product of an 8-step iterative process (Figure 2.1) that begins by identifying a project area (Step 1), deciding on a watershed to map or remap (Step 2), and gathering technical data such as hydrological, infrastructural, land use, and population data (Step 3). A Flood Insurance Study is produced and then shared with community officials to review and provide feedback (Step 4). Once the preliminary FIRM is issued (Step 5), the FIRM can be amended or revised through individual or community appeals (Step 6; FEMA, 2019a). Individual property owners can submit a Letter of Map Amendment to provide data showing to show that their property is not within the SFHA. Community officials can submit a Letter of Map Revision (LOMR) using new scientific or technical data to revise a flood map. Both the LOMA and the LOMR do not actually lead to a physically revised flood map—the changes are documented in letter format only. The Chief Executive Officer (CEO) of a community is the only person who can submit a Physical Map Revision (PMR) to FEMA to physically change the flood zones on a FIRM. Both the PMR and LOMR are typically prepared by experts contracted by local governments. As such, these revisions are costly and resource-intensive endeavors. Once the appeals period expires, a letter of final determination is sent to notify the CEO that the community has six months to adopt a compliant floodplain management ordinance (Step 7) before the new regulatory FIRM becomes effective (Step 8). The case study presented in this chapter will analyze the production, revision, validation, communication and use of FEMA maps in NYC since 1981.

1.3. Knowledge systems analysis

Knowledge systems analysis is a useful framework to explore the underlying ideas, rationales, social practices, and institutional structures that define sustainability, resilience, and environmental problems. The framework has been applied to analyze a variety of socio-environmental issues, including sustainability visions (Muñoz-Erickson, 2014b) (Muñoz-Erickson 2014), green infrastructure (Matsler, 2017), cloudburst flood resilience (Rosenzweig et al., 2019), integration of citizen and technical flood risk knowledge (Ramsey et al., 2019), and the scalar politics of coastal flood risk (Rozance et al., 2019).

Like systems in general, knowledge systems are described in terms of the functions, elements, and complexities of the systems (Miller & Muñoz-Erickson, 2018). The core functions of a knowledge system include the production, validation, review, communication, and use of knowledge. For our FEMA case, the process of developing the FEMA flood map is what defines this knowledge system. The steps shown in Figure 2.1 reflect the various actors involved in how this knowledge system works, including the production of the flood map by FEMA engineers and city leaders (Steps 1 to 3), the review and validation of the maps by local community leaders (Steps 4, 6, and 7), its communication through the issuing of the preliminary FIRM (Step 5) and regulatory FIRM (Step 8), and its use in decision-making processes as to where to build, how high to build, and what flood insurance rates to charge homeowners. Elements of a knowledge system include the content of that knowledge (including its associated uncertainties), the values embedded in that knowledge, the epistemologies (or how we know what we know), and the institutional structures (people and organizations) through which knowledge is constructed and put to use. For the FIRM, knowledge consists of the actual flood maps that are produced and the knowledge claims that are made regarding those maps (e.g., homes in the FEMA 100-year flood zone have a 1% rate of flooding in any given year). Values may include how the knowledge system prioritizes urban and economic development versus restricting development in flood zones, decisions to set risk boundaries in terms of specific flood return periods (e.g., 100-year and 500-year flood zones), and decisions about how to balance historical data and future projections in setting risk zone boundaries. Epistemologies refer to how the problem is framed, types of evidence (e.g., rainfall data from the past 50 years, LiDAR satellite data, etc.), and the information technologies (e.g., hydrological models) used to produce flood maps. Structures include actors or stakeholders that are involved in the functions of the knowledge system. Analyzing knowledge system structures often reveals how power and authority are distributed and the consequences that these arrangements have on the production, communication, and use of knowledge (T. A. Muñoz-Erickson et al., 2017; T. A. Muñoz-Erickson & Cutts, 2016; Ramsey et al., 2019). The role of power and authority in the operations of the FEMA flood map knowledge system in NYC will also be explored in the next section.

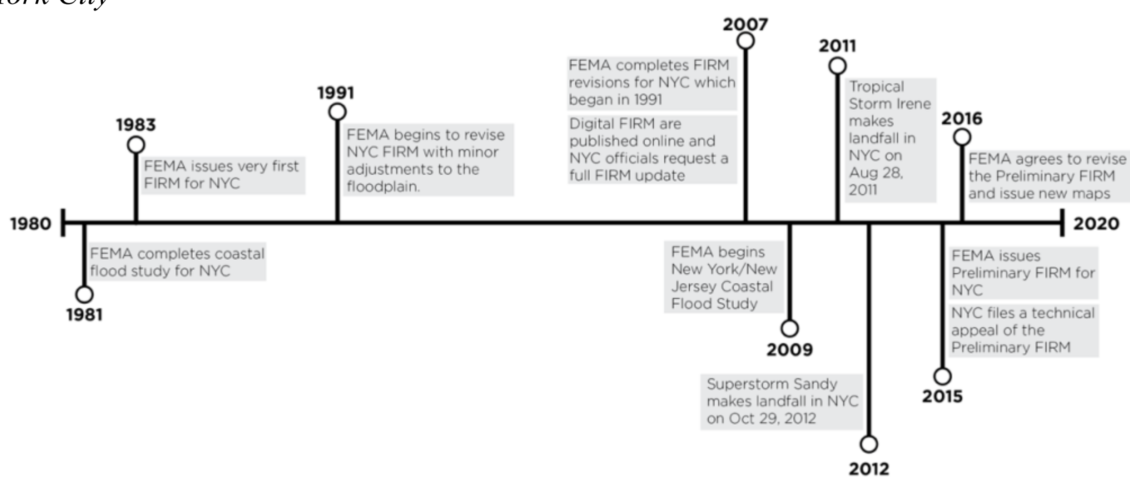
2. New York City flood map case study

"Our city needs precise flood maps that reflect real risks, both today and years from now, and we have to do that fairly." - NYC Mayor Bill de Blasio

To conduct the knowledge system analysis of FEMA flood maps for the NYC case study, we use the framework outlined above to review official FEMA products and documents, reports, academic publications, and newspaper articles containing accounts by various types of flood map users. The above quote by Mayor de Blasio highlights the main aspirations and challenges with flood risk mapping in NYC and the nation. City governments value accurate maps that reflect the "real" risks of floods and communicate reliable information about future flood risk to the public. Yet, city governments also wish to have this risk analysis done in a way that does not place unnecessary burdens on homeowners (e.g., higher insurance premiums or decreased home values) or slow down local economic growth (due to restrictions on development in ever-expanding flood zones). The technical flood mapping process is performed within this negotiation of values and risk tolerance. As such, flood maps are more than just technical products—they are maps with great social implications that warrant care in how they are produced so as to not disproportionally or inappropriately impact any particular social group or sector. At the same time, many hurdles must be overcome in efforts to include future flood risks into FEMA flood map products due to the large uncertainties inherent in future climate and sea-level projections. Through this case study, we use knowledge system analysis to illustrate both the technical and socio-political processes—spanning almost four decades (see Figure 2.2)—that went into the production, validation, communication, and use of FIRMs in NYC, and the implications this has for resilience to extreme flood events.

Figure 2.2

Timeline of Federal Emergency Management Agency Flood Map Production for New York City

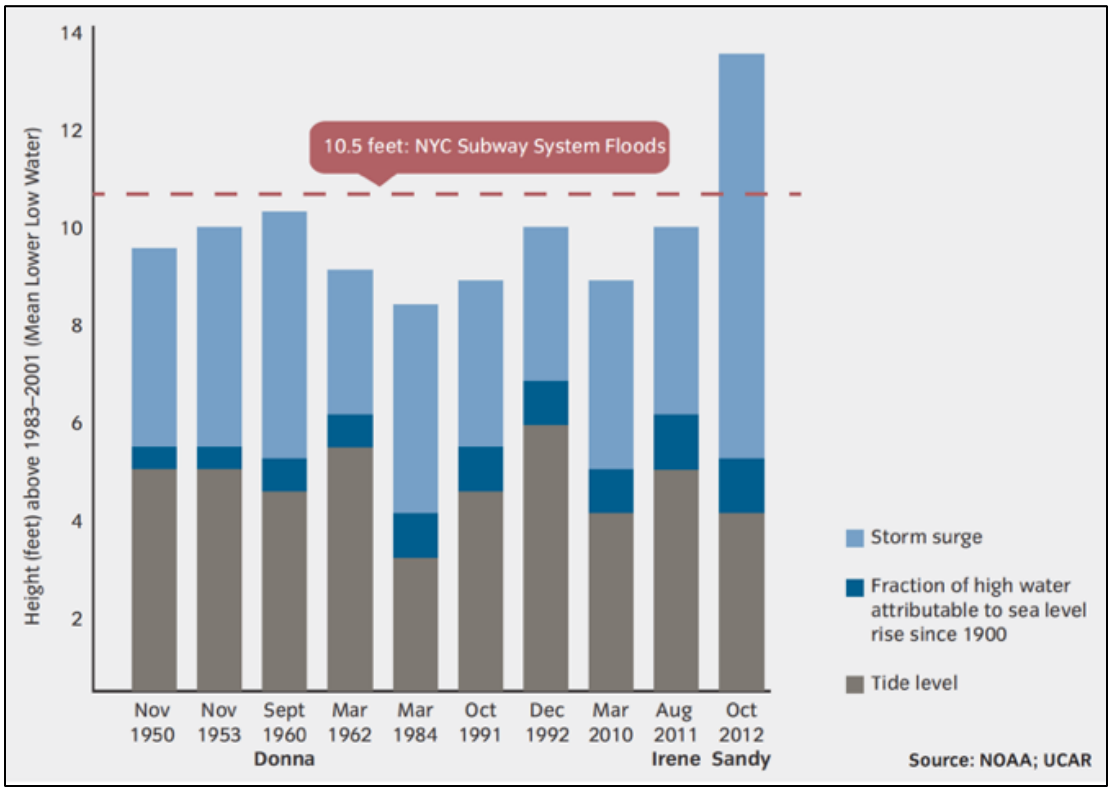


Note. Adapted from (City of New York, 2013).

Superstorm Sandy, which made landfall in NYC on Oct 29, 2012, was one of the worst natural disasters the city has experienced. Sandy was responsible for $19 billion in losses and 43 deaths throughout New York, as well as $65 billion in losses and 159 deaths nationwide (City of New York, 2013). Sandy's storm surge of 14+ feet (ft) left parts of NYC in ruins and nearly two million residents without power for up to two weeks (City of New York, 2013).

Figure 2.3

Historical High-Water Events in Lower Manhattan

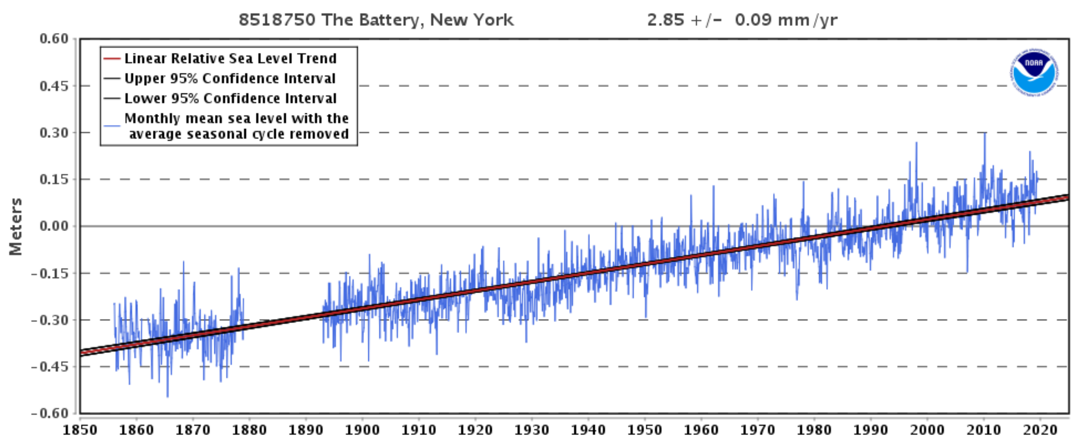


Note. Source: City of New York (2013). Used with permission of the New York City Department of City Planning.

The damage from Sandy resulted from a storm surge that was the highest in the historical tide gauge record—extending as far back as 1850—and exacerbated by a seasonal high tide that inundated areas well beyond FEMA flood zones. As seen in Figure 2.3, sea level rise also played a small but significant role in contributing to the record flood height. At the time of Sandy's landfall, the flood maps were grossly outdated—they did not reflect changes in climate and sea levels (see Figure 2.4), rapid land-use change, or advances in technology such as the development of more accurate elevation profiles from LiDAR (Parris, 2014).

Figure 2.4

Relative Sea Level Trend as Measured from The Battery Tide Gauge Station in NYC



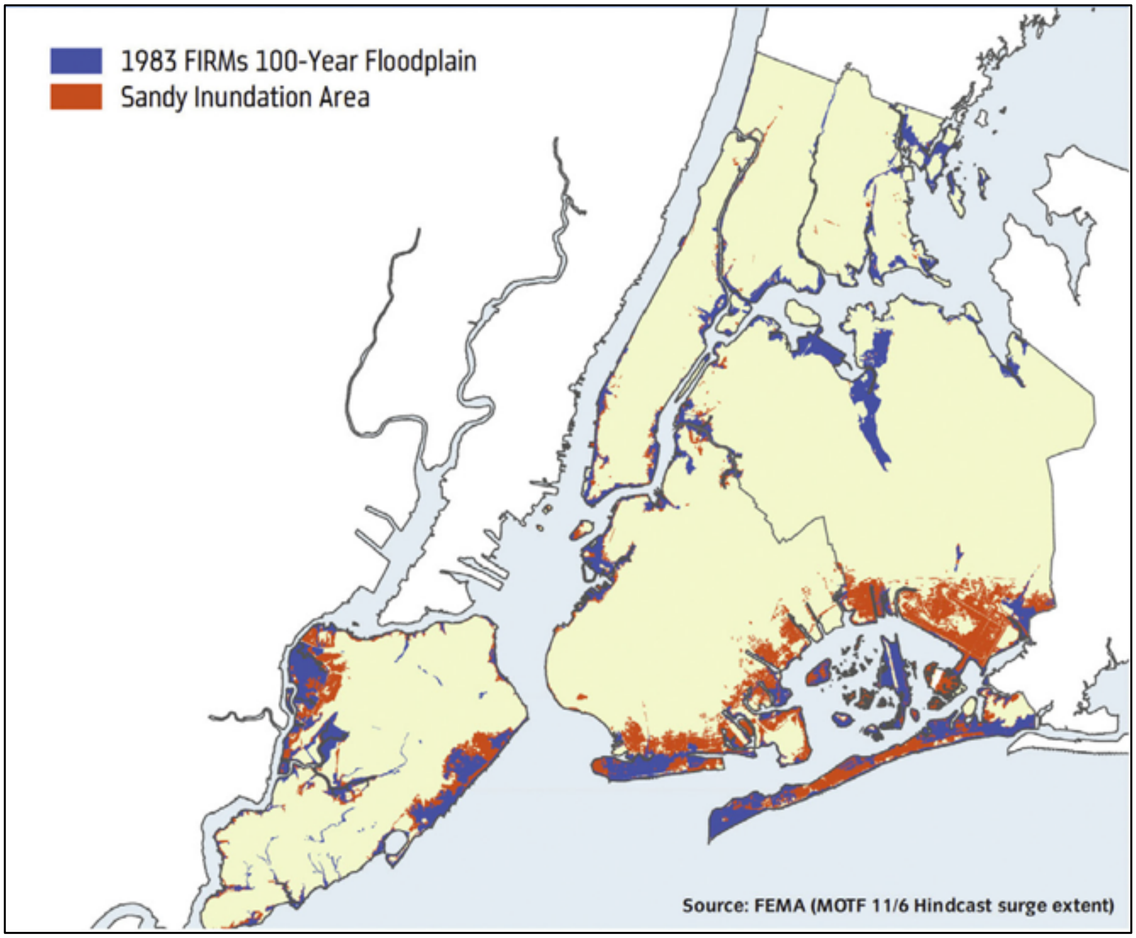
Note. Plotted values are monthly averages. The historic rate of sea level rise is 2.85 millimeters/year, or about 1 foot every 100 years (National Oceanic and Atmospheric Administration, 2019b).

The regulatory flood maps for NYC have not received a significant update since 1983, despite the legal requirement for flood maps to be updated every five years. From 1991 to 2007, flood map updates included new wetland and stream modeling but failed to include any elevation adjustments. In effect, these were very minor modifications to the original 1983 floodplains. The results were placed on satellite imagery, digitized, and made available online for general public consumption in 2007. Concerned about the inaccurate flood risk information being communicated to the public, local and state officials immediately called on FEMA to perform a full map update using the best scientific data and technology available. The update process did not begin until 2009 and had yet to be completed before Sandy struck in October of 2012 (see Figure 2.2 timeline).

The 2007 FIRM underestimated the scope of inundation that awaited the city during Sandy. Only 54% and 47% of the flooded area in Queens and Kings respectively was predicted by the 1983 flood maps during Sandy (Shaw et al., 2013). Figure 2.5 shows the vast swaths of the city inundated by Sandy, yet left out from the 1983 FIRM 100-year floodplain. However, Sandy was not calculated to be a 100-year storm; it was estimated by using outdated historical climate data to be a 1,000-year storm (Lin et al., 2012). However, several authors argue that climate change helped to intensify Superstorm Sandy (Dietrich, 2017; Parris, 2014; Sobel, 2014). Increases in sea levels alone could have accounted for half a foot of flooding during Sandy (Parris, 2014; Shaw et al., 2013). Lin et al. (2012) show that when taking into consideration changing climate and increasing sea levels, the current 100-year storm surge event in NYC has the potential to occur every 20 years or less and the present 500-year event has the potential to occur every 240 years or less by 2100. Thus, there are strong reasons to update flood maps regularly to reflect changing climate and sea levels. If the FEMA flood maps had been updated prior to Sandy to incorporate recent SLR and extreme precipitation and flooding events (e.g., the March 2010 nor'easter and Tropical Storm Irene in 2011), they may have more accurately reflected the extent of flood risk during Sandy and improved flood risk communication and resilience outcomes.

Figure 2.5

1983 Federal Emergency Management Agency Flood Insurance Rate Map and Sandy Inundation Area Comparison



Note. Source: City of New York (2013). Image used with permission of the New York City Department of City Planning.

After completing the Coastal Flood Study for New York in 2009, FEMA issued the 2015 Preliminary FIRM (P-FIRM) for NYC using new LiDAR data, more recent climatological data (e.g., Tropical Storm Irene and Superstorm Sandy were both included), and more sophisticated hydrologic modeling. The 2015 P-FIRM nearly doubled the building stock located in the 100-year flood zone from 36,000 to 71,500 units

(City of New York Mayor's Office of Recovery and Resiliency, 2015). Nearly twice as many New Yorkers would be required to pay for mandatory flood insurance after this update. The P-FIRM had the potential to aggravate the affordable housing crisis in NYC by expanding the reach of mandatory flood insurance and increasing existing premiums (Dixon et al., 2017). Consequently, the news was not welcomed by affected homeowners (Chen, 2018). Under public pressure to keep housing and insurance rates affordable, NYC pushed back by filing an appeal of the 2015 P-FIRM on scientific and technical grounds (Chen, 2018). The City's appeal was politically motivated, but had to be filed on scientific and/or technical grounds—FEMS's epistemology for creating and revising flood maps. As discussed in the section entitled 'Flood Insurance Rate Maps as Knowledge Systems', the Chief Executive Officer of a community has the sole legal authority to challenge FEMA's flood mapping expertise. The appeal must also be submitted within a 90-day period after a P-FIRM is issued. The New York City Mayor's Office contracted outside engineering firms, which included the design and consultancy firm Arcadis, to conduct the City's flood analysis. NYC's appeal claimed that scientific and technical errors—insufficient extratropical storm model validation and misrepresentation of tidal effects of extratropical storms—lead to the P-FIRM overstating the BFE by over 2 ft in many areas and presenting 35% larger SFHA boundaries (City of New York Mayor's Office of Recovery and Resiliency, 2015). However, NYC elsewhere claimed that the initial reason for the appeal was that "the revisions will assist New York City in making coastlines more resilient and climate ready, while ensuring homeowners are not required to purchase more insurance than their current flood risk requires" (City of New York, n.d.). The appeal was an attempt to reduce the extent of the new SFHA and

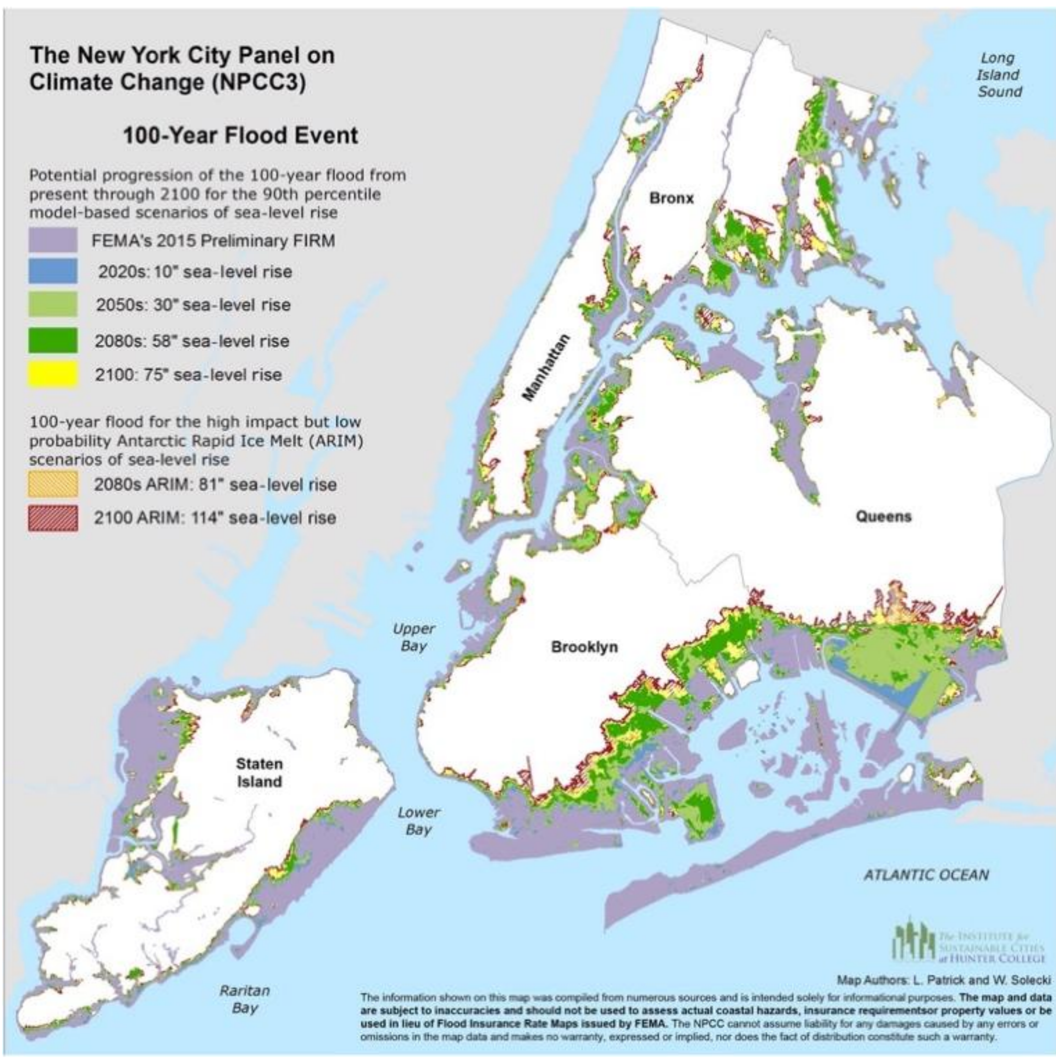
BFE in the P-FIRM (the political goal) while also updating the maps with more recent climate and storm data (the resiliency goal). Rather than 71,500 buildings in the SFHA, the new NYC analysis reduced the number of units to just 45,000—a 37% reduction—as shown on the P-FIRM. The appeal also provided extra time before an update could be issued—effectively saving property owners money as their insurance rates and requirement to purchase flood insurance would continue to be based on the 2007 FIRM SFHA boundaries. The City's appeal was successful. FEMA agreed in 2016 to revise the maps according to the City's analysis. However, as of December 2019, FEMA has still not issued any update to NYC's FIRM. As such, there are now three competing knowledge claims regarding claims regarding New Yorkers' FEMA-delineated flood risk, leaving residents in limbo regarding this risk (e.g., the current regulatory 2007 FIRM, the 2015 Preliminary FIRM, and NYC's flood analysis). While the City's political goal may have been achieved through this appeal, this state of uncertainty is a failure of the flood mapping knowledge system to clearly, timely, and definitively communicate flood risk to property owners for their individual resilience and adaptation decisions. For instance, a prospective homebuyer may unknowingly become vulnerable to floods by purchasing a new home that is within the SFHA on NYC's flood analysis, but does not fall within this zone according to the 2007 FIRM—the map currently used to determine flood risk for a property. For instance, many residents of Staten Island—one of the hardest hit places during Sandy—expressed frustration that they did not know their properties were at risk of flooding at the time they purchased their homes (Moore, 2018). The Morgan family—whose basement was destroyed in Sandy—said they would have at least moved their utilities out of the basement had they known Sandy was predicted to bring 11 ft of flooding—as shown on the P-FIRM—compared to the less than 1 ft shown on the 2007 FIRM (Shaw et al., 2013).

In contrast, there is actually a clear and definitive standard for resolving these competing flood risk knowledge claims for use in building construction at the city level. NYC adopted Local Law 96/13 which modified the City's building code to require all work permits for construction projects to be based on the more restrictive BFE and SFHA of either the 2007 FIRM or the P-FIRM (NYC Buildings, 2014). Additionally, the NYC Commissioner of Buildings issued a rule in 2013 that for buildings in the SFHA, 1 to 2 ft must be added to the BFE in order to determine the Design Flood Elevation (DFE). No dwelling units or mechanical equipment (e.g., electrical and HVAC systems) are permitted in floors below the DFE (New York City Planning Department, 2013). By decoupling the P-FIRM from insurance rate hikes, NYC was able to make use of this valuable knowledge for construction decisions without imposing new or higher flood insurance costs on residents.

While the P-FIRM and NYC's flood analysis incorporated more recent climate data, these maps still do not incorporate any anticipated future flood risk (e.g., sea level rise) for long-term residential or urban planning decisions. NYC addressed this knowledge gap in 2008 by creating a new knowledge system separate from the NFIP. The New York Panel on Climate Change (NPCC) is a panel of experts created by the NYC Mayor's Office to provide analysis of future climate change impacts such as extreme floods. FEMA is now collaborating with the NPCC to create "innovative, climate-smart flood maps" for NYC that incorporate the best available science regarding future sea levels and coastal storms for long-term planning and building purposes, while updating the FIRM to depict current risk for insurance purposes (Federal Emergency Management Agency, 2016). The NPCC recently published its projections of NYC's floodplain for 2100 and compared it to the 2015 P-FIRM (Patrick et al., 2019). The results indicate that the floodplain is likely to expand as NYC experiences additional sea level rise and more intense storm surges (Figure 2.6).

Figure 2.6

Projected 100-year Floodplain through 2100, as Compared to the 2015 Preliminary Flood Insurance Rate Map



Note. Source: Patrick et al. (2019).

The NPCC's anticipatory flood maps are not yet required for NYC's long-term planning decisions, but the City now has access to this valuable knowledge. While the NPCC has been helpful for the City to understand their future flood risk, individual New Yorkers are still largely in the dark. NYC has recently created a new position, Deputy Director of Climate Science and Risk Communication, to serve as a City liaison to the NPCC. There is hope that the creation of this new position may help communicate the NPCC's forward-looking flood risk maps to the general public.

The strategy of decoupling flood risk knowledge from insurance rates is at the core of this knowledge innovation for anticipatory flood resilience decision-making in NYC. Access to resources—money and experts—were also essential. NYC had the resources to convene the expert NPCC panel to produce this knowledge for the City's planning and decision-making. Yet, few cities have NYC's financial and university resources to be able to create an entirely new knowledge system—such as the NPCC—to augment the inadequate FEMA flood maps. From a social justice and equity perspective, it is important that FEMA step in to provide access to future-looking flood risk knowledge for resource-scarce cities. However, there is not a clear path forward for how FEMA will communicate future risks of flooding for community resilience and adaptation decisions. FEMA has been authorized to provide maps of future flood risk since the BWFIRA was enacted in 2012. However, the FEMA Technical Mapping Advisory Council's efforts have been stalled and their final report withheld, preventing legally binding guidance on how FEMA should move forward with communicating future flood risks. In the following section, we discuss some possible options for redesigning the NFIP based on this knowledge system analysis of NYC flood risk mapping.

3. Discussion and Conclusion

Understanding how the FEMA flood map knowledge system works is essential for the adaptive capacity and resilience of cities to climate change and extreme events. These maps guide a myriad of important decisions affecting urban form and community resilience both now and in the long-term future. Homeowners use this information to make individual decisions such as whether to buy a home, carry flood insurance for a home, how high to elevate a home, or simply whether or not to move a generator or other appliances out of their basement or ground floor. Developers use this information to decide where to build and the design of the building. City engineers use this information to determine where and how to build critical infrastructure throughout the city. As the U.S. Department of Homeland Security Office of the Inspector General (US Department of Homeland Security Office of the Inspector General, 2017) reported, it is imperative that we provide accurate and reliable flood risk information to the public, and this will require changes to the flood mapping process, management, and oversight. In essence, the DHS is calling for a knowledge system upgrade or redesign to modernize the flood mapping process given its expanded user network and salience.

As we have shown with the NYC case study, the FEMA flood map knowledge system has several social-political and technical challenges associated with it, including: outdated climate data, lack of anticipatory flood risk knowledge, difficult to interpret and communicate flood risks, lack of consideration of infrastructure or pluvial floods, politically motivated map revisions, a resource-intensive and inequitable revision process, and so on. How well a knowledge system produces quality knowledge for decision-making is not simply a matter of collecting the best scientific data and using the most sophisticated technology to produce a flood map; the distribution of power and authority also greatly influences the quality and accuracy of the knowledge claims produced by the knowledge system (e.g., the SFHA boundaries and BFE of the P-FIRM and NYC flood analyses). In NYC, the social (e.g., the formalized and routinized process of creating map products) and political (e.g., who wins and who loses from map updates, who has authority to challenge flood map knowledge claims, etc.) dynamics have played key roles in the production, review and validation, communication, and use of flood maps over the past four decades. Any redesign will need to address both the social-political and technical aspects of this knowledge system.

You might ask, what would an upgraded or redesigned flood mapping system look like and how could it be accomplished? The low-hanging fruit for an upgrade would be for FEMA to include non-regulatory future flood risk knowledge alongside their official regulatory map products; this would effectively decouple this information from determining insurance rates. As shown in the NYC case study, by decoupling the P-FIRM from insurance rates, NYC was able to use this valuable knowledge for building construction and zoning decisions to improve the long-term flood resilience of the City's built environment. A more transformative change to the entire flood mapping system would be to retire the use of the 100-year and 500-year flood zones given the well-documented misconceptions users have and the false sense of security they give to residents living outside of these zones. This technical change will also be inherently disruptive socio-politically as new federal legislation would need to be written and the entire NFIP – which provides disaster relief to flood victims—would need to be dramatically revised to accommodate this change. This redesign would likely require new legislation from the U.S. Congress. It would also likely require a shift in the values underpinning the knowledge system—which are notoriously difficult to change. Given the magnitude of recent flood disasters like Hurricane Katrina, Superstorm Sandy, Hurricane Harvey, and Hurricane María, it may become necessary to value the protection of lives and property more than is currently done relative to the value accorded to urban development and growth. The Special Flood Hazard Area—which restricts development in the 100-year flood zone—was chosen as a balance between these two values. The NFIP may require a recalibration of our nation's flood risk tolerance and values in order to fix this broken and broke program.

In closing, our analysis of how the FEMA FIRM knowledge system works sheds light on the underlying complex social and political dynamics involved in how we know, review and validate, communicate, and use flood risk knowledge. Knowledge about flood risks is more than the map that results from collecting data and running models to determine "real" flood risk for a property; it is the outcome of a highly contested co-production process between individual residents, experts (e.g., engineers and hydrologists), city officials, federal government agencies, and other stakeholders as they seek to map flood risk while trying to achieve their diverse and conflicting goals (e.g., minimizing flood insurance costs while improving the accuracy of flood maps). Many important technological innovations are being developed to improve how we calculate flood risks, including, for instance, advances in real-time flood sensor systems, sophisticated hydrological models, and use of high-resolution satellite data. These innovations will fall short, however, if they don't also address the non-technical and social aspects crucial to making knowledge systems work. In light of accelerated climate change and extreme coastal events, we suggest that more attention towards understanding flood risk as a knowledge systems problem can further advance resiliency goals for coastal cities.

4. Addendum: The Argument for Inclusive Flood Risk Knowledge Systems

The FEMA FIRM knowledge system is designed by and for technical experts. The knowledge systems analysis performed on the FEMA FIRM knowledge system illustrates the challenges that this knowledge system has in producing usable knowledge for decision-making by citizens, elected officials, and other non-technical actors. For example, while useful for technical actors (e.g., flood insurance agents and city public works engineers) the FIRM knowledge system's reliance on Annual Exceedance Probabilities and return periods produces flood risk knowledge that is often misconstrued by non-technical actors and used in making maladaptive decisions (e.g., purchasing a home that floods repeatedly but that is not labelled as located in a 100-year flood zone).

A recent flood map co-production exercise by Luke et al. (2018) found that stakeholders (e.g., non-profit and community leaders, city planners, natural resource managers) want flood maps that include: (1) quantitative as well as qualitative flood intensity scales to easily interpret the data, (2) flood scenario descriptions that report magnitudes of rainfall or streamflow relative to a specific historic event, (3) depictions of erosion potential, (4) depictions of standing water risk, and (5) depictions of the impact of pluvial floods (current maps are dominated by fluvial flood risk data). Current maps do not provide this knowledge. In short, it is important for FEMA to be aware of the needs of their users. Building more inclusive knowledge systems can help achieve that goal. Creating more inclusive knowledge system practices, such as knowledge co-production (Chapter 3), can help realign the knowledge system with users' needs to advance resiliency goals.

Being inclusive is not just about bringing diverse actors together and understanding their needs. In their comparative analysis of civic flood epistemology and FEMA FIRM epistemology in Puerto Rico, Ramsey et al. (2019, p.15) find that citizen knowledge shows "a more systematic understanding of the relationship between riverine and stormwater flooding, and its residents use their experiences and social networks to learn and prevent damages from floods". By opening-up knowledge systems (Cornell et al., 2013; Leach et al., 2010) – such as the FEMA FIRM knowledge system – to be more inclusive of different actors' needs, values, ideas, and knowledge, FEMA may be able to create non-regulatory products that better meet the needs of a more diverse group of both technical and non-technical actors while adding valuable knowledge that otherwise might be missing from a knowledge system (i.e., pluvial and stormwater flooding in the case of FEMA FIRM). As a result, FEMA may communicate its knowledge claims in a more comprehensive, understandable, and usable format for a broader representation of society to consume. As a federal government agency that provides flood risk knowledge for public consumption, it seems reasonable for FEMA to open-up its knowledge system routines and practices – to non-technical experts and knowledge – so that non-technical experts can improve their individual adaptation or resilience decisions (Luke et al., 2018).

CHAPTER 3

A SOCIAL-ECOLOGICAL-TECHNOLOGICAL SYSTEMS FRAMEWORK OF KNOWLEDGE CO-PRODUCTION

1. Introduction

The traditional loading-dock model of the science-policy interface has failed to deliver actionable knowledge to meet the needs of decision makers in the highly uncertain and complex age of the Anthropocene (Beier et al., 2017). Actionable knowledge is knowledge that people use to create the world (Argyris, 1993). The loading-dock model divorces knowledge making activities from the realm of practice in order to protect the credibility of knowledge. As a result, this approach has led to a knowledge-action gap. Many alternatives have been proposed in the literature to narrow this gap. Chief among them is the concept of knowledge co-production (Norström et al., 2020). Knowledge co-production is often cited as a key knowledge systems innovation for navigating the complexities of the Anthropocene (Harvey et al., 2019). While knowledge co-production has been successful in delivering some theorized outcomes – such as deepening understanding and improving knowledge use – it has not reached its full potential in the expected radical and transformative changes to society, nature, and the built environment that we need to make our cities more equitable, sustainable, and resilient (Jagannathan et al., 2019). In this Chapter, I argue that this shortcoming could be due in part to undertheorizing the interdependencies between social, ecological, and technological systems in which knowledge co-production processes are situated. For instance, the role of power and politics in shaping knowledge co-production processes and outcomes has been neglected in the sustainability science literature (C. A. Miller &

Wyborn, 2018; Wyborn et al., 2019); this field tends to focus too narrowly on the benefits of knowledge co-production and the criteria for successful implementation – neglecting to acknowledge and negotiate the larger social, ecological, and technological contexts in which co-production initiatives take place. Knowledge co-production in the sustainability science literature is framed as a means to an end: a deliberate and intentional organization of actors and knowledge for achieving specific purposes.

In contrast, the science and technology studies (STS) and public administration literatures frame co-production as a natural phenomenon of modern societies. Co-production happens regardless of intent since participants are inevitably embedded within social, political, and material structures. As such, this framing explicitly draws attention to power, authority, and conflict in co-production processes (C. A. Miller & Wyborn, 2018). Recent scholarship over the last few years has been calling for integrating these diverse framings of co-production to provide a richer framework for the design and implementation of knowledge co-production initiatives (Wyborn et al., 2019). In this chapter, I craft a conceptual framework of knowledge co-production that situates a co-production initiative within its broader context. Specifically, I draw from the literature on urban social-ecological-technological systems (Bixler et al., 2019; Grabowski et al., 2017; Grimm et al., 2017; Markolf et al., 2018) to embed knowledge co-production initiatives within their urban social-ecological-technological (SETS) context. By nesting knowledge co-production initiatives within their SETS context, this framework explicitly illustrates how the SETS context both shapes and is shaped by knowledge co-production efforts. While previous frameworks have attempted to situate knowledge co-production within their social and institutional contexts, the principal contribution of my framework is the additional explicit treatment of the couplings between knowledge co-production and the material world (i.e., ecosystems, technological systems).

The SETS Framework of Knowledge Co-production (SETS-FKC) can be used to design and monitor knowledge co-production initiatives to better acknowledge and address the social, ecological, and technological system arrangements with knowledge that shape co-production processes and outcomes – particularly in highly dynamic and complex urban systems. In order to transition our urban systems toward more inclusive, equitable, sustainable and resilient futures, we need to design and implement knowledge co-production initiatives that deliberately acknowledge and plan for the interdependencies in the larger SETS knowledge landscape. More intentional knowledge co-production designs may help give a voice to marginalized actors and perspectives that may otherwise go unheard. More intentional designs may also anticipate tensions, barriers, and legacies in the larger SETS knowledge landscape that could inhibit achieving the transformative outcomes required to build the sustainability and resilience of urban systems. By reconceptualizing knowledge co-production as situated within a particular SETS knowledge landscape, we can begin to design knowledge co-production initiatives to achieve more transformative outcomes.

In Section 2, I discuss the evolution of the science-policy interface from the loading-dock model to the development of the knowledge co-production model to show the utility of this mode of knowledge production in closing the knowledge-action gap. In Sections 3 and 4, I synthesize the literature on co-production from sustainability science, STS, and public administration to present an integrated concept of co-production. In Section 5, I bring insights from recent scholarship on urban SETS to reconceptualize knowledge co-production as situated with urban SETS. In Section 6, I present the SETS-FKC and discuss how to operationalize it in practice. In Section 7, I conclude with a few comments for why we must reconceptualize knowledge co-production as situated within its urban SETS knowledge landscape in order to improve its chances of achieving its theorized "great expectations" (Jagannathan et al., 2019).

2. The Science-Policy Interface

2.1. The traditional loading-dock model of the science-policy interface

The science-policy interface refers to the type of interaction – or lack thereof – between the producers of scientific knowledge (e.g., scientists) and users of this knowledge (e.g., decision makers). By decision makers, I employ an inclusive definition including government agencies, civic or non-profit organizations, businesses, and individual landholders (J. M. Grove et al., 2016). There are several frameworks of the science-policy interface and suggested approaches for improving the uptake of scientific knowledge. The literature identifies two broadly defined modes of knowledge production and use: Mode 1 (Gibbons et al., 1994) or the loading-dock mode (Cash et al., 2006), and interactive producer-user relationships like co-production (Bremer & Meisch, 2017; Lemos & Morehouse, 2005). The loading-dock model encompasses the linear mode of knowledge production where scientists produce knowledge and then drop it off on 'loading-docks' to be picked up and used by decision makers (Cash et al., 2006). The loading-dock approach intentionally keeps science separate from policy and decision-making with the goal to ensure that the science remains unbiased by political interests. The loading-dock model is inclusive of several variants (Beier et al., 2017). In the traditional ivory tower approach (J. M. Grove et al., 2016), scientists independently publish their work (i.e., basic science) in peer-reviewed journals and then that knowledge serendipitously finds its way to decision makers to guide their actions. In scientific consulting, a scientist may seek out clients and produce scientific knowledge tailored to a specific problem. Similarly, decision makers can seek out scientists as consultants. In another variant, intermediaries – who are neither scientists or decision-makers – can take on the role of communicating and translating scientific knowledge for decision-making contexts (J. M. Grove et al., 2016; Sitas et al., 2016)

Some scholars have argued for the need to maintain this boundary between basic science and policy in order to increase the credibility, legitimacy, and salience of the knowledge produced (Cash et al., 2003b, 2006). If scientists were to advocate for particular decisions or policies based on their research, those actions would undermine the credibility of their science – rendering the science as unusable (Cash et al., 2003). Similarly, if decision makers directly take part in the production of scientific research, the resulting scientific knowledge may be considered tainted by political interests (i.e., lacking credibility) and therefore also potentially unusable (Cash et al., 2003). If the knowledge produced inadvertently happens to be salient to a particular problem and also meets a decision maker's spatial (e.g., jurisdiction, watershed, etc.) and temporal scales (e.g., political tenure, budget cycle, etc.), then it may have a chance of being used (Beier et al., 2017; Lemos et al., 2012). Maintaining the boundary between science and decision-making may possibly increase the credibility and legitimacy of the science, but it may very well simultaneously decrease the relevance or saliency to decision-making as the knowledge produced – in the ivory tower – may be out of sync with a decision maker's needs. As such, managing the relationships between credibility, legitimacy, and salience is a persistent challenge at the science-policy interface (Cash et al., 2006; Daly & Dilling, 2019; Tang & Dessai, 2012).

2.2. Criticisms of the loading-dock model

There are several main criticisms of the loading-dock model. Some scholars argue that this linear model of knowledge production doesn't accurately represent the science-policy interface in practice and call for a more nuanced understanding (Owens et al., 2006). For instance, empirical results draw attention to the failure of the loading-dock approach in connecting peer-reviewed literature (i.e., the giant loading dock) to management action (Koontz & Thomas, 2018). Moreover, Mode 1 knowledge production has historically not been very effective at producing usable knowledge in decision-making contexts where the decision stakes are high and the knowledge about the problem is highly uncertain – such as sustainability and resilience problems (Beier et al., 2017; Funtowicz & Ravetz, 1993). When the consequences of decisions are ambiguous and knowledge about the problem is uncertain (Leach et al., 2010), new modes of knowledge production and use are required. Expertise for these problems is no longer the sole purview of scientists; according to Ludwig (2001), no such experts exist for these types of problems.

As such, scholars argue that given the unpredictable and highly dynamic conditions of the Anthropocene, a redesign of knowledge systems is critically needed to open up knowledge systems to integrate a plurality of diverse perspectives, embrace uncertainty, build anticipatory capacities, and increase stakeholder participation from across all sectors of society (Cornell et al., 2013; Feagan et al., 2019; Leach et al., 2010; T. A. Muñoz-Erickson et al., 2017).

2.3. Knowledge co-production as a knowledge systems innovation

There are many models and strategies proposed to better translate knowledge into action to guide the complex decisions of the Anthropocene (Beier et al., 2017; J. M. Grove et al., 2016; Kirchhoff et al., 2013; Meadow et al., 2015). These new approaches include participatory research, Mode 2 science, interactive research, post-normal science, social learning, civic science, transdisciplinary collaboration, joint knowledge production, action research, engaged or use-inspired scholarship, and knowledge co-production (Funtowicz & Ravetz, 1993; Gibbons et al., 1994; Hegger et al., 2012; Nordgren et al., 2016; Pahl-Wostl et al., 2007; Paul et al., 2018; Scholz & Steiner, 2015; Wyborn et al., 2019). Some scholars argue that the knowledge co-production concept is malleable: it encompasses all of these non-traditional approaches that expand the involvement of non-scientific actors into the knowledge production process (Norström et al., 2020).

In stark contrast to the loading-dock model, knowledge co-production calls for deliberate methods to democratize the knowledge production process by uniting diverse sectors of society together in the co-production of knowledge – including scientific and technical, interdisciplinary, local, tacit or experiential, and indigenous knowledge – to guide decision-making (Mach et al., 2019). Among its promised benefits, co-production is thought to deepen understanding, strengthen communities, increase knowledge usability in planning, and catalyze action (collectively called Scope 1 outcomes; Jagannathan et al., 2019). Knowledge co-production is also thought to have the potential to result in transformational or radical changes to social and natural systems (called Scope 2 outcomes; Jagannathan et al., 2019).

Knowledge co-production has been gaining significant attention in the sustainability science literature over the past decade (Bremer & Meisch, 2017). It is widely recognized in the literature as a critical innovation needed for navigating the complexities of the Anthropocene, yet how to best approach co-production processes remains unsettled (Harvey et al., 2019). Section 3 introduces the diverse intellectual histories of co-production and establishes part of the theoretical foundation for the development of the new SETS Framework of Knowledge Co-production.

3. Framing co-production

The concept of co-production has several independent intellectual origins – which occasionally overlap – including public administration (Brudney & England, 1983; E. Ostrom, 1973; Parks et al., 1981), science and technology studies (Jasanoff, 2004; Latour, 1990), and sustainability science (Cash et al., 2003a; Kates et al., 2001; Lemos et al., 2018). While a brief overview of these strands is provided in this section, an in-depth account of these diverse intellectual histories is provided by Miller and Wyborn (2018). In addition, Wyborn et al. (2019) present a synthesis of these three literature streams with the goal to contribute to the theory and practice of co-production in sustainability science. A typology of various lenses of co-production and how it is used across various literature strands is provided by Bremer and Meisch (2017).

3.1. Co-production in public administration

Co-production first appears in the public administration literature in the 1970s to describe the activities that citizens and public agents do to co-produce the design and delivery of public services (Garn, 1976; E. Ostrom, 1973; V. Ostrom & Ostrom, 1977a, 1977b; Percy, 1978). Garn et al. (1976) argue that the consumer is inherently part of public service production process – not just as a recipient. Public services are jointly produced by consumers (e.g., citizens, clients) and service providers (e.g., local governments, public institutions). Brudney and England (1983) conduct a review of the public administration literature and developed the following definition:

> "the coproduction model is defined by the degree of overlap between two sets of participants—regular producers (e.g., service agents, public administrators) and consumers (e.g., citizens, neighborhood associations). The resultant overlap represents joint production of services by these two groups, or 'co-production". (p. 63)

Public administration scholars have documented the co-production of services including public education (Davis & Ostrom, 1991), policing and security (E. Ostrom et al., 1978), healthcare (McMullin & Needham, 2018), and environmental services such as waste removal, and energy and water provision (Ranzato & Moretto, 2018). For instance, citizens can call into a police department to provide information that can lead to the arrest of a criminal or the return of stolen belongings - the production of the service. As such, citizens become co-producers of community security services along with police forces through the contribution of their activities (E. Ostrom et al., 1978). Similarly, the provision of public infrastructure services is co-produced. A resident may report the existence of poor performing infrastructure (e.g., potholes, flooding on roads, etc.) to their municipal representatives who then may act to repair the service. Residents may also provide input in community meetings on the funding, design, and placement of future infrastructure projects – ultimately influencing the provision of that service.

The meaning of co-production in this literature goes beyond citizens simply providing information or knowledge to public agencies; it also includes conflict, negotiation, and agreement between parties regarding the design, function, and evaluation of public services. This literature acknowledges the fundamental political nature of public service co-production in the exertion of power between public agencies and citizens in the pursuit of each party's particular goals and agendas (C. A. Miller & Wyborn, 2018; E. Ostrom et al., 1978). Power and conflict are unavoidable and must be acknowledged and negotiated in the co-production of services. The public administration literature uses co-production as a lens to understand the relationships, power imbalances, and conflict between public service providers, and their consumers. Co-production is a descriptive analytical tool in this literature rather than a normative goal to engage citizens in public service design and delivery to improve service (C. A. Miller & Wyborn, 2018). Framed in this way, this lens of co-production is used to help acknowledge and negotiate the unavoidable conflicts and power asymmetries between parties in order to improve public services.

3.2. Co-production in science and technology studies

Co-production in the science and technology studies (STS) literature focuses on how nature and society mutually constitute each other (Bremer & Meisch, 2017; Jasanoff, 2004; Latour, 1990, 1991). This framing of co-production was influenced by the constructivist theory of science; the idea that scientific knowledge is co-constructed rather than objective truth (Latour & Woolgar, 1979). Scientific knowledge is assembled not just by scientists, but through socially distributed work by regulatory agencies, the law, the public, and funding agencies (Jasanoff, 1990, 1995; C. A. Miller & Wyborn, 2018; Nowotny, 1993). According to this framing, the science-policy interface cannot have an impenetrable border; science cannot be completely divorced from politics and vice versa.

The common adage in this literature – the idiom of co-production – is that social order and natural order are co-produced. Jasanoff (2004), arguably one of the most influential authors of co-production in the STS field, states that "science and society are, in a word, co-produced, each underwriting the other's existence" (p. 17). In other words, how we know the world eventually makes the very world that we seek to understand. Employing the idiom of co-production, Miller and Wyborn argue that co-production "fashions the state of the world and everything in it: interdependent forms of knowing and imagining, along with the social, ecological, material, and technological arrangements that both shape and are shaped by them" (2018, p. 3). Jasanoff's idiom of co-production is used throughout the STS literature as a lens to analyze the co-production of artifacts, institutional routines and practices, knowledge, social orders, and power relations.

Like public administration, the STS literature views co-production through a descriptive lens; it does not dictate how co-production should happen. Instead, co-production in the STS literature focuses on unpacking the various inherent relationships and interdependencies between science, society, and nature (Bremer & Meisch, 2017; Jasanoff, 2004; Mach et al., 2019). The STS literature explores how science, society, and nature both make and remake each other (Bremer & Meisch, 2017).

3.3. Co-production in sustainability science

Due to the complex nature of sustainability problems and the failure of traditional (e.g., loading-dock) approaches to meet the needs of decision makers, sustainability scientists have been calling for co-production as a *means* to solve today's sustainability challenges (Beier et al., 2017; Cash et al., 2003a; Norström et al., 2020). Co-production is viewed as a means to an end, rather than a de facto aspect of contemporary societies. Sustainability science scholars typically employ the co-production concept to narrow the knowledge 'usability gap' (Briley et al., 2015; Lemos et al., 2012; Prokopy et al., 2017). Co-production in this literature places emphasis on bringing together multiple actors from diverse sectors of society to co-produce new knowledge for solving complex sustainability challenges. As in the public administration literature, there is a recognition that no experts exist in the traditional sense, but that all knowledge has merit. Norström et al. (2020) state that:

> "Researchers and practitioners alike are turning to knowledge co-production as a promising approach to make progress in this complex space…These approaches reject the notion that scientists alone identify the issue, research the problem, and then deliver knowledge to society, in favour of more interactive arrangements between academic and non-academic actors" (p. 1)

As in the case above, sustainability scholars tend to mention knowledge along with co-production (i.e., knowledge co-production). This reflects the emphasize on the co-creation of knowledge by diverse groups of actors rather than other products (e.g., public services). A large body of work in the sustainability science literature focuses on determining the factors that make knowledge usable or actionable, including its fitness, for decision-makering through the use of knowledge co-production (Cash et al., 2003a;

Clark et al., 2016; Lemos et al., 2012; Lemos & Morehouse, 2005; McNie, 2007). Co-production tends to be defined in sustainability science literature as "substantive interactions between producers and users of knowledge that results in knowledge that fits decision contexts" (Mach et al., 2019, p. 30). The sustainability science literature is saturated with how-to guides and principles for how to design co-production efforts in the pursuit of producing usable knowledge and meeting sustainability goals (Beier et al., 2017; Norström et al., 2020). For instance, Norström et al. (2020) argue that knowledge co-production initiatives should be context-based (situated in a particular context or place), pluralistic (integrating multiple ways of knowing and acting), goal-oriented (clearly defined, and shared goals), and interactive (on-going learning, frequent interactions between participants) in order to be successful.

In the sustainability science field, knowledge co-production is highly regarded as an effective way of translating knowledge to action (Beier et al., 2017; Bremer & Meisch, 2017; Jagannathan et al., 2019; Mach et al., 2019; Norström et al., 2020). For instance, Dilling and Lemos (2011) found that each of their empirical cases of successful uptake of seasonal climate forecasts involved some amount of interaction between both producers and users of climate forecasts. Given its promise to deliver more usable knowledge, the sustainability science literature frames co-production as a normative goal – a process that *should* be intentionally designed and implemented to increase knowledge uptake in decision-making – rather than a de facto aspect of reality (Cash et al., 2003a; Lemos et al., 2018; Norström et al., 2020). Lemos et al. (2012) claim that co-production efforts narrow the knowledge 'usability gap', especially for complex sustainability issues like applying climate knowledge. This makes co-production in sustainability science distinct from the public administration and STS literatures that view co-production primarily in a descriptive sense (Bremer & Meisch, 2017; C. A. Miller & Wyborn, 2018; Wyborn et al., 2019). Yet, recent critical scholarship on knowledge co-production has been questioning this underlying assumption that knowledge co-production is the most suitable approach in all situations and contexts (Jagannathan et al., 2019; Lemos et al., 2018; Turnhout et al., 2020; Wyborn et al., 2019). This critical body of scholarship is calling for more attention to the particular contexts and circumstances that warrant co-production (Lemos et al., 2018) and question if co-production initiatives are actually achieving the great expectations that co-production promises (Jagannathan et al., 2019). Jagannathan et al. (2019) empirically find that knowledge co-production initiatives tend to improve understanding, strengthen communities, and increase knowledge usability (i.e., Scope 1 outcomes). However, they find that knowledge co-production has failed to deliver on its promises for social transformation and empowerment (i.e., Scope 2 outcomes; Jagannathan et al., 2019). This could be due in part to the lack of recognition of the role of power and politics in the sustainability science framing of co-production. Miller and Wyborn (2018) critique sustainability science's normative framing of co-production and argue that this literature "too sanguinely assumes that social transformation through the application of science will occur peacefully, without conflict, power, or force. This is a mistake, as both STS and public administration analyses of co-production frequently make evident" (p.3). The next section details the attempt by various scholars to integrate these three literature streams to produce a more holistic concept of co-production to guide knowledge co-production efforts and promote transformative change.

4. Integrating co-production lenses

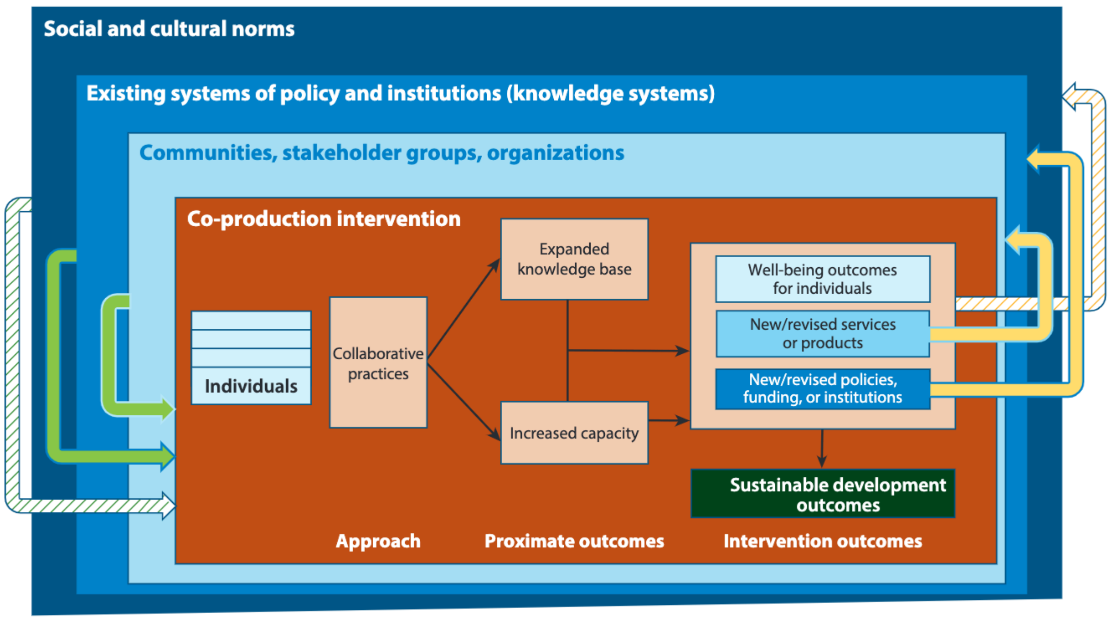
Some recent studies have attempted to integrate the normative and descriptive lens of co-production across the public administration, STS, and sustainability science literatures to construct a more holistic approach to design and analyze knowledge co-production initiatives (Daly & Dilling, 2019; Mach et al., 2019; C. A. Miller & Wyborn, 2018; Wyborn et al., 2019). Mach et al. (2019) call for knowledge co-production research to move beyond these simplistic normative and descriptive framings to focus on the complex socio-political and institutional contexts in which knowledge co-production initiatives are embedded. Despite the best intentions of practitioners of knowledge co-production, if they neglect to recognize the institutional cultures, organizational routines and practices, and epistemologies of various stakeholders in which a co-production initiative takes place, such co-production efforts are likely to have little impact (Mach et al., 2019). Similarly, Wyborn et al. (2019) argue:

> Co-production is an inherently political act, as it seeks to connect what we know about a problem with policies and actions that seek to change how that problem is addressed. This requires individuals and organizations engaged in these practices to acknowledge their role in motivating social and political change and attend to the tensions and trade-offs therein (p.21).

The use of the term inherent by Wyborn et al. (2019) above is telling. It is employing the STS framing of co-production – it is a fundamental aspect of reality. At the same time, this statement also reflects that there are individuals and organizations engaged in intentional knowledge co-production initiatives – reflecting the normative lens from sustainability science. Wyborn et al.'s (2019) conceptual model of co-production (Figure 3.1) integrates these two framings; it illustrates how knowledge co-production initiatives and their desired outcomes are nested in and interact within their larger socio-political and institutional contexts.

Figure 3.1

Nested Conceptual Framework of Co-production



Note. Source: Wyborn et al. (2019). Used with permission from Annual Reviews Inc.

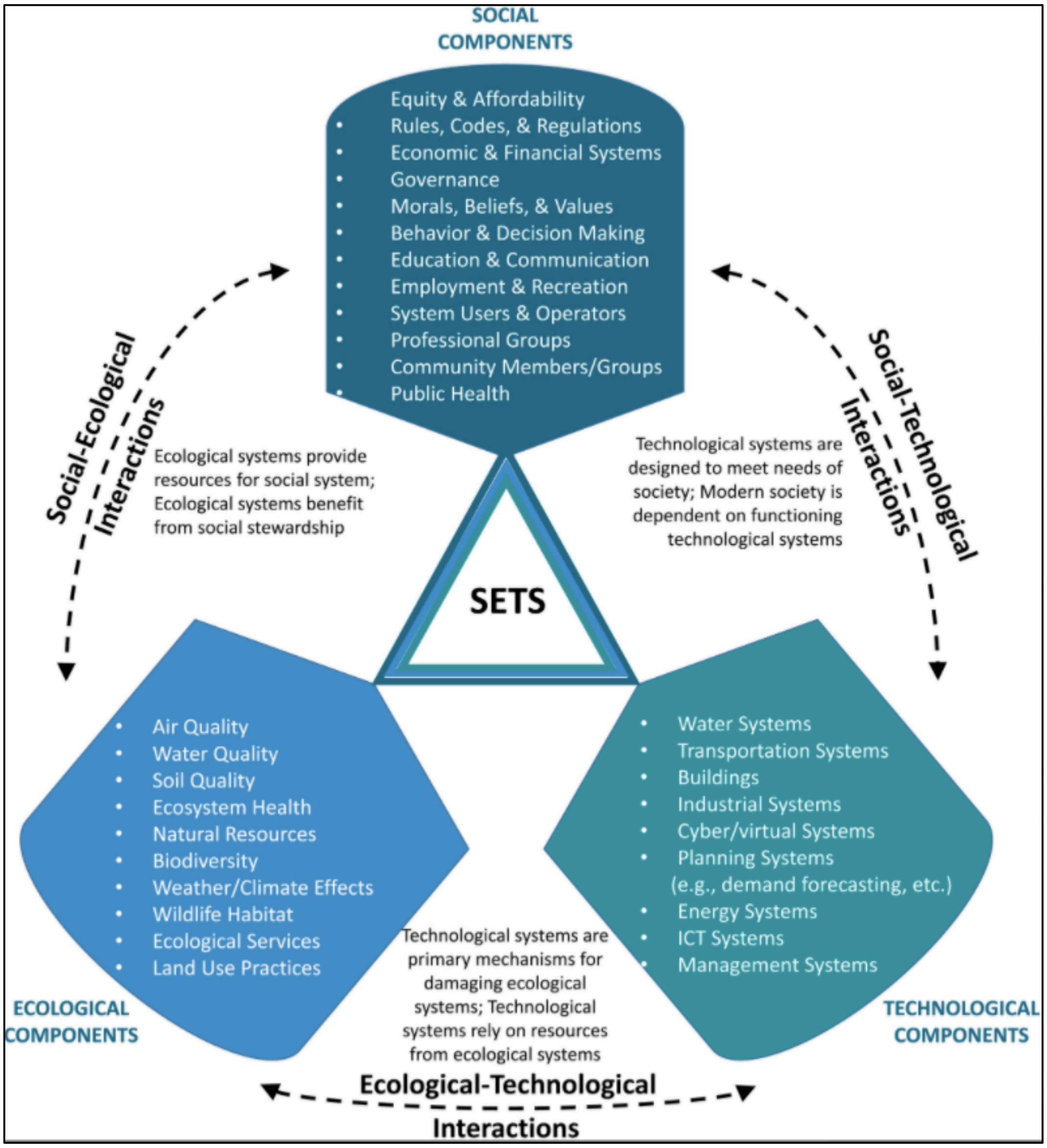
The interdependencies shown in Figure 3.1 between the co-production intervention's outcomes and their broader sociocultural context indicate that co-production interventions have the potential to transform or alter the systems in which they are embedded. Jagannathan et al. (2019) classifies the transformation of social, political, and institutional systems as Scope 2 outcomes (see Section 3.3). The conceptual framework for co-production that I present in Section 6 integrates the STS framing of co-production with the sustainability science framing of co-production; it is a modified version of Wyborn et al.'s (2019) conceptual framework with the addition of Jagannathan et al.'s (2019) Scope 1 and Scope 2 outcomes. Wyborn et al.'s (2019) conceptual model fails to explicitly show the full extent of the interdependencies between the natural and social orders that Jasanoff's (2004) idiom of co-production calls for. By employing a SETS perspective, the SETS-FKC (see Section 6) is a more holistic conceptualization of knowledge co-production initiatives that recognizes the inherent co-production of social, ecological, and technological systems. In the next section, I present the concept of SETS as conceptualized by various urban scholars.

5. Urban social-ecological-technological systems

Urban scholars argue for an integrated social-ecological-technological systems (SETS) lens through which to analyze urban systems and spaces (Bixler et al., 2019; Grabowski et al., 2017; Grimm et al., 2017; Markolf et al., 2018). These scholars call for integrating social-ecological systems perspectives (Berkes et al., 2003; Folke, 2006; B. Walker et al., 2004) with socio-technological systems perspectives (Bolton & Foxon, 2015; Hollnagel, 2014; A. Smith & Stirling, 2010). Moreover, the oft-overlooked interdependencies between ecological and technological systems (i.e., ecological-technological systems perspectives) are brought to the fore in these SETS frameworks (Grabowski et al., 2017; Markolf et al., 2018). For instance, urban infrastructure is traditionally thought of only along the technological dimension. However, technological systems often damage ecosystems when constructed and operated (e.g., dams, pipelines, water reclamation facilities), but they also rely on ecosystem services to function (Markolf et al., 2018). Concurrently, modern societies and metropolitan areas are dependent on infrastructure to function. As such, Markolf et al. (2018) reimagine infrastructure not in the traditional sense, but instead as “complex and interconnected social, ecological, and technological systems” (p.1638).

Figure 3.2

Illustration of the Social-Ecological-Technological Systems Components and Interactions for Urban Infrastructure Systems.



Note. Source: Markolf et al. (2018). Used with permission from John Wiley and Sons.

Bixler et al. (2019) expand this concept further by applying a SETS lens to entire urban metropolitan systems – not just for conceptualizing infrastructure in an integrated fashion; their framework integrates the social, ecological, and technological dimensions of urban systems and argues that metropolitan areas should be modeled as complex systems of interactions between diverse actors and processes intertwined with social and governance networks, political systems, institutions, policies and plans at various geographical and institutional scales (Bixler et al., 2019; Grabowski et al., 2017).

The interdependencies of the various dimensions of urban systems are clearly seen during disasters. Disasters are typically thought of as 'natural' disasters in public discourse. However, disasters have long since been recognized by scholars as largely the result of social or human factors (Smith, 2006). Our decisions for where and how to build houses and infrastructure, how to maintain or adapt that infrastructure, and the adaptive and anticipatory capacities of institutions and communities play a large role in accelerating or mitigating losses (both human and material) to disasters. For instance, Muñoz-Erickson et al. (2017) show that improvements in urban infrastructure design and function rest on upgrades to urban knowledge systems – the routines and processes for generating, validating, communicating, and using knowledge in policy and decision-making.

The disaster wrought by Hurricane Katrina is an illustrative case of the interdependencies between the social, ecological, and technological dimensions in urban contexts. The American Society of Civil Engineers admit that the US Army Corps of Engineers' infrastructure design standards and assumptions were a primary reason for levee failure during Hurricane Katrina (American Society of Civil Engineers, 2007). Of the many knowledge system failures, The USACE's faulty assumption to not consider land subsidence – which was a well-documented trend in New Orleans – resulted in levees that were a full two feet lower than the required design standards in some areas of the city (American Society of Civil Engineers, 2007). The USACE also failed to update its own levee design standards to accommodate the revised knowledge from the National Weather Service: maximum hurricane wind speeds in New Orleans were likely to be 151-160 mph as compared to the outdated estimates of 101-111 mph and the resulting storm surge that the levees were designed to protect against. In short, USACE's faulty assumptions and outdated knowledge worsened Hurricane Katrina's impact; it was as much a human-made disaster (i.e. a knowledge system failure) as a natural disaster (Miller & Muñoz-Erickson, 2018).

Section 6 below integrates this urban SETS lens with insights from STS and sustainability science to develop a more holistic model of knowledge co-production initiatives in urban contexts: the SETS-FKC.

6. SETS Framework of Knowledge Co-production

6.1 Couplings between knowledge and social systems

The SETS analytical lens described in Section 5 for conceptualizing urban systems complements Jasanoff's idiom of co-production (Jasanoff, 2004). The idiom of co-production is often used as a heuristic to explore the dynamic couplings between decision-making arrangements (e.g., governance systems) and knowledge systems; it helps to unpack how various governance arrangements shape knowledge systems, and how knowledge systems shape governance arrangements (Muñoz-Erickson, 2014a). Jasanoff describes the idiom of co-production as:

> Shorthand for the proposition that the ways in which we know and represent the world (both nature and society) are inseparable from the ways in which we choose to live in it. Knowledge and its material embodiments are at once products of

social work and constitutive of forms of social life; society cannot function without knowledge any more than knowledge can exist without appropriate social supports. (Jasanoff, 2004, p. 2)

As seen in the description above, the emphasis of the idiom of co-production is on the couplings between knowledge-making and social order. Miller and Muñoz-Erickson (2018) use the idiom of co-production to show how knowledge-making and decision-making arrangements co-evolve together into tightly coupled dynamic relationships that make it difficult for new knowledge and ideas to get taken up. As decision-making and knowledge-making arrangements tighten, they become obdurate to change. The creation of new knowledge-making routines and practices, like knowledge co-production initiatives, challenges existing couplings between knowledge-making and decision-making arrangements (Miller & Wyborn, 2018; Turnhout et al., 2020). Such knowledge innovations become difficult to scale as the old self-reinforcing knowledge-decision arrangements resist change (the landscape of existing knowledge and decision-making arrangements). As discussed in Section 3.3, this consideration is often neglected when designing and implementing knowledge co-production initiatives (Miller & Wyborn, 2018). This resistance, or obduracy, to knowledge innovation was clearly illustrated in Chapter 2 where I analyze attempts to update the FEMA flood mapping knowledge system in New York City. The FEMA flood risk mapping process produces regulatory flood maps – through a highly regulated and routinized process (Figure 2.1) – that are then used by insurance agents, homeowners, and city officials to make key decisions. I show how the FEMA flood mapping knowledge system has become tightly coupled with decision-making arrangements for whether or not to purchase flood insurance, buy a home, or build a property in a FEMA-delineated flood zone. New knowledge (e.g., new flood observations from Irene and Irma, sea level rise projections) all experienced significant resistance in being integrated into the tightly coupled knowledge-making and decision-making arrangement. As a result of the obduracy between these knowledge-making and decision-making arrangements, the FEMA flood maps in NYC have not seen a significant update since 1983. The routines and practices for producing flood maps are designed first and foremost for insurance decisions, regardless of their wide use by a variety of stakeholders. Scholars have called for upgrades like including pluvial flood hazards and using concrete reference points rather than Annual Exceedance Probabilities (AEP) to make them more useful for non-technical experts (Luke et al., 2018). Given the tight coupling with FIRM, regulations, and insurance decisions, these knowledge upgrades will need to be divorced from the current regulatory FIRM and instead be part of the growing non-regulatory flood map products being created by FEMA (Chaper 2; Luke et al., 2018).

6.2. Couplings between knowledge and technological systems

While the idiom of co-production has been used by scholars to unpack the dynamic interdependences between knowledge and society, few have applied it to conceptually or empirically analyze the material (technological and ecological) couplings with knowledge-making. The SETS lens (Section 5) invites one to think more critically about not just the dynamic interactions between social (e.g., governance, and decision-making) systems and knowledge-making, but also how the material world (i.e., ecological, and technological dimension) dynamically interacts with knowledge systems.

The idea that material artifacts have agency in affecting social systems predates the idiom of co-production and urban SETS concepts – it has roots in other STS scholarship (Winner, 1980). STS scholars developed the concept of techno-politics over the past several decades to illustrate this phenomenon (Hommels, 2005, 2020; Winner, 1980). In presenting his concept of technological momentum, Hughes (1994) argues that a "technological system can be both a cause and an effect: it can shape or be shaped by society" (p.29). Urban techno-politics conceptually and empirically advances knowledge about the political nature of material artifacts in cities. Foley et al. (2020) define urban techno-politics as "the combination of physical artifacts or other man-made objects that exist within the geo-political borders of the city and are constituted through arrangements of power and authority that embody, or enact political goals" (p. 324). Carse's (2012) Panama Canal case study clearly illustrates how the canal not only has been shaped by social systems, but how it now embodies a political weight of its own on social systems as a global technological artifact. Hughes (1994) claims that as technological artifacts and systems become larger and last longer, they begin to take on 'technological momentum' and resist change. This is similar to Hommels's (2005) concept of 'technological obduracy'; Like decision-making and knowledge-making arrangements, arrangements between technological artifacts and knowledge-making become intricately linked over time. In Chapter 2, the FEMA Flood Insurance Rate Maps (FIRM) are a form of technological artifact co-produced by the knowledge system. This artifact, in the New York City case, has remained mostly unchanged for the past 40 years. There are numerous knowledge systems that are tightly interwoven with the FEMA flood risk knowledge system to maintain the reproduction of this technical artifact (FIRM). One such system is the collection and certification of elevation certificates for homes and buildings. Once a building elevation is measured, validated, and certified it can be used to appeal a flood determination for a property as shown on a FIRM. The building elevation knowledge system and the FIRM knowledge system have co-evolved over time to 'speak' to each other. Attempts to include other ways of knowing, such as personal experience of flooding for a property, have not been successful. In Chapter 2, I also spoke about the use of Annual Exceedance Probabilities that are based on Intensity-Duration-Frequency (IDF) curves. IDF curves are a specific form of standardized engineering and hydrological routines and practices that have been in use for decades. The assumptions, rules, and practices to create IDF curves have also co-evolved with FEMA flood maps to create the 100-year and 500-year return periods that determine their respective flood zones. This engineering analysis has become intertwined with the FEMA FIRM production. As technical artifacts, FEMA FIRM demand technical knowledge – like elevation certificates and AEP. As such, FIRM – the technological artifact – could be viewed as having a form of inherent agency or power in the knowledge production process. Given its nearly forty year history in New York City, it has also developed its own 'technological momentum' (Hughes, 1994) or 'technological obduracy' (Hommels, 2005). Current scholarship on techno-politics hasn't focused enough specifically on how technology and knowledge systems are co-produced, and even less attention has been given to understanding their role in knowledge co-production. The framework I present in this Chapter helps to better connect these diverse literatures together so that knowledge professionals can better understand and articulate the couplings across technological systems and knowledge systems in co-producing knowledge.

6.3. Couplings between knowledge and ecological systems

The SETS lens invites us to also apply it to unpack the couplings between ecological systems and knowledge. A good deal of literature on social-ecological systems highlights the role that institutions, knowledge, and learning have on managing ecosystems and influencing their structures and functions. This literature includes concepts such as adaptive co-management (Berkes, 2009) adaptive governance (Armitage, 2008; Folke et al., 2005; P. Olsson et al., 2006) and co-productive governance (Wyborn, 2015). Wyborn (2015) discusses several empirical case studies that illustrate the role that social-ecological contexts (the material) have on the co-production of knowledge for conservation management. She shows how co-production reproduces relationships between contexts, knowledge processes, and visions that ultimately affect desired conservation outcomes and the success of adaptive governance initiatives.

One of the most compelling examples of knowledge and ecosystem couplings – called scientific forestry – is presented by James Scott in his book *Seeing Like a State*. In it, Scott (1998) explains how scientific forestry had evolved in the late eighteenth century to collect data about forests and model the total commercial output of wood that the state could use to generate revenue. In the effort to develop more sophisticated methods to determine the total commercial yield of a forest, the forest also co-evolved with the new knowledge production system: "through careful seeding, planting, and cutting, a forest [was created] that was easier for state foresters to count, manipulate, measure, and assess" (Scott, 1998, p. 46). The forest was eventually aligned to fit the knowledge production techniques used to understand it: the forest was transformed to be more legible. This example clearly illustrates how knowledge systems interact with the material, ecological world.

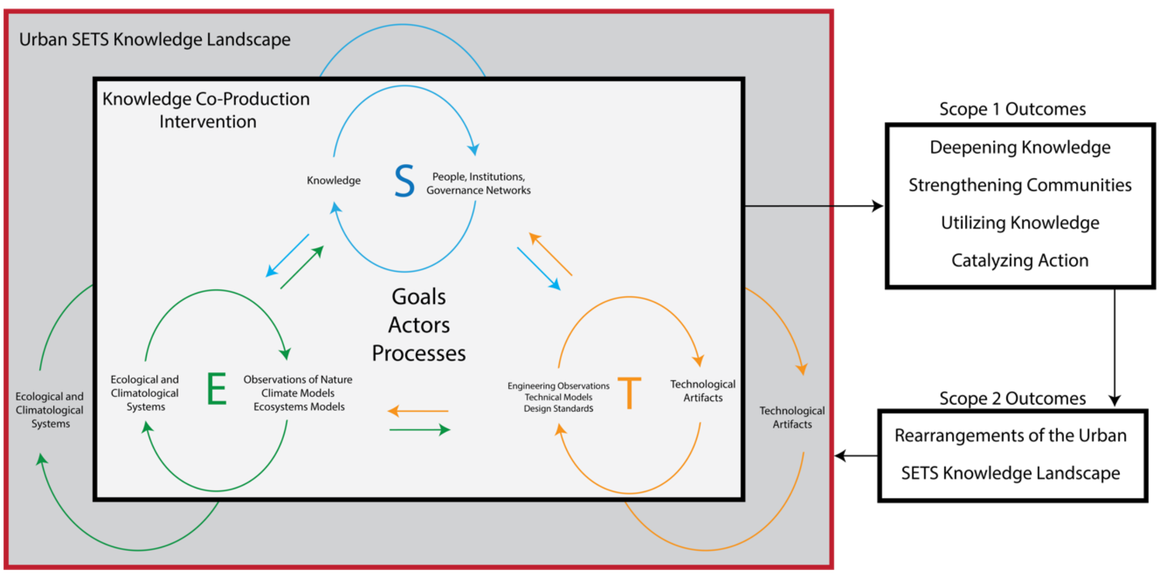
The FEMA case study in Chapter 2 also illustrates the couplings between knowledge and ecological systems. It illustrates the couplings between knowledge and ecological systems not just in a particular knowledge system, but also in the broader SETS knowledge landscape. For instance, there are local, national, and global knowledge systems that produce climate projections for what we expect the climate to be like in the future (Miller, 2004; Patrick et al., 2019; Reidmiller et al., 2018). These knowledge systems exist in the broader SETS landscape, but have not been taken up into the FEMA flood risk knowledge system. FEMA has systems in place to produce their own ecological modelling for predicting where and how floods are likely to occur – models that utilize available *historical* flood observations – not future projections. This shows how there are couplings between climate and knowledge and that one knowledge system may select particular ecological knowledge (historical flood observations at tidal stations and rain gauges throughout the city) at the expense of others (e.g., climate projections from the New York Panel on Climate Change or the National Climate Assessment).

6.4. A new framework of knowledge co-production

As described in Sections 6.1 through 6.3, knowledge is dynamically coupled with social-ecological-technological systems. There is a diverse and vast SETS landscape of existing couplings between knowledge, society, technology, and the environment. Knowledge co-production interventions seek to create new forms of uniting ways of knowing and acting in the world (Wyborn et al., 2019). However, knowledge co-production interventions do not take place in a vacuum; Knowledge co-production interventions are situated within an existing SETS knowledge landscape. I present below the SETS Framework of Knowledge Co-production (SETS-FKC; Figure 3.3) to illustrate how a knowledge co-production intervention dynamically interacts with SETS knowledge (i.e., social, ecological, and technological knowledge) and structures (i.e., people and institutions, technological artifacts, ecological systems) both from within an initiative and between its broader urban SETS knowledge landscape.

Figure 3.3

SETS Framework of Knowledge Co-production



Note. This figure illustrates the interdependencies between deliberate knowledge co-production interventions (consisting of knowledge, goals, actors, processes, and outcomes) and the broader Social (S), Ecological (E) and Technological (T) knowledge landscape in which those interventions are inextricably and dynamically coupled in cities. The components illustrated in the knowledge co-production interventions are mirrored in the urban SETS knowledge landscape. Scope 1 outcomes are often short-lived, whereas Scope 2 outcomes fundamentally rearrange the social, ecological, and technological couplings in the urban SETS landscape.

Figure 3.3 also illustrates the Scope 1 and Scope 2 outcomes that Jagannathan et al. (2019) have identified in the knowledge co-production literature. My framework makes clear that Scope 2 outcomes cannot be achieved without building new forms of knowledge co-production that simultaneously attempt to realign the existing configurations of SETS knowledge and structures in the urban SETS knowledge landscape. New modes of connecting knowledge with action – like knowledge co-production – will select from various knowledges in the SETS knowledge landscape to inform adaptation choices, which led to investments to restore or replace infrastructure or ecosystems, and then led to transformations in the SETS structures and knowledge arrangements over the long-term (Scope 2 outcomes).

6.5. Operationalizing the SETS Framework of Knowledge Co-production

The SETS Framework of Knowledge Co-production can be used to design, monitor, and evaluate knowledge co-production initiatives. This section operationalizes the SETS-FKC by providing a series of key questions for practitioners and researchers to consider when designing, monitoring, and evaluating the outcomes of knowledge co-production interventions. These questions are derived from carefully thinking through the nuances and implications of the dynamic couplings illustrated in Figure 3.3. Table 3.1 presents the questions as written for designing knowledge co-production interventions, but can be readily adjusted for other purposes (i.e., monitoring, evaluation).

Table 3.1

Operationalizing the SETS Framework of Knowledge Co-production

Component	Attribute	Key Questions for Analysis
Existing Urban SETS Knowledge Landscape	Knowledge and Social System (KSS) Interactions	Who are the primary knowledge producers and experts in the city relevant to the problem? Who are the primary decision-makers or users in the city relevant to the problem? What social data and information are relevant to the problem? What existing knowledge-making and decision-making routines, practices, norms, regulations, etc. are relevant to the problem? What difficulties (e.g., tightly coupled knowledge and decision-making routines and practices) do you anticipate encountering in trying to alter the existing knowledge-making and decision-making arrangements? What strategies will you employ to realign knowledge and decision-making practices to achieve your initiatives' goals?
	Knowledge and Technological System (KTS) Interactions	What relevant technological artifacts (buildings, infrastructure systems, software and tools, visualizations and maps, etc.) have been produced that the initiative will try to supplement, update, or replace? What technological data and information are relevant to the problem? What difficulties (e.g., technological obduracies) do you anticipate encountering in trying to alter existing knowledge/technological system arrangements? What strategies will you employ to realign existing knowledge and technological arrangements to achieve your goals?
	Knowledge and Ecological System (KES) Interactions	What environmental or ecological structures matter to your problem? What ecological and climate knowledge are relevant to your problem? What difficulties (e.g., ecosystem legacies, lack of availability of data, etc.) do you anticipate encountering in trying to alter knowledge/ecological system arrangements? What strategies will you employ to realign existing knowledge and ecosystem arrangements to achieve your goals?
	SETS Interactions	What is the extent – if any – of the interactions between the KSS, KTS, and KES knowledge arrangements? Are these SETS interactions tightly or loosely coupled and how? What likely resistances might arise to knowledge co-production from the coupling of knowledge across the KSS, KTS, and KES knowledge arrangements?
Core Knowledge Co-production Initiative	Goals	What will be the goals of the initiative?
	Actors	Who should be part of this initiative? How will the actors deal with power asymmetries from the SETS knowledge landscape and between participants?

	Who will be considered the experts? How will trust be developed between participants? What material artifacts – if any – will the initiative engage with or produce? What agency do they have – if any?
Knowledge	What types of social, ecological, and/or technological knowledge will the initiative engage with? How will the initiative deal with uncertain or incomplete knowledge? How will diverse visions be explored and negotiated to create a shared vision for the initiative?
Collaborative Processes	What characteristics will make this a knowledge co-production initiative? (i.e., diverse actors, frequent interactions, iterative processes, etc.) What will be the quantity and quality of the interactions between participants?
Scope 1 Outcomes	How will the initiative demonstrate evidence – or not – of deepening knowledge and understanding? How will the initiative demonstrate evidence – or not – of strengthening relationships and building trust? How will the initiative demonstrate evidence – or not – of knowledge utilization in planning and policy making? How will the initiative demonstrate evidence – or not – of catalyzing and implementing action on the ground? What opportunities and barriers (obduracies) do you anticipate the SETS knowledge landscape presenting in achieving each of the four Scope 1 knowledge co-production outcomes?
Scope 2 Outcomes	What long-term transformative or radical system changes does the initiative hope to achieve? What SETS knowledge landscape arrangements (KSS, KES, KTS, SETS interactions) will need to be targeted for updating/rearranging to achieve desired long-term transformative outcomes?

Note. The questions are framed for the design (pre-initiative) of the knowledge co-production initiative but can readily be adjusted for monitoring (during the initiative) or for evaluation (post-initiative) purposes.

In Chapter 4, I use many of these questions – derived from the SETS-FKC – to map and analyze two prominent case studies of sea level rise knowledge co-production in the Miami Metropolitan Area. As such, Chapter 4 serves as an example for how to actually perform an assessment of existing knowledge co-production initiatives.

7. Conclusion

The SETS-FKC is designed to be used by both practitioners and researchers as a heuristic to plan for, navigate, and analyze the inevitable SETS forces that a deliberate knowledge co-production intervention will encounter. My framework highlights the role that the SETS knowledge landscape plays not just in the design and outcomes of knowledge co-production, but throughout the entire co-production process. By not acknowledging the multiple existing tightly-coupled knowledge arrangements in the SETS knowledge landscape, co-production interventions depoliticize the co-production process (Turnhout et al., 2020) and undermine the very outcomes they are often intended to achieve (e.g., the empowerment of disenfranchised groups). By designing knowledge co-production initiatives from the outset to address the system obduracies present in the SETS knowledge landscape, initiatives have an improved – though not guaranteed – chance of success. Table 3.1 aids practitioners of knowledge co-production in operationalizing the SETS-FKC to carefully think through how to design initiatives to meet their intended outcomes. The SETS-FKC may help gauge what Scope 1 and 2 outcomes are likely, and what it would take to achieve them given the social, ecological, and technological system obduracy to change (Hommels, 2005; Miller & Muñoz-Erickson, 2018). The SETS-FKC also invites STS, SETS, and urban sustainability scholars to collectively conduct more empirical work to explore the myriad couplings between the material world, social structures, and knowledge co-production to inform how best to use this tool as a form of knowledge innovation for building more resilient cities. In closing, in order to transition our urban systems toward more inclusive, equitable, and resilient futures, knowledge co-production initiatives require concerned action to build new modes of knowledge production while realigning urban SETS knowledge arrangements to facilitate their growth and impact.

CHAPTER 4

KNOWLEDGE CO-PRODUCTION IN HIGHLY POLITICIZED URBAN CONTEXTS: LESSONS FROM THE CO-PRODUCTION OF SEA LEVEL RISE KNOWLEDGE IN THE MIAMI METROPOLITAN AREA

1. Introduction

Knowledge co-production is highly regarded as an effective means of creating more inclusive processes, strengthening communities, deepening knowledge, and linking knowledge to action to achieve short and long-term sustainability outcomes (Bremer & Meisch, 2017; Jagannathan et al., 2019; Lemos et al., 2012; Mach et al., 2019; Norström et al., 2020). Co-production is becoming progressively more common in academia: funding agencies and universities are increasingly asking scholars what the broader impacts are of their research and how they plan to mobilize their knowledge into action using co-production (Arnott et al., 2020). As a consequence, there has been an expansion in co-production scholarship to guide these efforts over the past decade (Bremer & Meisch, 2017; Wyborn et al., 2019). The majority of this knowledge co-production scholarship focuses on creating how-to guides and prescriptions for how co-production should be done to support both practitioners of knowledge co-production and those who seek to invest in these initiatives (Norström et al., 2020; Wyborn et al., 2019).

However, knowledge co-production is not necessarily the silver-bullet for achieving all of its purported outcomes in every circumstance. In particular contexts, other forms of knowledge production – like basic research – may be better suited to achieve specific desired results (Lemos et al., 2018; Turnhout et al., 2020; Wyborn et al., 2019). As such, it is important that sustainability scholars critically reflect on whether or not knowledge co-production's theoretical outcomes are being realized in practice and under which circumstances (Jagannathan et al., 2019; Lemos et al., 2018). Less scholarship has empirically and critically evaluated individual cases of knowledge co-production to explore under what conditions and contexts knowledge co-production is best suited. Lemos et al. (2018) call for future empirical studies to track what stakeholders are doing on the ground and what results they are achieving to inform better decisions for how and when to co-produce. This study seeks to help fill this gap in the literature by empirically analyzing two case studies of knowledge co-production in a highly politicized urban context.

In this Chapter, I ask **how and in what ways has knowledge co-production worked – or not – to achieve its theoretical outcomes in the highly politicized urban context of a flood-prone coastal metropolitan area fighting for its future?** According to knowledge co-production literature, knowledge co-production should deepen knowledge, strengthen communities, improve the uptake of knowledge in decision-making, catalyze action, and usher in radical transformations in some circumstances (Jagannathan et al., 2019). In this study, I will explore each of these outcomes individually to see if and how they are influenced by the unique social-ecological-technological systems (SETS) context present in highly contested flood-prone coastal metropolises like Miami.

In Chapter 3, I synthesized the literature on co-production from various fields to develop a social-ecological-technological systems framework of knowledge co-production. The SETS Framework of Knowledge Co-production (SETS-FKC) has been designed specifically to help identify the conditions and contexts in which knowledge co-production is best suited – the focus of this Chapter. The SETS Framework of Knowledge Co-production includes the components (i.e. goals, actors, artifacts, and knowledge), processes, and outcomes (i.e., Scope 1 and 2) of knowledge co-production initiatives. It also reveals how knowledge co-production initiatives are dynamically coupled within their unique SETS contexts and existing decision-making and knowledge-making arrangements.

In this Chapter, I conduct a rigorous empirical case study analysis of two prominent knowledge co-production initiatives that have taken place in the Miami Metropolitan Area over the past decade: The Southeast Florida Regional Climate Change Compact (Compact) and the Eyes on the Rise (EOTR) project which began in 2010 and 2014 respectively. Knowledge co-production initiatives are characterized by processes that seek to connect diverse groups of actors together in frequent interactions to produce new knowledge and practices, and achieve specific outcomes (Jagannathan et al., 2019; Mach et al., 2019; Norström et al., 2020; Wyborn et al., 2019). The Compact brings together government, civic, business, and academic actors together to co-produce new climate knowledge for urban resilience decisions and policy making in Southeast Florida. The EOTR project brings together academic and civic groups to co-produce new tools and products to help local communities deepen their understanding and awareness of sea level rise impacts to Southeast Florida. Since both initiatives contain the core characteristics of knowledge co-production (i.e., diverse groups of actors, frequent interactions, new knowledge and practices, and target outcomes) I classify them both as knowledge co-production. However, participants do not explicitly identify them as such. In this Chapter, I apply the SETS Framework of Knowledge Co-production (Chapter 3) to analyze each initiative. My analysis is guided by the key questions in Table 3.1 in Chapter 3. Urban areas in general are considered highly complex and contested environments (McPhearson, Haase, et al., 2016). I chose the Miami Metropolitan Area to conduct my case studies due to its highly contested and complex low-lying urban environment – it is representative of many cities around the world and the cities of the future. Currently, more than half of the world's population reside in cities and more than two-thirds of the world's largest cities (greater than 5 million) are located on the coast with less than 5 meters above sea level (Birkmann et al., 2010).

The Miami Metropolitan Area is one of the most urbanized stretches of land along the thousands of miles of US coastline (see Section 2.1). It is also very low-lying and flood-prone; the Miami Metropolitan Area is often referred to as 'ground-zero' for climate change as sea level rise poses an existential threat to the future of the city (Goodell, 2013). According to the Compact's most recent Unified Sea Level Rise Projection (Southeast Florida Regional Climate Change Compact, 2019) the region could see up to 8.6 feet of SLR by the end of the century – threatening to submerge the great majority the Miami Metropolitan Area (Strauss et al., 2015; Wanless, 2018). However, perceptions of uncertainty and incomplete knowledge regarding the future of the city invite heated public debate as to what the future holds. As such, the Miami Metropolitan Area serves as an appropriate location to explore how knowledge co-production initiatives work or not to achieve their purported outcomes in highly complex and contested urban areas.

Lessons from these two case studies in Miami can be instructive for scholars and practitioners in other cities who are and will be going through this in the future with regard to sea level rise or other existential climate impacts like long-term drought. These cases help to determine when and under what conditions knowledge co-production works to achieve its various theoretical outcomes (i.e., strengthening communities, deepening knowledge, utilizing knowledge in decision-making, catalyzing action, and transforming SETS toward more sustainable futures). Results of this study show that knowledge co-production should be conceptualized more broadly as situated within urban SETS rather than as isolated efforts – as it is often conceptualized. Both cases illustrate how powerful local actors – including technological artifacts – can influence knowledge co-production from both within and beyond an initiative. This broader conceptualization may help both researchers and practitioners to better connect knowledge co-production with its elusive transformative outcomes such as community empowerment (Turnhout et al., 2020).

In the next section, I provide a profile of my case study's geographical area (the Miami Metropolitan Area), a detailed account of my research methods, and my analytical framework. I present the results of the Compact and EOTR case studies in Sections 3 and 4 respectively. Section 5 concludes this chapter with a summary of the key lessons learned across both of the knowledge co-production initiatives and implications for practicing knowledge co-production in highly contested urban environments.

2. Methods

Section 2.1 of the Methods Section introduces the Miami Metropolitan Area, its geography, urbanization, demographics, and flood risk profile. This profile serves to show why Miami was chosen to identify case studies of knowledge co-production given its dense urban environment, and current and future flood risk. This is followed by

Section 2.2 which describes the field work I conducted as well as each of the research methods I employed in this mixed-methods case study.

2.1. Miami Metropolitan Area profile

2.1.1. Geography and demographic profile

The Miami Metropolitan Area (MMA) is made up of Miami-Dade, Broward, and Palm Beach Counties – the first, second, and third largest counties respectively in Florida by population. The MMA encompasses 62 unincorporated areas, 55 cities, 31 towns, and 17 villages each with their own administrative units and jurisdictions. Officially, the US Census Bureau classifies the metropolitan area as the Miami- Fort Lauderdale- West Palm Metropolitan Statistical Area. This area was formerly the Miami- Fort Lauderdale – Pompano Beach Metropolitan Statistical Area until 2013 when it was expanded to include all the way up through West Palm Beach. This change reflects the increasing urbanization and growth of the region – it is now the seventh largest Metropolitan Statistical Area in the United States with an estimated population of over six million inhabitants (Table 4.1).

Table 4.1

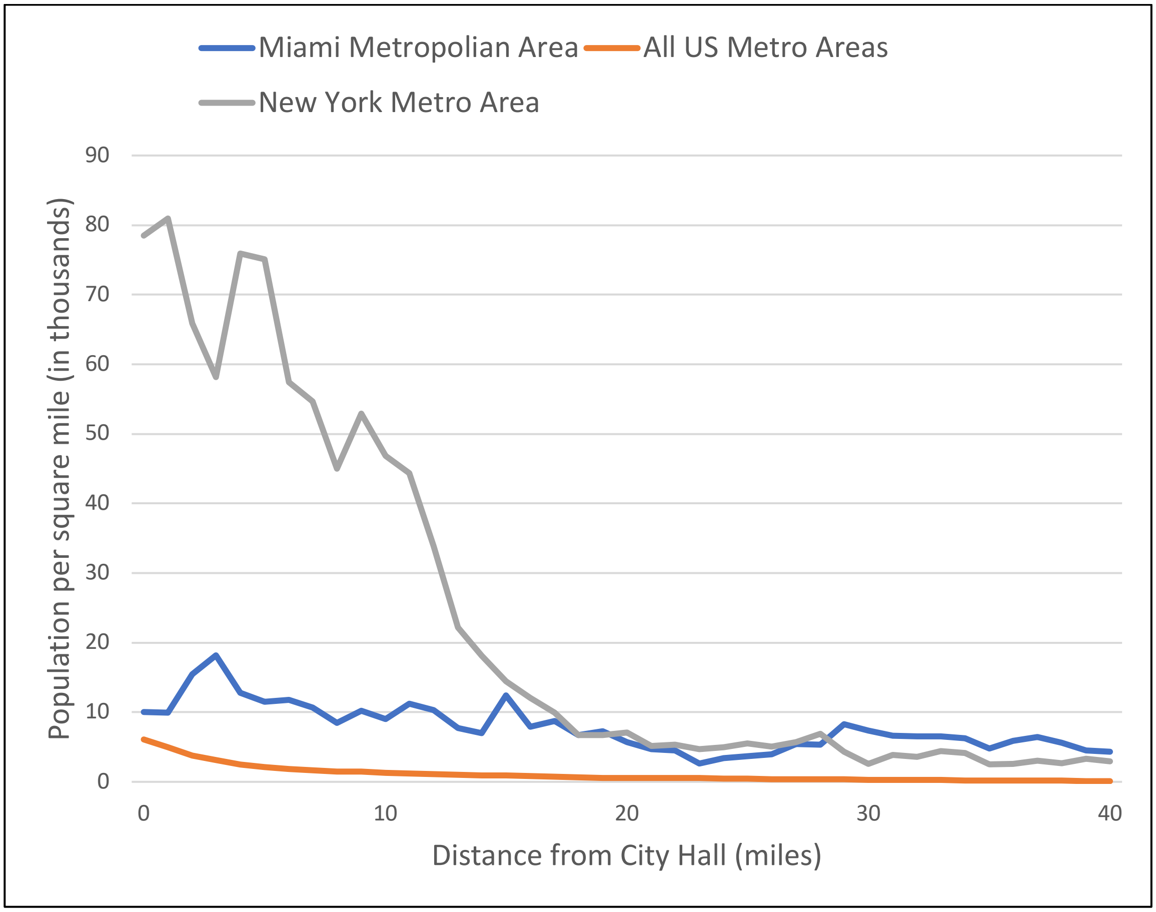
Demographics for the Miami Metropolitan Area, Select Cities, and Monroe County

Area	Population	% Foreign Born	% Foreign Born (Latin America)	% Hispanic	% White	% Black	% Other Race
Metro Area	6,070,944	40.4	86.7	44.7	30.9	20.2	2.9
Miami-Dade County	2,715,516	53.3	93.0	68.0	13.4	16.1	1.9
Broward County	1,909,151	33.7	80.0	29.1	37.2	27.5	4.2
Palm Beach County	1,446,227	25.0	73.8	21.9	55.3	18.1	3.2
Monroe County	76,325	19.1	68.5	23.9	66.9	6.6	1.6
Miami	451,214	58.2	94.3	72.5	10.7	15.1	1.2
Ft. Lauderdale	178,783	24.4	74.4	18.5	47.7	30.5	1.9
West Palm Beach	108,365	27.8	76.4	24.0	37.7	33.7	3.2
Miami Beach	91,826	53.7	70.4	55.6	37.6	3.0	2.8

Note. The Compact encompasses both the Miami Metropolitan Area and Monroe County. As such, I've added Monroe County. Data source: US Census Bureau 2018 ACS 5-yr estimates.

The MMA can be considered one of the most – if not the most – urbanized metropolitan area in the United States. Four of the top seven Metropolitan Statistical Areas are coastal – a reflection of the growing popularity of urban coastal areas in the US (Reidmiller et al., 2018). While New York City is technically the densest metropolitan area, and coastal metropolitan area, its density drops off sharply as you move about 10 miles away from the city center (Figure 4.1). Instead, if you plot a 40 mile radius from each US Metropolitan Statistical Area's city hall – the Miami MSA would clearly have the highest density starting at around 29 miles from the city center and matching that of NYC around at approximately 19 miles (see Figure 4.1).

Figure 4.1
Population-weighted Density by Distance from City Hall for US Metropolitan Areas

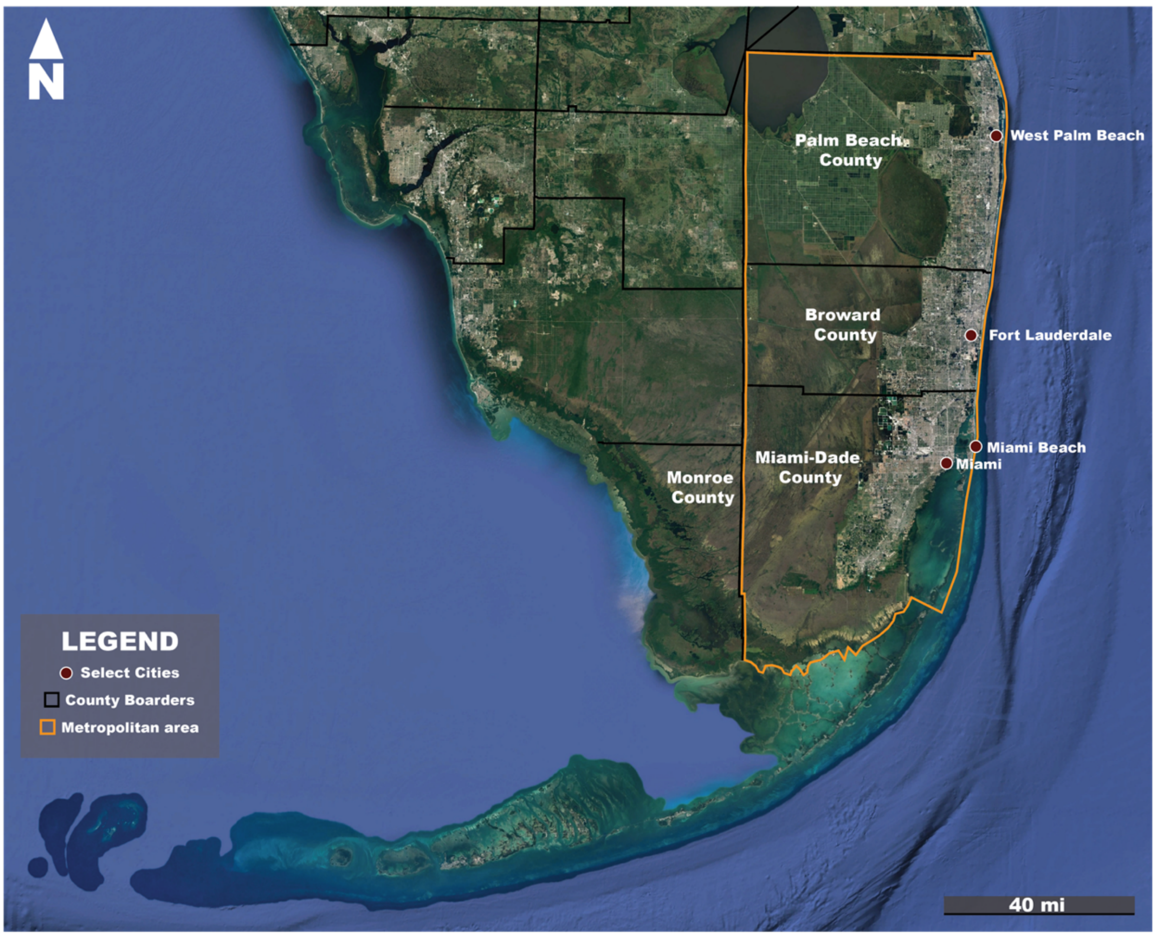


Note. Population-weighted density by distance from City Hall of the Miami- Fort Lauderdale- Pompano Beach MSA in comparison with the New York- New Jersey- Long Island MSA and the average of all MSAs in the United States. Data source: US Census Bureau 2010 Decennial Census. Graph author: Robert Hobbins.

This is due to the fact that the MMA is a very long and narrow conurbation of dense urban coastal development encompassing two large city centers (i.e., the City of Fort Lauderdale and the City of Miami). Its urban density doesn't drop off drastically as in the case of NYC. The great majority of Miami metro residents live within the vertical column of contiguous urbanized land sandwiched between the Everglades to the west and the Atlantic Ocean to the east (see Figure 4.2). The urbanized portion of the MMA hugs the coastline tightly; it is over 100 miles in length but only about 20 miles in width at its widest point.

Figure 4.2

Satellite Imagery of the Miami Metropolitan Area



Note. Satellite imagery of Southeast Florida identifying the Miami Metropolitan Area, the four counties of the Compact, and several major cities within the metro area. The basemap image is from Landsat. Map author: Robert Hobbins.

Figure 4.3 includes various images taken by the researcher from throughout the Miami Metropolitan Area showing its dense urban cores and hardened shorelines.

Figure 4.3

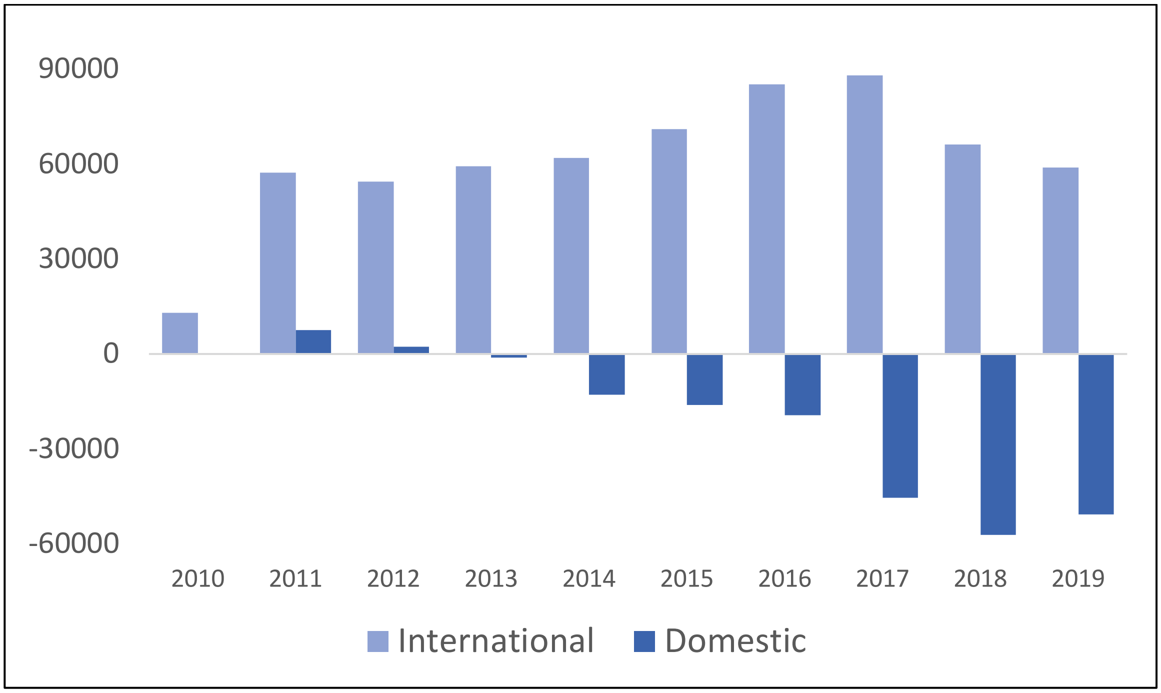
Images of the Miami Metropolitan Area Coastline

Note. Left image: Downtown Miami Skyline as viewed from Virginia Key. Photo taken by the author in October, 2017; Top right image: Downtown Miami's hardened coastline as viewed from across Biscayne Bay on the northwest corner of Brickell Key. Photo taken by the author on April, 2019; Bottom right image: The confluence of the Collins Canal (Miami River) with Biscayne Bay as viewed from the Brickell Avenue Bridge. Photo taken by the author in April, 2019.

The Miami metropolitan area has a peculiar migration pattern affecting its overall demographic makeup. In the five-year period between 2013 to 2018, the MSA increased in population by over 11%. However, this growth metric can be misleading. The MMA has actually been experiencing annual net domestic outmigration since 2013 (see Figure 4.4).

Figure 4.4

Domestic and International Migration Patterns Between 2010 to 2019 for the Miami Metropolitan Area



Note. Since 2013, the metro area has seen annual net domestic outmigration and increasing international immigration to the region. Data source: US Census Bureau ACS 1-yr estimates 2010-2019. Graph author: Robert Hobbins

The MMA's increasing population is attributed to significant international immigration to the area. Between 2010 to 2019, over 615,000 international immigrants have moved to the MMA – a trend showing some signs of slowing down in recent years. As of 2018, over 40% of the population is estimated to have been born outside of the United States. Of those born internationally, 86% arrived from a Latin American nation. Table 4.1 shows how these population dynamics have influenced the demographic makeup of the metropolitan region and a few of its major cities today.

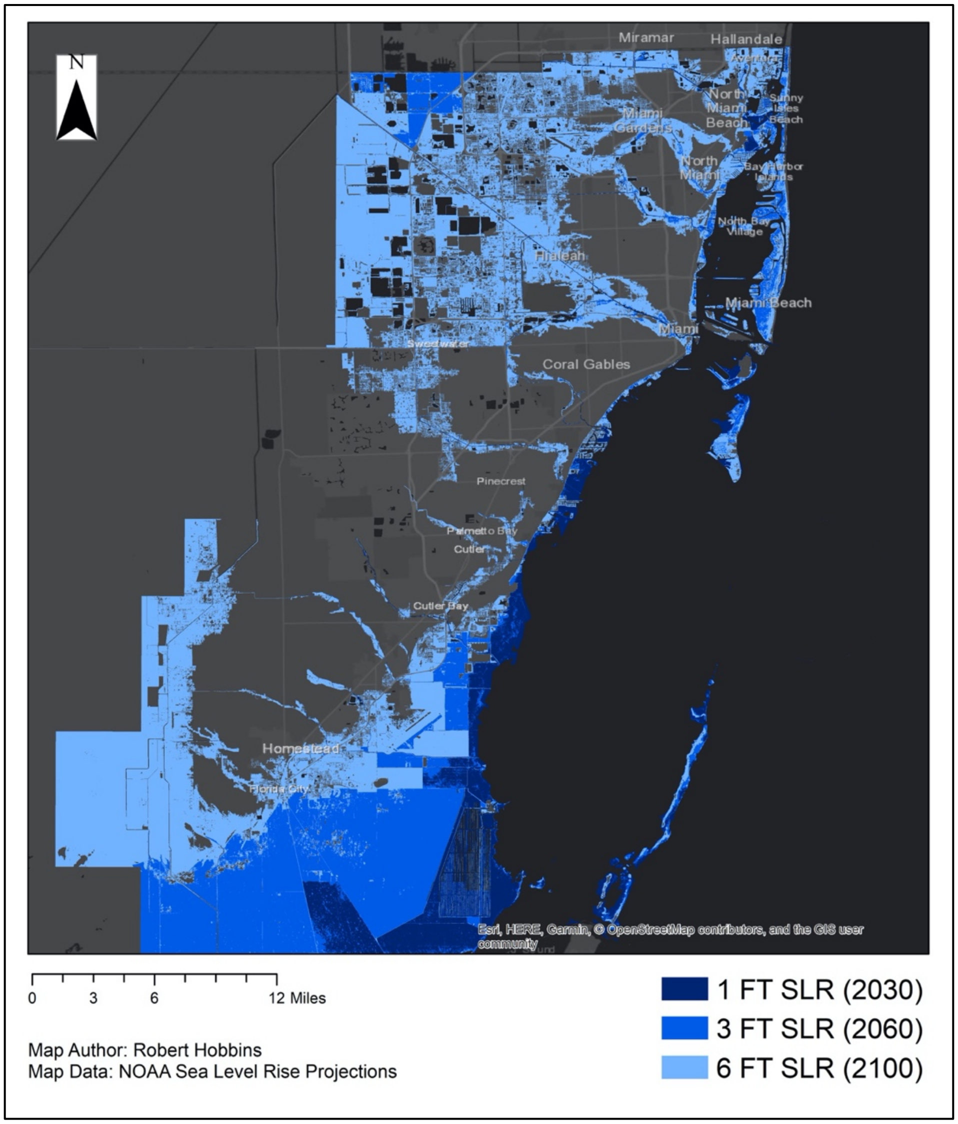
2.1.2. Flood risk profile

"South Florida is very complex because, unlike any other places, I call that three whammies: one whammy is the sea level rise. The other one is the water table coming up. And the other one is the rainfall changes. So, it could come from all sides and the vulnerability could be exacerbated because of that".
– Local government official

The United States is vulnerable to coastal floods as trillions of dollars in assets lie along its coastlines. The Atlantic coastline – a region of high concentration of people and property – is a hotspot for accelerated flooding and SLR (Ezer & Atkinson, 2014; Sweet et al., 2017). Florida is particularly vulnerable due to its high population, large investments along its coasts, unique geological features (i.e., porous limestone), and risk to hurricanes and SLR. Florida has over $2.86 trillion in assets deemed vulnerable to coastal floods and has suffered the most insured flood losses in the United States at $68.6 billion between 1986-2015 (National Oceanic and Atmospheric Administration, 2019a). Florida is also home to the second-most vulnerable city in the world, Miami, due to having a large asset exposure to SLR; Miami currently has $672 million in average annual asset losses to floods and could see as much as $2 billion in flood losses by 2050 due to SLR (Stephane Hallegatte et al., 2013). In regards to storm surge, Genovese and Green (2015) find that a single category 5 hurricane strike to Southeast Florida would cost tens of billions of dollars in flood damage alone – not taking into account wind damage. Miami also ranked nine on a worldwide list of the most vulnerable port cities in terms of exposed future population (4,795,000 individuals) to coastal floods in the 2070s (Hanson et al., 2011). A more recent analysis by Ghanbari et al. (2020) estimate that without major adaptation actions, SLR could cause over $68 billion in average annual losses from intensifying both acute (i.e., extreme storms) and chronic (i.e., nuisance flooding) coastal flooding in Miami-Dade County according to their model assuming just 60cm (~2ft) of SLR; the Miami-Dade area could see 2ft of SLR as early as 2050 in their extreme SLR scenario (Ghanbari et al., 2020). According to the Compact's most recent Unified Sea Level Rise Projections (Southeast Florida Regional Climate Change Compact, 2019) the region could see up to 8.6 ft by the end of the century – threatening to submerge the great majority of the Miami Metropolitan Area (see Figure 4.5; Strauss et al., 2015; Wanless, 2018).

Figure 4.5

Projected Sea Level Rise Inundation Map for Miami-Dade County

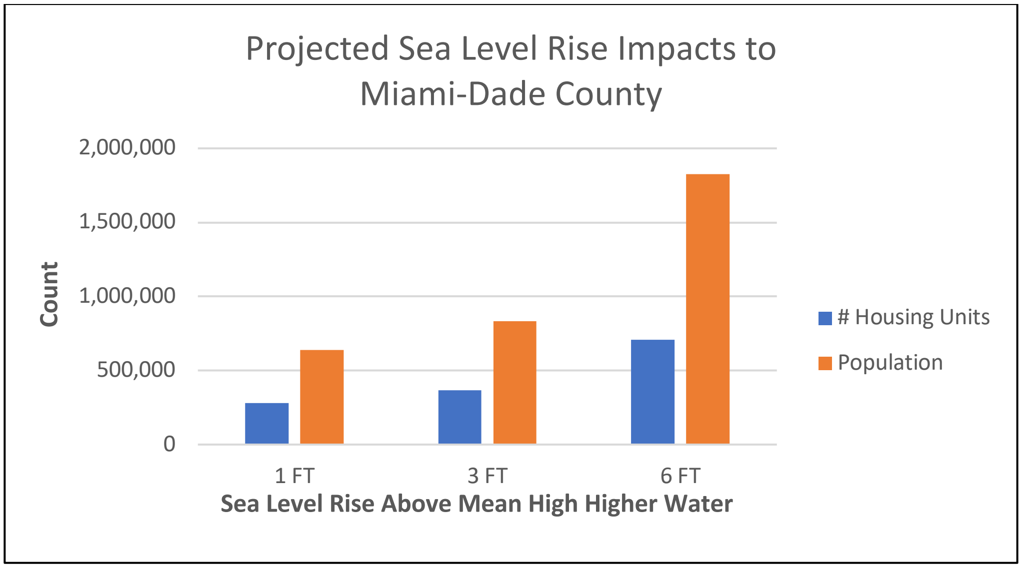


Note. Map of flooding for 1ft (light blue), 3ft (blue), and 6ft (dark blue) sea level rise scenarios for Miami-Dade County. Black areas represent current water bodies. Data source: NOAA Sea Level Rise Projections (2018). Map author: Robert Hobbins.

Comparing current US census data for housing and population with the NOAA six feet SLR scenario for Miami-Dade County (Figure 4.6), over 700,000 housing units and 1.8 million residents could be submerged without significant infrastructure adaptation actions. As such, SLR threatens the very existence of the MMA as it is today.

Figure 4.6

Projected Sea Level Rise Impacts to Miami-Dade County in 6 feet Scenario



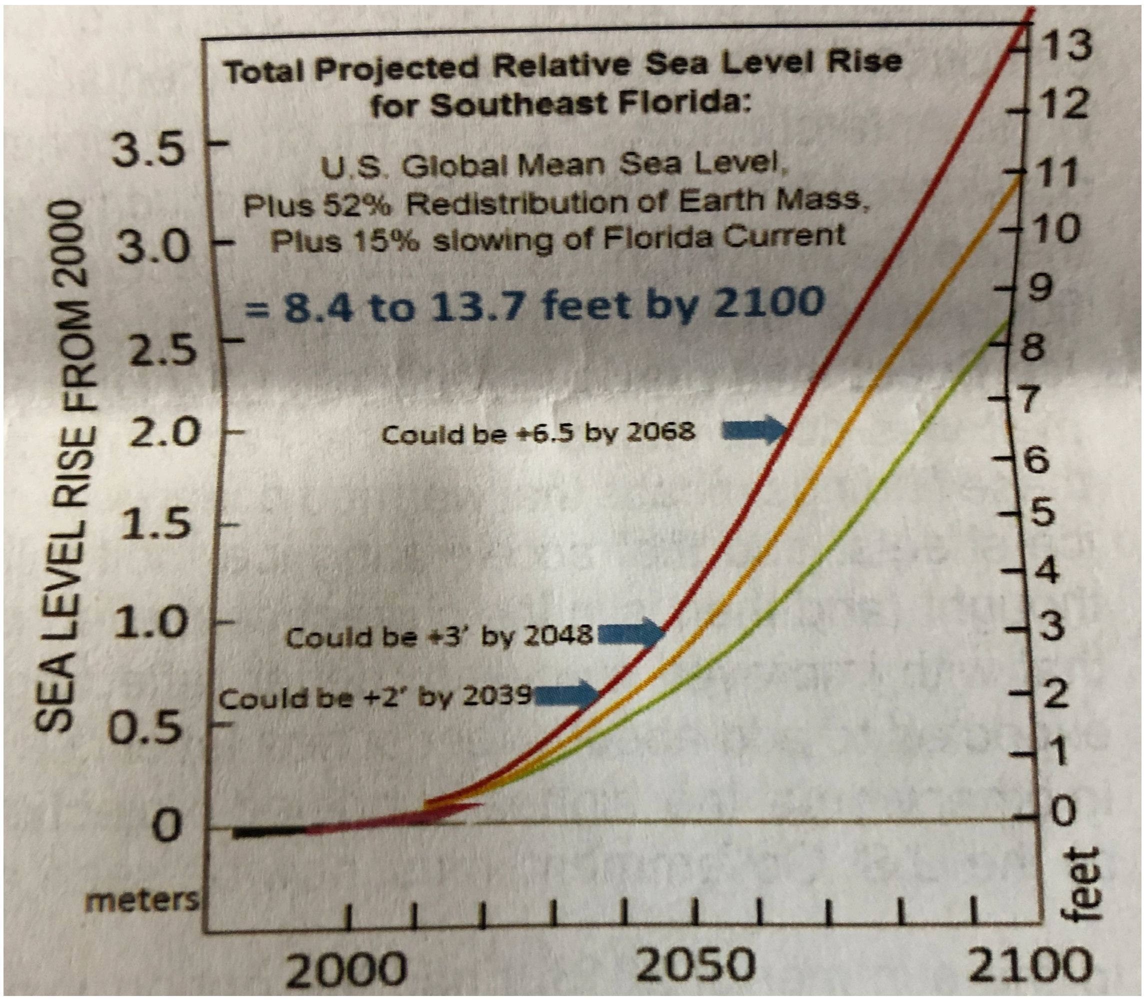
Note. Data sources: NOAA Sea Level Rise Projections and 2010 US Census and 2017 ACS housing data per census block. Graph author: Robert Hobbins.

However, some scholars argue that even six feet could be a conservative estimate for SLR at the end of the century for the Miami area – it doesn't fully take into account regional factors affecting local SLR (Wanless, 2018). A large degree of uncertainty in projecting the rate of SLR in Southeast Florida exists due to uncertainties of the rate of Antarctic ice sheet fracturing and collapse (Kopp et al., 2017; Strauss et al., 2015), and the rate of slowing of the gulf stream (Wanless, 2018). Taking these factors into account, Wanless (2018) modifies the US global SLR projections (Sweet et al., 2017) with the redistribution of Earth's mass due to melting glaciers, and the slowing of the Gulf Stream along the Florida coast to project as much as 13.5 feet by 2100 in the NOAA Extreme

Climate Scenario and 8.2 feet in the NOAA Intermediate High Scenario. Wanless's (2018) are the most extreme projections for the MMA that I am aware of (Figure 4.7).

Figure 4.7

Total Projected Relative Sea Level Rise for Southeast Florida



Note. Source: Wanless (2018). Used with permission from Harold Wanless.

Regardless of the uncertainty in projecting the depth and timing of future SLR, flooding is already an increasingly frequent problem in the Miami Metropolitan Area. Tide-induced flooding events (e.g., nuisance floods or sunny-day floods) have increased more than 400% since 2006. Over the same time period, the observed rate of SLR has increased threefold in Southeast Florida to nine mm/yr – well above the global average

(Wdowinski et al., 2016). It is within the abovementioned social and climatological contexts that both knowledge co-production initiatives take place.

2.2. Case study research methodology

This section provides an overview of the research methods that I employed to gather and analyze data for this study. Overall, I took an ethnographic case study approach (Hancock & Algozzine, 2006) that utilized an embedded mixed-methods design (Creswell, 2014). Ethnographic approaches include embedded interactions with the group of interest and often the researcher develops a rich understanding of the day-to-day lives and behaviors of the group (Hancock & Algozzine, 2006). My group of interest was resilience professionals from a variety of sectors within the Miami Metropolitan Area. Through my various field work experiences, I was genuinely engaged in the day-to-day resilience work taking place throughout the region. The embedded mixed-methods that I employed included semi-structured expert interviews, content analysis, online surveys, and participant observations. Creswell (2013) argues that mixed-methods research designs are excellent for getting a better understanding of the impact of an intervention program by collecting both qualitative and quantitative data over time. Mixed-methods studies help to gain a more in-depth understanding of quantitative results and allows for triangulation of the data to improve internal validity Creswell (2013).

2.2.1. Description of field work

I made several research trips to the Miami Metropolitan Area on seven separate occasions between 2017 to 2020 to become familiar with the local context (e.g., vulnerable low-lying areas of the city and infrastructure, new infrastructure projects, impacts from extreme events, etc.), conduct interviews, and complete numerous participant observations at various workshops and conferences related to climate resilience (see Table 4.2). In total, I spent 52 days in the metro area specifically for conducting field work for this ethnographic study. Additionally, I conducted several interviews via phone and Zoom when it was not possible to meet in person and participated in one virtual event.

Table 4.2

Overview of Case Study Field Work

Trip No.	Dates	Primary Locations	Research Activity
1	August 10 – 15, 2017	Miami; Miami Beach; West Palm Beach	10 personal communications (preliminary interviews) with resilience professionals in the metro area; Trips to vulnerable areas around these cities to become familiar with local context; Participant observation (City of Miami Sea Level Rise Committee Meeting)
2	October 22 – November 2, 2017	Miami; Miami Beach; Fort Lauderdale; West Palm Beach	Interviews; Trips to various areas of these cities to observe impacts from Hurricane Irma
3	February 27 – March 3, 2018	Miami Beach	Participant observation (Resilient Coastal Cities Innovation Lab); Interviews
4	October 23 – 26, 2018	Miami; Miami Beach;	Participant observation (2018 Annual Compact Summit & 10th Year Anniversary); Interviews
5	April 10 – 13, 2019	Miami	Participant observation (UREx SRN Miami Scenarios Workshop; Interviews
6	April 21 – 27, 2019	Miami; Miami Beach	Interviews; Participant observation (Empowering Capable Climate Communicators Symposium)
7	June 1 – 15, 2019	Fort Lauderdale; Miami	Participant observation (Miami Stormwater Master Plan Community Meeting); Interviews
8	October, 2020	Virtual	Participant observation (City of Miami Beach Draft Seawall Ordinance Meeting)

Note. Listed here are all research trips to the Miami Metropolitan Area or remote field work conducted between 2017 to 2020 and their primary objective.

2.2.2 Participant observations

The participant observations were the primary strategy I used to conduct my ethnographic fieldwork. Participant observations serve to provide a researcher with a rich context for their case studies – they know the nuances of being a participant in the case

(Russell, 2011). Participant observations were conducted with the goal to observe primarily how the knowledge products from the case studies were being utilized – or planned to be utilized – by various actors throughout the Miami Metropolitan Area. Participant observations were also incidentally helpful to identify potential actors to interview as I was attending events and getting to meet actors who are all working on coastal resilience issues in the region.

While I participated in a number of resilience-related events and workshops in the MMA, the most important was the Compact's 10th Anniversary Annual Summit in 2018. I attended this event to hear how participants reflected on how it started, its successes, and where they are headed in the future. I was able to listen to conversations and dialogues between various actors reflecting on what has been successful thus far and how the Compact may need to improve to better meet the needs of its stakeholders.

The Resilient Coastal Cities Innovation Lab – a project sponsored by a National Science Foundation Smart and Connected Communities Planning Grant - was a 4.5hr workshop that included participants from civic, business, academic, and government sectors. All participants were working on climate resilience in the Miami Metropolitan Area. The goal was to co-design and co-create an innovative smart city visualization platform that would meet users' diverse needs in building resilient coastal cities. During the workshop, participants matched existing tools with their intended uses and users. Participants also discussed what aspects made these tools usable or not for different purposes. The Resilient Coastal Cities Innovation Lab was particularly helpful in gaining nuanced insights into how various MMA actors found the EOTR SLR Toolbox useful or not and why.

I also attended the Urban Resilience to Extreme Events Sustainability Research Network's (UREx SRN) Miami Scenario Workshop. This was a full-day workshop. The scenario workshop was designed to identify challenges and opportunities for the future of Miami-Dade County, as well as to develop alternative positive visions of Miami-Dade in 2080. The goal was to develop both adaptive (resilient to various extreme weather events) and transformative (radical changes to create more equitable, just, and desirable futures) participatory visions of Miami-Dade County. The workshop also identified gaps in knowledge and coordination across the region. The rationale for attending this event included: (1) to gain a deeper understanding of the complexities of the social-ecological-technological system interactions in the region, (2) to observe the knowledge claims that diverse groups of actors make about current and future floods in the region, and (3) to build relationships with participants for future opportunities to interact for this project.

During the participant observations I took copious notes, archived and annotated relevant handouts and artifacts from the event (e.g. graphs of sea level rise projections, reports on climate adaptation implementation in the region, etc.), and took photographs of important slides being presented. While not all data and activities from the participant observations ended up being analyzed for this study (e.g., the UREx SRN Miami Scenario Workshop), they all served to provide me with a rich contextual background of the complex social, ecological, and technological contexts in which my case studies were being implemented, and who the key actors are in the region.

2.2.3. Interviews

I used a purposive and snowball sampling approach (Orcher, 2014) to elicit data from informed or expert stakeholders in the Miami Metropolitan Area who were either part of the knowledge co-production initiative or who were the prospective users of the knowledge generated by the initiative. All stakeholders interviewed were engaged in climate resilience related efforts within the Miami Metropolitan Area. In order to understand how various sectors of society participated – or not – in the knowledge co-production effort, I interviewed actors from various cross-sectors of society including local and regional government agencies, non-profit organizations, for-profit businesses and consultancies, and academia (see Table 4.3). I applied for and received exempt status from Arizona State University's Human Subjects Institutional Review Board prior to inviting individuals to be interviews (Appendix A). Twenty-two individuals were initially identified to be invited for an interview. Sixteen individuals agreed to be interviewed from that initial list. Interviewees often recommended additional stakeholders to reach out to in order to fill gaps in their own recollection or to provide a different perspective. Four additional interviewees were identified through snowball sampling. As I mention in Section 2.2.2, I also utilized some of the participant observations to connect with resilience professionals from throughout the region to follow up with in-depth semi-structured interviews. Seven additional interviewees were identified through participant observations. As such, I interviewed a total of twenty-seven participants out of thirty-five people contacted; six email invitations went unanswered, and two email invitations were declined due to being too busy or too sick. Prior to starting the twenty-seven formal interviews mentioned below, I also had an additional ten informal conversations in August 2017 to help frame the project and get a better understanding of the local context. In total, I spoke with thirty-seven different individuals over the course of this study to inform my analysis.

Table 4.3

Breakdown of Formal Interview Participants by Sector of Society

Sector	No. of Participants
Local Government	8
Regional Government	5
Non-Profit	5
For-Profit Business	3
Academia or Research	6
Total	27

I conducted twenty-seven initial formal semi-structured interviews and an additional two follow-up interviews for a total of twenty-nine recorded interviews. The follow-up interviews were helpful to get clarification when conflicting or new information was shared by another participant. The average length of each interview was 58.6 minutes. I stopped conducting new interviews when little to no new information was being gathered through successive interviews – the point of saturation (Guest et al., 2006).

Analytical memos were written immediately after each interview to document key points and themes discussed (Creswell, 2014). The interviews were first transcribed by the software Otter.ai and then refined by the author using MAXQDA 2020 transcription software to check for accuracy and update incorrect translations. A handful of interviews were transcribed directly by the author in MAXQDA 2020 without the assistance of Otter.ai. I uploaded my hand-written analytical memos for each of the interviews into the MAXQDA project.

2.2.4. Content analysis

In addition to the interviews and participant observation data, I archived scores of documents related to each of my case studies including official organization reports (e.g., local municipality reports on implementation, member survey reports, plans, etc.), website content, organization newsletters, case studies in online databases, local news articles, and peer-reviewed articles written about the organization. These documents were used primarily as a data triangulation tool (Creswell, 2014) to validate the information that I received from my interviewees and participant observations. As such, these were not coded and organized by themes. They only served to cross-check the results from other data sources.

2.2.5. Surveys

A climate resilience survey – consisting of forty-five questions – was administered over the course of two months in the Spring of 2019 to organizations in Miami-Dade County who work on urban resilience and sustainability issues in the region. This survey is based on questions from prior knowledge system research to reveal actor networks, visions, and knowledge preferences (T. A. Muñoz-Erickson, 2014a). This survey was conducted as part of my research on urban knowledge-action systems with the Urban Resilience to Extremes Sustainability Research Network (UREx SRN). The survey was primarily conducted to inform the design of the UREx SRN Scenario Workshops mentioned in Section 2.2.2. The Climate Resilience Survey falls under the Arizona State University Human Subjects Institutional Review Board exempt status for the UREx SRN (Appendix B).

The Climate Resilience Survey was a non-probabilistic purposive sample (Etikan et al., 2015) to a targeted group of stakeholders rather than randomly selected sample or inventory of stakeholders. I drafted a list of stakeholders to receive the survey from my interview work as well as online searches to identify a broader cross-section of individuals from throughout Miami-Dade County. This was then validated by the UREx SRN Miami City Team – a group consisting of local academic and practitioner resilience experts. The UREx SRN Miami City Team took this initial list and expanded it, and removed stakeholders as they felt necessary given their long-term expertise working on resilience issues in Southeast Florida. A total of 270 invitations were sent; 115 surveys were returned at least partially complete (43% response rate), and 99 were sufficiently completed (35% completion rate). The survey asked participants a range of questions including their preferred strategies to address climate change, visions, adaptation pathways, knowledge and collaboration networks, and organization information.

This dissertation utilizes the responses from three of the questions from the questionnaire. I only used the survey results to identify who was using the knowledge products from each of the two knowledge co-production cases, as well as to identify the future visions of the city from various stakeholders who participate in these projects. I analyzed the following two open-ended questions:

1 - Please list up to 5 organizations or groups that you go to for information, advice, data, or expertise related to climate change in Miami-Dade County. If possible, please provide the complete name of the organization or group and

2 - Imagine that you are given an unlimited budget and asked to design the cities that encompass Miami-Dade County in 2060 (~ 40 years from now). In two or

three sentences, please describe what vision or desired future you have for Miami-Dade County? For example, what are the key words that describe this desired future for you?

I also used one of the close-ended questions to group the knowledge and vision questions by organization type: "Please select one that describes the type of organization you work in or that you represent". The response options for the organization question included: Academic or Research Institution, Federal government agency, Formal non-profit group/organization e.g., 501(c)(3), 501(c)(4), or has applied, Informal non-profit group/organization e.g., community garden group or block club, Local government agency (e.g. city, municipality, village), Media, Private firm, for-profit business, Professional association, Regional government agency (e.g. county, Metro), State government agency, Tribal, Other (please specify). These options were then grouped together into non-governmental organization, government, or research for the purposes of analysis.

This study also qualitatively analyzes the results from the Compact's Municipal Implementation Survey conducted in 2014 among its local municipal leaders (Southeast Florida Regional Climate Change Compact, 2015a). This survey was not conducted by me; its methods have already been reported in detail by Vella et al. (2016).

2.3. Analysis

To organize the constellation of data from interviews, participant observations, and archives of documents, I used MAXQDA 2020 software to collate these data into one project. I read over all documents and interviews at least twice and marked the most significant sections (e.g., quotes, tables, charts, etc.) of the dataset for reference later. I used analytical memos (Creswell, 2014) to annotate the dataset and note any important and relevant content for synthesizing key themes and findings for this chapter.

To analyze the climate resilience survey data, I used PivotTables in Excel to summarize the percentages of stakeholders in each sector of society who responded that they sought out knowledge from either the Compact or the FIU Sea Level Solutions Center (SLSC). The open-ended responses were coded with '1' when present and '0' when absent for both the Compact and the SLSC.

To provide a holistic analysis of each knowledge co-production initiative, I utilized the SETS Framework of Knowledge Co-Production (see Chapter 3). The SETS Framework of Knowledge Co-production breaks down a knowledge co-production initiative into its goals, actors or participants, knowledge, processes, and outcomes (i.e., Scope 1 and Scope 2 outcomes). The SETS-FKC also invites the analyst to explore the dynamic interdependent arrangements of a knowledge co-production intervention with its SETS context. I analyzed each case study (i.e., the Compact, and the EOTR) by answering many of the key questions from Table 3.1.

In order to answer the key questions for the actor component, I used actor mapping to identify each actor who participated in the initiative and to plot their power within the initiative. The semi-structured interviews provided the main source of identification of the actors and their level of authority (Reed et al., 2009), and this was further validated and refined by relevant data obtained from the content analysis.

2.4. Limitations

The data used for this study comes from a variety of sources each with its own limitations. The Climate Resilience Survey was not a statistical random sample of all stakeholders in the Miami Metropolitan Area. The results from that survey are not intended to represent the total population. The documents reviewed for this study also have their own limitations. For instance, I reviewed the Compact's Municipal Implementation Survey Results and use these to determine how the Compact's knowledge is being used by local municipalities. As I did not conduct that survey, I cannot attest to the veracity of the data – it has been reported elsewhere (Vella et al., 2016). My interviews included some sensitive political issues. Some interviewees may have withheld some knowledge or information due to the fear of losing their jobs. While every measure was taken to protect the anonymity of my participants, this concern may have still caused some to withhold their full opinion or experience. While each of my data sources have their own limitations, it was my intention that a multi-method case study approach that triangulates these various data sources would enable me to get a completer and more accurate picture of each case study.

3. Case Study 1: The Southeast Florida Regional Climate Change Compact

The following sections analyze each of the key questions from Table 3.1 including the Compact's goals, actors, knowledge, process, and outcomes. A summary is provided at the end which summarizes the key lessons learned from the case.

3.1. Overview of the initiative (How did it begin and what are its goals?)

"The Compact is a fairly simple document that basically says we agree to work together on these issues, and that we're going to get together once a year" – County official

The Southeast Florida Regional Climate Change Compact (Compact) was established in 2010 through a non-binding resolution between Miami-Dade, Broward, Palm Beach, and Monroe Counties (see Figure 4.2 for the geographic area of this region) to work collaboratively on developing regional sea-level-rise projections and vulnerability assessments, regional climate mitigation and adaptation plans, legislative and advocacy programs, and convening once a year to reflect on the Compact's progress and agenda setting (Chassignet et al., 2017; Menees & Grannis, 2017; Vella et al., 2016). This cross-jurisdictional organization developed initially out of the need to coordinate advocacy efforts at the state and federal level regarding securing funding for climate adaptation projects to reduce regional climate risks like SLR. Each of the counties and organizations in the region were using vastly different SLR science and problem framings when meeting with congressional leaders to advocate in favor of the American Clean Energy and Security Act of 2009 (i.e.,Waxman-Markey Bill) – a bill that ultimately failed to pass in the US Senate (Participant observation, 2018). Several interviewees recounted that during those advocacy efforts, US congress staff told regional leaders that they really need to get on the same page regarding what is happening in the region and what the needs are. One county official succinctly described the governance and knowledge challenges that existed prior to the formation of the Compact:

> But the situation was that Miami-Dade had a climate change task force. Broward had a climate change task force. Palm Beach did not have a climate change task force, but they had a business group who was working on these things. Broward County was mapping vulnerability based upon one set of LIDAR data and sea level rise projections using a certain methodology. Miami-Dade was doing the exact same thing, and The Nature Conservancy was doing the exact same thing for the Keys. And so, we all generally knew about the work that the others were doing but we weren't sharing. Never were we looking at modifying our own

processes based upon the work that somebody else had done; we just acknowledged that it existed. We knew that different individuals were supporting different efforts. Maybe we had the same expert that was serving on the Miami-Dade task force, that was serving on our task force but we both ended up with different sea-level rise projections despite.

Officials from Southeast Florida realized the need to develop a uniform knowledge and information base for local climate resilience decision-making as well as a unified voice for climate advocacy work at the state and federal levels. In order to fill this knowledge and governance gap, the Compact was born. According to the Compact's website (Southeast Florida Regional Climate Change Compact, 2020b), the objectives are to:

- **Share regional tools and knowledge**. The Compact serves to create regional tools and standards, and transfer knowledge to build the local government capacity needed to implement regional climate solutions and avoid duplicative efforts.
- **Increase public support and political will**. Through a unified voice, the Compact provides the nonpartisan credibility, legitimacy, and continuity necessary for meaningful government action to address projected climate impacts.
- **Coordinate action**. The Compact catalyzes and supports the region's coordinated actions to accelerate the pace and impact of efforts that will increase the region's climate resilience.

3.2. Actor Mapping (Who are the actors and how is power distributed?)

The Compact has a unique governance and organizational structure that has evolved over the last decade since its inception. The Compact is not a new regional government entity; the decision-making authority is not vested in the Compact. Instead, the authority to implement the Compact's mission and objectives was granted by the Board of Commissioners of each member county by ratifying the Compact Resolution in 2010. The Compact is led by a Staff Steering Committee – who hold the voting rights of the Compact – that consists of up to two officials from each of the four Counties (up to eight total) and one municipal official from each County. As of 2018 the municipal representatives – which rotate often – were from West Palm Beach, Hollywood, Key West, and Miami Beach (Institute for Sustainable Communities, 2018). Each County is guaranteed two votes on the Steering Committee whether they cast those votes by two county representatives or a single representative (Menees & Grannis, 2017). The Counties and Cities typically assign high-ranking personnel such as county managers, deputy managers, sustainability and resilience directors, and environmental department directors to represent their interests on the Committee (Institute for Sustainable Communities, 2017). The Staff Steering Committee members serve as liaisons to the county and municipal governments that constitute the Compact. Additionally, four partner organizations serve as ex-officio members – without voting privileges – to the Compact Steering Committee including the Institute for Sustainable Communities (ISC), the South Florida Water Management District, The Nature Conservancy (TNC), and the South Florida Regional Planning Council. The ex-officio members provide advice and technical expertise to guide the Compact's efforts. Since 2009, the ISC – a non-profit organization – has been the managing entity supporting the Compact's activities. The ISC provides strategic, technical, administrative, and facilitative support for the Compact and serves as the fiscal agent for its grants (Menees & Grannis, 2017). The Compact has also benefits substantially – albeit informally – from the voluntary participation of state (e.g., Florida Department of Transportation, Florida Department of Community Affairs) and federal (e.g., NOAA, USGS, USACE, EPA Region IV) government agencies who typically provide technical advice for Compact initiatives and in Compact Work Groups (Adams & Gregg, 2020). According to the Compact's website (Southeast Florida Regional Climate Change Compact, 2020b):

> Today, the Compact represents a new form of regional climate governance designed to allow local governments to set the agenda for adaptation, while providing state and federal agencies with access to technical assistance and support. The Compact's work is widely recognized as one of the nation's leading examples of regional-scale climate action, and it continues to serve as an exemplary mechanism for collaboration on climate adaptation and mitigation efforts.

The Compact – born initially out of a multi-county government initiative – has been expanding its actor network beyond the four county administrations to foster closer relationships with other sectors of society including federal government, state government, local government, the business sector, research and higher education sector, the civic sector, and even international collaborators. Beginning in 2012, dozens of local municipalities throughout the four-county region signed onto the Mayor's Climate Action Pledge, pledging to support the efforts of the Compact and to implement the Compact's Regional Climate Action Plan (Vella et al., 2016). Just two years later, the Compact joined forces with Florida's academic community; the Compact signed an agreement in 2014 with the Florida Climate Institute (FCI) – a collaboration of ten of Florida's major universities that serves as an interdisciplinary network of scientists and research organizations who work on climate related research and projects throughout Florida. The FCI claims to have over 400 individual affiliates (Florida Climate Institute, 2020). The goal of the partnership agreement between the Compact and the FCI was to "bring the research community closer in line with the work of the Compact to help us really understand the risks - the expertise we need" – (Participant observation, 2018). The partnership agreement claims that this Compact-FCI partnership was designed to make scientific knowledge more effective since it will be more closely integrated into the public policy of Southeast Florida (Southeast Florida Regional Climate Change Compact & Florida Climate Institute, 2014). The idea to partner with the FCI also grew out of observations of successful academic-government partnerships in other areas of the US that have been successful in linking knowledge to action on climate resilience. One county government official reflected on the need to create a formal relationship with the academic community:

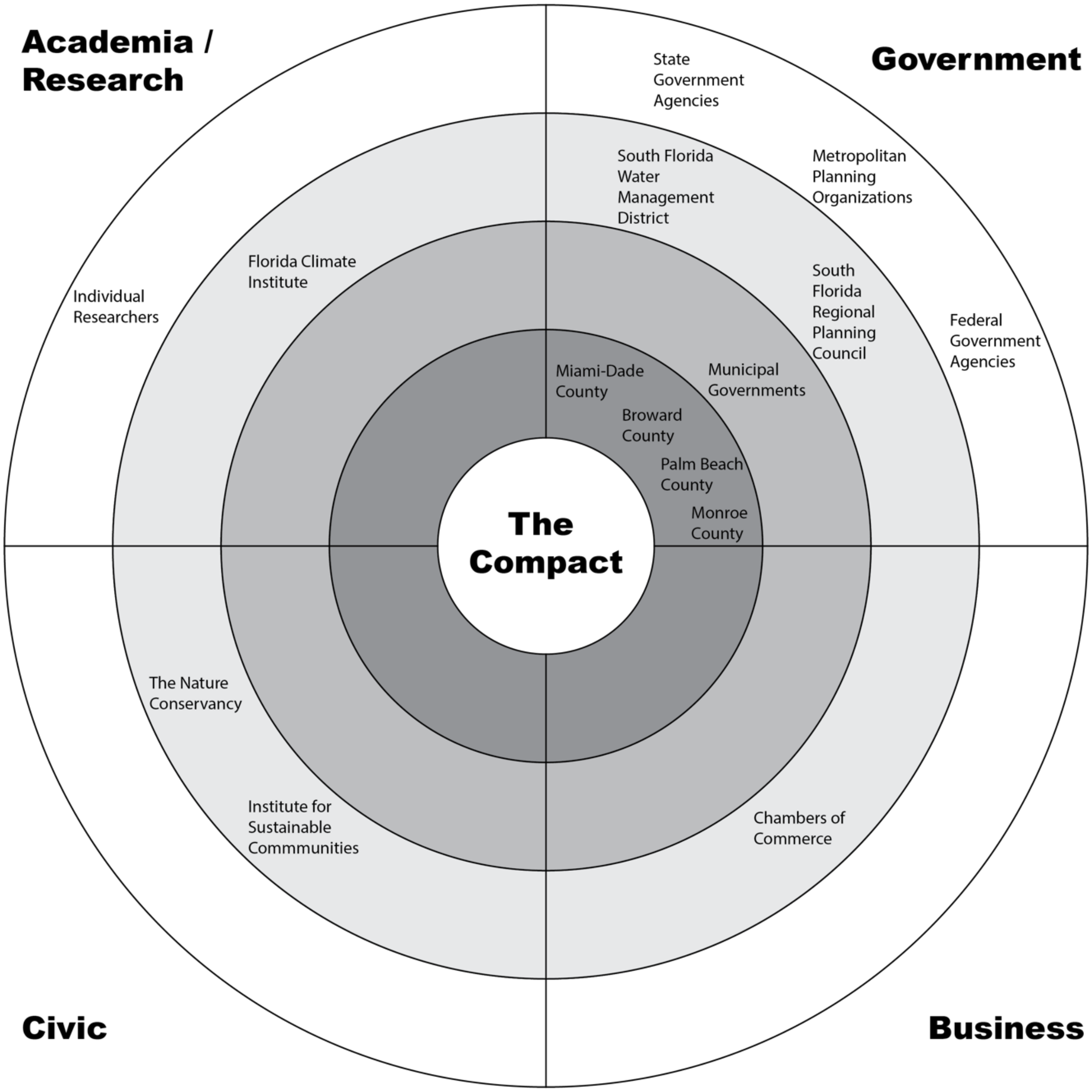
> That was driven by the fact that we saw communities out west in California who had these really rich and substantive relationships with their academic partners, and they were getting all this really great targeted research. And we were like, "well, where is ours?"

The Compact has also extended a hand to the private sector to more closely collaborate together. A Joint Statement on Collaboration for Regional Economic Resilience in Southeast Florida was signed in 2017 by the Mayors of the four Compact counties and their respective regional economic development community within their borders (i.e., Broward Workshop, Chamber of Commerce of the Palm Beaches, Greater Fort Lauderdale Alliance, Greater Fort Lauderdale Chamber of Commerce, Greater Hollywood Chamber of Commerce, Greater Miami Chamber of Commerce, Treasure Coast Regional Planning Councils). Broadly, this statement describes expanding business education on community and economic resilience, identify and advocate for state and federal investments needed for regional resilience, communicating the proactive and informed steps that the region is taking to national and global audiences, and encouraging broad participating by both municipal and business partners in these efforts (Southeast Florida Regional Climate Change Compact, 2017a). One Compact official reflected on the value of engaging with the business community more formally:

> As you find voids, you see that the need is far greater than the numbers that you have in your core little staff steering committee, that the expertise that's required is well beyond your own expertise, that the network of individuals needs to engage well beyond your influence. And so, who are the people? And increasingly, it's just... There's a phenomenal community that's out there and when we formally approached the business community, they said, 'well, what took you so long?'

Figure 4.8

Actor Map of the Southeast Florida Regional Climate Change Compact



Note. This actor map shows the current structure of the Compact's governance model and relationship with various actors across society. Actors wielding the most power in the governance network are closer to the center. Actors providing advice without formal relationships with the Compact are near the outer rings of the chart. Actors have been separated by their respective sector to show the level of participation across various sectors of society.

Despite the integration of various sectors of society into the governance structure of the Compact, the primary authority over the Compact has not changed over the past decade; it remains a heavily government-centric entity and several government staff with whom I spoke expressed the desire to keep it that way. Figure 4.8 shows an actor mapping (i.e., onion chart) of the various participants in the Compact and the power or influence they have on the Compact. At the very center are the four counties that signed the initial Compact Resolution in 2010. Each county wields two votes on the Steering Committee for a total of eight votes – they remain the dominant actors in the Compact. In the second ring from center are the municipal governments who are the responsible parties for implementing the Compact's plans. They hold less power than the Counties, but more than other actors in the chart since they are allotted a total of four votes on the Steering Committee. The third-from-center ring of the chart represents actors who wield no voting power but have formal or established relationships with the Compact either as non-voting members of the Steering Committee or through formal partnership agreements with the Compact. For example, a member of the South Florida Water Management District clarified that: "we are not an official partner. But we have been a collaborator - we are a partner, but we are not a signee to the Compact. Well, we provide technical assistance".

The outermost ring of the chart contains actors who volunteer on various work groups of the Compact – they tend to be those who provide only technical advice to the Compact. The most striking observation from Figure 4.8 is that the most powerful actors are all from the government sector. Moreover, the government sector is the most represented sector in the Compact's governance structure as it is represented at each level of influence on the Compact (i.e., present in each ring). It is important to note the relative lack of partnerships with actors from the civic community.

There are several groups of stakeholders who currently are underrepresented in the Compact – as shared by my interviewees. A few government officials shared that they would like to see more collaborations and new partnerships with the tourism and hotel sectors in the Compact. Also, while some non-profit organizations are active in the Compact, several other non-profit organizations which whom I spoke expressed that they would like to be more integrated into the Compact, to have their voices heard, and potentially take on leadership roles (Subject 14; Subject 15; Participant observation, 2018). For instance, Subject 15 – a local NGO leader – expressed that the government representatives in the Compact tend to take decisions on their own, without carefully considering the opinions and perspectives of the NGO leaders in particular:

> But when it comes to kind of offering input, when it comes to the kind of decisions made, I think there's a tendency for them to kind of want to do it on their own, which I think is just a natural result of bureaucracy.

Nevertheless, at least two non-profit organizations currently have significant leadership or facilitation roles with the Compact – the ISC and TNC. The ISC primarily provides managerial and facilitation support to the Compact rather than providing technical expertise or advice as other actors in the network do. The ISC functions as a sort of boundary organization to link all of the different actors together. The TNC is the principal non-profit organization who is directly engaged in and helps lead the co-production of the Compact's knowledge products (e.g., the TNC leads the Coastal Resilience Working Group). The TNC was recognized by County leaders since the beginning as holding significant technical knowledge on sea level rise risk and nature-based solutions for how to address it. TNC serves as a non-voting member of the Compact Steering Committee. Additionally, TNC coordinates and facilitates a key Compact work group: the Coastal Resilience Work Group. However, there has yet to be a formal agreement of engagement with the larger network of civic organizations in Southeast Florida who are focused on climate resilience, as has been done previously with the academic and business sectors. It is noteworthy that civic groups such as the Miami Climate Alliance – a coalition of over 100 civic organizations in Southeast Florida dedicated to building a more just, equitable, and resilient community – are not currently official or informal partners of the Compact. In short, the civic sector is indeed represented in the Compact, but doesn't seem to have as strong of an influence as the more central government actors – by design.

3.3. Knowledge (How do the actors know and imagine the city?)

The following sub-sections on knowledge will describe how participants of the Compact both know and imagine the future of the Miami Metropolitan Area. Section 3.3.1 discusses the sources of knowledge that the Compact relies on, inequalities between those knowledge sources (i.e., epistemic inequalities), epistemic uncertainty and managing uncertainty. Section 3.3.2 discusses who the experts are in the Compact. Section 3.3.3 discusses the interaction and negotiation of future visions of the city in the Compact.

3.3.1. Epistemology (How do the actors know what they know and don't know?)

Sources of knowledge & epistemic inequalities

The Compact, being a heavily government-centric entity, tends to favor government knowledge sources over other types of knowledge. As a case in point, the projections used by the Compact in their Unified Sea Level Rise Projections are all derived from government-led studies including from the United States Army Corps of Engineers, the National Oceanic and Atmospheric Administration, and the Intergovernmental Panel on Climate Change (IPCC). The Compact also relies heavily on science and technological knowledge as compared to other ways of knowing. The Technical Ad Hoc Work Group not only reviewed government projections and scenarios for climate change and sea level rise, but they conducted a thorough academic review of the peer-reviewed literature as well. The reliance on science and technical knowledge is reflected in the current makeup of the Compact; many scientists and technical experts have been invited to the Compact over the past decade to provide this type of knowledge (e.g., the Florida Climate Institute, the United States Army Corps of Engineers, the National Oceanic and Atmospheric Administration, the South Florida Water Management District, and The Nature Conservancy).

Part of the reliance on government and academic sources may be attributed to the perceived credibility and reliability of the data over other sources. One city official recalled that the Compact was determined that their projections be founded on "good science" in order for them to be usable. One NGO representative, argued that part of the reliance on government and academic data is attributed to their observation that there is usually a robust process to review and validate the data – a process that ensures less blatant errors:

> I think it is more validated, I think it is. If not formally peer reviewed, there's a lot of eyes on it, a lot of expert eyes on it. When it comes to private organizations and nonprofits, some of them I think are very good. But, you know, some of them I run into enough just factual errors coming from nonprofits, I'm seeing factual errors from everywhere, but I just feel more comfortable with governmental or academic data

As such, local and experiential knowledge tends to be less utilized in the Compact – though it does play a narrow role. As is typical of government operations in general, the public is often called on to provide comments on draft products. For instance, the RCAP 2.0 says that it was developed through a "through extensive stakeholder engagement, expert direction, and public input" (Southeast Florida Regional Climate Change Compact, 2017b). In short, local and experiential knowledge sources are used in validating the Compact's knowledge, but have taken a back seat to governmental, scientific, and technical knowledge and expertise in the initial knowledge generation.

Epistemic uncertainty

Uncertainty has played a central role in the Compact since its creation. The Compact was initially formed to try to make sense of all of the different projections of sea level rise that various Southeast Florida actors had been using. To illustrate and consolidate all of the various projections of SLR in use at the time, the Compact members put together the "tower of babel slide" (Participant Observation, 2018; Table 4.4). It illustrated the vast differences in projections in use and highlighted how incomplete their knowledge was about future flood risks to the region.

Table 4.4

Sea Level Rise Projections for Southeast Florida Used by Local Governments Prior to the Compact.

Projection	Year Developed	Reference Year	Sea-Level-Rise Range (inches)			
			2030	2050	2060	2100
Historic Tide Gauge Data at Key West		2000	2.5	4.5	5	9
Miami-Dade Climate Change Advisory Task Force	2007	2000	N/A	>18	N/A	36-60
Broward County Climate Change Task Force	2009	2000	3-9	N/A	10-20	24-48
South Florida Water Management District	2009	1990	N/A	N/A	5-20	N/A
US Army Corps of Engineers	2009	2010	3-7	7.0-17.5	9-24	19.5-57
Florida Atlantic University – Resilient Waters	2009	2000	4.5-7	9-15	11.5-20	24-48

Note. Adapted from: (Southeast Florida Regional Climate Change Compact, 2011).

If the region was to take collective and coordinated action to address SLR, there was a need to figure out how to make sense of and apply this uncertain and incomplete knowledge into adaptation decision-making in the region (Subject 1; 7; 20; 25). The Technical Ad Hoc Work Group (Tech WG) – made up of local, regional, and federal government officials as well as local scientists – was first convened in 2010 to vet the latest peer-reviewed science and come to a consensus regarding the region's vulnerability to sea level rise (Southeast Florida Regional Climate Change Compact, 2011).

The meetings of the first round of the Tech WG in 2011 were contentious as participants deliberated the scientific data, their values and visions of the future, and policy recommendations. These tensions were due to having a diverse group of academics, government leaders, and government scientists in the Tech WG who each brought their own data or studies, values, and desired visions of the future to each meeting (Subject 2, 25, 26). There was a need to carefully vet the global and local scientific knowledge due to the high levels of uncertainty in determining the rates of gulf stream slowing, ice sheet melting, thermal expansion of the ocean, and other factors influencing local SLR in Southeast Florida. Some academics in the group were proposing to include the highest or most extreme projections available at the time to guide local policy. There were suggestions from academics that we may have to retreat from the most vulnerable areas of the region based on the extreme projections. The extreme scenarios did not bode well with some government officials given the intense political environment at the time (e.g., the contentious public discourse regarding sea level rise and climate change). They were concerned with how their constituents would react – and whether or not including extreme projections would simply cause stakeholders to not find the data credible or actionable (Subject 20). For instance, some County representatives were not comfortable using any projection greater than two feet of SLR – regardless of the level of uncertainty – as greater than two feet would cause significant alarm for their constituents; it could have meant that large portions of their County would become uninhabitable without significant adaptation action. One city official recalled that "they didn't want to do anything that was more than two feet, which either means really low balling or don't look out very far". They also shared some insight into the socio-political context at the time: "personally, I think we are low-balling what the expected risk will be. They don't want to scare the public and the investment community".

As such, there were disagreements about how far into the future was reasonable to project due to the high level of uncertainty involved in long-term projections. The group significantly debated whether to show projections out to only 2060 – where there is a bit less uncertainty – or out to as far as 2100. Given the competing values and opinions, the group spent nearly six months deliberating the latest science in several meetings until everyone could come to an agreement on which projections and timeline to use given the uncertainty in the data. For the first projections, the group took a conservative approach and only projected out to 2060 with an additional section at the end of the report discussing the science for beyond 2060 (Southeast Florida Regional Climate Change Compact, 2011; Subject 25; 26).

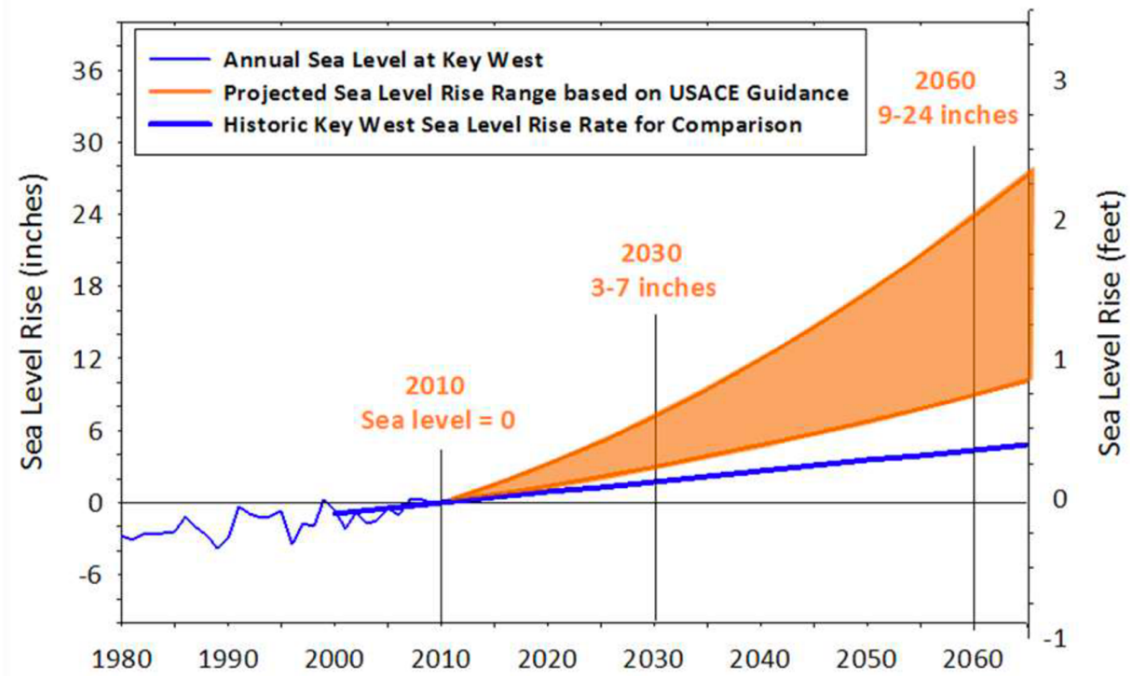
One interviewee who participated in the discussions recalled that "if it wasn't a government number, it was ignored". Government, and especially federal government, knowledge held more credibility and respect in the meetings. As a case in point, it took a representative from the USACE to mediate tensions in the first round of the Tech WG and convince other government representatives to consider projections further into the future than they originally planned. One participant commented that the group was highly influenced by this particular comment from the federal representative:

> And he simply said, the US government has to look out at least 100 years because the things we build are supposed to last 100 years, plus it may take 20 years after we start thinking about it to get it built. So, we look out 100 to 120 years.

The USACE's representative's comments convinced the government representatives in the group to consider projections further into the future than they originally planned. One of the government scientists shared that in the end, the group decided to publish the USACE's SLR projections as a compromise. Figure 4.9 shows the first iteration of the Compact's Unified Sea Level Rise Projections.

Figure 4.9

The Compact's 2011 Unified Sea Level Rise Projections

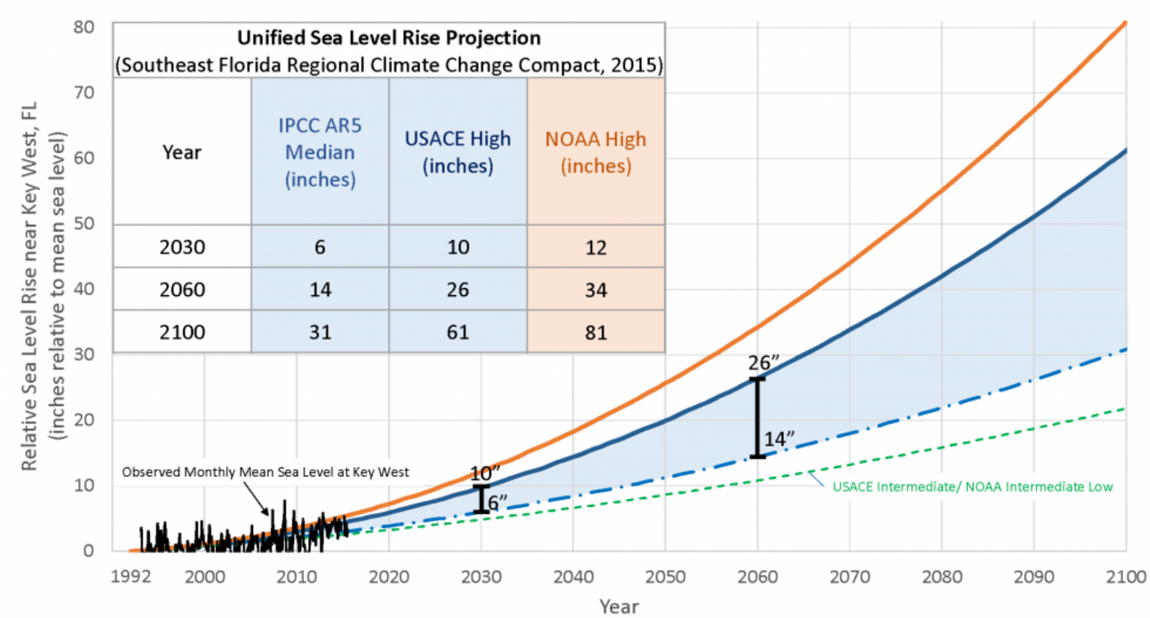


Note. Prepared by the Compact's Technical Ad Hoc Work Group. The projection uses historic tidal information from 1913 to 1999 from Key West, Florida to extrapolate the historical sea level rise rate at Key West (the thick blue line). The upper and lower bounds demarcating the projected sea level rise range (Orange) were determined using 2009 USACE intermediate and high curves, and the historical tidal information from Key West. Source: Southeast Florida Regional Climate Change Compact (2011). Used with permission from the Compact.

The Tech WG decided it was important to meet and update their projections once every four to five years to ensure that the region's projections stay relevant and timely as new data emerges. In 2015, the group met for the second time. One Tech WG representative recalled that in the second iteration, the group "stopped arguing about the science" and focused on interpreting the data for the region and how to use it in policy and planning. The Tech WG ultimately ended up projecting out to 2100 in their second meeting – beyond the 2060 timeline from 2011 (Figure 4.10). However, the group decided not to include the most extreme projection from NOAA, even though it was available at the time. The consensus continued to be not to show projections that could unduly alarm the public since there was no way to be sure which projections would actually become reality – there was just too much uncertainty.

Figure 4.10

The Compact's 2015 Unified Sea Level Rise Projections

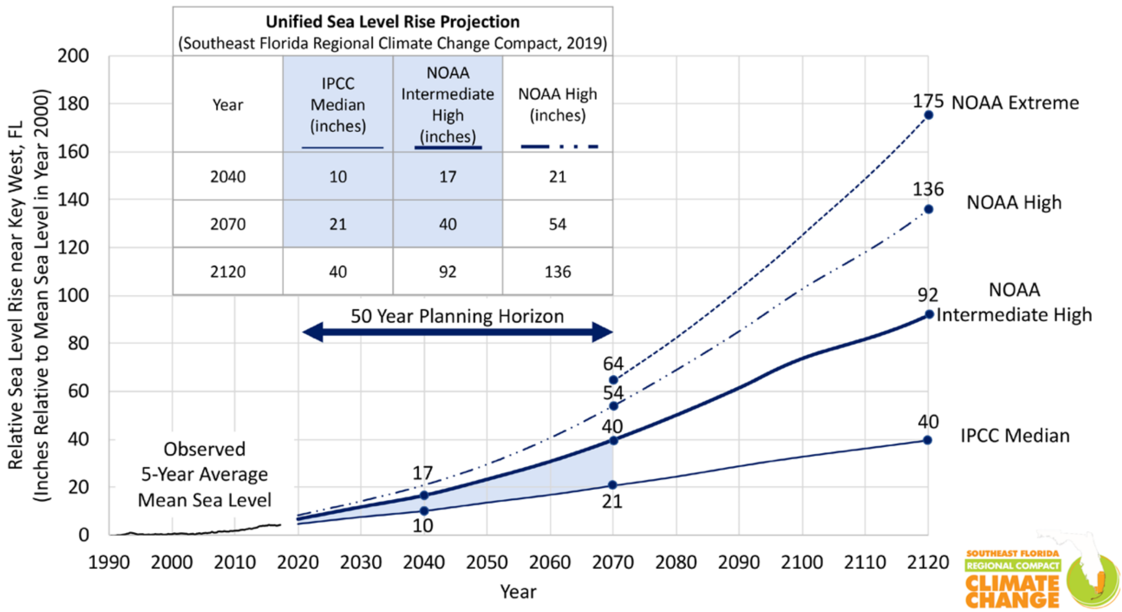


Note. Prepared by the Technical Ad Hoc Work Group. All projections are based on mean sea level at Key West, Florida. The IPCC AR5 RCP8.5 scenario is the lowest boundary (blue dashed line). The USACE High curve represents the middle solid blue line. The NOAA High curve is the uppermost boundary (solid orange line). Source: Southeast Florida Regional Climate Change Compact (2015b). Used with permission from the Compact.

Most recently, the Tech WG met in 2019 to review the latest scientific evidence and SLR projections. In this latest iteration of the Tech WG's projections, they decided on providing the most extreme projection from NOAA in their Unified SLR Projections (Figure 4.11). A member survey conducted by the Compact in 2019 showed that many members did indeed wish to see the full range of possible futures that the region could experience (Compact representative). As such, the Tech WG responded to this need and included the NOAA extreme scenario on their projections. The Compact's (2019) Unified Sea Level Projections report, however, made sure to mention that the NOAA Extreme curve was "included for informational purposes, not for application" (Southeast Florida Regional Climate Change Compact, 2019, p. 4). The Tech WG also decided to expand the timeline all the way out to 2120 – approximately 100 years from now (Figure 4.11). As some critical infrastructure built today will last 100 years into the future, they believed it was necessary to provide this expanded timeline out to 2120. This was also the planning practice that the USACE representative recommended in the first Tech WG meeting. The fact that federal agencies had begun projecting out that far also played a role in the Tech WG selecting that timeline.

Figure 4.11

The Compact's 2019 Unified Sea Level Rise Projections



Note. Prepared by the Compact's Technical Ad Hoc Work Group. All curves are referenced to mean sea level at Key West tide station. Source: Southeast Florida Regional Climate Change Compact (2019). Used with permission from the Compact.

3.3.2. Expertise (Who are the experts?)

As mentioned in section 3.3.1, governmental, scientific, and technical knowledge are the primary knowledge sources utilized by the Compact. Often, interviewees spoke of academics and government technical experts or scientists when they refer to experts in the Compact. Many senior leaders of the Compact whom I interviewed were proud of the expertise that the FCI and affiliated scientists provide to the Compact. Technical professionals, such as hydrologists from the South Florida Water Management District, planners from the South Florida Regional Planning Council, or representatives from federal agencies are often referred to as experts in both my interviews and in Compact documentation The Compact stacks their ranks with scientists and technical experts in order to build the credibility of their knowledge products for use in local decision-making. For instance, the Compact refers to this expertise in building the credibility of the Unified SLR Projections:

> The Unified Sea Level Rise Projection are the only regionally-coordinated and locally-specific sea level rise projections for the Southeast Florida region. The projections are updated regularly by a qualified group of scientists and experts, so planners should consider the projections to be both scientifically sound and timely (Southeast Florida Regional Climate Change Compact, 2012a, p. 6).

Ultimately, it is government knowledge sources and expertise that have held the highest status in the Compact. For instance, in the first Technical Ad Hoc Work Group, one member recalled that if it wasn't government data, it was often ignored. It was a federal government representative from the USACE that commanded the respect of most participants – as a technical expert – and helped that contentious meeting come to a final consensus for what SLR projections to use in their report.

3.3.3. Visions (How do actors envision the future and how are those visions negotiated?)

The Compact has a mix of different organizations (e.g., academic, government scientists, government officials, and non-profit organizations) represented each with their own visions of the future for the Miami Metropolitan Area. These divergent visions have been a significant cause of some of the tensions mentioned in Section 3.3.1, as I describe below. I have identified four distinct visions across the UREx SRN Climate Resilience Survey, participant observations, and individual interviews. The visions present in these data tend to map fairly well onto one of these four distinct visions (i.e., visions of the Miami Metropolitan Area near the end of the century)

The first vision represents complete retreat from the coastline. In this vision, the Miami Metropolitan Area is completely submerged. One academic with whom I spoke – who has been engaged with Compact activities since its formation – shared that their personal view is that they think SLR will "probably be thirty feet by the end of the century". At thirty feet, the great majority of the region is submerged leaving a very small portion of the region still habitable (Harlem, 2008). One Compact Steering Committee member called this the most "doom and gloom" vision of the region, as it doesn't allow for any adaptation solutions to solve the problem. These statements show that some members of the Compact personally espouse or are aware of a highly dystopian view of the future of the region – one that assumes a significant to total retreat of the region must occur. I call this vision the *Atlantis* vision, named after the now famous article written by Jeff Goodell (2013) in the Rolling Stone that extensively describes this future and some of the actors who embrace it.

The second vision represents significant retreat from the coastline. In this vision, the Miami Metropolitan Area begins to take the shape and culture of the Florida Keys (Cox & Cox, 2016). This vision occurs when there is moderate SLR that submerges most, but not all of the region (Harlem, 2008; see Section 4). It also assumes that our social, ecological, and technological solutions won't matter much to stop the rise. At least one city mayor within the Miami Metropolitan Area – and Compact – espouses this vision (Goodell, 2013). Pete Harlem often discussed this Florida Keys-like scenario and referred to it as *Margaritaville* (Cox & Cox, 2016). As such, I call this scenario *Margaritaville.*

The third vision represents partial retreat from the coastline. In this vision, only the lowest-lying areas need to be retreated from as our solutions will mostly maintain life as it is today. Several government officials – who are involved with the Compact – shared this more positive vision that includes comprehensive strategies to tackle rising seas. This vision acknowledges that SLR will likely take place, but also places significant confidence in the social, ecological, and technological solutions to remedy the problem. For instance, one County resilience official shared their vision on the Climate Resilience Survey:

> We have transitioned areas prone to flooding for natural or public space that is not significantly impacted when flooded, and is available for recreation or increased natural space when not flooded. Density is increased in areas of higher elevations, particularly along transit corridors. Energy is primarily produced from renewable sources and transportation is primarily by elevated rail and other improved public transportation options.

This vision shows that some retreat may be necessary in flood-prone areas along with several adaptation strategies, like elevated rail, to ensure that life continues in the region. One representative from a local NGO who participates in the Compact shared a similar vision, on the Climate Resilience Survey, in which partial retreat may be needed: "retreat from low areas which are converted to natural or green/grey systems with coastal flood protection benefits and other co-benefits". I dub these shared visions *Living with Water*. While this term is present in regional resilience planning documents, those documents do not discuss retreat. As such, this is a term that I have assigned to this vision rather than an official vision presented in local planning documents or discourse.

The fourth vision represents zero to no retreat from the coastline. In this vision, our resilience solutions will maintain life as it is today with little to no change. A Compact government scientist's vision, also captured from the Climate Resilience Survey, was blunt about the role of adaptation solutions in guaranteeing the region's future: "levees, sea walls and pumps, elevated roads and buildings". This vision acknowledges that SLR may happen, but instead only focuses on the solutions that will maintain current conditions. Another Compact member shared an iteration of this vision for the region, also from the Climate Resilience Survey:

> Sourcing energy from solar creates local, well-paid jobs in the green economy; use of infill, mixed-use, transit-oriented development; accessible and affordable public transit systems; vibrant, accessible greenspaces, multi-use public parks and significantly increased urban tree canopy are providing a multitude of benefits to residents; expansion of affordable, dignified, well-designed housing integrated within city fabric and accessible to social services; preservation of our historic buildings and structures; all new homes/structures are developed to enhanced codes that include solar, efficiency requirements, flood protection.

Similar to the government scientist's vision, this vision does not mention retreat at all. It focuses on *preservation* of historic buildings and structures while utilizing a range of social, ecological, and technological strategies to maintain or improve existing quality of life, infrastructure, and economic growth and opportunities. The County officials who would not accept any SLR projection over two feet during the Compact's first Tech WG meetings (see Section 3.3.1) also espouse this vision. Lastly, Wakefield's (2019) analysis of the City of Miami Beach's – a key local municipality in the Compact – future vision finds that: “rather than utopian transformation, what is sought in this large-scale engineering project is the maintenance of current property values, tourism, and luxury lifestyles amidst rising seas” (p. 41). Based on Wakefield's (2019) findings, the City of Miami Beach’s vision would also be a version of this same theme. The visions above are all iterations of what I call the *We Will Innovate* vision. The focus of this vision is on protection, maintenance, and possible improvement of the status-quo despite any future SLR risk. The use of innovation here reflects the aspiration to innovate by finding and employing new solutions – often technical – to address the SLR problem. This vision’s name is not referenced directly by local actors – it has been assigned by me to capture the nature of this particular vision and its aspiration.

The uncertainty in future SLR has created these bifurcated visions due to the question of whether or not the region will survive through the end of the century. These divergent visions reflect the answer to two key questions: (1) how much SLR does one expect the region to have? and (2) how much trust does one have in our future social, ecological, and technological innovations to meet any future SLR challenges?:

- ***Atlantis*****:** Total or nearly total retreat of the region. A shared vision in which SLR will overwhelm the ability of our social, ecological, and technological solutions to adapt to future floods. The region will likely have to retreat almost entirely. If we are lucky, a few very small areas of the region will remain.
- ***Margaritaville*****:** Significant retreat. A shared vision in which moderate SLR will occur, but likely not the most extreme SLR scenario. Our social,

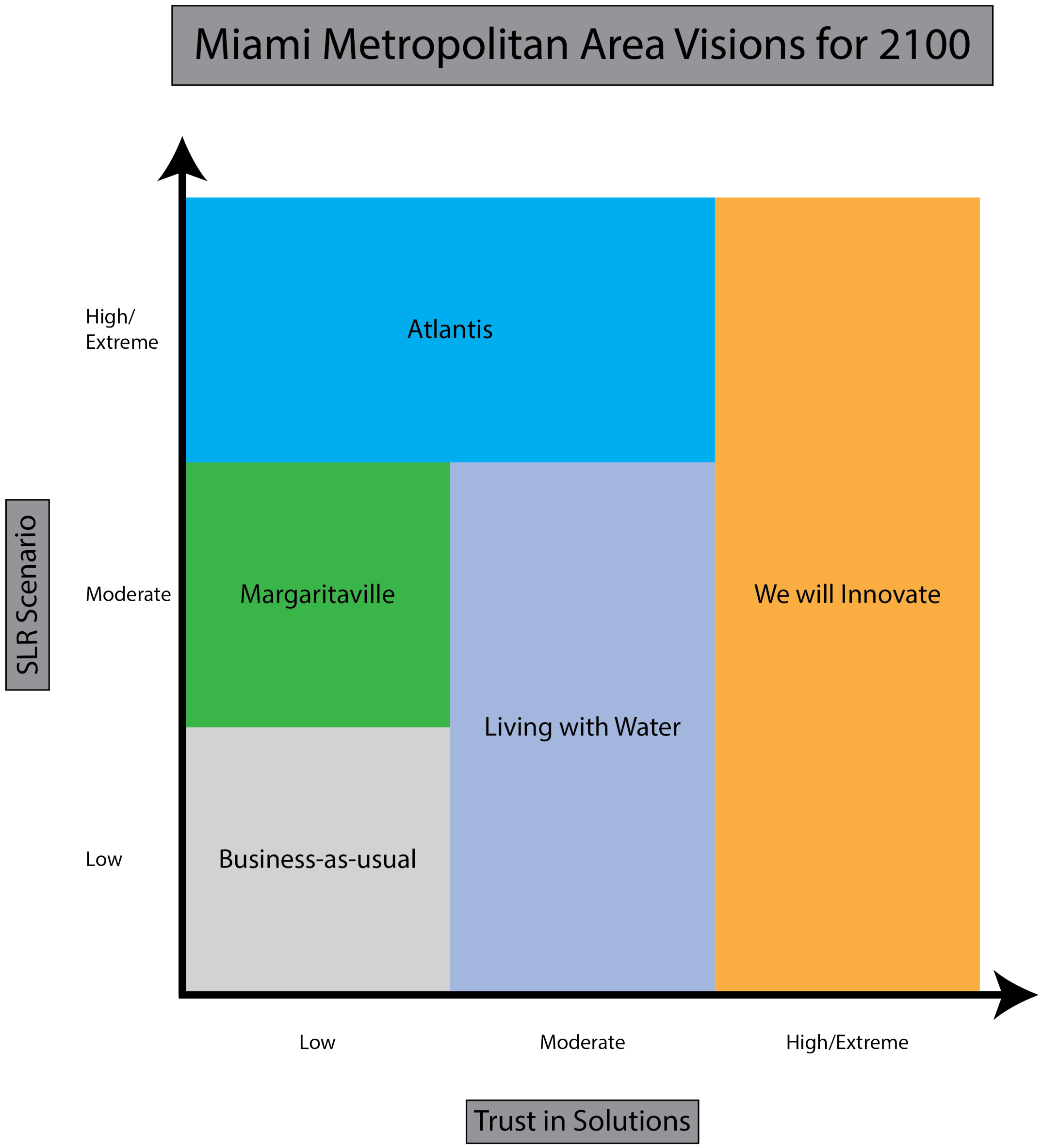
ecological, and technological adaptations will likely be overwhelmed, but a habitable Florida Keys like archipelago of islands will be left.

- ***Living with Water*****:** Partial retreat. A shared vision in which SLR will occur, but likely not the most extreme SLR scenario. Our social, ecological, and technological adaptations will enable us to continue living in the region. Some retreat of low-lying areas to higher ground is likely necessary due to moderate SLR.
- ***We Will Innovate*****:** Little to no retreat. A shared vision in which SLR may or may not occur. Even in the worst-case scenario, our social, ecological, and technological innovations will meet the challenge with little to no need to retreat or slow down current development trends.

If one plots these visions onto a grid of SLR Scenarios and Trust in Solutions from low to high (Figure 4.12), there is one additional vision that emerges. A vision where little to no SLR occurs and there is also low trust in - or no need at all for - social, ecological, and technological solutions. I did not encounter anyone in my sample that espoused this business-as-usual scenario. I mention it here only as it completes the full spectrum of possible visions – as plotted by SLR Scenario and Trust in Solutions – for the Miami Metropolitan Area.

Figure 4.12

Miami Metropolitan Area Visions for 2100



Note. Vertical axis is what one expects the depth of sea level rise to be by 2100 (SLR scenario). The horizontal axis plots trust in solutions, or how likely our social, ecological, and technological innovations and fixes will do in solving the problem.

While these visions are all represented in the Compact by various actors and to various degrees, the Compact's consensus or shared vision can be identified through analyzing the Compact's formal documents and reports – the result of numerous deliberations and negotiations by its members. It can also be seen in how Compact leaders talked about the Compact to all of their constituents in the 10th Annual Summit. The Compact's 2019 Unified SLR Projections call for integrating some level of future SLR into local planning – they do acknowledge that SLR is likely to happen in both the near- and long-term (Southeast Florida Regional Climate Change Compact, 2019). However, The Compact's approach is largely to protect rather than retreat. The Compact's RCAP aims to "protect the assets of the region's unique quality of life and economy, guiding future investments, and fostering livable, sustainable and resilient communities" (Southeast Florida Regional Climate Change Compact, 2015a, p. 5). The plan offers social, ecological, and technological strategies to overcome future risks such as SLR. Not only is the Compact's focus on protection, but there is a notable absence of any mention of retreat or partial retreat in both iterations of the Compact's regional climate adaptation plans (Southeast Florida Regional Climate Change Compact, 2012b, 2017b) including the section on Risk Reduction and Emergency Management. In addition, while attending the Compact's 10th Annual Summit, Steve Adams – Director of Urban Resilience for the ISC – publicly reflected on his vision of the Compact: "we build a way to be able to talk to each other about our hopes and dreams, this place and **for our children who we hope will be able to live here as we have**". This statement reflects a focus on maintaining and protecting the current way and quality of life for current and future generations. The exclusion of retreat as a resilience strategy for current for future low-lying areas (as reflected in its absence from official Compact documents, several participants' expressed visions, and the Compact's leadership's focus on protecting the current way of life for future generations) indicates that the Compact's vision more closely aligns with the *We Will Innovate* vision.

3.4. The process (What is the quantity and quality of the interaction between participants?)

The Compact features a variety of routines and processes rather than one formal set of practices. This is due to the fact that it consists of various Standing and Ad Hoc Work Groups. Each of these teams meet separately. The Standing Work Groups (i.e., Policy Team, Summit Planning Team, Regional Climate Team, Shoreline Resilience Working Group, and Municipal Work Group) meet on a regular basis whereas the Ad Hoc Work Groups (i.e., Technical Ad Hoc Work Group, Compact Inundation Mapping and Vulnerability Work Group, Regional Indicators Work Group, Regional Greenhouse Gas Inventory Work Group) meet as needed. These work groups are each made up of actors across various sectors represented by the Compact (for a full overview of each of these work groups and the actors involved see GCC, 2017). There are also several implementation and capacity building workshops provided to members every year.

The Compact has a clear set of routines and practices to ensure that its knowledge products stay up to date. For instance, the Regional Climate Team is responsible for developing and renewing the Regional Climate Action Plan every 5 years. They have produced two iterations of the Compact's Regional Climate Action Plan to date (Southeast Florida Regional Climate Change Compact, 2012b, 2017b). The most recent RCAP took over one year of intensive stakeholder engagement, expert direction, and public input (Southeast Florida Regional Climate Change Compact, 2017b). The Tech WG is responsible for developing and updating the Unified Sea Level Rise Projections.

As described in 3.3.1, the Tech WG goes through a rigorous deliberative and iterative process over the course of a minimum of six months, every four to five years, to update the Compact's Unified SLR Projections (Subject 2; Subject 25). In addition to the formal routines and processes, members of the Compact report speaking informally to other members on a daily basis to share knowledge and information between organizations.

In summary, the Compact has substantive and frequent interactions between many of its participants. For those who don't participate on a regular or informal basis, the Compact also offers an annual summit for all members and the general public to attend and keep up to date on the Compact's initiative and future directions.

3.5. Outcomes (What outcomes has this initiative achieved?)

3.5.1. Scope 1 Outcomes

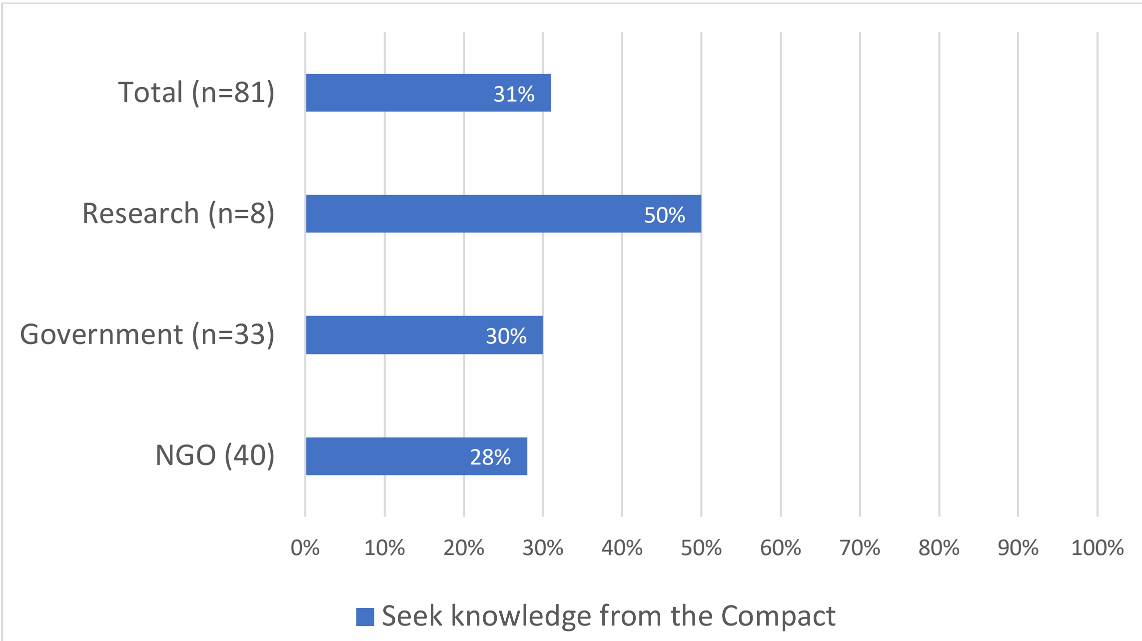
Deepening knowledge

The Compact was first born out of the need to streamline the production and validation of SLR knowledge– and then took on the role of coordinating planning and action across Southeast Florida. As such, deepening knowledge has been a core function of the Compact's initiative from the outset. The Compact has put together a variety of knowledge resources to educate South Floridians about the vulnerability of the region to climate change and sea level rise. Since its creation in 2010, there have been three iterations of the Compact's Unified SLR Projections (i.e., in 2011, 2015, and 2019), a 2012 Inundation Mapping and Vulnerability Assessment, two iterations of the Regional Climate Adaptation Plan (i.e., in 2012 and 2017), a GHG Inventory in 2015, a dozen annual summits, over a dozen implementation workshops, and much more. The Georgetown Climate Center claims that: "the Compact was able to develop robust, scientific research to help the individual local governments better understand the risks posed by climate change" (Menees & Grannis, 2017, p. 6). Prior to the Compact, local governments expressed frustration trying to understand and interpret national and global climate science data for relevance at the local level. There was a need to figure out what this meant for the unique climate and geology of Southeast Florida. One City of Miami Beach official shared that the primary benefit of the Compact for her was that "the science has been localized and operationalized". Now, city officials can make sense of this climate data and then put it to action (see Catalyzing Action in this Section).

When asking interviewees about their primary source of knowledge and expertise regarding climate change and sea level rise to the region, the Compact is often mentioned – especially by local government actors. The same trend can be seen in the UREx SRN Climate Resilience Survey (see Section 2). When asked, "please list up to 5 organizations or groups that you go to for information, advice, data, or expertise related to climate change in Miami-Dade County", 31% of organizations listed the Compact as one of their 5 primary sources of knowledge (see Figure 4.13 for breakdown by sector). The Survey results suggest that the Compact serves as an influential and salient knowledge source for stakeholders in Miami-Dade County.

Figure 4.13

Popularity of the Compact as a Source of Climate Knowledge



Note. This chart shows the percent of survey respondents, by organization type, who indicated that they consider the Compact as one of their top 5 knowledge sources. Precents are within-group rather than across-group.

These results only apply to Miami-Dade County, rather than the entire Miami Metropolitan Area.

Strengthening Communities

The Compact has been particularly successful in building trust within and across sectors and increasing the capacity to plan for and adapt to flood risk. The Compact created a new platform for a diverse group of local actors to work toward a common goal, build trust, and create new relationships along the way. Prior to the Compact's formation, members of the four counties didn't have a streamlined means of communicating and sharing knowledge together on common issues. Subject 7 recalled that prior to the Compact communities were working on the problem independently: there was little to no coordination and communication across local communities and sectors regarding resilience to SLR: “you've got neighboring communities, all the maps look different, all the [SLR] projections are different, and it was just ludicrous”. Now, diverse groups of actors collaborate together on producing shared climate resilience knowledge and receive frequent training to build up local capacity:

> The Compact puts together easily two or three trainings a year where you can send your staff to learn how to do GIS something, or... just different tools – whether it's adaptation or mitigation or anything else. I find great value in that collaboration. And part of that is breaking down the silos and really working beyond your walls. So, I'm a big fan. (Local government official)

The Compact created scales of efficiency; no longer were multiple actors working independently on producing and validating new SLR knowledge. Instead, limited financial and human resources were now freed up to focus on taking action. Many small cities within the region do not have the massive budgets and resources that the Counties and neighboring cities, like the City of Miami Beach, have access to. Now, all of the members in the Compact can benefit from the knowledge, resources, and connections through the Compact:

> By creating a platform for these agencies to provide support that would benefit the region as a whole, the Compact was also able to bring in scientific expertise from individuals and agencies that may not have engaged with each of the counties on an individual basis (Menees & Grannis, 2017, p. 6)

As such, the economies of scale that the Compact created have significantly increased the capacity of small cities in the region to address climate change and SLR issues in their own communities (Menees & Grannis, 2017; Southeast Florida Regional Climate Change Compact, 2015a).

There is both a formal and informal flow of knowledge, information, and resources across the member organizations of the initiative. Several members that I spoke with reported contacting other Compact members on a daily basis – both within and across the various sectors represented by the Compact. These are often informal calls. Formally, the Compact has plenty of meetings and events for members to be engaged with each other on a regular basis. These include annual summits where members and even the public attend to track progress, set future agendas and goals, and network; regular implementation workshops and trainings for members to build capacity; five Standing Work Groups that meet on a regular basis; and at least four additional Ad Hoc Work Groups that meet as needed to work on specific projects (Menees & Grannis, 2017).

The trust and relationships built through participation in the Compact have set the foundation for leveraging other resources. For instance, several member organizations (i.e., Miami-Dade County, the City of Miami, and the City of Miami) partnered together to submit the successful application – The Greater Miami and the Beaches – to the Rockefeller Foundation's 100 Resilient Cities (100RC) initiative in 2016 (The Miami Foundation, 2016). These bonds and relationships extend across sectors as well. The FCI's partnership with the Compact has helped both organizations to leverage new funding for academic research projects that serve the interests of both organizations. The Compact helps to show funding agencies the relevance of the science to local decision-making, and the FCI's new research ultimately benefits the Compact by expanding its scientific knowledge base (Menees & Grannis, 2017).

Utilization of knowledge in decision-making

The Compact has gone to great lengths to assist local municipalities in applying its knowledge into local policies and plans; the Compact has published scores of guidance documents to help municipalities integrate various Compact knowledge products into local plans and policies. For instance, the Compact's "*Integrating the Unified Sea Level Rise Projection into Local Plans*" contains numerous examples of how the Unified SLR projections have been utilized by local governments in policies and plans, and includes draft language that other governments can readily use in their own plans and policies (Southeast Florida Regional Climate Change Compact, 2012a). This scaffolding strategy seems to have been effective in promoting the uptake of the Compact's knowledge into actual policies and plans, as I will describe below.

The Compact published the Southeast Florida Regional Climate Action Plan (RCAP) in 2012 and was adopted by all four Compact counties in 2014 (Southeast Florida Regional Climate Change Compact, 2015a). The RCAP includes 110 action items written to guide local policies and projects related to transportation planning, water management and infrastructure, natural systems, agriculture, energy, risk reduction and emergency management, public outreach, and public policy (Southeast Florida Regional Climate Change Compact, 2012b). The ISC conducted their Municipal Implementation Survey in 2014. 55 of the 108 municipalities within the Compact's geographical region completed the self-reporting online survey. The results indicated that the top ten cities had implementation rates between 42% - 60% of all 110 RCAP actions (Southeast

Florida Regional Climate Change Compact, 2015a). Table 4.5 shows a sample of the implementation rates from a few of the cities in the region.

Table 4.5

Municipal Implementation Rates from the Compact's 2014 Municipal Implementation Survey

City	County	Implementation Rate (%)
Miami	Miami-Dade	16
Miami Beach	Miami-Dade	55
West Palm Beach	Palm Beach County	42
Fort Lauderdale	Broward	42
Key West	Monroe County	59

At the County level, there is evidence that "the comprehensive plans have integrated the unified projections in the narratives of document elements, directly in policy language, and by embedding the unified projections graph into the document or appendix" (Southeast Florida Regional Climate Change Compact, 2012a). For example, Miami-Dade's Comprehensive Development Master Plan incorporates climate change and sea level rise policies and objectives in various parts of the plan (e.g., transportation, coastal management, land use; RCAP Implementation Guide, 2012). Broward County's Comprehensive Plan mentions their long-term planning horizon as 2060 being consistent with the planning horizon suggested in the Compact's 2011 Unified SLR Projections (Southeast Florida Regional Climate Change Compact, 2012a).

As discussed in Section 3.4, The Compact renews its RCAP every five years. In 2017, the Compact published RCAP 2.0 which expanded the number of recommended actions to 142 (Southeast Florida Regional Climate Change Compact, 2017b). RCAP 2.0 is an online interactive tool that allows anyone to create a customizable implementation plan (another example of helpful scaffolding). The ISC conducted a comprehensive member survey in 2019 to assess how members across all sectors are implementing its revised RCAP 2.0 as well as the Compact's other knowledge products – this was a larger sample than the previous municipal survey. A Compact representative reported that the survey showed the vast majority of actions are being implemented by cities or counties, but there was also evidence of implementation by non-profit organizations and the private sector. The projections are being used largely for "education and communication with the public and stakeholders, requirements for planning design and permitting standards for infrastructure and facilities, policy and ordinance inclusion and local government plans" (Compact official). The types of plans that were most commonly cited as incorporating the Unified SLR projections were local hazard mitigation plans, comprehensive plans, and stormwater plans. For instance, RCAP 2.0 includes an item ST-01, Sustainable Communities and Transportation – Incorporate projections into plans. According to the member survey results (Southeast Florida Regional Climate Change Compact, 2020a), at least 45 local municipalities reported to have incorporated the projections into their local plans (e.g., comprehensive, transportation, infrastructure, and/or capital improvement plans). I also spoke with several local NGO leaders who expressed using the Compact's knowledge often for climate change education, outreach and advocacy (Subject 15; 16; 20). These NGO leaders use the Compact's projections in community presentations and climate change advocacy work. They expressed that since these projections are the official projections that the region has vetted, using these in presentations and in their advocacy work give them more credibility and legitimacy – especially with government actors (Subject 15).

In summary, it is clear that the Compact's knowledge products have had significant influence on planning practice and design throughout the Miami Metropolitan Area. Knowledge utilization examples can be seen across all sectors of society – not only by government actors and organizations.

Catalyzing Action

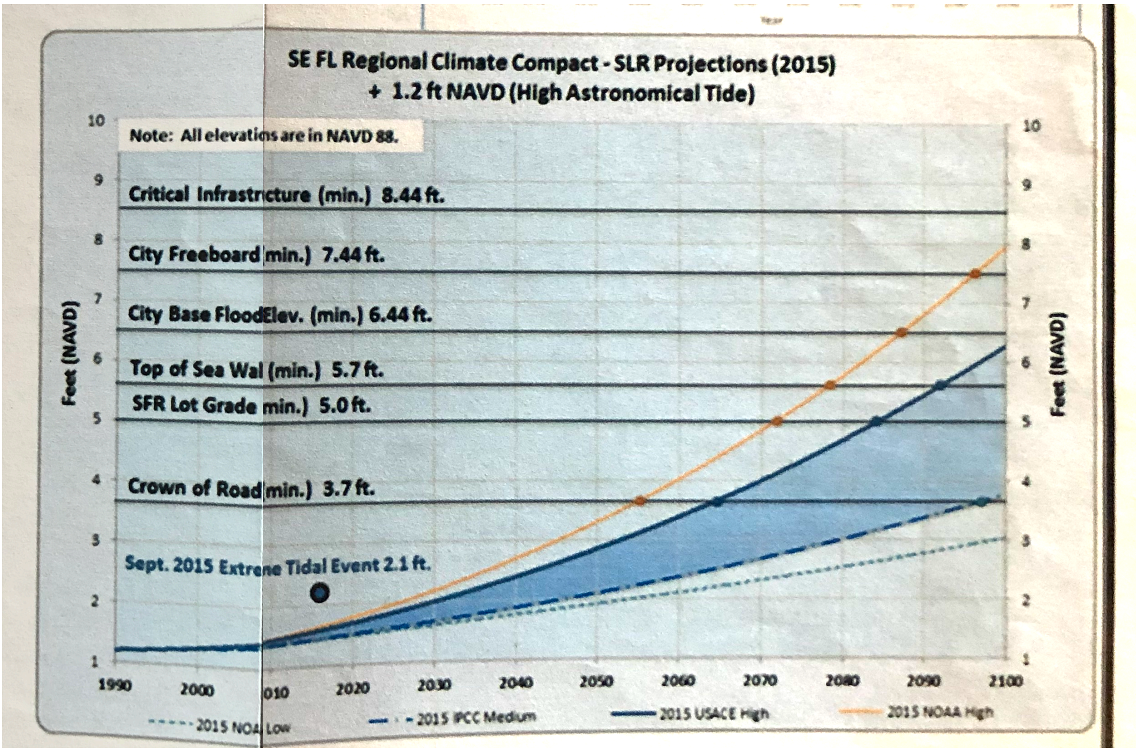
There is significant evidence of the Compact's knowledge being utilized in various climate adaptation and resilience projects throughout the Miami Metropolitan Area. After the 2014 Municipal implementation survey, a Municipal Working Group was established to provide support to local municipalities in implementing the Compact's guidance and plans (Southeast Florida Regional Climate Change Compact, 2015a). Their guidance has been helpful in translating knowledge into on-the-ground action, such as the case I will present below from the City of Miami Beach.

Example from the City of Miami Beach

The City of Miami Beach adopted the Compact's 2015 Unified SLR Projections in March 2019 for planning purposes (City of Miami Beach, 2019). However, the city has not just integrated these projections in their plans, but have taken actual adaptation actions based on this data. The Department of Public Works for the City of Miami Beach took the Compact's projections, added 1.2 feet North American Vertical Datum (NAVD) to factor in observed astronomical high tide for Miami Beach, and then assigned the minimum elevations that various capital projects should be design for under the various SLR scenarios in the Compact's projections (Figure 4.14).

Figure 4.14

The City of Miami Beach's Sea Level Rise Guidance for Future Capital Projects



Note. The curves are derived from the Compact's 2015 Unified Sea Level Rise. This was in use as of mid-2019. Source: An official from the City of Miami Beach

These were not technically design standards, but instead design guidelines based upon the lifespan and criticalness of the infrastructure or project. The City planned for elevations based on the life expectancy of the infrastructure: "in the end, we're going to be planning for the timeframes in which that infrastructure is going to last" (City of Miami Beach official).

For some infrastructure, such as roads, these guidelines have since become design standards. Roads have short lifespan; paved roads have a life expectancy of between twenty to thirty years (National Cooperative Highway Research program, 2012). At the time, the City's data showed that Miami Beach had experienced as much as a 1.7 foot king tide back in 2013. The City “felt like the crown of road should be at least a foot higher than what we see in the ocean or the Bay” (City of Miami Beach official). As such, that put their baseline at 2.7 feet even without anticipated SLR. One City of Miami Beach public works employee recalled that “we're saying, a foot is probably only good for 20 years based on the [Compact’s SLR] scenario projections”. As such, they then added an additional one foot of SLR to that baseline to get their design guideline of 3.7 feet for the crown of the road for the next twenty years. By planning for roads at 3.7 feet NAVD, the City of Miami Beach aimed to keep their roads dry through around 2055 based on the NOAA High curve from the Compact’s projections.

> The 3.7 foot NAVD88 standard is based on minimizing potential flooding associated with tides, rainfall, and sea level rise, to around the year 2055. This estimate is based on engineering models and the Southeast Florida Regional Climate Change Compact Unified Sea Level Rise Projection. (City of Miami Beach, 2020)

Roads built today would likely need to be rebuilt prior to 2055. So, while rebuilding the road twenty to thirty years later, it could then be raised as needed. However, for more critical infrastructure with longer lifespans – such as wastewater treatment facilities – the guidance recommends elevating to 8.44 feet NAVD. This would theoretically keep a Miami Beach wastewater treatment facility dry out beyond 2100 based on the Compact’s 2015 Unified SLR Projections.

The City of Miami Beach has indeed been raising their roads throughout the city. Any road that was below 3.7 NAVD has been or will be raised to meet the City’s new design guidelines (City of Miami Beach, 2019). For instance, the road elevation in the

Sunset Harbour Neighborhood was raised about three feet to meet these new design standards (City of Miami Beach, 2020). I acknowledge that raising roads has been the subject of criticism from some local Miami Beach residents (A. Harris, 2020). However, the example above is provided solely as an illustration of how the projections have been applied in local adaptation projects – not as an evaluation of the appropriateness of the strategy.

Raising roads have not been the only action taken by the City. In 2016, the Miami Beach Mayor and City Commission passed resolution 2016-29454 which required that all new public and private seawalls be constructed at a minimum elevation of 5.70 feet NAVD – As of 2020, a new seawall ordinance has been drafted to ensure that all future private and public projects meet this new design standard (Participant observation, 2020).

3.5.2. Scope 2 Outcomes

Put in evaluative terms to assess the achievement of transformative Scope 2 outcomes, Table 3.1 asks the following question: what SETS knowledge landscape arrangements have been updated or rearranged to achieve the Compact's long-term transformative outcomes? Below, I unpack some of the Compact's achievements and shortcomings while posing additional questions for future studies of the Compact, and current Compact leaders, to explore more in-depth.

Nearly all of my interviewees who were familiar with the Compact reported that it transformed the way the region collaborates and shares knowledge across jurisdictions and sectors. In other words, the Compact has likely rearranged some of the couplings between knowledge and decision-making (i.e., a governance innovation) throughout

Southeast Florida. This finding is corroborated by an in-depth analysis of the Compact's governance network performed by Vella et al (2016) who find that:

> The Compact's decision forums have allowed for deliberations that have helped to coordinate the efforts of previously independent systems of users, knowledge, authorities, and organized interests. This has mobilized climate action by strengthening administrative networks for collaboration regionally across local government boundaries (p.374).

As mentioned throughout Section 3, participants report collaborating in a variety of modes through the Compact – workshops, summits, work group participation, and even daily phone calls for knowledge and information sharing. Moreover, local and regional government agencies now look to the Compact to get their climate risk knowledge. Pre-Compact, there was a large diversity of methods, data, observations, and claims about how much flooding the region was likely to experience over the next several decades (see Figure 4.4). Many of these were knowledge from global or national sources, like the International Panel on Climate Change, and did not take into consideration local climatological and geological dynamics (Wanless, 2018). The Compact's projections now do (Southeast Florida Regional Climate Change Compact, 2019). Also, prior to the Compact, few local government agencies were using future-oriented projections of floods in their planning and policies. With the generation and validation of the Compact's Unified Sea Level Rise Projections and a new governance network that has co-evolved with it, the region is beginning to see much higher utilization of knowledge and on-the-ground action (Southeast Florida Regional Climate Change Compact, 2015a). As such, there is evidence of new alignments occurring and stabilizing between knowledge, governance, and decision-making in the SETS knowledge landscape.

The Compact's Unified Sea Level Rise Projections have become a political actor. The projections are now a technological artifact (Hughes, 1994) with clear roles and routines that have been established for its reproduction every four to five years by the Compact's Tech WG. The projections are then used to alter urban form and change the flood risk profile of certain areas of the city – like the City of Miami Beach's road infrastructure projects, seawall raising projects, and new building's first flood elevation requirements. Also, the region's waterways, like Indian Creek in the City of Miami Beach, are being transformed both technologically (i.e., adding new and higher seawalls along riverbeds) and ecologically (i.e., adding mangroves along riverbeds) to better armor them for rising seas. This shows that the new projections – a form of technical knowledge – have begun to tightly couple with both urban ecological and technological landscapes (the material world). New forms of uniting SETS knowledge with action seem to be gaining momentum or obduracy in rearranging particular aspects of the prior SETS knowledge landscape that existed pre-Compact. In short, there have been new ways of uniting knowledge and action that have emerged and are stabilizing in the region. Future research can evaluate their long-term stabilization and new arrangements that may emerge over time as the initiative matures.

However, the governance innovation mentioned earlier has not been without its shortcomings. As I have shown in Section 3.2, the Compact remains a government-centric organization. The governance transformation is most evident in connecting government actors horizontally (i.e., between local governments) and vertically (i.e., from local to global governments) across administrative jurisdictions. More can still be done to connect government organizations across academic, civic, and business sectors. There have been incremental efforts by the Compact to better integrate these non-governmental sectors (see Section 3.2), but I would caution against labeling those efforts as transformative. Instead, my case study analysis suggests that the nature of these interactions across other sectors tends to mirror the existing SETS knowledge landscape that existed prior to the Compact; SETS knowledge arrangements that tend to be more elitist, and exclusive rather than inclusive in both their knowledge co-production process and resilience outcomes (K. Grove et al., 2020; Vella et al., 2016; Wakefield, 2019). For instance, Wakefield (2019) critiques the City of Miami Beach's approach as a form of 'back-loop urbanism'. She argues that the city's transformation of their urban infrastructure and technical regulations (based on the Compact's projections) have shown that maintaining the current way of life there is now a real possibility. However, she argues that maintaining the current way of life serves only specific interests (e.g., real estate developers, and the ultra-wealthy). More attention to the existing SETS knowledge-action configurations, and deliberate efforts to rearrange them are likely necessary to transform the Compact into a more inclusive knowledge co-production initiative that produces outcomes for a broader representation of society. Just adding new civic actors to the initiative may not be sufficient without addressing existing knowledge-power dynamics in the urban SETS knowledge landscape.

3.6 Summary and discussion of the Compact case study

The Compact was created out of the need to expand the governance of climate resilience across jurisdictions and sectors in Southeast Florida. A need that occurred also due to ecological factors: the fact that the region was experiencing accelerated frequency and intensity of floods – perceived to be the result of SLR. While there is representation from across various sectors of society in the Miami Metropolitan Area, government actors tend to wield the most power and influence in the initiative. This power is also responsible for steering the types of knowledge and expertise that are mobilized in the Compact. The Compact prioritizes governmental knowledge and holds government experts in high regard. However, other scientific and technical knowledge is also acknowledged and carefully considered along with the government knowledge. Similarly, expertise is invited from academia and other organizations that can provide technical expertise (e.g., such as TNC). Local and experiential knowledge and expertise play a very minor role – if any. The focus on government, scientific, and technical knowledge and expertise is done intentionally to ensure higher perceived legitimacy and credibility of the Compact's knowledge products for use by its principal stakeholders – local government agencies.

Several distinct visions are present within the Compact including *Atlantis, Margaritaville, Living with Water, and We will Innovate.* Through various modes of engagement participants have negotiated these visions – sometimes in contentiously – in order to craft official Compact knowledge. These visions have had a significant impact on the production of the Compact's knowledge products such as the Unified Sea Level Rise Projections (Southeast Florida Regional Climate Change Compact, 2011, 2015b, 2019) and the Regional Climate Adaptation Plans (Southeast Florida Regional Climate Change Compact, 2012b, 2017b). For instance, by projecting extreme SLR scenarios, some Compact members, who were government actors, worried that those projections would encode and encourage 'doom and gloom' visions such as *Atlantis* and *Margaritaville* to spread – visions that would likely show that SLR could overwhelm the region's ability to sufficiently adapt and find solutions. Instead, the Compact has employed a solutions-centric vision held by most government actors in the network: *We will Innovate*. This vision essentially imagines a future in which social, ecological, and technological innovations will overcome any risks that SLR may present. A vision in which retreat is not an option. By broadening out the Compact's actor network to include more civic and academic actors, there is a risk that there could be more pressure put on the shared *We will Innovate* vision to adopt visions with partial or complete managed retreat over time. Currently, the government-centric leadership has the control over this shared vision. By integrating diverse actors more closely in the network and providing them more power over its process and knowledge products, the *We will Innovate* vision risks being overtaken by a different vision. As such, the initiative is unlikely to broaden out its representation in the near-term.

In terms of Scope 1 outcomes, Section 3.5 has shown that the Compact has deepened climate knowledge, strengthened communities, increased the utilization of knowledge in decision-making, and has catalyzed adaptation actions to build resilience. The Compact has created, validated, and communicated knowledge on climate change and sea level rise. As such, it has deepened climate knowledge throughout the region – many actors throughout the Miami Metropolitan Area report seeking out the Compact as one of their principal knowledge sources on climate change and resilience. The Compact has focused on creating credible and legitimate knowledge by utilizing governmental, scientific, and technical knowledge and expertise. They also focus on making sure the knowledge they produce is relevant to the local context and environment. Since the knowledge is considered by many to be credible, legitimate, and relevant, this has resulted in the utilization of its knowledge products in plans and outreach particularly by municipal actors, but also by civic and private actors. The Compact has provided significant support to practitioners for implementing each of its various products, through its various implementation guides and work groups (e.g., Municipal Work Group). This scaffolding has helped to catalyze action and put its knowledge products into use. For instance, the City of Miami Beach has utilized the Compact's knowledge not only in its plans and policies, but in design standards for infrastructure like roads, sea walls, and buildings - into on-the-ground projects and experiments.

The Compact has shown evidence over its 10-year history in transforming or rearranging some aspects of the SETS knowledge landscape in which it is situated. It seems likely that the Compact has rearranged the couplings between climate knowledge and governance – a governance innovation – throughout Southeast Florida. In particular, it has created significant vertical and horizontal connections across government jurisdictions. The Compact's Unified Sea Level Rise Projections have become a technological artifact with technological obduracy. The projections are integrated into plans, policies, and eventually alter the urban landscape. New climate projects – guided by the projections – create new living shorelines as well as hard infrastructure upgrades to armor coastlines and riverbeds. The altered landscape then changes the food risk profile of the city and the flood vulnerability analyses performed by the Compact. The altered landscape also impacts couplings with other prominent flood risk knowledge systems like FEMA flood maps (see Chapter 2). As such, new couplings between ecological knowledge and ecosystems as well as technological knowledge and infrastructure systems have emerged, are stabilizing, and are even altering established knowledge systems in the urban SETS knowledge landscape like the FEMA FIRM.

While it has engaged academic, civic, and business actors, it is not clear if this inclusion has been *enough* to be considered a transformative Scope 2 outcome versus a Scope 1 - strengthening communities – outcome. The types of engagement with civic actors, in particular, were already common in the region prior to the Compact (K. Grove et al., 2020). The Compact case study shows the strong alignment between types of actors, power, knowledge sources and expertise, visions, and outcomes in the evolution of the co-production initiative. A more egalitarian and inclusive structure – with more representation and power afforded to civic, academic, and private actors – would likely espouse a different shared vision, influence the types of knowledge that count (e.g., more local and experiential knowledge would likely be included), produce different knowledge products, and then ultimately would alter the nature of the outcomes of the initiative. The current system, like many of today's knowledge systems (Chapter 1; Fazey et al., 2020), tends to be elitist and exclusive, maintaining existing knowledge-power relationships, and producing outcomes for elite city actors (K. Grove et al., 2020; Wakefield, 2019).

As a comparison to the government-centric Compact case, I analyze a more civic-centric and academic-centric knowledge co-production initiative in the following section, The Eyes on the Rise Project.

4. Case Study 2: Eyes on the Rise

"What's fascinating is that the technical elements rely upon the political elements"

– EOTR participant

The following sections analyze many of the key questions from Table 3.1 including the EOTR's goals, actors, knowledge, process, and outcomes. A summary is provided at the end which summarizes the key lessons learned from the case.

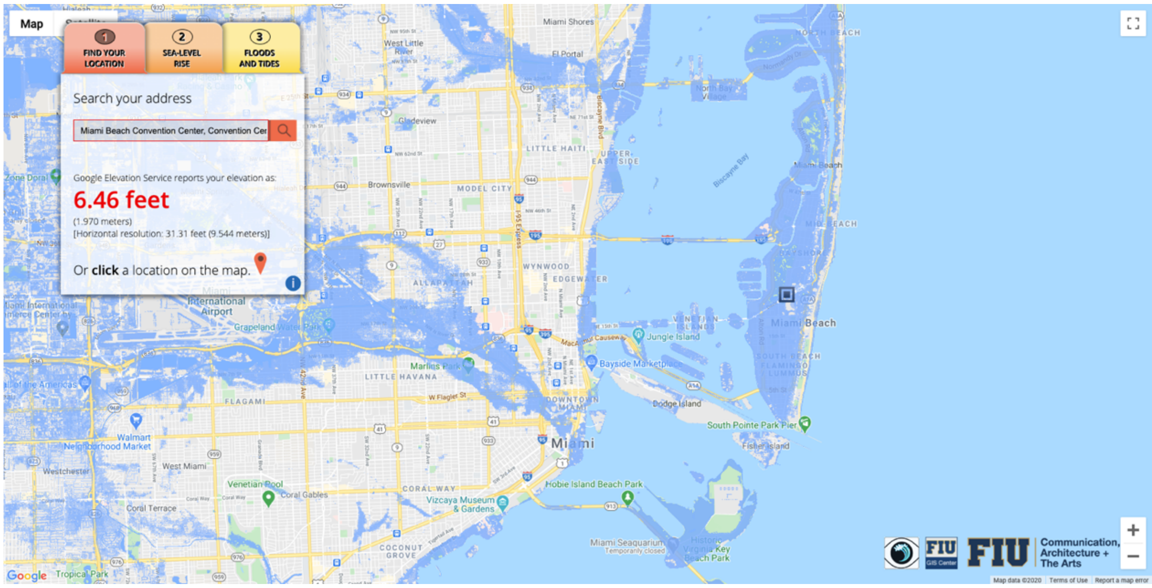
4.1. Overview of the initiative (How did it begin and what are its goals?)

Overview

The Eyes on the Rise (EOTR) project began as an interdisciplinary collaborative effort between several professors from the School of Communication + Journalism (Formerly the School of Journalism and Mass Communication) and the Geographic Information Systems (GIS) Center at Florida International University (FIU). The project also included non-academic partners from the media, civic organizations, and a government agency. Funding for the project came from a $35,000 award from the Online News Association Challenge Fund for Innovation in Journalism Education in 2014. The primary aim of the EOTR project was to "raise awareness and educate South Florida communities about the impact, challenges and threats of sea level rise, to create solutions for a sustainable future" (Florida International University, n.d.). The project was multifaceted: it included video documentaries, citizen science flood reporting, and an interactive sea level rise viewer called the Sea Level Rise Toolbox (SLR Toolbox; Figure 4.15). The latter has become the flagship product of the project and the center of scores of news reports over the last six years; hence why I focus on the EOTR's SLR Toolbox production, communication, and use as the principal focus of this analysis.

Figure 4.15

The Eyes on the Rise Sea Level Rise Toolbox User Interface



Note. This is a screenshot of the interactive user interface of the Eyes on the Rise Sea Level Rise Toolbox application showing six feet of sea level rise and the Google API reported elevation for the Miami Beach Convention Center. The black square in the center of the City of Miami Beach indicates the location of the Convention Center. At an elevation of 6.46 ft, the Convention Center is not inundated in the six feet SLR scenario. Source: Eyes on the Rise (2020). Used with permission from the Eyes on the Rise team.

Goals/Aims

According to the EOTR program's website, the SLR Toolbox was designed specifically to "inform citizens of South Florida about the potential impact of sea level rise in their neighborhoods" (Eyes on the Rise, 2016a). This aligns with what I was told during interviews with EOTR participants. For instance, one participant shared that the intention of the toolbox was:

> To make the sea level rise projections that Pete Harlem, a name you may have heard before, had created on still maps. We wanted to put that in a dynamic form.

So, it would animate a little bit and you could look at it by location. (EOTR member)

The late Peter Harlem, former Scientist for the Southern Environmental Research Center and Coordinator for the GIS Center at FIU, is well recognized throughout South Florida as one of the first to create advanced sea level rise inundation mapping using high-resolution Light Detection and Ranging (LiDAR) satellite imagery (Florida International University GIS Center, n.d.). Harlem's SLR inundation maps were published as early as 2008. Harlem's static maps illustrate the extent of flooding from SLR to the Miami Metropolitan Area (Harlem, 2008). The EOTR project aimed to create a user-friendly interactive tool to share Harlem's static inundation maps with the broader Miami area – the SLR Toolbox (Subject 17; Subject 18). In other words, the application served to connect cutting-edge SLR projections – at the time – to potential users in the community in a relevant interactive format (e.g., you can look up your own property address to see the depth of flooding projected). It shows the extend of SLR inundation – up to 6 feet of SLR – at the parcel level across Miami-Dade, Broward, and Palm Beach Counties. This was the one of the first – if not the first – open-sourced products to provide SLR risk information at the parcel level (Subject 17; Subject 18). Users can type in their address in the tri-county area and view flood statistics and a map of inundation for their property.

4.2. Actor Mapping (Who are the actors and how is power distributed?)

As mentioned in Section 4.1, the EOTR initiative was led by an interdisciplinary group of FIU academics who partnered with several local organizations to design and implement the project. As stated in the grant proposal, "this is a hyperlocal project that builds on partnerships and projects with local media, educational organizations and community groups" (Online News Association, n.d.). Dozens of journalists, scientists, technology experts, students, and local residents contributed to the development of the EOTR project and SLR Toolbox (Eyes on the Rise, 2016a).

The FIU School of Communication + Journalism held the most power in guiding the project as they were the group who had the initial idea and were awarded the funding. They were joined by the FIU GIS Center to provide the technical expertise necessary to visualize the late Pete Harlem's data in an interactive way. Local high school and FIU students were given opportunities to collect flooding data in real time citizen science campaigns as well as develop video documentaries to tell stories about SLR and flooding throughout the region. As such, students contributed significantly to the knowledge being produced by the EOTR project – including the SLR Toolbox.

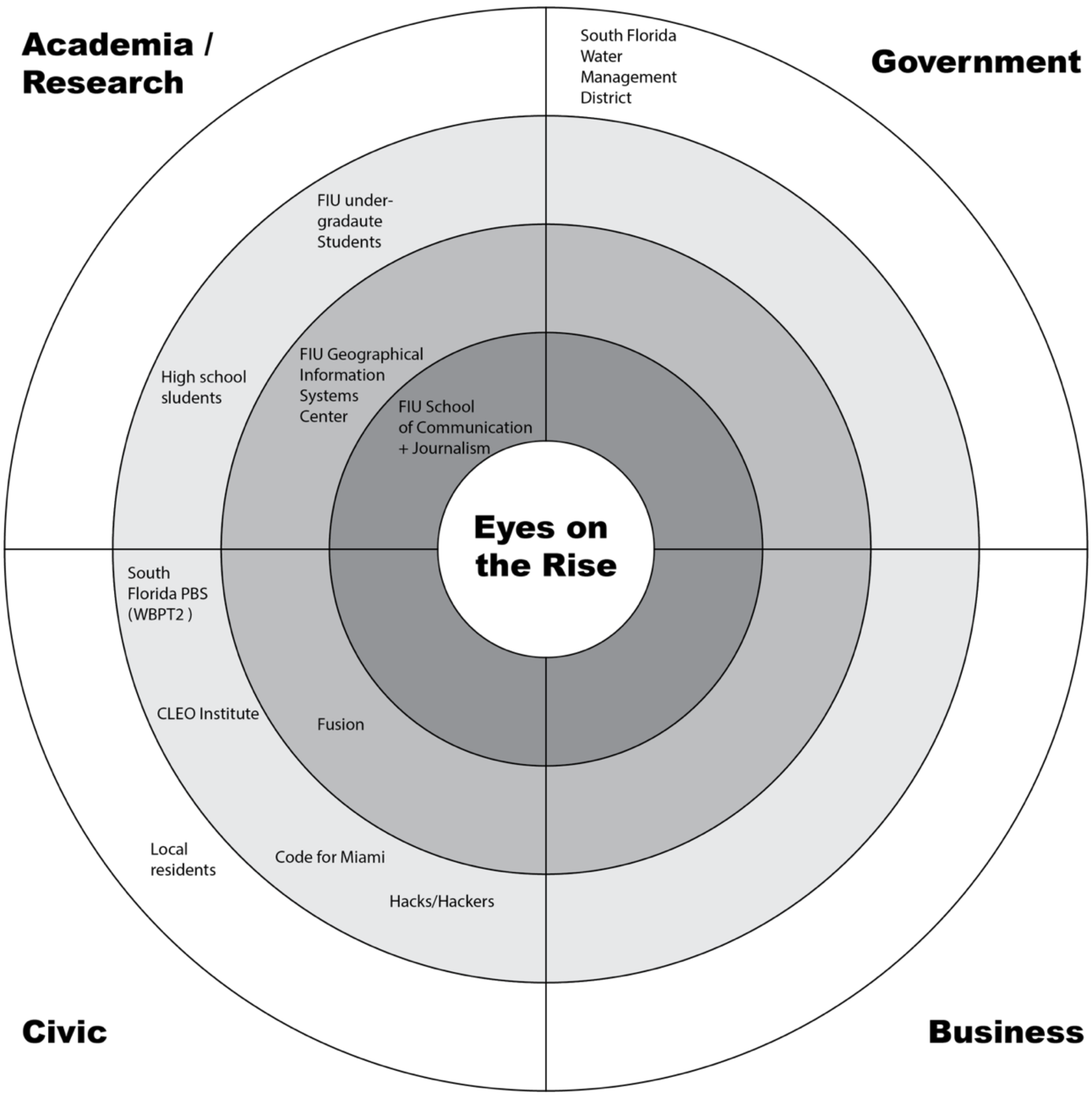
Several civic groups partnered with the EOTR team in the design, implementation, and communication of the project. Civic groups included designers and technical experts (Hacks/Hackers Miami; Code for Miami), local educational leaders (CLEO Institute), local and national media (PBS, Fusion Media) and even some individual residents. Hacks/Hackers Miami is a group that matches hackers who understand how to use technologies to filter and visualize information with journalists who use technology to tell stories. Code for Miami brings together designers, developers, idea-makers, and data gurus to develop open-sourced technologies for government and civic projects. Both of these groups assisted in the technical development of the open-sources SLR Toolbox. The CLEO institute is a civic organization committed to community outreach and education about the climate crisis. The CLEO institute also works to mobilize action for a more resilient future for Southeast Florida. The CLEO institute helped to communicate the products of the EOTR initiative to the greater Miami community. The media was also a key partner. The local PBS station (WBPT2) partnered with the EOTR project to quickly communicate the products from the initiative out to the community via news media. The national cable and website news organization, Fusion, helped the team to revise the user interface and also reported on the application in the media (Wile, 2015). Lastly, students and some local residents attended organized citizen science campaigns during king tide days to both learn about SLR as well as capture real-time flooding data across the city that was integrated into the EOTR database.

There was limited involvement from the government and business sectors. The initial grant proposal included a partnership with the Southeast Florida Water Management District (District) – the only planned government partnership. Based on the interviews and document analysis, it seems that this initial partnership did not materialize – or it was intended to be very minimal. The District was not mentioned by any interviewee as a significant collaborator. Thus, this relationship is shown in Figure 4.16 in the outermost ring. There were no official or informal business partnerships with the EOTR project mentioned in any of my interviews or documents that I reviewed.

In summary, the EOTR project was largely an interdisciplinary academic and civic knowledge co-production initiative. The power to guide the initiative and its products was primarily located within the FIU School of Communication + Journalism and the FIU GIS Center – the academic actors. Figure 4.16 below illustrates the position of actors across various sectors of society within this co-production initiative based on their power and influence on the design and implementation of the project. Note that this actor map only illustrates members of the initiative; it doesn't include non-participants who ultimately ended up influencing the project. Those actors and their influence on the EOTR initiative will be discussed in Section 4.3.

Figure 4.16

Actor Map of the Eyes on the Rise Knowledge Co-production Initiative



Note. Actors have been separated by their respective sector to show the level of participation across various sectors of society. Actors wielding the most power in the initiative are closer to the center.

4.3. Knowledge (how do the actors know and imagine the city?)

The following sub-sections on knowledge will describe how participants of the EOTR project both know and imagine the future of the city. Section 4.3.1 discusses the sources of knowledge that the EOTR project relies on, inequalities between those knowledge sources (i.e., epistemic inequalities), epistemic uncertainty and managing uncertainty. Section 4.3.2 discusses who the experts are in the project. Section 4.3.3 discusses the interaction and negotiation of future visions of the city in the EOTR project.

4.3.1. Epistemology (How do the actors know what they know and don't know?)

Sources of knowledge & epistemic inequalities

This project utilizes a variety of knowledge sources including scientific and technical knowledge, local knowledge, experiential knowledge, and storytelling. Scientific and technical knowledge are the primary knowledge sources used to create the SLR Toolbox – it is the principal epistemology for the initiative. However, science and technology are not the only source of knowledge that this initiative engages with. The project also utilizes storytelling and narratives by FIU students to create video documentaries to provide context to the SLR Toolbox and to make a call for action on climate change. The project also utilizes local or experiential knowledge: local citizen- and student- reported observations. These came in the form of 311 reports; 311 reports are submitted by local residents, validated, and published by the city. The project also includes a citizen science component that the team dubbed "crowd hydrology" (Online News Association, n.d.). Team members at FIU organized field campaigns for students and community members to collect real-time flooding measurements and photos from around the region during king tide season. One of the EOTR members elaborated on these last two knowledge types:

> First of all, we have uploaded the 311 flood reports. We basically got the entire data of 311 for a time period. And then we used a keyword search to just get all the flood related incidences, but the flood could be a broken pipe. A flood could also be somebody who drained the pool, right. Or, it could be of course weather related. It could be broken infrastructure, a pump station that stopped working, your drainage system may be blocked by palm tree leaves. So these could all cause flooding right. So at any rate, we have the 311 data. And then we also have the student data on king tide days. Those were from journalism students of a class, part of a class assignment. They went in those October days to collect king tide day flooding data.

Yet, while local and experiential knowledge (e.g., the crowd hydrology) was produced and documented, it had not been given as central a focus in the application as Harlem's hydrological modeling and elevation data that make up the core of the SLR Toolbox. The flood measurements and photographs taken by students and residents during citizen science campaigns have not been made available online in a consistently transparent fashion. They are typically only shown during the data collection campaign and then closed afterwards. Also, the 311 data is not maintained and updated as new data comes in. The quote above from Subject 17 reveals that at least some of the developers of the SLR Toolbox found 311 data as lacking accuracy and could be misleading (e.g. a flooding due to draining a pool versus a legitimate flood from tides or rainfall).

There were critical tensions between the use of these different epistemologies within the co-production initiative. For instance, academics from the FIU School of Communication + Journalism wanted to create scenes using virtual reality to illustrate to the community what a bad high tide might look like in a particular neighborhood. However, the technical experts on the team wanted to be sure that this was done accurately and justifiable by the quantitative scientific data. When the social scientists, natural scientists, and computer programmers all came together to discuss how to make this happen, it was decided that it was nearly impossible for the team to produce the virtual reality tool with very high accuracy given the resources they had. As one team member put it:

> The tension was - I wanted to do something with virtual reality to show what - in this particular neighborhood - what a bad high tide might be. Which would from a storytelling purposes would just be putting water there. And then relying on the reporter and the science and engineering behind it - and [name withheld] was very opposed to doing that - it was too simplistic. We didn't have the LiDAR data. We don't know the topography. We don't know if the water is going to flow this way or that way. And I said, right...what can we do and not do? So we sat around with all of these programmers - and once I found out how complicated that was to do this accurately - like 100% accurately - which is impossible - I said ok let's not do it. It was that negotiation between the storytellers who do care about accuracy and scientists who do care about facts.

As this example illustrates, the team had to make trade-offs between using qualitative (e.g., stories and visuals) and quantitative (e.g., flood depth levels and probabilities of flooding) knowledge. In the end the team resorted to quantitatively supported knowledge claims as they believed it would help increase the credibility of the application, and therefore its use.

Epistemic uncertainty

The EOTR project team decided not to include any claims about the timing and depth of flooding due to SLR. They argued that there was too much uncertainty (i.e., to many competing alternative scenarios) regarding the projected year when a certain depth of SLR may occur. As a result, the team's concern was that this uncertainty would distract from the value of the tool in visualizing the extent of flooding and invite unnecessary criticism of the scientific foundation of the application's data. The team made the following statement to their granting organization, the Online News Association, a year into the project:

> Our initial design for the Sea Level Rise Toolbox app included an option to let users see how sea level rise might impact their geographic area based on years – to include a visualization of what might happen in 2020, 2030, etc. However, there are several different scientific models that show what might happen at different years, and we were afraid that individuals interested in minimizing the potential impact of sea level rise would be able to criticize our application because of this. So, our application shows a visualization of the impact of sea level rise based on feet of sea level rise (Online News Association, n.d.).

As shown above, the team decided not to state when a certain level of rise would happen. This was a strategy to try to build credibility under conditions of high uncertainty. The plan was that by avoiding assigning a date, they may avoid criticism, and maintain the scientific credibility of the application. By maintaining the scientific credibility, they hoped that it would remain a viable and usable tool for the public. However, as I will describe in Section 4.3.3, they were not able to avoid the criticism after all. Some actors were concerned with simply showing the depth of SLR – as it effectively pinned divergent visions of the future against each other.

4.3.2. Expertise (who are the experts?)

The epistemic inequalities mentioned in Section 4.3.1 mirror the types of expertise that the knowledge co-production initiative tended to value over others. There were major tensions – sometimes productive tensions – in deciding whose knowledge counts and how. Several social scientists felt that their contributions to and ideas for the project were held in less esteem than the natural scientists' contributions; that they didn't have as valuable expertise:

> We realized that the environmental scientists only saw us putting together new stories. Not as able to contribute much. That we were just to decipher their information and relay it in an interesting way […] Right, so it was a tension between who is the expert here. Who are the experts? Environmental scientists tend to be bad at relaying stories to audiences. And so, we [journalists] are the experts in that, but we are not just the experts in putting together a press-release or putting together a staged photo (Subject 12).

For instance, the technical experts on the team put together the first iteration of the user interface for the application. One of the team members recalled that it wasn't particularly user-friendly: "it just had no real meaning to it. I mean, it was just not good information design". The social scientists were determined to improve on that design to focus on its ease of use rather than just the technical content that it was to convey – which was the expertise of the technical and natural scientists. At one point, the team brought in an outside media company, Fusion, to work with the team on the interface design. Fusion effectively helped to mediate the tension between the social scientists and technical experts and put together the simple and clear interface design that ended up in the final version.

4.3.3. Visions (How do actors envision the future and how are those visions negotiated?)

Some of Pete Harlem's SLR maps paint grim illustrations – or visions – of what the Miami Metropolitan Area may look like in various plausible futures. At six feet of SLR, only 44% of the land surface of Miami-Dade County remains (Harlem, 2008). Harlem (2008) dubbed the six feet SLR scenario the "onset of Florida Keys-like environment" or *Margaritaville* (see Section 3.3.3 and Figure 4.12). In comparison, at twelve feet of SLR only three percent of Miami-Dade County remains (Harlem, 2008). Harlem had actually run his SLR model all the way out to thirty feet of SLR (what I call the *Atlantis* vision in Section 3.3.3) and these projections were made available to the project team (Subject 17). By choosing to project a maximum of six feet of SLR, the EOTR project effectively encodes the *Margaritaville* vision of the future of the Miami Metropolitan Area – a moderately dystopian vision of the future of the region: "The only the exposed land in Dade and Broward Counties will be a string of islands inhabited by a relatively small population of easygoing but hardy hurricane veterans, a place [Pete] Harlem has nicknamed "Margaritaville" (Cox & Cox, 2016, p. 184).

To project anything more than six feet, at the time, was seen as too politically risky (Subjects 12; 18). The Compact's projections – viewed as the agreed-upon projections for the region – had released their first Unified Sea Level Rise Projections in 2011 (see Figure 4.9; Southeast Florida Regional Climate Change Compact, 2011). The design team was aware of these projections and referred to them often when deciding on how much rise was appropriate to show (Subject 18). The Compact's projections were based on federal sources – so were considered to be credible and legitimate (Subject 15). The highest amount of SLR reported in the Compact's first Unified SLR projections was only two feet (occurring in 2060) at the time of development of the SLR Toolbox. That curve was actually the high curve from the USACE's models. In 2015, around the same time of publication of the SLR Toolbox, the Compact published their next set of vetted projections which showed a maximum rise of 6.75 ft by 2100 according to the NOAA High curve (see Figure 4.10; Southeast Florida Regional Climate Change Compact, 2015b). Somewhere between two to six feet was considered for the interactive SLR Toolbox. One EOTR team member elaborated on the choice of six feet:

> That's six feet because we built it in 2014. And - which was really when sea level rise was just becoming, and not even for everybody - acceptable conversation in South Florida. And it was still a little bit controversial - actually quite controversial! But it was coming into the discussion. So, we felt if we went beyond six feet, we would unduly alarm people.

As mentioned earlier, the thirty feet SLR scenario would have encoded the *Atlantis* vision; a vision that submerges about half of all of Florida (EOTR participant). By showing that, the fear was that local government and developers who hold a more solutions-oriented vision would reject the tool and potentially retaliate. Since six feet of SLR was somewhat within the local expert discourse already at the time, it was "enough to scare the public" because South Florida is already "so flat, we don't really have a whole lot of elevation to go with" (EOTR participant). However, the decision to map six feet of SLR in the interactive SLR Toolbox did still end up troubling some Miami Metropolitan Area stakeholders.

The EOTR initiative, its data, and vision, was not only directed by its participants, but it was also greatly influenced by outside actors in the SETS context in which it was situated. In particular, the local political, institutional, and economic systems. As stated on the project report submitted to the granting institution: "sea level rise is a politically charged issue. We had to modify parts of our plan to avoid becoming embroiled in political conflicts" (Online News Association, n.d.). There was a persistent fear of major retaliation by the local social and political elite who had vested interests in keeping this data – and the dystopian vision it encodes – as inaccessible as possible. This fear altered the dynamics between participants and ultimately influenced the knowledge products that were produced.

As an example of how contentious this issue was in Florida at the time, former Governor Rick Scott prohibited any talk about climate change throughout the state government:

> If you want to secure state funding, you need to avoid terminology such as climate change, right. Or sea level rise. Rather you'd use, you know, disaster response - or you would use extreme events or you would use water management. (EOTR participant).

Several interviewees mentioned that the denial of climate change and sea-level-rise by the state government may have been a strategy to maintain current economic development and growth in the region. One EOTR member shared their opinion of the political environment at the time of publication of the SLR Toolbox:

> In 2014, 2015, and 2016 when politicians and businesses were still trying to deny the potential effects of SLR on a number of things including local economy, issues of race and forced migration, developers and the constant push for luxury high rises in areas where the multi-county coalition was publishing very clear indicators of what places were going to flood and what places were not.

Several project team members had a fear of retaliation from local developers, politicians, the FIU administration, and other people in positions of power and influence who had a vested interest in maintaining the status quo (Subject 12, 17, 18). There was legitimate fear of retaliation on their lives and property. For instance, one member shared that: “the people that we are concerned with freaking out are the developers - because of the power that they have. Remember I told you that some people in the room were concerned about car bombs. They are not lying”. No physical threats ever materialized as far as I am aware. However, in meetings with local government officials, members of the project team recalled significant difficulty and dilemmas in meeting their project goals while not creating friction between university administrators and local government agencies:

> We were kind of thrown out to the wolves and forced to kind of navigate all of these sorts of issues of politics, and ethics and data - whose data? How do we tell the story that is based in data that they may not like?

What data might “they” not like? Data that may not fit the future visions held by powerful local stakeholders. Local governments were working hard to show their communities that they were taking action on sea level rise and that it is was under control – some local governments were spending millions on SLR adaptation projects during that time (Subject 23). As such, many of the local governments had a solutions-centric vision (the *We will Innovate* vision; see Section 3.3.3). The *We Will Innovate* vision was and remains the dominant vision by local and regional government actors as evidenced by the Compact's effective adoption of *We Will Innovate* vision (Section 3.3.3).

The SLR Toolbox application and the citizen-science campaigns threatened to promote an alternative vision (*Margaritaville*); a vision which showed that the problem could be larger than the local governments are able to address with technological solutions. Local government officials were concerned that this could create unnecessary fear in the community rather than be simply constructive SLR awareness and promoting solutions. A County official was concerned that alarming the public with 'doom and gloom' visions of the future could cause some residents to move out, which could reduce the local governments' tax base, and as a consequence, also reduce their ability to pay for the very adaptation actions and infrastructure upgrades needed to solve the problem (Subject 4). As a result, some meetings between the EOTR team and local governments officials became contentious: "Lots of screaming on the phone by the officials" (EOTR participant). This was manifestation of the stark differences in the visions of the future that EOTR team had as compared to the local authorities.

FIU administrators eventually became involved too. FIU administrators were concerned about how the massive promotion by the media and use of the application by local residents may negatively affect the delicate and critical relationship between the university and local governments. The EOTR team felt pressured from FIU administrators to ensure that the stories they told did not "push any bad buttons" as one participant recalled. FIU administrators began issuing their own demands on how the EOTR project and its products were to be crafted, discussed, and communicated to the public. FIU executives wanted to have a uniform voice and vision regarding the future of the region and the threat of SLR. A vision that was already being established through another FIU entity- the burgeoning Sea Level Solutions Center (SLSC). As is clearly reflected in its name, The SLSC was focused on being part of the *solution* to the problem. A SLSC representative shared their organization's vision of Miami-Dade's future on the Climate Resilience Survey:

> **Embraces opportunities** for building resilience with every new project based on a framework for evaluating costs and benefits of each **project and interventions** anticipated when targets are not met in social, ecological and technological dimensions.

This vision is closely aligned with the *We Will Innovate* vision that prioritizes social, ecological, and technological interventions (i.e., solutions) to future SLR issues. It also avoids mentioning retreat – a key indicator of the *We Will Innovate* vision. The SLSC was busy building close relationships with local government leaders to assist them in identifying and scaling up SLR solutions and innovative projects. The EOTR project, on the other hand, was perceived by some local government actors as fearmongering (Subject 23) and not portraying a constructive and solutions-oriented approach. As such, the EOTR project threatened to jeopardize the delicate burgeoning relationship between the FIU SLSC and local government agencies. The EOTR's SLR Toolbox was viewed as promoting an alternative vision of a submerged Southeast Florida – closely aligned with

Pete Harlem's *Margaritaville* – one that doesn't take into account future massive infrastructure projects and adaptation actions that the city has done or plans to do. It illustrates a dystopian vision rather than the positive vision the SLSC was trying help cities work toward – even though it wasn't as dystopian as the *Atlantis* vision (see Section 3).

From the institutional perspective, FIU administrators saw a need to align these two initiatives and mediate their contrasting visions of the future. One EOTR participant reflected on this institutional pressure to streamline FIU's initiatives:

> So for example, when we went out to Indian Creek and did our data collection and ran into to the media, there are parts of FIU who were not please. But the whole thing has to do with branding. You know, and also you don't want the journalism department running off and doing one thing and when the Sea Level Solution Center is trying to establish credibility and doing another. That's not saying anything negative about anyone, it's just a matter of you want to try to focus and streamline.

One of the ways that the project team addressed these concerns from FIU leadership and local governments was by adding a legal disclaimer onto the SLR Toolbox that acknowledged some of the limitations of the data: "the data and maps in this tool illustrate the scale of potential flooding, not the exact location, and do not account for erosion, subsidence, or future construction" (Eyes on the Rise, 2016a). Basically, this disclaimer pointed out that the vision it encodes doesn't consider technological solutions or innovations at all – it is not a solutions-oriented vision. While the competing FIU visions were not entirely harmonized, the EOTR project was nevertheless moved under the SLSC umbrella.

Given these political fears and institutional pressures, projecting Harlem's maps out to thirty feet of SLR – a very dystopian vision where only three percent of Miami-Dade was left (i.e., the *Atlantis* vision) – was absolutely out of the question for the team to include at the time. Instead, a six feet SLR vision of the future – *Margaritaville* – was the maximum the group could tolerate given the perceived and real pressures they were experiencing.

4.4. The process (What is the quantity and quality of the interaction between participants?)

The majority of successful knowledge co-production initiatives share a similar pattern of frequent and substantive interactions between the various participants in the initiative (Dilling & Lemos, 2011). Based on my interviews with project members, it was clear to me that the project team met frequently and had open lines of communication. Also, this process was iterative. The SLR Toolbox went through many iterations.

The team would set goals, take action, gather feedback, make adjustments, and iteratively move through the project together. It needed to be iterative especially given all of the challenges and pressures that the team experienced throughout the duration of the project (see Section 4.3). Although the diversity of actors presented challenges and tensions throughout the project, this diversity was also recognized as one of the project's greatest assets in producing an effective final product:

> There's always a group interaction. We have multiple group meetings and our group always have people from all these different aspects together. So we also - through interaction with each other, we understood what you can do, what you can bring, and what's the limitation. (EOTR participant)

As a case in point, an EOTR participant shared that a few members wanted to use a house icon to visualize or put into perspective the depth of flooding from SLR – but that idea was rejected by the technical experts as too sensationalistic. In the end, most participants came to an agreement that it was "probably a better idea to be less in your face, because the information – if you had never seen it before – was already dramatic". The final form of the application was the product of intensive and substantive negotiations between a diverse group of actors with very different perspectives, expertise, epistemologies, knowledge, visions, ideas, and opinions.

4.5. Outcomes (What outcomes has this initiative achieved?)

4.5.1. Scope 1 Outcomes

Deepening understanding

The EOTR project's primary aim was educational; to educate both students and the community at large about the plausible future impacts of SLR to the Miami Metropolitan Area. Student participants indeed deepened their understanding of how SLR could impact their communities. Reflecting on the citizen science component of the EOTR project, one participant shared that "the goal of the sending the people out is to educate the people really. More than really to collect amazing data that we'll use and be able to use". Not only did this help deepen understanding among hundreds of students, but students also became communicators of their newfound understanding to family and friends: One of the EOTR professors expressed that "we were surprised to the degree that students were going home and talking to their families about the environment and sea level rise" (Lincoff, 2015). Thus, the educational impact from the citizen science component extended beyond just the individual students' experiences to impact a larger constituency in their communities.

The SLR Toolbox received enormous media attention – by design. This was a major strategic success of the initiative. The media partners were a major asset in getting the word out about the SLR Toolbox to the local community. Dozens of local news outlets reported on the app to both English and Spanish audiences. Given the large percentage of Hispanics who live in the Miami Metropolitan Area (see Miami Metropolitan Area Profile in Section 2.1.1), having Spanish media attention likely helped grow the potential userbase for the SLR Toolbox. Overall, that media attention brought a lot of interest in the app and new users of the tool. One participant discussed the impact that the SLR Toolbox application has had in across South Florida:

> And for most people in South Florida - for a lot of people in South Florida that was the first time that they had a real encounter with sea level rise. The potential impact of sea level rise on their neighborhoods, they're, you know, they've all heard about it. Most people had heard about it, but it was something that was going to happen far away in the future, somewhere else, you know, and then to see it right there, on the app that their home was quite vulnerable. That was a big wake up call to a lot of people, and it's had, you know, over a million hits, well over a million hits, like multiple millions of hits, I think two or 3 million by now.

In addition to media appearances, the CLEO institute – the civic educational outreach organization partner – presented the tool and discussed its utility at several local workshops and events attended by hundreds of attendees (Eyes on the Rise, 2016b). In short, this knowledge co-production initiative's greatest asset was their strategic linkages to media outlets and community education organizations. These valuable connections helped raise awareness of SLR Toolbox to more local residents, and ultimately raised awareness of plausible future sea level rise impacts to their neighborhoods.

While acknowledging its utility in educating the community about SLR, some local government officials expressed concern over whether or not the app has created undue fear in the community due to the simplicity or lack of sophistication of the application:

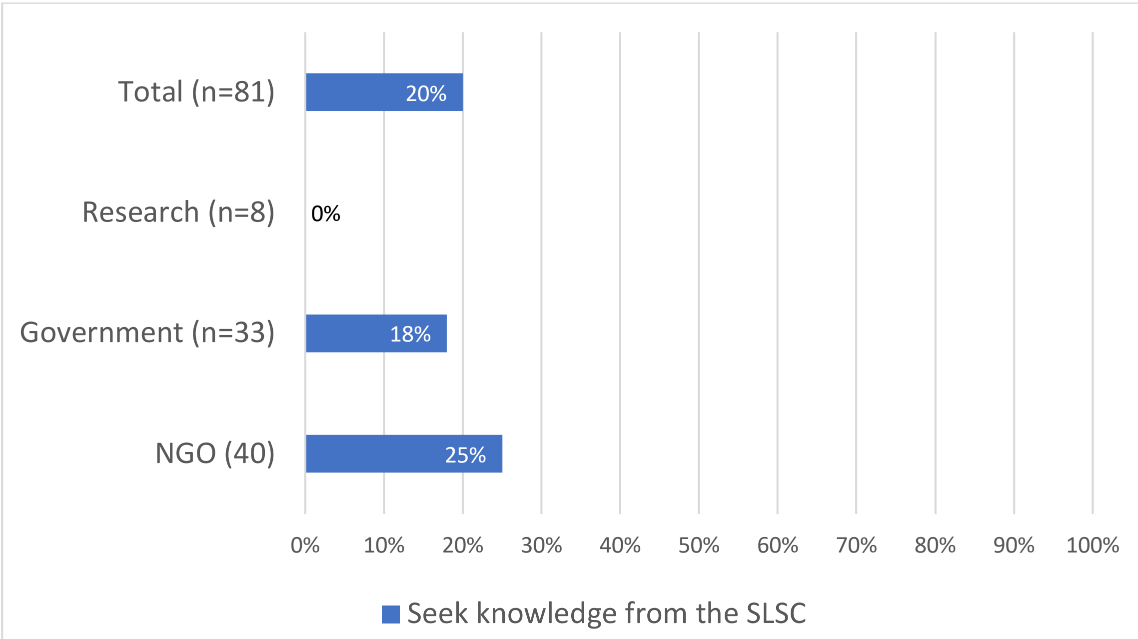
> I think that it provides a good visualization tool for people who want to like see, like, what does sea level rise mean? But the challenge is that doesn't take into account the infrastructure upgrades that the city is doing. So, I think it potentially could create fear. You know, if someone doesn't - for the average person who may not understand that the city is investing, and we're, you know, we're investing hundreds of millions of dollars in order to protect the city. (Local government official)

So, while it has been successful in educating the community, some experts question whether local citizens may have been misled by the tool due to the average citizen not having a *deep enough understanding* of all of the nuances in determining where and when flooding will occur. Though, this lack of sophistication has been argued by several team members to be an important aspect of the application's success within the community – since it was very easy to understand.

Shortly after the Eyes on the Rise Project began, it was grouped under the larger umbrella of the Sea Level Solutions Center (SLSC) at FIU. The SLSC is known in the Miami Metropolitan Area as the primary organization responsible for the development of the EOTR project – the EOTR project is listed under the SLSC's past projects on its website (Florida International University, 2020). When asked on the UREx SRN Climate Resilience Survey (see Section 2) "please list up to 5 organizations or groups that you go to for information, advice, data, or expertise related to climate change in Miami-Dade County" 20% of organizations listed the Sea Level Solutions Center as one of their five primary sources of knowledge (see Figure 4.17 for breakdown by sector). None of the researchers mentioned SLSC in part because several were already at FIU or simply mentioned FIU without indicating the SLSC specifically. Only one survey respondent – a NGO – specifically identified the EOTR program as a source of knowledge. However, more than 43% of respondents identified Florida International University as one of their five primary knowledge sources. It is clear that FIU and the SLSC are influential sources of local knowledge on climate change and sea level rise knowledge. It is likely that the SLSC has received some of its popularity as a knowledge source due to its leadership and association with the EOTR project – given the familiarity of the project across the majority of my interviews. However, the SLSC has dozens of other initiatives and associated faculty that are not associated specifically to the EOTR project.

Figure 4.17

Popularity of the Sea Level Solutions Center as a Source of Climate Knowledge



Note. This chart shows the percent of survey respondents, by organization type, who indicated that they consider the Sea Level Solutions Center as one of their top 5 knowledge sources. Precents are within-group rather than across-group.

The next section discusses the application's utility – or lack thereof – for planning and decision-making.

Utilization of knowledge in decision-making and catalyzing action

The SLR Toolbox has not been taken up into official policies and planning in the region, nor has it been used directly by government agencies to implement adaptation actions. The simplicity and misalignment with the local government vision have been the main culprit for why it has not been taken up in planning and decision-making by local governments. The SLR Toolbox is often dismissed in the local engineering and city planning offices as an unsophisticated or simplistic bathtub model of flooding that doesn't take into account adaptation actions (Subject 9; Subject 22; Subject 23; Subject

27). It generally does not meet their needs for infrastructure and planning decisions. These officials generally caution about its inappropriate use at the individual household level as well. The following quote from a local official summarizes the general sentiment from local government agencies regarding the application:

> That was yeah that's useful for the citizens- we have no use for it. Because what we have here, we are using models [dynamic hydrological models]. Yeah, but I think it's useful to give an idea - that gives an idea what would be the dry weather flooding, anyway and gives us an idea that I'm in trouble or I'm not in trouble. A lot is driven by the topography. And, depending on the DEM they are using, some DEMs are better, some are worse. They're not detailed enough for people to do a decision-making in terms of one house - it doesn't do that. (County technical expert)

This County technical expert brings up that they have their own flooding models for planning and decision-making. Their models are dynamic and model how water would move across the topography – rather than just modeling where the low areas are in the city and how they would be filled up as sea levels rise (e.g. the bathtub model the SLR Toolbox uses). The official also calls into question what Digital Elevation Model (DEM) they used to create the application. The SLR Toolbox App uses an older DEM – since it was created in 2014. An average community user would not typically question these technical considerations. However, local government officials demand the latest and highest resolution data to make it actionable for planning and infrastructure projects. Since the SLR Toolbox app uses antiquated DEM, it is therefore dismissed as unusable. Another local government official shared that “professionally I don't use it”. This official prefers to use more sophisticated flood models coupled with property elevation certificates instead to analyze a particular property's or area's flood risk.

In short, the simplicity of the SLR Toolbox has made it useful for expanding citizen's knowledge of SLR, but not very useful for local planning practice and infrastructure design. Additionally, the conflicting visions between the EOTR project and local governments have negatively influenced the uptake and promotion of the SLR Toolbox by at least some local government officials.

Strengthening communities

The EOTR project did create stronger bonds between the academic and civic actors during the project. The EOTR leadership had built strong relationships with the local civic groups such as Hacks/Hackers, Code for Miami, and the CLEO Institute. Some of these relationships are still strong today. For instance, a small subset of former EOTR team members are working with Code for Miami volunteers to build a new flood tracker tool. However, the full team no longer collaborates together; this is largely due to intellectual property disputes that spread as the project matured. It became contested as to who owns the intellectual property of the SLR Toolbox App. Was it owned by the entire project team? Florida International University? The individual(s) who made the most significant contributions to the project? Or, was the project truly open-sourced and owned by no one? Ultimately, the lack of clarity regarding the intellectual property of the SLR Toolbox caused a breakdown in trust within the group. Some members blamed the intellectual property dispute for the discontinuance of the collaborative knowledge co-production initiative and dissolution of the team. While other knowledge co-production initiatives in the literature report improved trust building and relationships (Jagannathan et al., 2019), this is likely not possible without a very clear understanding from the outset of the intellectual property rights of the products of collaborative knowledge co-production initiatives.

4.5.2. Scope 2 Outcomes

Put in evaluative terms to assess the achievement of transformative Scope 2 outcomes, Table 3.1 asks the following question: what SETS knowledge landscape arrangements have been rearranged to achieve the EOTR's long-term transformative outcomes? Below, I unpack some of the EOTR's achievements and shortcomings while posing additional questions for future studies of the initiative, and current EOTR leaders, to explore more in-depth.

One of the primary limiting factors for achieving the long-term sustainability of its intended outcomes was access to resources. The EOTR project started with a modest $35,000 of grant funds. While acknowledging the important successes achieved (see Section 4.5.1), each participant interviewed also reflected on the budget constraints that limited the greater impact that the project could have had in initiating rearrangements of the urban SETS knowledge landscape. For example, one participant shared that "we tried a few times to get some money, to take it to the next level, and it just was not forthcoming. We just couldn't get the money". In order for the initiative to transform the urban SETS knowledge landscape and usher in radical transformations toward a more sustainable and resilient region, more resources were likely needed. That being said, there were some interesting interactions between the initiative and the larger SETS context that are worth mentioning – even though funding was an issue in scaling them up.

My interviewees did not frame the outcomes of this initiative as particularly transformative or radical. They did, however, discuss how the EOTR SLR Toolbox was one of the first, if not the first, visualization of SLR impacts at the local level (e.g., parcel level) in Southeast Florida. This was a need – at the time – that was not previously addressed through existing knowledge and tools present in the SETS knowledge landscape (e.g., FEMA flood maps). In my view, this was a novel addition to the SETS knowledge landscape at the time. Since the initiative began in 2014, numerous other tools have been developed (e.g., Climate Central, FloodIQ, Coastal Risk Consulting's Flood Scores, etc.) to do essentially the same thing. The tools mentioned above have had access to much more financial resources to sustain their development, maintain their platforms, and gain prominence within the urban SETS knowledge landscape. On the other hand, the EOTR SLR Toolbox has been mostly unchanged over its 5-year history. One of my EOTR interviewees called attention to the fact that these visualization tools have a shelf-life of only a few years if they are not maintained and updated to reflect new conditions and better technological advancements. The need to continue to be perceived as state-of-the-art. In other words, as the SETS knowledge landscape shifts and new technological tools and artifacts become available and take root, others can become obsolete. The SLR Toolbox is at risk of losing the burgeoning 'technological momentum' that it enjoyed in the first several years of the initiative (i.e., its web interface has enjoyed over two to three million individual interactions since it launched in 2015). However, there are ideas for how to integrate new technical data and flood observations (ecosystem knowledge) into this technological artifact to maintain its inertia as a critical knowledge source in the region. Some EOTR leaders discussed the possibility of deploying smart sensors around the city to collect flood data in real time and display it on the app interface. This idea shows how the SLR Toolbox has the potential to take on more momentum and co-evolve with new technological and ecological knowledge, however, limited access to funds may prevent that from actually occurring. It would be helpful for future studies to track the long-term evolution of the SLR Toolbox to see if it becomes obsolete or how it evolves in the future to maintain its salience in the region. If the team eventually secures new funding, it would be interesting to see how the development of new SETS knowledge, like smart flood sensors placed around the city, co-evolve with future iterations of the SLR Toolbox. There is also a rich amount of data from the Smart and Connected Communities Innovation Labs that could be useful in analyzing how the SLR Toolbox interacts within the larger SETS knowledge landscape of many other flood risk knowledge and tools. Future research could more carefully analyze the data from those workshops to tease out the tensions and opportunities between this knowledge co-production initiative and the larger SETS knowledge landscape.

The SLR Toolbox may have had an impact on shifting public discourse and perception of flood risk throughout the region. This is an open question that is worth exploring in future research. A few interviewees had mentioned some anecdotal evidence that this could have been a significant – and perhaps transformative - outcome of the initiative. In November 2017, the City of Miami passed the Miami Forever Bond – worth over $400 million – to reduce flood risks, improve access to affordable housing, and a number of other objectives. Approximately $200 million was slated specifically for flood risk reduction and sea level rise adaptation projects (e.g., installing pump stations, constructing sea walls, upgrading storm water systems, etc.). As stated on City of

Miami's website, the bond: "mitigates the impact of severe current and future sea-level rise, flood risks and vulnerabilities through strategic infrastructure investments" (City of Miami, n.d.). Approximately 57 percent of Miami voters voted in support of the general obligation bond – the City's first major SLR ballot measure victory. This suggest increased community awareness and knowledge about the risks and need for adaptation actions. The Miami Forever Bond is an example of increasing citizen interest in flood mitigation and sea level rise adaptation initiatives throughout the region. However, I cannot conclusively claim that the EOTR SLR Toolbox application itself has had a significant impact on public perception in favor of flood risk mitigation. I can only qualitatively state that this is just one example of how the public awareness of the issues surrounding SLR in the region has likely increased since the publication of the SLR Toolbox. This newfound awareness may have impacted the technological system by ushering in billions of dollars of investments in new flood risk reduction infrastructure projects, such as the Miami Forever Bond projects. This could be a potential example of how this technical artifact influenced public awareness, which then influenced public policy, and in turn may have physically altered the urban landscape with the Miami Forever Bond SLR adaptation projects. The altered physical landscape then may then cause less flooding in the City of Miami. Less flooding would mean less citizen science reports of floods during King Tide events as reported in the SLR Toolbox – completing the cycle and illustrating the interdependencies in the urban SETS knowledge landscape.

4.6. Summary and discussion of the EOTR case study

The Eyes on the Rise Project was created by a coalition of primarily academic and civic actors to develop a SLR Toolbox that would visualize Pete Harlem's static maps of

SLR into a user-friendly interactive application. SLR Toolbox was designed to be used to educate the Miami Metropolitan Area community regarding the future risks of SLR. Very few, if any, government or business actors were participants in the knowledge co-production effort. Florida International University professors, technical experts, and students were the central actors of this project followed by civic and media organizations such as the CLEO Institute, Fusion, and Code for Miami. As an academic-led initiative, scientific and technical knowledge held the most weight, followed by storytelling and local or experiential knowledge sources. Expertise was a highly contested aspect of this initiative; there was a lot of tension between who the experts were. This project included a lot of scientific and technical information, but it also included a lot of artistic, design, and storytelling knowledge. Scientific and technical knowledge was regarded in slightly more esteem than the artistic, design, and storytelling knowledge. As a result, the main "experts" of this initiative were the natural science and technical experts, with design and storytelling expertise an important but inferior type of expertise. Expertise was also influenced by the perceived credibility of the knowledge products that they would produce. By erring on the side of scientific and technical knowledge, it was assumed that the products would get less criticism and enjoy broader support and use.

The EOTR project had the ability to map the *Atlantis* vision of the Miami Metropolitan Area given Harlem's SLR maps that went out to 30 feet. However, there was a fear that mapping that vision would invite too much criticism and retaliation from the local elite – those who it was assumed held a vision more closely related to the *We will Innovate* or *Living with Water* visions. While there wasn't inherent friction among team members regarding what vision to project, there were fears about how the products would be received from outside. As a result, the team chose to project up to the *Margaritaville* vision – or up to 6 feet of SLR without any adaptation solutions modelled. That vision was already enough to "scare the public*"* as one participant recalled*.* This shows that visions held by powerful actors outside of an initiative can have a significant impact on the shared visions within a knowledge co-production initiative as well as influence the knowledge products that are produced by the initiative. Not only was outside influence subtly affecting the dynamics of the initiative, but there were substantive interactions from outside actors (i.e., FIU administrators, local government officials) that ended up steering the initiative and its products. These interactions were intended to shift the vision that the EOTR espoused to a more solutions-oriented vision like the *We will Innovate* vision espoused by the FIU's SLSC.

In terms of Scope 1 outcomes, the deepening understanding outcome is the most prominent. This was the initial goal of the project, and it seems to have been achieved as measured by the education and outreach efforts that the initiative undertook. The inclusion of media representatives in the initiative was instrumental in connecting the initiative's knowledge with the general public – including in a variety of language formats. The SLR Toolbox had millions of hits, suggesting broad engagement throughout the Miami Metropolitan Area.

The outcome of strengthening communities had mixed results. While there were improved relationships across academia, NGO, and media – some of which continue today – the core academic team's trust and relationships ultimately broke down. This was mostly due to an intellectual property dispute over the ownership of the knowledge co-production initiative's flagship product: the SLR Toolbox. This example illustrates some of the difficulties in doing knowledge co-production within academia. Professors need to provide evidence of their efforts and success to achieve tenure. Tenure-based systems need to have a way to acknowledge joint knowledge products. Without such incentive structures that favor co-production, the academic incentive system creates a context where intellectual property disputes are likely to emerge in other academic-centric knowledge co-production initiatives as well. For future academic-led knowledge co-production initiatives, it is imperative to clearly articulate ownership of shared knowledge products from the outset to avoid falling into the trap of intellectual property disputes.

In terms of utilizing knowledge for decision-making and catalyzing action, the project did not have a significant influence on governmental policies, plans, and action. This is likely the result of a lack of inclusion of government actors in the production of the initiative, and the misalignment of the *Margaritaville* vision with the solution-centric *We will Innovate* vision espoused by most local government leaders at the time. Moreover, the initiative was designed for community education and outreach, rather than to achieve these government-centric planning and implementation outcomes. It is also important to note that government and technical experts have a need for the latest state-of-the-art data whereas community members may not. With the initiative's focus on community education and outreach, there was less focus on ensuring that the data was kept updated and state-of-the-art. This made it less useful for government actors as time went by and the data became obsolete.

In terms of Scope 2 outcomes, the most prominent outcome was the creation of a novel tool, at the time, called the SLR Toolbox. This tool generated over two million hits on its web interface – signaling that it was communicated and used widely throughout the region. The tool developed technological momentum during its formative years (i.e., 2015-2017). Recently, however, the tool has been fading in importance due to lack of maintenance and perception of not being state-of-the-art. This illustrates the importance of securing financial and staff resources in stabilizing the long-term sustainability of a new coupling between SETS knowledge (e.g., flood risk observations, models, flood maps, etc.) and structures (e.g., buildings, roads, rivers, green space, etc.). However, it seems plausible that the EOTR project could have had a transformative impact on public perceptions of flood risk as evidenced by majority public support for massive infrastructure solutions like the Miami Forever Bond – though this claim will need to be systematically explored in a future study.

One of the most important findings from this case study is that outside actors can wield significant power in influencing the shared visions and knowledge products that knowledge co-production initiatives create in highly contested urban contexts. Power asymmetries between participants are not the only dynamics to acknowledged and addressed – knowledge co-production must consider the existing power asymmetries already established in the broader urban social context.

This case study also illustrates the lock-in and positive feedback loops between the actors, knowledge and expertise, products, and the outcomes. Firstly, the academic actors favored scientific knowledge and expertise over other sources of knowledge and expertise. This led to the production of scientific-based knowledge for public consumption. If this initiative was more civic- centric instead, perhaps local and experiential knowledge would have been prioritized higher, and the crowd-hydrology and storytelling component would have taken on greater significance than they were given.

Secondly, by focusing on deepening knowledge and educating the community, the initiative compromised its ability to provide actionable knowledge for government politics, plans, and actions. While this is not necessarily a "failure" to achieve these outcomes, it only shows the importance of having to clearly articulate one's goals at the start of an initiative to ensure that they are met. It may not be possible to achieve *all* of a knowledge co-production's theoretical outcomes within the same initiative, as this case study clearly shows the trade-offs in achieving particular outcomes at the expense of others.

5. Conclusion

Knowledge co-production has shown great promise in deepening knowledge, strengthening communities and making them more inclusive, and uniting knowledge and action (Arnott et al., 2020; Dilling & Lemos, 2011; Jagannathan et al., 2019; Mach et al., 2019; Norström et al., 2020). However, knowledge co-production shouldn't be assumed to be a panacea for achieving *all* of these outcomes in *all* circumstances (Lemos et al., 2018; C. A. Miller & Wyborn, 2018; Wyborn et al., 2019). In other words, context matters. Scholars have acknowledged a need for empirical work to reveal exactly how context matters to determine when and where knowledge co-production may be most appropriate (Lemos et al., 2018; C. A. Miller & Wyborn, 2018). In this study, I've applied the SETS Framework of Knowledge Co-production (Chapter 3) to explore how and in what ways has knowledge co-production worked – or not – to achieve its theoretical outcomes in the highly politicized urban context of a flood-prone coastal metropolitan area fighting for its future. The SETS Framework of Knowledge Co-production is specifically designed to reveal the couplings between the social, ecological, technological systems arrangements with knowledge and the various components of a knowledge co-production initiative – including its outcomes. Context in my case study refers to these couplings across diverse SETS knowledge and structures.

I chose the Miami Metropolitan Area to conduct my field work due to its heavy urbanization together with its relatively high vulnerability to current and future floods (Ghanbari et al., 2020; Stephane Hallegatte et al., 2013; Hanson et al., 2011). Urban areas are complex and contested spaces (Elmqvist et al., 2018; Feagan et al., 2019; McPhearson, Haase, et al., 2016). Coupled with the existential threat of SLR (Ghanbari et al., 2020; Sweet et al., 2017; Wanless, 2018), the dense MMA presents a unique opportunity to explore how the co-production of climate and sea level rise knowledge in the Miami Metropolitan Area is impacted by its highly urbanized and politicized environment. I selected two prominent knowledge co-production initiatives in the MMA that were distinct from each other – yet both sought to produce new knowledge regarding future flood risk to the region. One was government-centric, the Compact, and the other was an academic-civic centric, the EOTR. Next, I discuss some of the main findings across both of these initiatives.

5.1. Influence of the SETS context on the formation of the initiative

The existing social, ecological and technological contexts played a large role in the creation of both of these initiatives. Both the Compact and the EOTR initiatives were born out of the recognition that sea levels were rising faster than the global average in Southeast Florida and something would need to be done about it – or face the undesirable outcome of retreating from the region as property and infrastructure went underwater. As such, the ecological context was the original impetus for the need for these co-production initiatives to form. There were also a plethora of technological tools (Figure 4.4) that existed or were being developed prior to both initiatives. Both the Compact and EOTR initiatives sought to rearrange the existing relationships that diverse actors in the MMA had with this ecological and technological knowledge in order to build a more resilient metropolitan area.

Both initiatives reported a need to better understand and communicate about this problem – but for different primary audiences. The Compact members recognized that the existing siloed governmental systems were inadequate to meet the challenge of combating SLR – there was a need for a new way to collaborate, communicate, and take action across government jurisdictions. Therefore, Compact founders sought to transform the way the region's governance system functioned – and the knowledge it selected from to action on – by creating the Compact. Similarly, the EOTR project recognized that there was little to no future flood risk knowledge making it to individual residents – the EOTR project would supplement or replace existing knowledge systems like the FEMA flood maps (See Chapter 2) in communicating what the flood risk is for specific properties throughout the region. Both projects sought to transform or upgrade the existing couplings and arrangements in the urban SETS knowledge landscape.

5.2. Lock-in and positive feedback loops

The initial framing and actors involved in the creation of a knowledge co-production initiative serve to lock-in particular outcomes while also locking-out others. For instance, the Compact was formed initially by a group of mostly government officials who signed The Compact Resolution. These representatives were already powerful actors in the region – they had the financial and staff resources along with the legitimacy to shape the city and region in the way they saw fit. Although the Compact has evolved to integrate various sectors of society into the initiative (i.e., academia, business, and civic groups), government actors continue to be the locus of control over the initiative. This power has resulted in prioritizing government knowledge and expertise over other epistemologies. This prioritization of government knowledge has greatly influenced the knowledge products that result from the various processes within the Compact, such as the creation of the Compact's Unified SLR Projections; these projections tend to utilize government science and planning knowledge over other sources like academic or local knowledge. As a result, the Compact's products are largely utilized by local and regional government agencies for both planning purposes and implementation of on-the-ground projects – since they are seen as more credible and legitimate for government use. Although civic actors expressed the desire to play a larger role in the deliberations and decisions in the Compact, their knowledge and visions are marginalized due to this positive feedback loop between government actors, knowledge, and use. This lock-in makes it difficult to achieve a more egalitarian or inclusive governance structure to truly meet the objective of strengthening communities. While the Compact may not have fully strengthened communities across sectors, it has helped achieve significant strength of communities - both horizontally and vertically - between government actors. This example shows how the Compact was able to find some success in utilizing knowledge in decision-making and catalyzing action, but at the expense of truly creating an inclusive governance network across different sectors of society (i.e., strengthening communities).

Similarly, the EOTR initiative has a positive feedback loop across its academic actors, prioritization of scientific and technical knowledge and expertise, and use of its knowledge products for academic and educational purposes. The academic actors wielded both the funding and resources for the initiative. The civic actors played minor roles in the initiative. Moreover, the civic knowledge components (i.e., 311 flood reports, citizen science campaigns, storytelling) of the initiative took a back seat to the scientific and technical components of the SLR Toolbox. Not surprisingly, the educational component of this initiative was its strongest reported outcome. In short, there was an academic-centric feedback loop that locked in these types of actors, knowledge, and outcomes.

5.3. Contested visions both from within and beyond

These two case studies both show that in contexts where there are divergent visions of the future – like in the Miami Metropolitan Area – the difficulty of reconciling alternative visions among diverse actors limits the ability of knowledge co-production efforts to build the foundations of trust and strong relationships. Those in positions of power will seek to ensure that their vision of the future wins as the dominate shared vision of the initiative. In this politically-charged context, knowledge co-production initiatives may prove futile to achieve their goal to build inclusiveness and strengthen communities across diverse sectors of society – such as what occurred in the Compact case study. I also found that not only is there intense friction and negotiations that occur among the participants of these initiatives, but that outside actors (those already wielding significant power in the urban SETS) can sometimes become nearly as powerful or influential on the project as the participants themselves. The EOTR project illustrated this coupling well. Local city governments and the FIU administration were not technically part of the co-production initiative at the outset, nevertheless, they exerted significant power and influence on the team, their shared vision, and the SLR Toolbox design. Ultimately, the EOTR team members had to engage with these outside actors and adjust the project accordingly to be in closer alignment with their vision. As such, I find that visions of the future city played a key role in moderating what knowledge gets produced, communicated, and ultimately utilized in planning and decision-making in the city. Powerful actors within the urban SETS can have great influence from both within and beyond an initiative to steer its knowledge products in their favor.

5.4. Key takeaways

When dealing with deep uncertainty and incomplete knowledge in complex and contested urban contexts, like the Miami Metropolitan Area, the urban SETS knowledge landscape played a critical role in influencing what: (1) goals and objectives were set, (2) visions were promoted, (3) knowledge, data and expertise mattered, (4) process was employed, and (5) outcomes were achieved. In particular, it was the powerful and elite actors within the urban SETS knowledge landscape that had influenced each of these components of the knowledge co-production initiatives in the pursuit to maintain control of a uniform vision of the metropolitan area – one where the city will innovate and thrive despite any future SLR risks (i.e., *We will Innovate* vision).

What these two case studies have shown is that knowledge co-production is a highly political practice that is steeped in unequal power relations. However, is not enough to simply acknowledge and negotiate the power asymmetries between participants in a knowledge co-production initiative (Turnhout et al., 2020). In highly politicized urban environments, like low-lying coastal areas fighting for their future in the age of the Anthropocene, it is important to also acknowledge and plan for the inevitable influence of *external* powerful actors (including the agency and power of existing and competing technological artifacts) in order to achieve the desired results and not feel as if you have been "thrown to the wolves".

In conclusion, there is a need to conceptualize knowledge co-production as not isolated projects with their own internal dynamics - as is typically done - but as in dynamic interaction within their larger urban SETS knowledge landscape (Chapter 3; Wyborn et al., 2019). By more broadly conceptualizing knowledge co-production in this way, we may also get closer to achieving the Scope 2 transformative outcomes that have proven to be very elusive in practice (Turnhout et al., 2020).

CHAPTER 5

KNOWLEDGE SYSTEM INNOVATION FOR RESILIENT COASTAL CITIES: SYNTHESIS AND PROPOSITIONS

1. Introduction

The great majority of today's knowledge systems are unequipped to produce the knowledge and wisdom needed to transform our urban social, ecological, and technological systems along more equitable, inclusive, and resilient pathways in the age of the Anthropocene (Crow, 2007; Fazey et al., 2020; Feagan et al., 2019; T. A. Muñoz-Erickson et al., 2017). The challenges of Anthropocene – rapidly changing environmental conditions and unpredictable outcomes that threaten to exceed our planetary boundaries (Rockström et al., 2009; Steffen et al., 2018) – require that humanity design and scale new (T. A. Muñoz-Erickson et al., 2017) and radical (Fazey et al., 2020) ways of linking knowledge and action. Without transformational actions, in contrast to incremental actions, even 'robust' cities may face existential threats due to climate change (Kates et al., 2012). To meet this existential crisis, cities will need not only physical infrastructure innovations, but also innovations in our knowledge infrastructure – what I call knowledge system innovations (T. R. Miller et al., 2018; T. A. Muñoz-Erickson et al., 2017). We need innovations in the ways we organize, visualize, think about, design and plan, and act to build more equitable, inclusive, and resilient cities and communities.

What might these knowledge innovations look like? For example, sustainability scholars have argued that we must redesign or transform knowledge systems – the practices and routines that shape how knowledge gets produced, validated, communicated, and used – into more open, democratized, and egalitarian processes

(Cornell et al., 2013; Fazey et al., 2020; Feagan et al., 2019; Leach et al., 2010; Norström et al., 2020). Knowledge co-production offers hope that by connecting diverse city actors and knowledge together in frequent and iterative processes, we can create new ways of connecting knowledge to action and build more resilient and sustainable cities (Arnott et al., 2020; Bremer & Meisch, 2017; Dilling & Lemos, 2011; Mach et al., 2019; Norström et al., 2020; Wyborn et al., 2019). However, many of the promised radical and transformative outcomes of knowledge co-production – such as community empowerment and inclusive processes – are found to be elusive or underreported in practice (Jagannathan et al., 2019; Lemos et al., 2018; Turnhout et al., 2020). This could be largely due to the under-theorization of power and politics in knowledge co-production literature (Lemos et al., 2018; C. A. Miller & Wyborn, 2018; Wyborn et al., 2019). I've built on these recent critical discussions and integrated them with the SETS literature (Grabowski et al., 2017; Markolf et al., 2018) by creating the SETS Framework of Knowledge Co-Production (Chapter 3). This framework supports efforts by scholars to (re)politicize the depoliticized concept of knowledge co-production in the literature and in practice (Turnhout et al., 2020). This framework can be used to conceptualize and design knowledge co-production initiatives within their broader SETS knowledge landscapes and consider the inevitable and unavoidable interdependencies between them.

While recent scholarship has attempted to provide new conceptual framings of knowledge co-production that better account for social-political dynamics influencing knowledge co-production initiatives, less scholarship has focused on empirical investigations of how unique circumstances and contexts affect knowledge co-production outcomes (Lemos et al., 2018). To address this gap in the literature, I've analyzed several case studies of knowledge systems and co-production (Chapter 2; 4). These three empirical cases studies provide rich lessons for the knowledge innovations needed to build more equitable, inclusive, and resilient urban futures – particularly in urban coastal areas.

In this concluding Chapter, I synthesize and reflect on the theoretical insights from the knowledge systems and knowledge co-production literatures, and the lessons learned from the three empirical cases presented in this dissertation (i.e., Chapter 2 - FEMA flood mapping; Chapter 4 – the Compact and Eyes on the Rise) spanning across two of the most highly urbanized and vulnerable coastal areas in the world (i.e., New York City and the Miami Metropolitan Area) and ask: what knowledge system innovations are needed to build more equitable, inclusive, and resilient cities in the age of the Anthropocene? I've identified six key themes across my dissertation work and present these in Section 2.

2. Six propositions for knowledge system innovation for resilient coastal cities

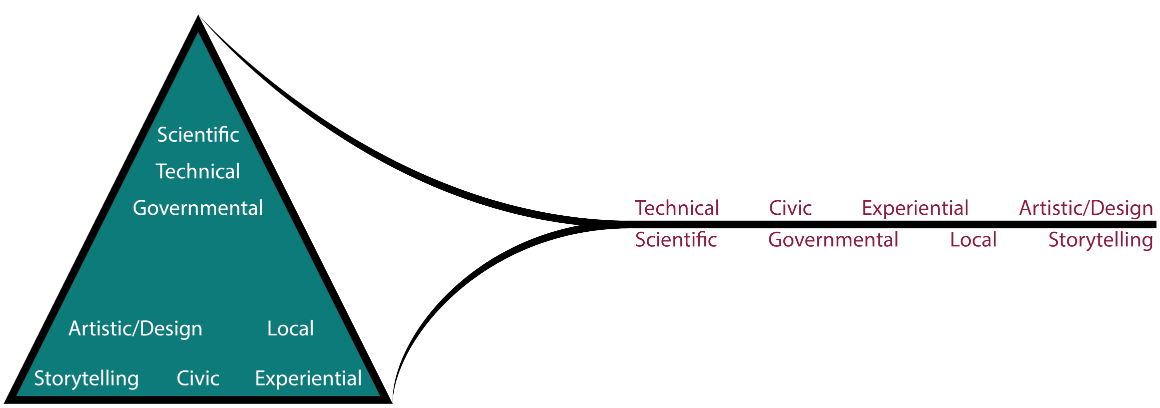
In order to promote, facilitate, and catalyze the knowledge innovations we need, I offer six propositions: (1) Flatten the knowledge hierarchy, (2) Create and negotiate plural and positive visions of the future, (3) Mind the trade-offs: Carefully construct knowledge co-production initiatives to achieve desired outcomes, and (4) Acknowledge and anticipate the influence of power and authority within and beyond knowledge co-production initiatives, (5) Build anticipatory capacities to act under deep uncertainty and incomplete knowledge, and (6) Identify and invest in knowledge innovations. The following sections describe each of these propositions, scholarly work that supports them, and lessons from each case study for why each is important. There are very important positive feedbacks and synergies between each of these propositions. In pursuing one proposition, practitioners are also likely to help advance another. These interactions and positive feedbacks will also be highlighted in the description of each proposition. In the following sections, I discuss each proposition at length.

2.1. Flatten the knowledge hierarchy

The knowledge innovations we need – and the realization of the transformative outcomes of knowledge co-production (Jagannathan et al., 2019) – will not be possible without first questioning and transforming our society's underlying assumptions and values (Fazey et al., 2020). We must question the ontological, epistemological and ethical commitments (or 'starting points') of knowledge systems (Wijsman & Feagan, 2019). Across all three case studies, it was clear that scientific and technical knowledge dominated all other ways of knowing.

Figure 5.1

Flatten the Knowledge Hierarchy



Note. Science, technological and governmental knowledge are often seen as superior to other ways of knowing. By flattening the knowledge system, diverse forms of knowledge are recognized as able to provide important knowledge for urban resilience actions.

In the FEMA case, FEMA will only acknowledge a request to modify their flood maps if provided with technical hydrological data and information – homeowner knowledge about historical flooding in their neighborhood is dismissed. 'Community' participation in this knowledge system is primarily limited to city and state engineers, hydrologists, floodplain managers – all technical experts. The Compact relied heavily on governmental and the peer-reviewed scientific literature as the foundation of their analysis, plans, and courses of action. There was very little representation from civic leaders, and very minor engagement of local community members within the initiative – an indication of the marginalization of non-technical actors and knowledge (Vella et al., 2016). The EOTR initiative attempted to incorporate artistic features, storytelling, and other non-scientific ways of knowing and communicating in their knowledge products. Nevertheless, the EOTR team tended to favor the development and communication of scientifically-sound knowledge at the expense of the other forms of knowledge that the initiative engaged with. The perceived lack of credibility of these other forms of knowledge tended to marginalize them throughout the initiative. Expertise, in all three cases, was largely held by the scientific and technical experts – particularly from the natural sciences.

We need to alter our assumptions regarding what and whose knowledge counts for pursuing resiliency goals (Meerow & Newell, 2019). This will require a fundamental shift in the way society values and assigns credibility to scientific and technical knowledge above all other forms of knowing, such as indigenous, feminist, local and experiential knowledge (Fazey et al., 2020; Leach et al., 2010; Wijsman & Feagan, 2019). While scientific knowledge is assumed to be objective and free of bias by the general public – and hence more credible and legitimate (Cash et al., 2003a) – many scholars have pointed out that science is actually laden with various forms of bias: "Philosophers of science have begun to realize that the ideal of pure and value-free science is at best just that—an ideal—and that all scientific practice involves all kinds of value-judgments" (Wilholt, 2009, p. 92). However, this shouldn't detract from the value of scientific knowledge, but instead open up other ways of knowing that have been marginalized due to the perceived superiority of scientific knowledge. Additionally, by acknowledging that science is not value-free, universities may provide greater flexibility in allowing – and even encouraging or incentivizing – scientists to organize and mobilize their critical knowledge in new ways as policy advocates (Bassett, 2020). In the EOTR case, some members of the team were viewed as being too sensationalistic. There was a fear that the team would be viewed as advocates, rather than scientists by challenging the dominant narratives and visions that the local political and social elites held. Some team members felt frustrated by the limitations placed on the way they designed and crafted their knowledge within this dominant natural science hierarchy. By questioning this hierarchical structure and the superiority of scientific and technical knowledge, we may open up other ways of producing, communicating, and using knowledge to in order to create more equitable, inclusive, and resilient futures. We are desperately in need of a more egalitarian approach to assigning value to different forms of knowledge and tearing down the current dominant hierarchy of knowledge in society (Cornell et al., 2013; Fazey et al., 2020). Feagan et al. (2019) call on future scholarship to explore how:

> These different ways of knowing might be used to transform specific urban knowledge systems that are currently in place, to align with diverse societal

needs, and to open up new pathways for designing how cities sense, anticipate, adapt to, and learn from extreme weather events. (p. 1)

In knowledge co-production initiatives in particular, we will need to elevate the role of community stakeholders as equal to scientific and technical experts (Klenk et al., 2015). In summary, by opening up knowledge systems to include diverse forms of knowledge and expertise – and eliminating the hierarchy between them – we may be able to create the necessary conditions for the types of knowledge innovations we need to meet the challenges we face in the age of the Anthropocene.

2.2. Create and negotiate plural and positive visions of the future

The case studies in Chapter 4 highlight the role that stakeholders' visions play in shaping the knowledge co-production process and outcomes. Flood and SLR maps and projections attempt to identify where, how much, and when flooding may occur in the future. My case studies show that not only are they technical products, but designer's or producer's visions of the future play a role in their development. In addition, prospective flood and SLR maps of vulnerable coastal cities elicit and cause the user to reconcile their vision of the future with the vision encoded in the maps. This is largely because flood maps have significant implications for future land use and infrastructure design. Flood maps determine where and how future development will occur and whether or not current land use practices will need to be altered. In coastal cities in particular, they also encode or strongly suggest where and when retreat may need to take place. Given the political nature of retreat in coastal areas, flood maps tend to be viewed within stakeholders' future visions of the city – and whether that includes partial or total retreat of the coastline. In highly urbanized and populated low-lying coastal metropolises, like the Miami Metropolitan Area, these flood maps and projections pin alternative visions of the future against each other.

Throughout all three case studies, knowledge and data that were associated with alternative visions of the future were often ignored or outright rejected if they didn't align with dominant visions. One EOTR interviewee lamented:

> We were kind of thrown out to the wolves and forced to kind of navigate all of these sorts of issues of politics, and ethics and data - whose data? How do we tell the story that is based in data that they may not like?

In each case, knowledge and data that aligned with a vision that maintained current economic and social systems were promoted, and those which didn't were demoted. The Eyes on the Rise team felt pressured to alter their data – or at least change the way they framed their story – so that it would more closely align with the *We will Innovate* vision held by local political and institutional elites. The *We will Innovate* vision, focuses on maintaining current social and economic conditions – conditions which favor developers and the ultrawealthy (Wakefield, 2019). In the Compact case study, the government-centric initiative ensured that the *We will Innovate* vision took hold over all of the initiative's knowledge products. Especially in its formative years, actors who discussed data and knowledge that didn't fit with this vision were often on the defensive and not as well represented. The government-centric makeup of the Compact reinforces their hold over this shared vision of maintaining the status quo and quality of life in the Miami Metropolitan Area. For instance, there has been little room for civic actors to engage in the initiative in a substantive way and integrate alternative visions that they may hold into the regional vulnerability analyses, policies, and plans that drive climate adaptation actions throughout the region (Vella et al., 2016).

These results are consistent with findings in the literature that suggest most of today's knowledge systems support "existing ways of doing things, reinforcing existing social, economic and political forms of power and thus limiting emergence of more creative ways of working with global challenges" (Fazey et al., 2020, p. 9). Even in the Compact's innovative approach to regional climate governance, it continues to maintain existing power relationships and the exclusion of certain sectors of society (Vella et al., 2016; Wakefield, 2019). In order to promote more innovative modes of knowledge production for urban resilience, we may need to first open new spaces to safely and deliberately negotiate alternative visions of the future by a plurality of city actors (Feagan et al., 2019; L. M. Harris et al., 2018; Leach et al., 2010).

As seen in my case studies, city visions tended to either be dystopian or maintaining the status quo. It may be helpful to facilitate the creation of more inspirational and aspirational positive futures (Fazey et al., 2020; McPhearson, Iwaniec, et al., 2016) to connect knowledge and action for transformation. Such positive visions may be the "basis to initiate real action and guide change" (McPhearson, Iwaniec, et al., 2016, p. 2). These visions should be crafted from a broad representation of society to be as pluralistic as possible (Fazey et al., 2020; Norström et al., 2020). By injecting more positive visions into city discourses, perhaps other innovative ways of connecting knowledge and action will be able to scale up without as much resistance as was experienced in the EOTR case. Maps should be created of these future visions that integrate both knowledge about future flood risks with knowledge about desirable futures and solutions to get there. In this way, prospective flood maps will encode visions that are not just from a few or from dominant elite, but that represent the desires and aspirations of a broad cross-section of society (Fazey et al., 2020; Iwaniec et al., 2020). These can then be communicated widely and used by broad sectors of society to employ strategies to help achieve that shared and plural vision.

For instance, the Louisiana's Coastal Protection and Restoration Authority's Master Plan process and Planning Tool is a co-produced flood mapping project that features an intensive stakeholder deliberative process to articulate visions, values, alternative solutions, and food risk knowledge all into one decision support tool that shows both the extent of plausible future flooding along with desired solutions to address it (Wong-Parodi et al., 2020). It is widely viewed as a successful decision support tool that builds trust and legitimacy for the $50 billion worth of flood management projects that the state is planning to implement (Wong-Parodi et al., 2020). More project like this are needed in coastal cities, but they are also extremely resource-intensive undertakings (see Section 2.5).

2.3. Mind the trade-offs: Carefully construct knowledge co-production initiatives to achieve desired outcomes

Each of the knowledge co-production case studies illustrate how the initial design of an initiative locks-in certain outcomes at the expense of others. In the Compact case, the government-centric design has been effective in connecting the knowledge produced by the initiative with action by local governments. The Compact has shown relatively high efficacy in integrating its knowledge into local government policies, plans, and on-the-ground adaptation projects. However, this has been at the expense of achieving other aspirational knowledge co-production outcomes like empowering community residents – building their capacity to anticipate and implement their own adaptation actions. The exclusion of broad participation from the civic sector ensures the implementation of the government-centric vision while further marginalizing the voice and visions of local community members.

In the Eyes on the Rise project, the academic-centric project was successful in achieving its educational outcomes, but it had little to no direct influence on local government policy, plans, and adaptation actions. The focus on deepening community knowledge meant that they decreased the usability of the knowledge by local government agencies. These different users have very different needs when interacting with a flood map. Government actors needed state-of-the-art scientific information that more-or-less aligns with their vision of the future. Government actors tended to have more technical expertise and wanted more complexity and higher resolution of maps. Community members need credible knowledge, but in a format that is simple and easy-to-understand. By providing community members with a usable knowledge product, the product simultaneously became unusable for government planning and infrastructure design.

2.4. Acknowledge and anticipate the influence of power and authority within and beyond knowledge co-production initiatives

Many scholars have warned that care is needed to acknowledge, plan for, and mediate power dynamics between participants in knowledge co-production initiatives (Fazey et al., 2020; Lemos et al., 2018; McPhearson, Iwaniec, et al., 2016; Turnhout et al., 2020). There was clearly a significant display of power and authority between participants across all three case studies. For instance, the government actors in the

Compact maintained their power and authority over the Compact – despite its evolution and inclusion of other sectors of society. There were critical tensions between the social scientists and natural scientists in the EOTR initiative reflecting the perceived higher esteem of natural science knowledge over artistic and design knowledge in society.

All three case studies (Chapters 2 and 4) reveal that we must consider the existing power asymmetries present in the social, political, institutional, technological, and ecological contexts in which knowledge co-production initiatives are situated (Turnhout et al., 2020; Wyborn et al., 2019). Not only are there power dynamics between participants, but external actors and technological artifacts can influence the dynamics and products of knowledge co-production. This was most apparent in the Eyes on the Rise project where both the local institutional and political elites ultimately affected the internal dynamics among participants and the products of the initiative. Their effect was not only direct influence. The perception on how the knowledge would be received by these external actors was also a force of its own in steering the discussions and outputs of the initiative. Similarly, the main take-away from the FEMA case study (as discussed in both Chapters 2 and 3) was that FEMA flood maps are as much of a social product as a technical one; existing socio-political factors – and the influence of powerful local elites – largely prevented the FEMA flood maps from the updates they needed to better reflect changing flood risk conditions in New York City.

This proposition is not only about recognizing and addressing the power of people and institutions. The SETS-FKC also highlights that technological artifacts and systems can have power or agency of their own and develop 'technological momentum' or 'technological obduracy' and resist change – both the artifact and the knowledge systems arrangements supporting it resist this change. The analysis performed in Chapter 2 and the discussion in Chapter 3 clearly illustrate how the technological artifact of the FEMA flood maps became a political actor itself in attempts to update New York City's flood risk. This artifact has co-evolved with stabilized knowledge- and decision-making arrangements around it to provide it with the technical knowledge it needs to reproduce itself (e.g., the production of AEP and LiDAR satellite imagery). These arrangements are self-reinforcing and are difficult to untangle. As seen in Chapter 2, the New York City FIRM has not been updated significantly since 1983. While climate change may have significantly altered climatological and ecological conditions (Crutzen, 2002; Reidmiller et al., 2018; Rockström et al., 2009), the technological momentum built up around using historical climate data is difficult to change and has resisted attempts to include more recent flood data as well as future sea level rise and flood projections. As such, we can say that the FEMA FIRM is now a political agent. It is important to both recognize and realign the couplings between technological systems and artifacts and the knowledge systems responsible for their reproduction in order to advance knowledge innovation for resilient cities.

I presented the SETS Framework of Knowledge Co-production in Chapter 3. The SETS Framework of Knowledge Co-production is designed to be used by both practitioners and researchers as a heuristic to plan for, navigate, and analyze the inevitable social, technological, and ecological couplings with knowledge that a deliberate knowledge co-production intervention will encounter throughout its design and implementation. More intentional knowledge co-production designs may anticipate tensions, barriers, and legacies in the larger SETS knowledge landscape that could inhibit achieving the transformative outcomes required to build the sustainability and resilience of urban systems. More intentional and inclusive knowledge co-production designs may also help give a voice to marginalized actors and perspectives that may otherwise go unheard (Fazey et al., 2020). By reconceptualizing knowledge co-production as situated within a particular SETS knowledge landscape – rather than isolated initiatives – we can begin to design knowledge co-production initiatives to achieve more transformative outcomes. Knowledge innovations will require concerted action to simultaneously build new modes of knowledge production while realigning urban SETS to facilitate their growth and impact.

2.5 Build anticipatory capacities to act under deep uncertainty and incomplete knowledge

In coastal cities, capacity will need to be built to plan and act under conditions of deep uncertainty: when knowledge about climate impacts – like sea level rise – are too uncertain and too unpredictable (Haasnoot et al., 2013; Hall et al., 2019; Hill et al., 2008; Marchau et al., 2019; Stults & Larsen, 2018; van Dorsser et al., 2020; W. E. Walker et al., 2013). Rather than the traditional 'Predict and Plan' (e.g., downscaling, vulnerability assessments, climate scenarios, low-regret strategies) approaches, scholars recommend 'Adapt and Monitor' (e.g., adaptive management, dynamic adaptive policy pathways, scenario planning, monitoring changing conditions) approaches (Quay, 2010; Stults & Larsen, 2018). In other words, to take action first and then monitor and adjust your strategies as conditions change and they lose effectives. Planning practice (Stults & Larsen, 2018), infrastructure design (Chester et al., 2020; Helmrich & Chester, 2020), and decision-making (Hall et al., 2019; S. Hallegatte et al., 2012) all must change to a prospective rather than the pervasive retrospective approach.

Fazey et al.'s (2020) principal argument was that we do not need more knowledge; instead, we need more *wisdom* about how to act in this world. Reflecting on humanity's inherent technological and knowledge limits, Michael Crow suggests that the central question for humanity in the age of the Anthropocene is whether: "we will be able to position ourselves to choose wisely among alternative future trajectories or will simply blunder onward". (Crow, 2007, p. 2). As such, we must build the anticipatory capacities of knowledge systems to sense, adjust, and be reflexive (Muñoz-Erickson et al., 2021). These anticipatory capacities not only need to assist decision makers to adjust approaches to changing environmental conditions, but also to emergent political circumstances: "Knowledge-action systems must be able to also anticipate, manage, and address the politics that emerge as cities reconfigure themselves to address sustainability" (T. A. Muñoz-Erickson, 2014b).

There are both innovative social and technical knowledge system approaches to build these anticipatory capacities. Marchau et al. (2019) synthesize the literature and present a variety of technical decision-making approaches that can help practitioners act under conditions of deep uncertainty including robust decision-making, dynamic adaptive policy pathways, dynamic adaptive planning, info-gap decision theory, and engineering options analysis. Kwakkel and Haasnoot (2019) describe a taxonomy of tools that each of the above strategies employ in concert, including: vulnerability analysis, robustness metrics (comparing alternatives), generation of scenarios (expert opinion, global or local), generation of policy alternatives, and policy architectures (protective adaptivity, or dynamic adaptivity).

In addition to these technical approaches, novel social and governance approaches can help to determine how to act as well. Strategies from Section 2.4 can help with acting under political uncertainties. Also, by flattening the knowledge hierarchy (Section 2.1) and creating plural visions of the future (Section 2.2) we can incorporate more diverse ways of knowing how to act in various situations. In the Compact case study, I presented how the City of Miami Beach used technical approaches for planning and design under uncertainty – planning for infrastructure design based on the expected lifespan and level of service of infrastructure (a technological strategic innovation). However, the technological decision-making innovation wasn't enough by itself. The City of Miami Beach installed pump systems that diverted stormwater into Biscayne Bay (City of Miami Beach, 2019). While these have decreased nuisance floods in select parts of the city, they have also been a source of water quality issues in the Bay (Wakefield, 2019). The pumps did not initially treat the stormwater prior to draining it into the Bay resulting in bacteria and viruses entering the Bay due to septic tank leaks. In the Summer of 2020, Biscayne Bay suffered an extreme degradation of water quality that killed off a significant amount of marine life and restricted recreational and tourism use in the Bay. Moreover, while raised roads keep the roads dry and usable, the strategy is a source of bitterness by local residents who now find their properties below road level and flooded as a result (A. Harris, 2020). This approach was driven by the government-centric *We will Innovate* vision. By opening-up and broadening-out knowledge systems (Cornell et al., 2013; Leach et al., 2010; T. A. Muñoz-Erickson, 2014b) to incorporate diverse knowledge and visions, we can envision a future city that takes into account a diverse set of desired conditions and then act in accordance with those vision. Participatory 'Adapt and Monitor' planning approaches, like scenario planning (Iwaniec et al., 2020; Stults & Larsen, 2018), can help to build these shared visions along with the strategies and pathways to get there. These planning, design, and decision-making approaches embrace – rather than try to reduce or manage – the irreducible uncertainties common to the conditions of the Anthropocene (Chester et al., 2020; Helmrich & Chester, 2020).

2.6. Identify and invest in knowledge innovations

Knowledge system innovations for resilient coastal cities are not able to be crafted and scaled without adequate and efficient utilization of resources (Burch, 2010). Knowledge production is a very resource-intensive process. Each of my knowledge system case studies clearly demonstrated the role that access to resources played – in some instances constraining efforts and in others enabling them. In the Eyes on the Rise case, all of the participants bemoaned the lack of financial resources in enabling them to create and scale up their innovative ideas. They were able to do all of their work within their initial award budget of only $35,000 from the Online News Association. Nevertheless, many of their novel ideas and upgrades went unrealized due to the lack of additional financial resources. They applied for scores of grants to try to secure additional funds but were unsuccessful. The lack of funding was a major factor in the ultimate dissolution of the project team and lack of maintenance of the knowledge infrastructure they carefully built. In the NYC FEMA flood mapping case study, the New York City spent a lot of money and staff time to create their own technical study to appeal FEMA's 2015 Preliminary FIRM. They were ultimately successful. New York City had access to the funds, expertise, and staff to be able to successfully produce knowledge that countered that of FEMA's. Small cities and communities may not be able to challenge FEMA's flood risk knowledge due to having much less resources to do so. In contrast, the Compact illustrates how a knowledge co-production initiative can create economies of scale to enable resource-scarce cities to innovate. Small cities actually benefitted substantially by having access to the knowledge, expertise, and other resources that the Compact was able to organize for its member Counties. The Compact was able to secure national grants (e.g., from the Kresge Foundation) and also leveraged the Compact to secure other grants to support both novel scientific research and practice (Menees & Grannis, 2017). Small cities within the Compact have access now to local, regional, national, and even international expertise that they may not have had otherwise (Menees & Grannis, 2017). The increased access to knowledge, expertise, and guidance from the Compact has help the region overall to have a coordinated and uniform approach to understanding and adapting to floods – a regional climate problem – across its jurisdictional boundaries. In the Compact case, access to resources has been a key factor in driving the success of this project.

In the process of investing in knowledge innovations, sponsors can have a more profound role in enabling and catalyzing change than the traditional one-way pipeline of 'sponsor – project team – user' knowledge production relationship (Arnott et al., 2020). Arnott et al. (2020) offer an impact-oriented funding model as an alternative that restructures this one-way relationship and invites significant and frequent interactions between sponsors, producers, and users in the co-production of new knowledge.

3. Conclusion

The overarching argument of this dissertation is that the majority of today's knowledge systems are unequipped to produce the knowledge and wisdom needed to transform our urban social, ecological, and technological systems along more equitable, inclusive, and resilient pathways in the age of the Anthropocene (Crow, 2007; Fazey et al., 2020; Feagan et al., 2019; T. A. Muñoz-Erickson et al., 2017). We need both physical infrastructure innovations (Chester et al., 2020) as well as knowledge innovations (Crow, 2007; T. A. Muñoz-Erickson et al., 2017) to meet the complex and intractable challenges of the Anthropocene. Today's knowledge systems tend to be exclusive, elitist, driven by science and technology knowledge and expertise, and are exploitive rather than empowering (Fazey et al., 2020). This dissertation has made both conceptual (Chapter 3) and empirical contributions (Chapters 2 and 4) to the knowledge systems and knowledge co-production literature. In this final chapter, by synthesizing across the literature and my case studies, I've presented several propositions that knowledge professionals (both scholars and practitioners) can employ to help scale up the knowledge system innovations we need to build more equitable, inclusive, and resilient coastal cities – especially for coastal cities vying for their future. These include:

(1) Flatten the knowledge hierarchy.

(2) Create and negotiate plural and positive visions of the future.

(3) Mind the trade-offs: Carefully construct knowledge co-production initiatives to achieve desired outcomes.

(4) Acknowledge and anticipate the influence of power and authority within and beyond knowledge co-production initiatives.

(5) Build anticipatory capacities to act under deep uncertainty and incomplete knowledge

(6) Identify and invest in knowledge innovations

These six propositions can help to remedy many of the failures of today's knowledge systems, while scaling up the knowledge innovations we need to build more equitable, inclusive, and resilient cities in the age of the Anthropocene. For instance, by applying each of these propositions in concert, we may be able to create more inclusive or egalitarian knowledge system routines and practices that can produce more equitable outcomes for a broader cross-section of society. By flattening the knowledge hierarchy, we recognize the value that citizen knowledge about flood risk has for advancing flood resilience in cities (Luke et al., 2018; Ramsey et al., 2019; Sanders et al., 2020). By creating and negotiating plural and positive visions of the future (proposition 2), we help cities to choose among alternative pathways for the future – in a more inclusive knowledge co-production process – and decide how to act given our incomplete knowledge about future conditions and outcomes (Bennett et al., 2016; Crow, 2007). By minding the trade-offs (proposition 3), we can ensure that our knowledge co-production designs align with the outcomes we want to build more inclusive knowledge systems and generate equitable outcomes (e.g., strengthening and empowering communities). By acknowledging the power, agency, and obduracy of SETS arrangements (proposition 4), we can build new modes of knowledge co-production that simultaneously realign urban SETS so that new way of connecting knowledge and action emerge that promote inclusive, equitable, and resilient urban futures. By building anticipatory capacities to act (proposition 5), we can create new decision-making routines and processes (e.g., dynamic adaptive policy pathways, participatory scenario planning, multi-criteria assessments) that elicit knowledge, goals, preferences, values, and visions from a diverse representation of stakeholders to guide urban resilience policy and planning; this may also help with making sure that outcomes serve not just elite and powerful groups, but traditionally marginalized groups as well. By identifying and investing in knowledge innovations (proposition 6), we can provide critical resources and support to knowledge co-production initiatives that seek to broaden out and open-up knowledge systems (Arnott et al., 2020; Cornell et al., 2013). In summary, these propositions collectively aid knowledge professionals in redesigning the knowledge systems we need for building more inclusive, equitable, and resilient cities.

While these propositions were written specifically in the context of coastal cities dealing with existential climate threats, many of these propositions can be applied to facilitating innovations for adapting to other complex and intractable environmental issues where the consequences and probabilities are unknown (e.g., droughts, heat waves, earthquakes, and global pandemic crises). In closing, knowledge systems analysis (Chapter 2), the SETS-FKC (Chapter 3) and the six propositions (Chapter 5) can all be used to stress-test, re-design, and monitor knowledge systems to guide the knowledge innovations we need to build more resilient cities.

CHAPTER 6

CONCLUDING REMARKS AND FUTURE DIRECTIONS

My dissertation has concluded in several important propositions for designing knowledge systems to build more equitable, inclusive, and resilient cities: (1) Flatten the knowledge hierarchy, (2) Create and negotiate plural and positive visions of the future, (3) Mind the trade-offs: Carefully construct knowledge co-production initiatives to achieve desired outcomes, and (4) Acknowledge and anticipate the influence of power and authority within and beyond knowledge co-production initiatives, (5) Build anticipatory capacities to act under deep uncertainty and incomplete knowledge, and (6) Identify and invest in knowledge innovations. I am especially interested in future research and practice to design new knowledge systems that are inclusive of multiple perspectives and actors (Propositions 1 and 2) and that build the anticipatory capacities of local governments to act under deep uncertainty (Proposition 5). I have some thoughts and a concrete proposal in development to chart new research in these two important areas.

I plan to focus on *how* to design inclusive knowledge systems for building more equitable and resilient cities. As I described in Chapter 4, I had the privilege to be a participant observer in two innovative projects that I believe could demonstrate how to *operationalize* these propositions: the Smart and Connected Communities Resilient Coastal Cities planning grant project and the UREx SRN Miami Scenarios Workshop. I am considering analyzing one or both of these initiatives more in-depth as innovative approaches for reconfiguring urban SETS knowledge landscapes to advance sustainability and resilience goals – particularly inclusivity. These two initiatives demonstrate novel strategies for creating more inclusive knowledge systems that address procedural justice and distributional justice critiques of many of today's knowledge systems (Fazey et al., 2020; Feagan et al., 2019; Wijsman & Feagan, 2019).

I am also intrigued by the Dynamic Adaptation Policy Pathways (DAPP) approach (Haasnoot et al., 2013; Hall et al., 2019; Kwakkel & Haasnoot, 2019) as an innovative approach for advancing resilience efforts under deep uncertainty. I have drafted a proposal that I will likely submit during my postdoc at Georgia State University to collaborate with local governments in the Southeast Atlantic (e.g., Atlanta, Puerto Rico, Miami) to build their capacity to employ this innovative approach to decision-making. Several of my interviewees in the MMA discussed interest in, and the value of, the DAPP approach to decision-making but cautioned that existing knowledge-making and decision-making arrangements make it very difficult to actually employ it. Given insights from my dissertation cases, the work I plan to do to analyze the Resilient Coastal Cities and UREx SRN Miami Scenario Workshop, and the new SETS Framework of Knowledge Co-production, I plan to co-create new SETS knowledge arrangements that can build the capacity of local government officials to employ this strategy and other innovative strategies to act under deep uncertainty.

For the remainder of my career as a sustainability scientist, I plan to continue working on urban sustainability challenges that have the following characteristics: (1) system disturbances like extreme weather events (shocks) and sea level rise (stressors), (2) deep uncertainty about the future magnitude and probability of impacts, and (3) complex urban issues spanning social, ecological, and technological systems.

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APPENDIX A

ASU IRB EXEMPTION LETTER FOR STUDY 00007126

EXEMPTION
GRANTED

Clark Miller

Future of Innovation in Society, School
for the 480/965-1778

Clark.Miller@asu.edu

Dear Clark Miller:

On 10/18/2017 the ASU IRB reviewed the following protocol:

Type of Review:	Initial Study
Title:	Anticipating coastal flood risk in a non-stationary climate: A critical analysis of flood risk knowledge systems in three US coastal cities
Investigator:	Clark Miller
IRB ID:	STUDY00007126
Funding:	Name: National Science Foundation (NSF), Funding Source ID: 1737626; Name: National Science Foundation (NSF), Funding Source ID: SES 1444755
Grant Title:	
Grant ID:	
Documents Reviewed:	• Urban Resilience to Extremes SRN NSF Grant, Category: Sponsor Attachment; • Resilient Coastal Communities NSF Grant Forms.pdf, Category: Sponsor Attachment; • Consent Form, Category: Consent Form; • Interview Invitation Letter, Category: Recruitment Materials; • IRB Protocol: Anticipating Coastal Flood Risk, Category: IRB Protocol; • Semi-Structured Interview Prompts, Category: Measures (Survey questions/Interview questions /interview guides/focus group questions);

The IRB determined that the protocol is considered exempt pursuant to Federal Regulations 45CFR46 (2) Tests, surveys, interviews, or observation on 10/18/2017.

In conducting this protocol you are required to follow the requirements listed in the INVESTIGATOR MANUAL (HRP-103).

Sincerely,

IRB Administrator

cc: Robert Hobbins
Robert Hobbins
Tischa Munoz

APPENDIX B

ASU IRB EXEMPTION LETTER FOR STUDY 00004605

EXEMPTION
GRANTED

Charles Redman
Sustainability, School of
480/965-2923

CHARLES.REDMAN@asu.edu

Dear Charles Redman:

On 12/12/2016 the ASU IRB reviewed the following protocol:

Type of Review:	Modification
Title:	Participatory Scenario Development for Urban Resilience to Weather-Related Extreme Events
Investigator:	Charles Redman
IRB ID:	STUDY00004605
Funding:	Name: National Science Foundation (NSF), Grant Office ID: FP00000038, Funding Source ID: 1444755
Grant Title:	None
Grant ID:	None
Documents Reviewed:	• FP00000038-Redman-FP.pdf, Category: Sponsor Attachment; • Survey invitation email Spanish, Category: Recruitment Materials; • Survey invitation email English, Category: Recruitment Materials; • UREx Scenarios Survey English version, Category: Measures (Survey questions/Interview questions /interview guides/focus group questions); • Workshop Consent with Agenda, Category: Consent Form; • IB submission letter for external members, Category: Off-site authorizations (school permission, other IRB approvals, Tribal permission etc); • UREx Scenarios Survey_Spanish version, Category: Measures (Survey questions/Interview questions /interview guides/focus group questions); • UREx Scenarios Protocol Form, Category: IRB

	Protocol; • Survey recruitment email, Category: Recruitment Materials; • Signed Translation Certification Form, Category: Translations; • Survey Consent, Category: Consent Form;

The IRB determined that the protocol is considered exempt pursuant to Federal Regulations 45CFR46 (2) Tests, surveys, interviews, or observation on 12/12/2016.

In conducting this protocol you are required to follow the requirements listed in the INVESTIGATOR MANUAL (HRP-103).

Sincerely,

IRB Administrator

cc: Angela Grobstein
Michaela Jones
Nancy Grimm
Elizabeth Cook
Charles Redman
Melissa Davidson
Tischa Munoz
David Iwaniec

BIOGRAPHICAL SKETCH

Robert Jonathan Hobbins was born in Youngstown, Ohio in 1984. He earned his BS in Physics and Astronomy in 2007 and his Master of Education in Secondary Science Education from The Ohio State University in 2008. In 2008, Robert moved to Arizona to teach physical science courses to middle and high school students at Sonoran Science Academy – Tucson. Robert relocated to Phoenix in 2012 to serve as Sonoran Schools' Associate Superintendent of Curriculum and Instruction for its nine Arizona K-12 campuses. While serving as Associate Superintendent, Robert began his training to become an urban sustainability scientist. Robert started his Master of Science in Community Resources and Development – Sustainable Communities at Arizona State University (ASU) in 2014. For his master's thesis, he used scenario planning and mental modeling techniques to elicit stakeholder's mental models of the complex social-ecological-technological system affecting the future quality of Arizona's night sky. Robert completed his MS in 2016 and received a two-year fellowship from the Urban Resilience to Extremes Sustainability Research Network (UREx SRN) to start his PhD full-time at the School of Sustainability at ASU. From 2019-2020, Robert received funding from the National Science Foundation to support him as a Research Intern at the USDA Forest Service International Institute of Tropical Forestry in San Juan, Puerto Rico. During this internship, Robert worked on both UREx SRN and San Juan Ultra Long-Term Research Area (San Juan ULTRA) projects with the goal to better connect the research outputs from these projects with action on the ground to build more just, resilient, and sustainable futures for local residents in San Juan. After completion of his PhD at ASU, Robert will continue his urban resilience scholarship at the Urban Studies Institute at Georgia State University as a Postdoctoral Fellow. Robert was also recently appointed as a Board Member to the Sonoran Schools Inc. Corporate Board where he will continue his K-12 educational leadership and service.