



Evaluating Effectiveness in Climate Change Adaptation and Socially-Engaged Climate Research

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**EVALUATING EFFECTIVENESS IN CLIMATE CHANGE ADAPTATION AND
SOCIALY-ENGAGED CLIMATE RESEARCH**

by

Bonnie Jean 'Gigi' Owen

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SCHOOL OF GEOGRAPHY AND DEVELOPMENT

In Partial Fulfillment of the Requirements

For the Degree of

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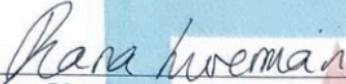
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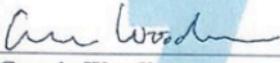
THE UNIVERSITY OF ARIZONA
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As members of the Dissertation Committee, we certify that we have read the dissertation prepared by Gigi Owen, titled *Evaluating Effectiveness in Climate Change Adaptation and Socially-Engaged Climate Research* and recommend that it be accepted as fulfilling the dissertation requirement for the Degree of Doctor of Philosophy.



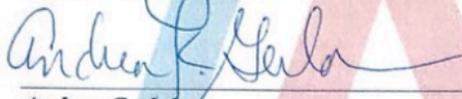
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Date: August 6th 2019



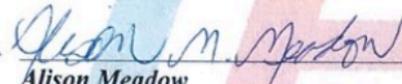
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Final approval and acceptance of this dissertation is contingent upon the candidate's submission of the final copies of the dissertation to the Graduate College.

I hereby certify that I have read this dissertation prepared under my direction and recommend that it be accepted as fulfilling the dissertation requirement.



Diana Liverman
Dissertation Committee Chair
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ARIZONA

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Dedication

To Bleu, with gratitude

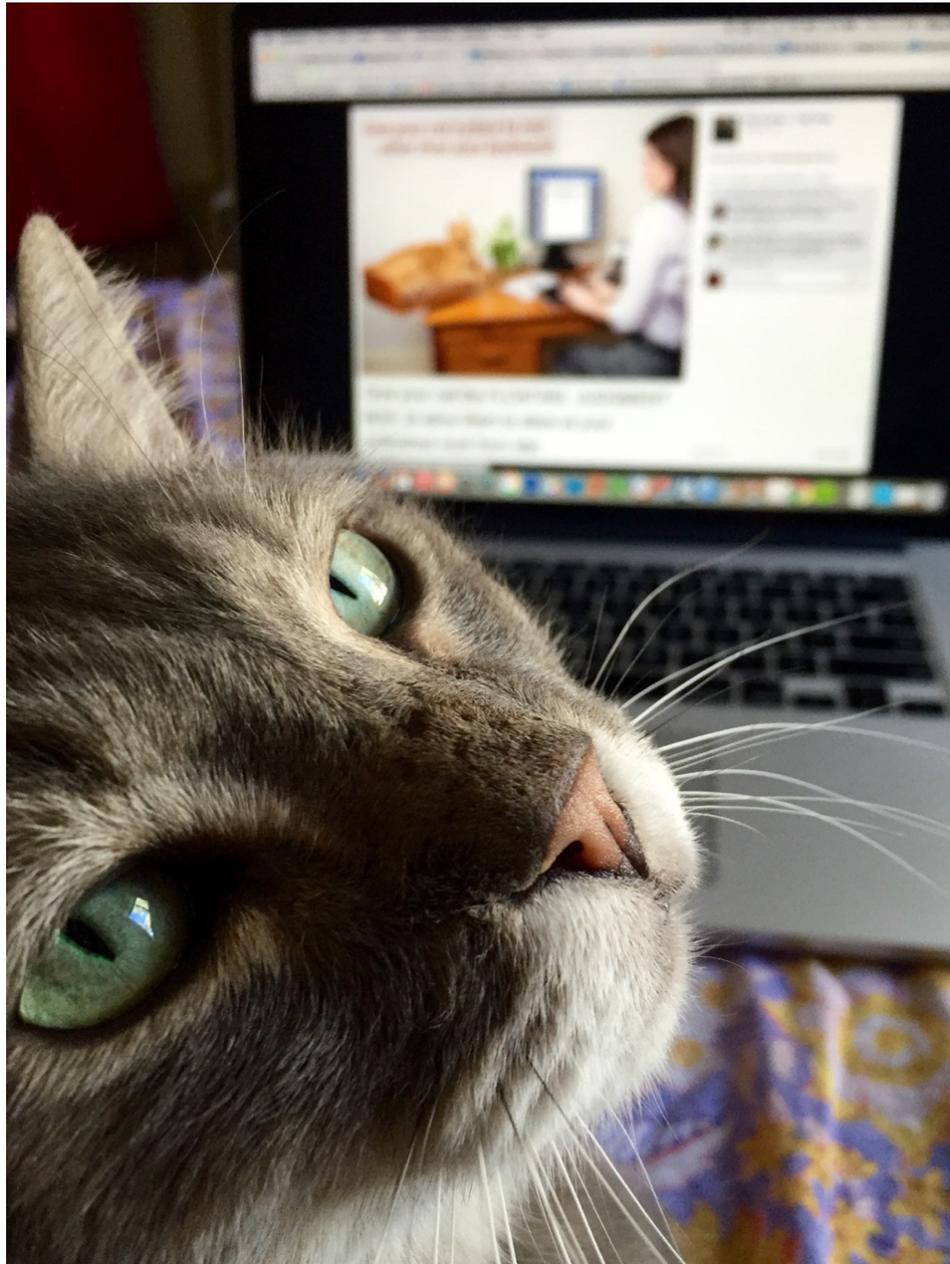


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ABSTRACT

Climate change, due to global warming caused by humans, has become an increasingly critical issue over the past few decades. Society's deeper understanding of, experiences with, and communication about climate change have motivated action toward the mitigation of global warming and adaptation to its associated impacts. An underlying message from the scientific community is that society needs to act now and with good judgement (IPCC 2018). This message prompts further questions, including: How do people know which actions to take? What activities will have the most impact? What approaches to adaptation and mitigation are most equitable? What roles should science and scientists play in responding to the threats of global warming? Evaluation, a necessary but often missing component of climate action, can help answer these questions through systematic assessment of the outcomes and impacts of mitigation, adaptation, and associated research practices.

In my dissertation, I investigate adaptation responses to climate change occurring globally, by analyzing adaptation initiatives that have shown some degree of effectiveness around the world; and regionally, by evaluating the socially-engaged and use-inspired theories and practices of a climate research program in the U.S. Southwest. My research asks the following three questions: a) What are the outcomes and impacts of climate change adaptation and socially-engaged climate research? b) What approaches constitute successful adaptation and research practices? c) How is knowledge produced and mobilized for use in addressing complex societal and environmental issues?

In my first dissertation paper, I document findings from a systematic review of research literature on effective adaptation initiatives. I analyze 110 adaptation case

studies from literature published between 2007 and 2018. The act of cataloging adaptation activities produces insights for current and future climate action in three main areas: understanding the common attributes of effective adaptation initiatives; identifying gaps in adaptation research and practice that address equality, justice, and power dynamics; and establishing priorities for evaluating adaptation initiatives.

My second and third dissertation papers draw from a six-year program evaluation of the Climate Assessment for the Southwest (CLIMAS) research program. This program has roots in the theories of socially-engaged research and co-producing knowledge with non-academic partners. I describe an evolution in understanding how the CLIMAS program fosters and contributes to a climate adaptive and resilient U.S. Southwest region. I investigate the outcomes of CLIMAS-related research based on researcher perspectives and examine how researchers envision the broader societal impacts of their work. These papers contribute to current theory and practice of socially-engaged science by identifying and demonstrating how social interactions inform climate knowledge production. They also provide insight for similar types of research organizations that are considering conducting program evaluations.

INTRODUCTION

Since beginning my doctoral journey in the School of Geography and Development at the University of Arizona in 2010, I have observed a distinct shift in people's opinions about the earth's changing climate. In early days, when mentioning my research interests on the social impacts of climate change to friends, acquaintances, and peers, I was typically met with indifference. *I don't think climate change is important*, people often replied. *I saw those photos of the polar bears. It's so sad, but it doesn't really impact me or my life.* Other times I was met with skepticism—*I'm just not convinced that climate change is real.* In recent years, I have noticed drastically different responses during these types of exchanges. *Thank you for your work! Climate change is so important. I feel helpless. What can we do?* As people increasingly experience the impacts of climate change, and as scientific understanding and communication about climate continue to develop, it seems that society is becoming more responsive to the past, present, and future social and environmental threats posed by global warming.

My personal experience mirrors broader trends regarding public perception and international responses to climate change. For example, in the United States, Gallup polls show that the amount of “concerned believers”—those who think climate change is caused by human activity, that it poses a serious threat in their lifetime, and believe that representations of climate change in the media are accurate or underestimated—increased from 33 percent in 2010 to 51 percent in 2019 (Saad 2019). On a global scale, political and scientific consensus continues to build regarding the realities and causes of climate change. At the 2015 United Nations Climate Change Conference in Paris, a global agreement was reached by the majority of world leaders to limit global warming to less

than 2° Celsius above pre-industrial levels¹ through a variety of mitigation and carbon reduction efforts.

A special report by the Intergovernmental Panel on Climate Change (IPCC) in 2018 documented the impacts of global warming of 1.5° Celsius. This report, aimed to strengthen global initiatives to respond to risks associated with climate change, shows scientific agreement that: 1) human activities have already caused warming between 0.8° to 1.2° Celsius, with some regions like the Arctic warming greater than the global average; 2) if global warming continues to increase at its current rate, it is likely to reach 1.5° Celsius between 2030 and 2052; 3) natural and human systems are already experiencing a wide range of climate-related risks and will be seriously impacted at 2° Celsius; 4) adaptation and mitigation efforts will help reduce current and future climate-related risks; and 5) sustaining net zero anthropogenic carbon emissions and decreasing the radiative forcing of trace gases (i.e., the greenhouse effect) would significantly reduce human-caused global warming for multiple decades. To keep warming under 1.5° Celsius, the report recommends that emissions be cut in half by 2030 and be net neutral by 2050. However, even if society meets these emission reductions, impacts will persist because of the warming that has already occurred and the greenhouse gases that will remain in the atmosphere for years. In some cases, impacts will be permanent and irreversible.

An underlying message from the scientific climate change community and other concerned individuals and organizations is that society needs to act now and with good judgment. But how do people know which actions to take? What activities will have the

¹ Pre-industrial levels refer to average global temperatures before the Industrial Revolution, which occurred from 1750 to 1850.

most impact? What approaches to adaptation and mitigation are most equitable? What roles should science and scientists play in responding to the threats of global warming?

While climate-related mitigation and adaptation activities and research have the potential to generate positive societal and environmental change, outcomes can also cause harm or create new risks. Some activities, for example, have been shown to be maladaptive (Barnett and O'Neill 2010), by increasing greenhouse gas emissions (Farbotko and Waitt 2011); intensifying vulnerabilities and risks faced in other communities (van Voorst and Hellman 2015); generating high economic, social, and environmental costs (Work et al. 2018); and limiting people's abilities to adapt in the future (Christian-Smith et al. 2015). There is an urgent need to develop monitoring and evaluation processes to help guide emerging climate initiatives and climate research practices. The fundamental objective of my dissertation is to address these issues by investigating the outcomes and impacts of climate science and climate adaptation initiatives. Using theoretical frameworks and methodological tools from the fields of political ecology, science and technology studies, and evaluation theory, I examine the factors that constitute effective climate change adaptation activities and research practices.

In this chapter, I review the literature in which my dissertation is grounded. Included in this discussion are several theoretical concepts and methodologies that form the foundation of my research (see Figure 1). First, I provide brief overviews of political ecology, science and technology studies, and evaluation theory. I also discuss scholarship that addresses the nexus of these three fields. In addition, I discuss the field of climate change adaptation and climate-related research as it relates to themes from these three

bodies of literature. Then, I introduce three research articles that comprise my dissertation and connect them to these bodies of literature.

Literature Review

Anthropogenic climate change is inherently intertwined with science (Demeritt 2015). The industrial revolution and subsequent technological advances based on new scientific discoveries increased the amounts of greenhouse gases emitted into the atmosphere. Scientific instruments were necessary to first detect, then to monitor and project changes in global temperatures. Society relied on scientists to explain the basic physical science of climate change. Management of climate-related risks and mitigation of emissions often depends on newly developed technologies, such as engineered systems that absorb or transform carbon dioxide, enhanced infrastructure that will help people adjust to changing environmental conditions, or new genetic materials to help agricultural crops survive extreme heat, drought, and frosts.

Of course, science is not the only influential player in terms of causation, understanding, and dealing with climate change. For example, in terms of causation, political economic factors like trade agreements and global capitalism have played equally important roles (Clark and York 2005). In terms of understanding, narratives and stories help people make sense of global warming including its causes and associated risks (Jones and Song 2014). People's perceptions of and knowledge of local climate conditions have also proved to be valuable for monitoring environmental change (Alessa et al. 2016). In terms of solutions, individual and institutional relationships and social

contracts are necessary components of coping, adaptation, and mitigation strategies (O'Brien et al. 2009)

In these regards, climate change encapsulates Ulrich Beck's concepts of reflexive modernization (1994) and risk society (1992). For Beck, the by-products of technological and industrial progress involve the creation of new types of hazards and societal risks. In his book, *Risk Society: Towards a New Modernity* (1992), he discusses how new hazards like smog pollution and nuclear fallout cannot be contained by space or time; they are global in geographic scale, impact future generations, and cannot be accurately predicted. Management of these new types of risk is complicated. Negative impacts tend to be layered, cumulative, and inequitably distributed across different populations, which means that accountability for these impacts is not easily attributable to a particular source. Risk is embedded in complex amalgamations of environment, politics, culture, and economics and are tied to individual actions and choices, as well as laws, regulations, and enacted and enforced by organizations and government agencies. Consequently, there are no easy solutions for managing the dangers of a continuously evolving risk society. Furthermore, the scientific and technological solutions generated to combat new societal dangers and environmental threats are designed, regulated, and funded by individuals, institutions, companies, and governmental bodies that are rooted in the economic and political structures of modernity that produced these dangers and threats.

The roles that science and scientists play in creating, defining, and solving complex problems like climate change must therefore be examined. Theoretical concepts at the intersection between the fields of political ecology and science and technology studies further illuminate this need. Political ecology is multidisciplinary with roots in

human geography; it broadly focuses on how social, political, and economic factors impact environmental issues, and in turn how the environment shapes society, politics, and economics. Science and technology studies stems from multiple disciplines including sociology, philosophy, and history; it focuses on how society influences scientific research and technological innovation and, in turn, how science and technology influence society. The intersection of these two fields interrogates the politics of environmental science and the ways in which knowledge is produced, circulated, and applied to societal and environmental issues (Goldman and Turner 2011). Evaluation theory provides a grounded approach to systematically investigate the social and political dynamics of knowledge production, distribution, and application. I apply these three bodies of literature to climate change adaptation and socially-engaged climate research (Figure 1).

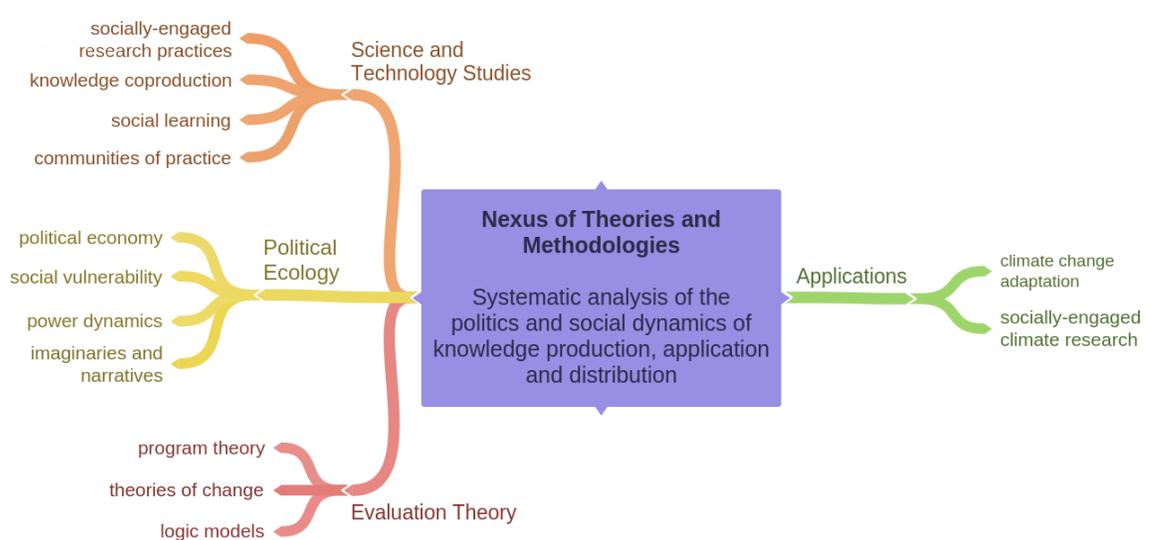


Figure 1. Diagram showing how theories and methodologies from political ecology, science and technology studies, and evaluation are used to frame my dissertation, how they connect to one another, and how they apply to climate change adaptation and socially-engaged climate research.

Political Ecology

Political ecology seeks to reveal the underlying social, political, economic, and ecological factors that produce environmental issues. Analytic tools within this field, such as environmental narratives,² discourse analysis,³ and assemblage theory,⁴ help contextualize and uncover relationships between humans, non-humans, and the physical environment. Central themes include explicit investigations of political-economic processes that 1) regulate and facilitate people's access to, decisions about, and use of natural resources; and 2) influence environmental change and how this change is portrayed, visually represented, and understood.

The field of political ecology grew out of Marxist and structuralist critiques of 1960s cultural ecology, agrarian political economy, and risk and natural hazards research (Watts 2015). Critique of risk and hazard management converged on research traditions developed by three U.S. human-environment scholars, namely Ian Burton, Robert Kates, and Gilbert White. Approaches to risk reduction within this school of thought focused on understanding the physical attributes of hazards themselves, such as severity, intensity, and frequency of extreme events and people's exposure to these hazards. Solutions to reducing exposure focused on a series of "purposive adjustments" (Burton et al. 1978)

² Environmental narratives are used to examine social and biophysical processes that shape human-environment dynamics. Narrative analysis helps reveal the politics, culture, and other forces that influence these dynamics (Cronon 1992).

³ Discourse analysis helps researchers understand "the ways in which knowledge is formulated and validated by society as truth" (Dittmer 2010: 275). Discourse analysis is important for political ecology and social justice work because it helps unpack dominant narratives and meanings about the environment, resources, and social interactions.

⁴ Assemblage theory decenters the human and incorporates non-human actors and things that can hold positions of power, in terms of their relationships to other things and actors (Deleuze and Guattari 1987; DeLanda 2006). This theory uses an analytical framework that gives agency to nonhumans as a way to understand how multiple entities act upon and toward one another.

that would “rearrange or manipulate nature...and involve a rearrangement or alteration of human behavior” (Burton et al. 1968: 11). Some of these adaptations to risk included improving technologies to help manage nature and reduce exposure to hazards, such as flood-control dams, irrigation for arid-land agriculture, snow removal, and improved weather forecasting (Burton et al. 1968).

Solutions that sought to change or influence human behavior were based on the notion that the environmental disasters often result from human decisions. For example, White (1945) outlined how damages and destruction from flooding resulted from poor planning choices like building homes within a floodplain. Therefore, he concluded that scientifically informed planning and decisions could help people avoid future flood risk. This approach opened up a new realm of human-environment research, one that continues to influence contemporary thinking regarding environmental management and planning. Critics such as Michael Watts (1983a; 1983b) and Eric Waddell (1977), however, argued that these technological and behavioral approaches to environmental management and risk ignored the underlying social, political, and economic drivers that create environmental risk in the first place and influence the types of options available to people.

In the 1970s, political ecology scholars began questioning the ‘naturalness’ of natural disasters (e.g., O’Keefe et al. 1976) and worked to reveal the political, economic, and social factors that created conditions of precarity and vulnerability. Watts (1983a), for example, demonstrated how colonial development and the introduction of capital in Northern Nigeria in the early 1900s changed the economy, terms of production and subsistence, and adaptive structures that local communities had created to deal with the

harsh realities of living in an arid landscape. While people had experienced extreme drought and famine in the pre-colonial era, it became more difficult to cope with drought and food shortage under colonial and capitalist modes of production, which Watts argued were maladapted to the desert climate. “From a political-economic perspective,” he wrote, “...an environmental crisis not only probes the darkest corners of environmental relations but throws into sharp relief the organization and structure of social systems at large” (Watts 1983a: 352).

Other early political ecology work focused on land degradation issues in non-Western and rural parts of the world and called attention to the construction of scientific models and representations of these issues (e.g., Blaikie 1985; Blaikie and Brookfield 1987). As the field evolved, researchers expanded the scope of their research to explore: 1) relationships between environmental degradation and marginalized populations; 2) outcomes of conservation and ecological control; 3) conflicts that arise from people’s exclusion or access to natural resources; 4) emergence and development of political identities as connected to environmental issues; and 5) physical characteristics of the environment and their influence on political, economic, and social systems (Robbins 2012).

Key theoretical frameworks, concepts, and methodologies from political ecology influenced the underlying themes of my dissertation research. First, frameworks regarding the production of environmental risk influenced my thinking about the relationships between adaptation and social vulnerability to climate change and climate variability. Rather than investigating only the biophysical climate-risks, political ecology brings attention to the social, political, and economic factors that actively produce

vulnerability (Dooling and Simon 2012). In Appendix A, for example, I refer to O'Brien and Leichenko's (2010) term "double exposure." In the context of climate change, this term explains how people are simultaneously exposed to physical risks such as the impacts of extreme weather events and to risks created by socioeconomic and political interests such as international trade policies and funding decisions. Adaptation initiatives may not effectively reduce vulnerability if they solely focus on addressing exposure to risk—the symptoms of vulnerability—without also addressing the underlying systemic issues—the root causes of vulnerability (Bankoff et al. 2004; Dooling and Simon 2012).

A second and related influence from political ecology includes themes regarding environmental justice, which "as a tradition of analysis involves documenting cases of environmental racism or injustice and demonstrating...that the exposure risks are significant and unquestionably associated with historically disenfranchised groups" (Robbins 2012: 74). Within this tradition of analysis, Tschakert (2012) identifies political ecology's strength as "its capacity to persist in the contestation of inequalities, marginalization, and injustices in access to and control over resources, neoliberal politics of environmental change, and dominant environmental narratives" (147). Justice can be defined as distributive, which seeks equitable distribution of natural resources or environmental risks (see Rawls 1971), and as procedural, which seeks equitable representation and participation in the political and social processes surrounding environmental issues (see Sen 2009). Forsyth (2014) argues that the notion of justice should also be applied to how environmental risks and solutions are defined or perceived and by whom. In Appendix A, I search for evidence of both distributive and procedural justice in climate change adaptation activities. Specifically, I investigate how researchers

address or fail to address the inclusion of diverse types of knowledge and expertise, fair distribution of adaptation benefits, and imbalanced power relationships within adaptation processes.

A third influence from political ecology draws from making sense of the “politics of knowledge” (Watts and Peet 2004: 23). The analytical tools of political ecology reveal the existence of numerous ontologies (understandings of what the world is) and epistemologies (how people understand the world). These revelations, as Dittmer (2010) claims, signal the need to examine “the ways in which knowledge is formulated and validated by society as truth” (275). For example, Western scientific knowledge is upheld as an objective, logical, and rational way to understand the social and natural world. This privilege is often used to reduce other ways people make sense of the world “as nonscientific, tradition-bound, overly risk-adverse, and shaped by superstition or simply biased” (Goldman and Turner 2011: 9). “Social power that shapes on-the-ground impacts,” continue Goldman and Turner, “operates in the realms of knowledge production and circulation as well (often far from the place of application). Therefore, to fully analyze environmental politics, political ecologists need to not see divergent knowledge claims as the starting point for politics but instead seek to understand how these knowledge claims are constructed” (10). To do so, several political ecology scholars have looked to the field of science and technology studies to understand the ways that knowledge is produced and to uncover the unbalanced power dynamics between standard scientific knowledge and other types of knowledges (e.g., Brosius et al. 1998; Nadasdy 1999; Sundberg 2003).

Finally, a fourth influence is methodological—the use of discourse, narratives, and imaginaries to understand how environmental issues are perceived, studied, and represented. As Feindt and Oels (2005) argue, “the articulation of an environmental problem shapes if and how the problem is dealt with” (162). Peet and Watts (1996) introduce the concept of “environmental imaginaries” (37), which Forsyth (2004) describes as “the frameworks through which different individuals or societies perceive and evaluate aspects of environmental change” (37). Discourse and narrative analysis cast light on these typically implicit framings, which can lead to greater understanding about how environmental issues are identified and potentially solved. In Appendix C, I co-construct narratives with scientists in a climate research program to understand how they connect their research activities to societal change. I use the notion of imaginaries to draw attention to how researchers envision or imagine a climate-resilient future world and to explain how researchers envision contributing to that climate-resilient world.

Science and technology studies

The interdisciplinary field of science and technology studies arose at a similar point in time as political ecology. In the 1970s and 1980s, researchers from academic disciplines such as sociology, economics, history, and philosophy began to develop theories about the relationships between science, technology, and society. The basis of this body of literature rests on the theory that science and society are mutually constitutive. Knowledge is inextricable from the social practices involved in conducting science as well as the societal structures that allow science production to occur. In turn, society is molded and constructed by scientific practices and technological innovation.

Scholars argued against the notion that science could put forward fully objective truths about the world (Rohracher 2015). Early work focused on the impacts that contemporary societal interests had on scientific knowledge claims and how scientific data had been historically legitimized, substantiated, or rejected based on political and cultural norms (e.g., MacKenzie 1978; Mulkay 1979). Other scholars used the scientific laboratory as a site of analysis to demonstrate how scientific knowledge meant to inform global issues emanated from localized practices and knowledge cultures (e.g., Latour and Woolgar 1979; Lynch 1982).

In the 1980s, science and technology scholars expanded their studies to investigate the dialectic between technological innovation and societal development and progress. Bruno Latour (1988), largely based on his work regarding Louis Pasteur's quest to make an anthrax vaccine, introduced actor-network theory to describe the relationships and power dynamics that emerged between humans, nonhumans, material things, and ideas in the production of scientific knowledge. In actor-network theory, knowledge is understood as "produced by local and global actors through the acts of inscribing scientific facts and practices" (Phadke 2011: 246), in which the actors play multiple roles and include humans and nonhumans.

The role of scientists in knowledge production was further developed with the introduction of feminist theory to science and technology studies. Standpoint theory, as conceptualized by Sandra Harding (1986), illuminated how the experiences and viewpoints of non-male scientists were underrepresented in a cis-male-dominated field. "The feminist standpoint," explains Thompson (2015), "stressed the relevance of the social positioning of the knower to the content of what is known" (1). Donna Haraway

(1991) built on these ideas to develop the concept of situated knowledges, in which scientific knowledge production is viewed as an embodied and socially constructed practice. This ontological shift further disrupted the taken-for-granted objectivity of Western science and scientific expertise and promoted the incorporation of other types of knowledge and ways of understanding the world. Situated knowledges typically reject traditional binary typologies that structure ways of being, such as human/nonhuman, nature/society, technological/natural, and virtual/real (Whatmore 2002; Wilson 2009), and privilege “hybrid” (Haraway 1991) ontologies and epistemologies as more accurate approaches to being in, understanding, and representing the world.

In the United States (U.S.), the conceptualization of how science brings about innovation and social change can be traced back to the post World War II era when the first clear articulation of non-war federal science policy was put forward by Vannevar Bush (Guston et al. 2001; Castree 2016). The vision that Bush formulated in a report to President Truman—*Science, the Endless Frontier* (1945)—emphasized the need for government support for science to continue during post-war times. Research and technology, he believed, would spur innovations in health, agriculture, national security, and other forms of public welfare. But Bush also emphasized that the “freedom of inquiry must be preserved. As long as universities are vigorous and healthy and their scientists are free to pursue the truth wherever it may lead, there will be a flow of new scientific knowledge to those who can apply it to practical problems in Government, in industry, or elsewhere” (1945). This linear view of science assumed that scientists would develop a repository of new information to ultimately advance societal goals; however, it did not articulate the mechanisms to ensure that the “flow” of knowledge from science to society

would occur. Among the reasons for this separation, or boundary, between science and its application, was the concern that science shaped in close proximity to politics would become captive to political interests (Guston et al. 2000).

Science and technology studies opened new avenues for breaking through these boundaries and exploring more inclusive forms of knowledge production. In the 1990s, several scholars began to formulate theories about integrating science with other knowledge systems through public engagement. Researchers believed that integrated scientific practices would not only produce more accurate data and information, but that this data could also be used to solve complex societal and environmental issues like climate change and environmental risk (Demeritt 2015). These scholars, some directly and some indirectly tied to the field of science and technology studies, began to develop new knowledge production theories and practices. Silvio Funtowicz and Jerome Ravetz (1993), for example, argued that the complexities involved in emergent environmental and societal issues called for new methods of inquiry, or a post-normal science, in which “facts are uncertain, values in dispute, stakes high and decisions urgent” (744). Post-normal science was developed as an alternative to traditional or basic forms of research and aimed to legitimize multiple forms of knowledge beyond those produced through standard academic systems. A similar framework was called Mode 2 science, conceptualized by Gibbons et al. (1994) and further developed by Nowotny et al. (2001), which called for increased diversity in the types of knowledge production. Gibbons et al. (1994) distinguished this form of knowledge from Mode 1 science, which they described as basic research that relied on expert knowledge housed within academic disciplines. Mode 2 science was characterized by transdisciplinary research models that aimed to

integrate knowledges produced across multiple academic disciplines with other types of knowledges, specifically those produced outside of academic settings.

Scholars continued to develop concepts that grew from these combinations of theories about knowledge production. In the mid-to-late 1990s, Sheila Jasanoff and Brian Wynne (1998) conceptualized the process of knowledge coproduction as the mutually constituted nature of scientific and technological development with social, cultural, political, and economic influences, or “the simultaneous production of knowledge and social order” (Jasanoff 1996: 393). Boundary organizations, as defined by David Guston et al. (2000), were sites that enabled and facilitated intentional knowledge coproduction across the boundaries between the realms of science, policy, and society. Through the generation of boundary objects, scientific, political, and societal networks could produce common sets or “standardized packages” (Fujimara 1988) of products, processes, theories, methods, and tools (Guston et al. 2000). Social learning systems, a framework first put forward by Étienne Wenger in 1998, drew upon similar concepts. Social learning systems, Wenger argued, aimed to build people’s capacity to identify and respond to complex problems through social engagement and shared knowledge. Learning occurred within emergent communities of practice that organized around collectively identified problems, interests, and skills (Wenger 1998; Wenger 2000; Pahl-Wostl 2004). Membership connected people and organizations across multiple boundaries such as geographic location, academic discipline, and type of expertise. The “process of learning,” as Gerlak and Heikkila (2011) explain, “can be understood as a set of actions that allow new information or knowledge to be acquired, processed and shared, and transferred across individuals within a group” (621). Through the creation of shared

artifacts, language, customs, and visions for the future, people within communities of practice could innovate and implement solutions for common societal and environmental issues.

Knowledge production requires various dimensions of social interaction (e.g., McMullin 1992; Longino 2002). Research about the social production of science has been used to develop theories and methods for socially-engaged research practices to generate “use-inspired” (Stokes 1997) knowledge that is useful-for and usable-by society to confront complex problems. However, if scientists want their research to inform social problems, it is important that research processes incorporate multiple types of expertise and knowledge. This process requires building social and institutional relationships over time, establishing trust and credibility, developing avenues for ongoing communication, and integrating these interactions into research and practice (Lemos and Morehouse 2005; Gerlak and Heikkila 2011).

A growing body of literature describes several avenues to achieve usable science (e.g., Dilling and Lemos 2011), actionable science (e.g., Beier et al. 2017), or usable knowledge (e.g., Clark et al. 2016). These types of participatory research involve collaborations between scientists and key public participants or stakeholders. Together, collaborators identify a problem, define research questions, design the project, conduct the study, and apply research findings (Van de Ven 2007). Serrao-Neumann and Coudrain (2018) write that socially-engaged research approaches call attention to underlying power relations within knowledge production that uphold certain forms of expertise as more legitimate and relevant than others. Pahl-Wostl et al. (2007) argue that collaborative research can destabilize these power relationships. Within a well-

functioning socially-engaged research initiative, academic knowledge should not hold a higher position of power or value. While formal disciplinary knowledge, training, and expertise are valuable, their decentralization serves to prioritize and promote other types of expertise and ways of knowing.

In Appendices B and C, I draw from concepts and frameworks in science and technology studies to analyze a socially-engaged climate research program. This research program was founded upon theories of transdisciplinarity and knowledge coproduction between university-based scientists and non-academic partners and stakeholders. These theories emphasize the importance of social connections built between individuals and institutions. Gibbons et al. (1994) argue that knowledge production “is above all embodied in people and the ways they are interacting in socially organized forms” (17). Organizations in the field of transdisciplinary research and services must develop and maintain relationships that are grounded in trust and accountability. Specifically, I use theoretical frameworks regarding social learning systems and communities of practice to emphasize the importance of these relationships and to understand the roles that this research program plays within the learning system.

Evaluation theory and methodologies

Evaluation is an active and diverse field of research with multiple real-world applications. In its simplest form evaluation involves the purposeful assessment of the value, worth, and merit of an activity, product, program, system, or process. People often use evaluation findings to make decisions about the item being evaluated, such as how to improve a product, design a program, or whether to continue funding a project. Three

distinct, but often interrelated, types of evaluation exist: developmental, formative, and summative. Developmental evaluation focuses on testing and refining the initial designs of something; formative evaluation focuses on improvement by learning about a process and implementing lessons learned; summative evaluation focuses on measuring outcomes, indicating progress, and showing accountability (Preskill and Russ-Eft 2005). While there are many fields of evaluation theory and practice, I focus here on the development of program theory.

In the U.S., early evaluation practices sprang from the need to assess federal social programs in health, education, and housing that were initiated under the Kennedy and Johnson administrations. As federal spending for these programs grew in the 1960s and 1970s, government agencies were called upon to show the impact their programs had on improving social issues regarding poverty, homelessness, literacy, and physical and mental health (Shadish and Luellen 2005). The professional field of evaluation evolved to meet these needs; theories and methods drew from several disciplines in the social sciences, including anthropology, psychology, and education. Over time, the theory and practice of evaluation has expanded to assess several types of programs, including those associated with international development, environmental and agricultural management, and scientific research.

One approach to evaluation design is called theory-based program evaluation, which revolves around a clearly articulated theory that describes how program activities lead to particular outcomes. This theory of change (Funnell and Rogers 2011) or impact model (Bamberger et al. 2012) outlines a narrative logic for how a program operates. Often these theories of change are worked into logic models that link activities and

outputs to outcomes and broader impacts. Specific indicators are developed that are monitored over time to test if and how outcomes and impacts are achieved. The definitions and values for inputs, outputs, outcomes, and impacts are variable and relative to different institutional and social contexts (Funnell and Rogers 2011: 297). Another important component of the logic model involves explicitly identifying any underlying assumptions about how outcomes will be achieved. Finally, potential or existing external factors that could influence outcomes are described.

Evaluation theory and methodologies provide an underlying theme of my dissertation. In Appendix A, I investigate how researchers currently use of evaluation in understand the effectiveness of climate adaptation activities. Appendices B and C draw from my research design that is grounded in theory-based program evaluation and rely on theories of change and logic models for data collection and analysis. I use theory-based evaluation as outlined by Funnell and Rogers (2011). When I was designing this research in 2011 and 2012, their comprehensive descriptions of the evaluation process, design, and methods for data collection and analysis seemed to best fit the objectives of the program I was evaluating. I compare anticipated project outcomes to outcomes that were achieved over the course of the evaluation. To categorize project outcomes, I use a conceptual typology adapted from Meagher and Martin (2017) and Meagher and Lyall (2013). These outcome categories include: *capacity building*—developing networks or providing the information necessary to engage in a particular activity; *instrumental*—direct influence or use in policy, practice, or decision-making; *conceptual*—changes in thinking, raising awareness, or improving understanding; *enduring connectivity*—relationships lasting

beyond a particular project or activity; and *attitudinal or cultural shifts*—changes in attitudes toward engaging in collaborative activities or knowledge exchange.

Nexus of political ecology, science and technology studies, and evaluation theory

The combination of political ecology and science and technology frameworks cultivate a better understanding about how the “politics of knowledge” influence the “production, application, and circulation of environmental knowledge” (Goldman and Turner 2011: 2). Production entails examination of research funding, research questions and methodologies, and evaluation to understand research impact. Application involves the use of scientific data and technology in environmental management, economic and environmental policy-making, and increased awareness about societal and environmental issues. Circulation encompasses the ways in which knowledge is communicated, to whom, by whom, through what media, and for what purposes. While the processes of production, application, and circulation of environmental knowledge can be examined independently, they are thoroughly contingent upon and constituted by one another.

The fields of political ecology and science and technology studies overlap in multiple ways. Scholars in both fields present challenges to the objectivity and epistemic privilege of scientific knowledge. Both call attention to the embodied processes of science production by investigating the situated knowledges of scientific researchers. The analytical tools of political ecology and science and technology studies call into question researchers’ own privileges and power in knowledge creation, application, and dissemination, as well as the systems that support and produce unevenly distributed power and privilege. Researchers in both fields identify the advantages of public

participation and involvement of diverse types of expertise in the process of knowledge production. Furthermore, both fields are based on the social construction of scientific knowledge—without diving so deep into relativism that the scientific process becomes irrelevant (Demeritt 1996). The value and usefulness of physical, natural, and social scientific research is typically maintained.

Part of the problem with Western science, explains Tim Forsyth (2011), “lies with the assumptions inherent within positivism” (33) or the creation of “‘positive’ or confident predictions about the world based upon trends inferred from smaller samples of the world” (32). Furthermore, Forsyth argues, these generalizable or universal predictions are frequently inaccurate, do not account for the root causes of environmental problems, and promote solutions that have unintended negative outcomes (34). Consideration of the implicit values and assumptions that guide scientific research practices may be useful in developing more effective approaches to dealing with environmental risk and global environmental changes.

In order to understand the role of the researcher in the ethics and politics of scientific knowledge creation, application, and circulation, Juanita Sundberg (2015) draws on Gayatri Spivak’s notion of “homework” (1990) through her suggestion that researchers analyze their own ontological and epistemological viewpoints. While Sundberg offers valuable self-reflexive questions to help researchers do this homework, the field of evaluation offers rigorous methodological tools to help systematically uncover these underlying ontological and epistemological assumptions that guide socially-engaged research. The process of building a logic model narrative asks scientists to clarify their research objectives and explain how they will accomplish them, why they

want to accomplish them, and how they think accomplishing them will contribute to solving societal issues. This process helps illuminate researchers' underlying assumptions about the value, usefulness, and impact of their work, which can then be tested through evaluation. Researchers can apply what they learn through the evaluation process to improve and refine future research endeavors.

Applications to climate change adaptation

Climate change is expected to have significant impacts on social and environmental systems around the world, such as drought, flood, sea level rise, and floods (IPCC 2014). In many places, climate change impacts are already being experienced. Adaptation to the impacts of climate change is comprised of multiple and interrelated definitions, concepts, and objectives (Smit and Wandel 2006). Three main objectives for adaptation are increasing resilience, reducing vulnerability, and enhancing adaptive capacity. Resilience deals with the ability of a social or ecological system to recover from shock and stress (Nelson et al 2010). Vulnerability is the susceptibility to harm when exposed to an external hazard (Yamin et al. 2005). Adaptive capacity refers to the potential to respond to changing stresses and shocks to manage or reduce risk (Engle 2011). The differences between these terms are nuanced as the objectives themselves are typically interrelated. The IPCC (2014), for example, refers to adaptive capacity as one piece of vulnerability, in combination with exposure and sensitivity.

The overlapping social, political, and economic realms of climate change adaptation are complex. There are many different types of actors (e.g., researchers, policy-makers, government officials, community members), organizations (e.g., The

United Nations Framework Convention on Climate Change (UNFCCC), World Bank, Oxfam, USAID), adaptation and mitigation funding programs (e.g., the Adaptation Fund, the World Bank's Climate Investment Funds, the UNFCCC's Global Environmental Facility), and national action plans (e.g., National Adaptation Programmes of Action (NAPAs)). Millions of dollars have been distributed for adaptation projects to the world's 'least developed countries' whose residents are deemed as the most vulnerable to climate change. Multiple nations have vested interests in climate adaptation and mitigation policies, and increasing numbers of "non-nation-state-actors," described as "all actors operating at local, regional, national, and international levels that are not nation-states" (Okereke et al. 2009: 58) are gaining relevance and influence in global climate politics. Emerging debates about power, policy, justice, and equity have drawn much attention in current debates within political ecology and geography (Bäckstrand 2008; Newell 2008; Okereke 2008; Bickerstaff and Agyeman 2009; Bulkeley et al. 2012). The governance of adaptation initiatives and funding processes is situated at a critical juncture that combines varying spatial scales of interaction with competing interests in resources, in a global context that is plagued by injustice, inequality, and marginalization.

In theory, adaptation initiatives hold the potential to improve social, economic, political, and environmental systems. However, in practice, evidence suggests that these adaptation responses do not often work as intended. Barriers impede adaptation efforts, such as inadequate funding, policies that do not support adaptation, competing resource needs, and lack of certainty about the future (Moser and Ekstrom 2010; Biesbroek et al. 2013). Critical analyses of adaptation projects draw attention to the failures and negative consequences of adaptation (Barnett and O'Neill 2010; Eriksen et al. 2011; Christian-

Smith et al. 2015; Lonsdale et al. 2015); the burdens of adaptation that fall on some populations and not others (Fankhauser and McDermott 2014; Shi et al. 2016); and the inequalities in distribution regarding climate risk and adaptation benefits (Bohle et al. 1994; Ribot et al. 1996; Füssel 2007). Adaptation initiatives are often under-developed (Preston et al. 2011), produce unintended consequences (Dooling and Simon 2012), or are planned but rarely implemented (Bierbaum et al. 2013; Mimura et al. 2014). Most plans opt towards low-risk strategies toward capacity building and information sharing (Preston et al. 2011) or propose incremental changes to activities that are already happening (Kates et al. 2012).

Social vulnerability is a central theme in climate change adaptation and has been the topic of much debate in scholarly literature. Many definitions of vulnerability exist (Dow 1992; Janssen et al. 2006; Füssel 2007; O'Brien et al. 2007). Neil Adger (2006) calls vulnerability “a powerful analytic tool for describing states of susceptibility to harm, powerlessness, and marginality of both physical and social systems, and for guiding normative analysis of actions to enhance well-being through reduction of risk” (268). Vulnerability can be understood as both biophysical and socioeconomic exposure to risk (e.g., Fussel 2007). It is important to note that vulnerability is not a static condition. As Bohle et al. (1994) describe it, vulnerability is “a multi-layered and multidimensional social space defined by the determinate political, economic and institutional capabilities of people in specific places at specific times” (39). Furthermore, Dooling and Simon (2012) argue that the conditions of exposure to risk are actively created by past and current political, economic, environmental, and social processes.

Multiple techniques exist to assess social vulnerability, but several scholars note the difficulty in adequately monitoring and documenting its nuanced and shifting nature (Liverman 1990; Luers et al. 2003; Turner et al. 2003). The most successful vulnerability assessments, according to Eakin and Luers (2006), tend to be locally specific and participatory. The use of vulnerability assessments in adaptation governance and funding can reinforce structural inequality (Okereke et al. 2009; Clark 2010; Farbotko 2010). Gregory Bankoff (2004), for example, argues that the act of documenting and labeling a group of people as vulnerable can strengthen existing power dynamics between those who are deemed vulnerable and those who are not.

Critical geography perspectives have helped advance scientific understandings of the human dimensions of climate change. Diana Liverman (2015) reviews how political ecologists such as Hallie Eakin, Karen O'Brien, Robin Leichenko, and Jesse Ribot have been instrumental in connecting climate vulnerability to global political economic processes. O'Brien and Leichenko (2000), for example, use the concept of double exposure to explain how the simultaneous experiences of vulnerability to climate change and vulnerability to economic globalization creates complex and interwoven layers of risk. Other political ecologists, like Bäckstrand and Lövbrand (2006) analyze dominant narratives used in policy-making, management, and governance of climate change, with the aim of uncovering conflicting claims to knowledge and power dynamics that underpin these narratives. "Policies," they argue, "are not neutral tools but rather a product of discursive struggles. Accordingly, policy discourses favor certain descriptions of reality, empower certain actors while marginalizing others" (52). Bumpus and Liverman (2008) analyze the costs and benefits of climate policies and practices associated with carbon

offsets and trading and argue that there are competing ways to view and understand the impact of a flourishing carbon market. This approach to controlling carbon emissions provides economic incentives for reducing the amount of pollution released into the atmosphere. Some policy-makers and governments view carbon trading as a ‘win-win’ solution. Others view carbon trading as a ‘loophole’ through which countries or corporations can avoid reducing their actual production and emission of carbon. In all cases, the costs and benefits of practices and policies associated with climate adaptation and mitigation projects are not distributed equally.

Adaptation researchers and practitioners have spent a considerable amount of time deliberating how to develop climate change adaptation plans, enhance the resilience of cities and systems, improve people’s capacity to adapt, and understand local and regional implications climate change (National Research Council 2010; Bierbaum et al. 2013; Mimura et al. 2014; USGCRP 2018). While several strategies, activities, funds, and policies for adaptation have been developed, very few of these have been evaluated for their effectiveness or ineffectiveness. The adaptation community has identified the need to evaluate these initiatives (Moser and Ekstrom 2010; Lonsdale et al. 2015; Christensen et al. 2018). Not only can this knowledge be used to make future adaptation plans, strategies, and actions more effective, but it could also help reduce the amount of negative consequences and adaptation failures.

Over the last few years, a growing number of researchers and practitioners have begun to evaluate adaptation initiatives. Several frameworks and methods for assessing adaptation have been developed (e.g., de Franca Doria 2009; Moser and Ekstrom 2010; Eriksen et al. 2011; Sanahuja 2011; Spearman and McGray 2011; Bours et al. 2013;

Moser and Boykoff 2013; Vogel et al. 2016; Christensen et al. 2018). Few of these frameworks, however, contain concrete ways to derive standardized metrics or indicators to compare outcomes across multiple adaptation projects (Christensen and Martinez 2018). As the IPCC notes, determining the right metrics and indicators to monitor progress across adaptation initiatives is not straightforward, in part because different people and agencies have substantially different uses for evaluation (2014; deConinck et al. 2018). Project funders often desire more summative, or outcome focused, evaluations to aid in future funding decisions. Global funding organizations, like the UNFCCC, support the development of standardized metrics to compare outcomes across projects worldwide (Möhner 2018). Other organizations or communities want to use evaluation to inform learning and project development (Ford et al. 2013). Multiple frameworks, indicators, and metrics may be necessary to capture the variety of uses for this information (Bierbaum et al. 2013).

A growing number of researchers have also begun to evaluate the impact of climate-related research and climate services.⁵ Scholars have described and tested evaluation frameworks and methodologies to measure progress in use-inspired (e.g., McNie 2008; Ferguson et al. 2016) and transdisciplinary (e.g., Roux et al. 2010; Belcher et al. 2016) climate research programs, and programs that engage in knowledge co-production (e.g., Fazey et al. 2014; Wall et al. 2016). Socially-engaged and participatory approaches have the potential to improve societal and environmental issues, and arguably more so than traditional models of science (Kates et al. 2001; Nowotny et al. 2001; Cash

⁵ Climate services are climate data and information products designed to support decision-making and planning (Hewitt et al. 2012).

et al. 2003; Lemos and Morehouse 2005; Pahl-Wostl et al. 2007). However, it is unclear specifically if and how collaborative knowledge production results in societal improvement (Zscheischler et al. 2018). Lemos et al. (2012) point to the “persistent gap between knowledge production and use” (789). Although climate science has quickly progressed, its application in planning and decision making has not developed as fast (Miles et al. 2006). Likewise, Lang et al. (2012) note that scientists’ expectations of the outcomes of collaborative research are often much greater than what occurs in reality. There is an urgent need to monitor and analyze how socially-engaged climate research and information improve adaptive capacity, reduce vulnerability, and increase resilience in response to the societal and environmental threats associated with climate change.

Introduction to my dissertation research

My dissertation research uses theories, concepts, and methods from political ecology, science and technology studies, and evaluation to investigate the outcomes and effectiveness of 1) climate change adaptation practices around the world and 2) socially-engaged research theories and practices in the U.S. Southwest. My dissertation is comprised of three articles that contribute these bodies of literature. As a whole, my work explores the progress made towards adapting to climate change, as well as the continuing and emergent challenges involved in adaptation processes. My overarching research questions are:

- ***What are the outcomes and impacts of climate change adaptation and socially-engaged climate research?***

- *What approaches constitute successful adaptation and research practices?
What does it mean to be successful?*
- *How is knowledge produced and mobilized for use in addressing complex societal and environmental issues?*

In the following section I provide further context for each article.

Appendix A: What makes climate change adaptation effective? A systematic literature review

This paper asks the following research questions:

- What types of activities constitute effective climate change adaptation initiatives that have been implemented and assessed?
- How is effectiveness of climate change adaptation initiatives measured or indicated?
- How do researchers address key components of adaptation effectiveness such as justice and fair distribution of benefits?
- How can the practice of evaluation for climate change adaptation be improved?

Concern about the impacts of climate change has grown significantly since the early 2000s. In response, adaptation initiatives that span a wide variety of activities, policies, concepts, and platforms have been launched. Multilateral funding agreements, such as the Adaptation Fund and the Green Climate Fund sponsored by the UNFCCC, have increased funding for climate adaptation research. Several adaptation initiatives supported by governmental, non-governmental organizations, and local communities

have resulted in improved infrastructure and technology, new policies and environmental management operations, measures to reduce environmental risk and hazards, and increased access to natural resources. Despite the growth in adaptation theory and funding initiatives, there is little consensus on what constitutes effective adaptation practices.

In this paper, I identify and analyze adaptation initiatives that have been implemented around the world with some degree of effectiveness. Through a systematic review of the research literature, I collected 94 articles that described one or more adaptation initiatives that were a) implemented beyond initial planning stages; b) responded to climate change related issues; and c) was at least partially successful. In total, I categorized 110 adaptation initiatives using the Intergovernmental Panel on Climate Change *AR5 Climate Change 2014: Impacts, Adaptation, and Vulnerability Report*.

Climate change adaptation practices are embedded within local environmental, social, and political contexts and are comprised of mixed ontologies, epistemologies, definitions, objectives, and approaches. The literature review provides a useful summary of current adaptation practice. By categorizing and analyzing effective outcomes from adaptation projects in a variety of social, political, and environmental contexts, this study contributes to ongoing dialogues regarding adaptation success and can be used to advise and guide current and future adaptation projects. My analysis offers clarity on what constitutes effective adaptation, identifies emerging research gaps, and suggests ways to establish routine evaluation in practice.

Appendix B: Contextualizing climate science: Applying social learning systems theory to knowledge production, climate services, and use-inspired research

This paper asks the following research questions:

- How are theoretical frameworks that support socially-engaged, transdisciplinary, and use-inspired research applied in practice?
- How have the practices of socially-engaged, transdisciplinary, and use-inspired research influenced the theories about these types of approaches?
- How does evaluation improve socially-engaged, transdisciplinary, and use-inspired research programs?

This paper uses findings from a six-year evaluation of the Climate Assessment for the Southwest (CLIMAS) program. This federally-funded climate research program was founded on the theories of use-inspired and socially-engaged research, knowledge coproduction, and transdisciplinarity. The evaluation revealed gaps in understanding how the CLIMAS program functioned on a theoretical and a practical level; the inclusion of social learning systems theory helps fill this gap. While social learning systems theory has been applied to adaptive and community-based resource management and climate change adaptation projects and programs, it has not been explicitly identified as a guiding framework for conducting socially-engaged climate research.

Scholars in political ecology and science and technology studies call attention to the privileges afforded to Western scientific forms of knowledge production. Socially-engaged forms of research call for the decentering of scientific knowledge and for increased diversity in representation of other types of knowledge. A social learning

systems theoretical framework decenters the CLIMAS program as being central to the adaptation and research initiatives being conducted in the U.S. Southwest. This approach centers communities of practice as the site of knowledge production, in which multiple types of expertise aid in the production, application, and circulation of climate knowledge. Communities of practice encourage the development of inter-personal and inter-organizational relationships through iterative interactions throughout time. For CLIMAS, these interactions include opportunities to share knowledge and resources and to devise strategies to solve regional climate issues. Inclusion of this model demonstrates an evolution of the theory and practice for use-inspired, socially-engaged, and transdisciplinary research. This paper provides an example for climate research and climate service programs that are based in these theories and practices.

Appendix C: Evaluating climate research: Scientists' visions of a climate resilient U.S. Southwest

This paper asks the following research questions:

- How do socially-engaged research practices contribute, or fail to contribute, to environmental and societal change?
- How do the visions that researchers imagine regarding the impact of their work compare and contrast to the outcomes that they actually achieve?
- How does systematic program evaluation improve the practice of socially-engaged research?

This article uses qualitative and quantitative results from the CLIMAS program evaluation described in Appendix B. Many scholars agree that socially-engaged science and participatory research practices are necessary to address complex environmental and societal problems like climate change. However, it is debatable if and how these types of collaborative knowledge production result in tangible, real-world outcomes (Zscheischler et al. 2018). Scientists' expectations for the outcomes of collaborative research, such as societal and environmental change, tend to be more ambitious in theory than in practice (Lang et al. 2012). As Forsyth (2011) points out, "The objectives and basic framings used to underpin scientific research...need to be opened to greater scrutiny" (44). There is a need to demonstrate and evaluate the outcomes of socially-engaged research. The indicators, methods, and approaches for evaluating research impacts are still developing and evolving.

The notion of imaginary, or a framework "through which different individuals or societies perceive and evaluate aspects of...change" (Peet and Watts 1996: 37), is often used by political ecologists and science and technology scholars. In this article, I use Jasanoff's (2015) construction of the socio-technical imaginary as a way to understand CLIMAS researchers' visions for achieving societal and environmental change. I connect the articulation of this vision to evaluation methodologies that involve the articulation of a theory of change or logic model narrative.

I compare researchers' anticipated project outcomes to those that were achieved during the six-year evaluation process. Quantitative and qualitative analyses show several contributions made by CLIMAS researchers toward increasing climate resilience in the U.S. Southwest. Findings were used to improve internal CLIMAS program management

and to improve researchers' approaches to socially-engaged research. This paper describes how theories of change and logic models help make tacit assumptions and research goals explicit. They aim to reveal underlying epistemologies and ontologies—what researchers think about the world, how they think about the world, and how they think the world should be. An extensive body of literature discusses the theoretical components of socially-engaged research and research evaluation. However, only a small—albeit growing—number of empirical examples exist. This paper provides an example for socially-engaged research organizations who are considering conducting program evaluations.

CONCLUSION

This dissertation aims to bring awareness to the impacts and outcomes of current climate change adaptation-related activities and research. My three core papers focus on the evaluation of 1) a breadth of initiatives around the globe that demonstrably improve societal and environmental adaptation to climate change; and 2) the socially-engaged and use-inspired theories and practices of a climate research program in the U.S. Southwest. The first topic is addressed in Appendix A and the second topic is addressed in Appendices B and C.

The overarching message from my dissertation research states: Climate change and its associated impacts demands the world's immediate attention. Human society already has the scientific understanding, technological capacity, and financial means to address climate change and climate variability. But, as a society, we need to continuously question our intentions and reflect upon the outcomes of our actions, to ensure that they are actually providing benefit to the people and systems that need them most. Systematic evaluation can help regulate adaptation and research processes by tracking progress, seeking accountability, and guiding future actions.

In Appendix A, I document findings from a systematic review of research literature on effective adaptation initiatives. I analyze 110 adaptation case studies from literature published between 2007 and 2018. In this paper, I ask:

- What types of activities constitute effective climate change adaptation initiatives that have been implemented and assessed?
- How is effectiveness of these initiatives measured or indicated?

- How do researchers address key components of adaptation effectiveness such as equality and justice?
- How can the practice of evaluation for climate change adaptation be improved?

In Appendices B and C, I draw from a six-year program evaluation that I conducted of the Climate Assessment for the Southwest (CLIMAS), a socially-engaged and use-inspired climate research program. CLIMAS researchers come from a variety of disciplinary backgrounds, across the social and physical sciences and collaborate with diverse, non-academic research partners. Researchers approach the practice of socially-engaged and use-inspired research in multiple ways, however all CLIMAS projects aim to improve regional environmental and societal issues related to climate variability and change. Appendix B outlines an evolution in the underlying theories about how CLIMAS researchers foster and contribute to a climate adaptive and resilient U.S. Southwest region. Appendix C investigates the outcomes and contributions that CLIMAS researchers have made over the past six years, as well as how researchers envision their role in helping the Southwest adapt to climate variability and climate change. In these papers, I ask:

- How are theoretical frameworks that support socially-engaged, transdisciplinary, and use-inspired research applied in practice?
- How have the practices of socially-engaged, transdisciplinary, and use-inspired research influenced the theories about these types of approaches?
- How do socially-engaged research practices contribute, or fail to contribute, to environmental and societal change?

- How do the visions that researchers imagine regarding the impact of their work compare and contrast to the outcomes that they actually achieve?
- How does the systematic application of evaluation methodologies help improve the practice of socially-engaged research?

Summary of findings: Appendix A

In Appendix A, entitled “What makes climate change adaptation effective? A systematic literature review,” I identify 110 adaptation initiatives that have been implemented around the world and show some degree of success. Adaptation to climate change can encompass several kinds of activities and there is little consensus on what counts as effective adaptation in practice. In 2014, the IPCC identified approximately 125 types of adaptation activities that fell under three broad categories: 1) social, 2) institutional, and 3) physical and structural. The act of analyzing recent adaptation initiatives helps draw a current picture of adaptation practices across multiple social, political, and environmental contexts. My analysis offers clarity on what constitutes effective adaptation activities, identifies emerging research needs, and suggests ways to establish routine evaluation to inform adaptation practice.

The activities most frequently represented in my dataset fell into the social adaptation category, which was divided into three subcategories: behavioral, informational, and educational. Of these, behavioral changes such as switching agricultural crops and implementing different practices such as planting and harvesting dates, applications of fertilizer or compost, or conserving soil and water resources occurred often. Gathering systematic monitoring and remote sensing data and developing

decision support tools were frequent informational activities. Educational activities such as knowledge sharing and learning platforms, sharing local and traditional knowledge, and extension services were prevalent.

The category of institutional adaptations was also separated into three subcategories: policies and programs, economic options, and laws and regulations. Policies and programs such as ecosystem-based management, community-based programs, adaptive management, and other resource management approaches were common in my dataset. In terms of economic options, issuing financial incentives or penalties were often successful, as were the development of community cooperative association and marketing platforms. Adaptation activities involving laws and regulations did not happen very frequently, except for the establishment of protected areas.

Physical and structural adaptation activities were broken down into four subcategories: ecosystem-based adaptations, engineered and built environments, technological innovation, and services. Ecological restoration, increasing biological diversity, and agroecological practices occurred most frequently among the ecosystem-based activities. Establishing infrastructure for water supply and irrigation, water storage, water management, and water harvesting were favored adaptations in engineered and built environmental activities. Technological innovations included the development of new crop and animal varieties through genetic alterations as well as the development of new information and communication technologies. The services subcategory, which included activities such as emergency, health, and municipal services, was the least represented in the entire dataset.

The act of cataloging these activities suggests several things about the current activities that comprise adaptation. First, all adaptation initiatives in my dataset incorporated multiple activities; no single activity was successful in isolation. A second and related factor is that adaptation initiatives did not easily fall into distinct categories. In fact, the most effective adaptation activities blended across categories that were synergistic and built upon each other. For example, the development of local cooperative associations improved individual and community access to resources, improved livelihoods by offering financial assistance and helping members increase their income, and facilitated learning and knowledge sharing within and across communities. Third, adaptation activities are not equivalent to each other—some involve very specific actions (e.g., building a coastal wall) and others describe a general approach (e.g. adaptive management). The review of adaptation initiatives that have been implemented and assessed provides a rich inventory for communities, organizations, governments, and individuals who are interested in implementing similar initiatives.

In addition to the analysis of types of adaptation initiatives, I identified five indicators that researchers used to demonstrate effective adaptation outcomes. These indicators were: 1) reductions in risk and vulnerability; 2) evidence of resilient social systems; 3) improved environments and ecosystems; 4) increased economic resources; and 5) enhanced governance and institutions. Eleven activities showed higher than average rates of effectiveness across three or more of these indicators. These activities included implementing agroecology and agroforestry practices, changing crop patterns and dates, creating community cooperative associations, raising awareness about climate-related challenges and solutions, enhancing agricultural extension programs, and

livelihood diversification. Central components of these activities draw attention to collaborative decision-making practices; community-based and institutionalized approaches for sharing physical, financial, and informational resources; and techniques that simultaneously enhanced human wellbeing, institutional relations, and environmental security.

Implications from this study include the following four points:

- 1) Evaluation must be prioritized. Countless ideas, techniques, and opinions regarding how to address global change exist, which are based on a variety of ways of knowing and being in the world, as well as different desires for the future. Systematic evaluation can help incorporate this diversity into well-informed, better planned, and more successful adaptation outcomes.
- 2) Scientists who claim to inform adaptation activities must engage more directly with on-the-ground efforts and document this engagement in the research literature. In regard to climate change, it is not good enough to produce strong science without finding ways to apply and communicate about it.
- 3) While many adaptation organizations desire standardized indicators and metrics to guide funding and policy decisions, the feasibility of standardizing evaluation is questionable. Given the multiplicity of definitions, objectives, and approaches inherent within adaptation, there is currently little evidence to support the practicality, usefulness, or need for standardized evaluation. Evaluation design and methods should be grounded in the local expertise and locally-determined needs. Metrics and indicators should be appropriate and meaningful to local participants.

- 4) Additional research gaps that emerged from this analysis call attention to issues of justice and equality, including representation of diverse types of knowledge and expertise, fair distribution of adaptation benefits, and imbalanced power dynamics within adaptation processes. Evaluation should be used to prioritize the needs and objectives of the communities at the highest risk.

Summary of findings: Appendices B and C

These two dissertation papers arose from a six-year evaluation of the Climate Assessment for the Southwest (CLIMAS), a regional climate research and services program. In 2012, I implemented a long-term monitoring strategy to better understand the program's impact on climate adaptation and resilience in the Southwest region of the U.S. This evaluation accomplished three main objectives. It 1) provided information about the theoretical frameworks that CLIMAS researchers used to conduct socially-engaged research and deliver climate services; 2) demonstrated how CLIMAS projects, information, and services contributed—and failed to contribute—to regional societal and environmental change, using quantitative and qualitative indicators; and 3) compared real-world outcomes of socially-engaged research projects to the accomplishments that researchers envisioned achieving. Appendix B, titled “Contextualizing climate science: Applying social learning systems theory to knowledge production, climate services, and use-inspired research,” mainly addresses the first subject and Appendix C, titled “Evaluating climate research: Scientists’ visions of a climate resilient U.S. Southwest” focuses on the last two subjects.

In Appendix B, written with Daniel Ferguson and Ben McMahan, we propose a revised conceptual model of CLIMAS's program theory. Developing the appropriate knowledge to address complex issues, such as climate change, requires approaches that situate science within the social contexts of these problems. While the CLIMAS program is rooted in socially-engaged and use-inspired research, through the process of evaluation we discovered that a social learning systems framework supplies a missing theoretical component in understanding how the program operates. In this paper, we illustrate this new framework by translating its theoretical principles into practice. In addition to generating scientific knowledge—the program's primary purpose—CLIMAS researchers perform five additional core functions within the social learning system for regional climate resilience in the U.S. Southwest. These functions are communicating, convening, consulting, collaborating, and training.

Social learning systems theory provides one way to understand the process of contextualizing scientific practice. Understanding the CLIMAS program as one piece of a larger social learning system—rather than the driver of the system—reveals the importance of developing and fostering different types of social interactions that aid in knowledge production. This model decentralizes the university as a traditional site of knowledge production and instead supports the development of communities of practice to determine how knowledge is produced, communicated, and valued. Communities of practice, usually comprised of people from a variety of backgrounds with multiple types of expertise, develop around a commonly defined issue or need. They provide the foundation for establishing relationships and creating opportunities for learning and innovation. CLIMAS helps foster and maintain these relationships and opportunities for

sharing and innovation, which requires practice and skill, especially when maneuvering through institutional, political, and economic barriers.

In Appendix C, I detail the methodological process of designing the evaluation of 10 CLIMAS projects that occurred between 2012 and 2018. This process involved coproducing a series of narratives with CLIMAS researchers to define their research objectives, project outputs, and anticipated outcomes. These narratives, or logic models, helped researchers articulate their oftentimes implicitly-held visions about how their research activities connect to outcomes and contribute to societal change. In this paper, I compared project outcomes that researchers anticipated to project outcomes that were actually achieved over the course of the evaluation. Quantitative and qualitative results detail several contributions that the CLIMAS program has made toward increasing regional climate resilience and adaptive capacity in the U.S. Southwest.

To categorize project outcomes quantitatively, I used a conceptual typology describing five types of outcomes (Meagher and Martin 2017; Meagher and Lyall 2013), which were:

- *capacity building outcomes*: developing collaborations or providing the information and training necessary to engage in a particular activity;
- *instrumental outcomes*: direct influence or use in policy, practice, or decision-making;
- *conceptual outcomes*: changes in thinking, raising awareness, or improving understanding of an issue;
- *enduring connectivity outcomes*: relationships lasting beyond the course of a particular project or activity; and

- *attitudinal or cultural shifts outcomes*: changes in institutional, group, or individual attitudes regarding issues or toward engaging in collaborative activities or knowledge exchange.

CLIMAS researchers achieved 61 outcomes in total, spread relatively evenly across the five categories. Capacity building outcomes were the most frequent (26.2%), followed by instrumental outcomes (21.3%), conceptual outcomes (19.7%), and enduring connectivity outcomes (19.7%). The smallest number of outcomes comprised the attitudinal or cultural type (13.1%). In Appendix C, I provide examples of project outcomes for each category. Out of the 61 outcomes achieved, 45 were anticipated by researchers at the beginning of the project and 16 were unanticipated. The unanticipated outcomes fell mostly into the enduring connectivity and instrumental types. Several anticipated outcomes (n=23) were not achieved by the end of the funding cycle in 2018, most of which fell into the instrumental outcomes category.

When envisioning the impact of their research, CLIMAS researchers were able to articulate realistic conceptual outcomes such as improving people's awareness and understanding of an issue. All anticipated conceptual outcomes were achieved; none were unanticipated. However, researchers generally envisioned the instrumental impacts of their work, such as informing policy, planning, and decision-making, to be greater than what occurred within a six-year timeframe. Out of the 22 instrumental outcomes that were initially identified as project goals, only eight actually occurred. Further exploration of these results revealed an implicit assumption in researchers' visions for how scientific information is applied in policy, planning, and decision-making. This assumption is rooted in the idea that the lack of scientific knowledge and information is the

fundamental barrier to a climate-resilient society; therefore, provision of this knowledge and information will directly inform policy, planning, or operational decision-making. However, political, social, and economic challenges often present stronger barriers than the lack of knowledge and information.

In this paper, I drew on qualitative findings from a collaborative project regarding drought monitoring and planning that was designed by CLIMAS researchers and members of the Hopi Department of Natural Resources (HDNR) in northeastern Arizona. These findings illustrated several barriers that CLIMAS researchers confronted in achieving their anticipated instrumental project outcomes. Barriers included changes in the severity of drought over time, personnel changes within tribal leadership and HDNR, and overestimating the role that scientific information would play in informing policy decisions. Exogenous factors in which this project was embedded also provided challenges, which included ongoing tensions regarding a local coal mining operation and mounting political unrest regarding tribal water rights. The evaluation process revealed insights about the project's successes and failures that may have otherwise been left unacknowledged or unexplored. CLIMAS researchers reviewed their original visions and objectives for the project and reflected upon what went right and what went wrong.

Appendices B and C both reinforce the need to establish routine monitoring and program evaluation as part of an evolving socially-engaged research practice. Four main objectives guided the CLIMAS program evaluation. The first objective was to demonstrate the program's contributions to building adaptive capacity and climate resilience in the Southwest. To meet this objective, I introduce social learning systems theory as a way to understand the CLIMAS's core contributions as socially-engaged and

use-inspired research program. As well, I report a number of qualitative and quantitative contributions that CLIMAS researchers have made towards addressing regional climate variability and climate change. The second objective was to establish monitoring practices to assess the CLIMAS program's value and impact. The process of developing a program theory of change and project logic models was valuable in developing qualitative and quantitative contributions of CLIMAS research and the program. In both papers I discuss improvements for a new cycle of CLIMAS program evaluation, which I explain in further detail in the future research section below. The third evaluation objective was to feed results back into program operations and funding decisions. Qualitative and quantitative results were used to inform several programmatic changes and also influenced the program's proposal for a new funding cycle. Finally, the fourth objective was to develop a better understanding of the impact of socially-engaged research. This evaluation helped reveal how the CLIMAS program contributes to and facilitates the development of a social learning system for climate resilience in the Southwest. CLIMAS is not the center of the social learning system but actively works to build and maintain it. Additionally, theories of change and logic models provided productive methods to investigate and better understand how researchers envision science as an effective tool for producing societal and environmental change.

Contributions to scholarly literature

My dissertation research offers several contributions to the academic literature. On a practical level, my review and analysis of adaptation in the first paper (Appendix A) contributes to the literature on climate change adaptation through a useful summary of

diverse adaptation activities as they are represented in current research literature. While several strategies, activities, and policies have been developed, very few of these have been implemented, let alone evaluated for their effectiveness. Multiple scholars of adaptation (e.g., Moser and Ekstrom 2010; Lonsdale et al. 2015; Christensen et al. 2018; de Coninck et al. 2018) have established the need to evaluate projects to help make future adaptation plans, strategies, and actions more effective and reduce the risk of adaptation failures.

In my paper I identify central components of adaptation initiatives that were effective across multiple indicators. These components include joint or collective approaches to decision-making; community-based and collaborative methods for sharing physical, financial, and informational resources; and techniques that simultaneously improve human wellbeing, institutional relations, and environmental security. Although physical infrastructure and technology played important roles in adaptation initiatives, they were not generally the key to success. Social and political factors were more prominent.

I also identify lessons for planning future adaptation initiatives. One lesson is to remember that effectiveness in one moment of time does not signify long-term success. Likewise, effectiveness in one community or institution does not indicate success in a different community or institution. Activities that were often represented as effective in my dataset, such as resource co-management, cooperative development, and agroecology techniques, do not guarantee effective reduction of future risk or vulnerability in every instance.

Like scholars in the field of political ecology, my analysis calls attention to the underlying causes of climate-related risk. For example, categorizing activities and their effectiveness brings awareness to the ways in which researchers choose to analyze success. Effectiveness can be measured in multiple ways. Some adaptation initiatives in my dataset were only effective at addressing biophysical threats of climate change. Many of these activities exemplify the structural adjustments approach to adaptation and tended to ignore the root causes of climate risk, vulnerability, and exposure. Other initiatives in my analysis did address, or at least acknowledge, the underlying systemic problems that caused or magnified vulnerability and exposure to risk. Researchers in adaptation should critically examine what it means to be successful, including how it is measured, defined, and represented in the literature.

This first paper also identifies important shortcomings within current adaptation practices in regard to equality, justice, and power—subjects of particular concern within political ecology. Several articles in this study demonstrate awareness of issues relating to justice in adaptation, but only a few offer solutions to address them. Justice in these cases were defined as both procedural and distributional. Authors identified the need to: increase diversity in representation regarding the knowledge and expertise used to guide adaptation initiatives; examine unequal power relations in terms of fair distribution of beneficial outcomes or environmental risks across populations; and examine unequal power dynamics within adaptation processes including the design of adaptation initiatives and their associated funding, research, and governance structures. Acknowledging the roles of equality, power relations, and justice in adaptation and evaluation is only a first step. The application of key indicators could help monitor trends regarding equality in

adaptation. These indicators might include critical examination of patterns in leadership; processes for policy-making and decision-making; exclusion from leadership or decision-making; communication, circulation, and accessibility of information; the types of knowledge used and considered valid; and equity in the distribution of adaptation benefits.

The second and third papers (Appendices B and C) contribute to the literature on political ecology and science and technology studies. Scholars at the nexus of these two fields examine the roles that scientific research and scientists play in creating, defining, and solving complex problems like climate change. While several scholars agree that engaged and participatory research approaches are better suited to improve societal and environmental issues than traditional models of science (e.g., Kates et al. 2001; Nowotny et al. 2001; Cash et al. 2003; Lemos and Morehouse 2005; Pahl-Wostl et al. 2007), it is still unclear if and how collaborative knowledge production results in societal improvement (Zscheischler et al. 2018). Clear demonstrations of the structural mechanisms that encourage the social interactions that inform knowledge production are needed (Kirchhoff et al. 2013). The promise of socially-engaged science offers the idea that collaborations between scientists and other members of society will produce outcomes that lead to societal and environmental change. There is a need to demonstrate and evaluate these outcomes (Vaughn and Dessai 2014; Lourenço et al. 2016). The research discussed in the second and third papers offer empirical data and analysis that advance understanding about the theories and practices involved in participatory and use-inspired research.

Political ecology and science and technology scholars interrogate the ways in which knowledge is produced, circulated, and applied to societal and environmental issues (Goldman and Turner 2011). However, there is also a need to develop and practice the methods necessary for conducting this type of interrogation. My description of methods in the third paper offers a practical approach to establishing routine and rigorous evaluation as a standard practice for scientists to incorporate into their own research practices. I suggest that theories of change and logic model narratives help researchers make their ontological and epistemological assumptions more explicit. These tools support questioning the centrality of science in decision making and in responding to climate change. The CLIMAS program evaluation offers an example for other socially-engaged research organizations who are considering conducting program evaluations.

Policy recommendations

My dissertation research produces policy insights for the evaluation of climate change adaptation activities and for policies regarding academic research on climate change. First, it is clear that evaluation is an essential part of the adaptation process. One issue that challenges its routine implementation involves deciding on the most appropriate indicators and metrics for measuring effectiveness. This decision will vary depending on the type of adaptation activity, the monetary, technological, and human resources available for monitoring and analysis, and the environmental and geographic contexts in which the activity is taking place, among several other variables. Scholars and evaluators have developed sets of quantitative metrics to measure effectiveness at multiple scales and across economic sectors and agencies (see Christiansen et al. 2018).

Others have explored qualitative indicators to indicate progress within the realms of human well-being, fundamental rights, agency, power, and equality (see Hicks et al. 2016). There are multiple ways to conduct evaluation for adaptation. No singular ‘right’ way exists.

However, international assessment and governing bodies such as the IPCC and UNFCCC continue to call for standardized indicators and metrics to compare outcomes across adaptation initiatives and guide funding and policy decisions (Bours et al. 2013; Arnott et al. 2016; deConinck et al. 2018). Theoretically, standardized metrics and indicators would encourage informed decision-making practices in global adaptation governance. As some evaluators point out, the feasibility of implementing standardized evaluation across global adaptation initiatives is questionable (Christiansen et al. 2018). Given the multiplicity of definitions, objectives, approaches, ontologies, and epistemologies inherent within the processes of adaptation, there is currently little evidence to support the usefulness, practicality, or need for standardized evaluation.

Based on my dissertation findings, one policy recommendation is to embrace the complexities of adaptation within the practice of evaluation. Metrics, indicators, and frameworks should be flexible enough to fit various social, environmental, and political contexts. Design and methods should incorporate the expertise and needs of those locally involved in the adaptation initiative. Metrics and indicators should be culturally appropriate and meaningful to local participants. Due to the urgency of climate-related threats to human and environmental systems, evaluation should prioritize the values, objectives, and needs of the people and systems at risk before the generation of standardized values for use by adaptation governance and funding organizations. Over

time and through the routine practice of evaluation, sets of appropriate methods, indicators, and metrics will likely emerge for standardized applications.

Regarding policies for academic climate change research, scientists within the adaptation community need to better integrate themselves into adaptation practice. From my systematic literature review, a disproportionate amount (69% or 1580/2294) of the articles returned in my Web of Knowledge search were only *informed by* adaptation research needs. However, most did not ultimately show how their findings were actually integrated into particular adaptation initiative. These articles provided models and scenarios, proposed adaptation frameworks or strategic plans, or presented results from risk or vulnerability assessments. These are all important components for informed climate action. Almost all of these articles included some iteration of the following sentence, usually in the conclusion: “It is imperative that [resource managers, planners, policy-makers] incorporate this new [concept, framework, model, information] to guide their decisions and actions.” But authors left readers with little indication that research findings were communicated to end-users or utilized in any capacity. This finding suggests that scientists expect their research to be useful for society in addressing climate change; however, they provide minimal evidence of applying or circulating that knowledge.

The obligation to communicate findings and engage with adaptation practitioners, policy-makers, and community members rests upon researchers. The scientific loading-dock model—in which researchers stockpile information that they assume will be useful in addressing societal problems—has been proven ineffective (Cash et al. 2006). Researchers must also demonstrate the value and impact that their findings have for

society. However, as several scholars note, formal research processes often conflict with what is needed to address complex adaptation problems facing societies around the world (Nowotny et al. 2001; Hulme 2010). Tension exists between the types of knowledge needed to address adaptation issues and conventional knowledge production systems, such as university-based research and academic publications. This conflict has inspired calls for “‘revolution’ in education and capacity building” (O’Brien et al. 2013), given rise to new integrated fields of inquiry like sustainability science (Kates et al. 2001), and propelled transdisciplinarity into the forefront of methodological innovation (Jahn et al. 2012; Pohl et al. 2017). A common thread underscoring these movements is the reality that scientists must be more engaged with society if the knowledge generated is to have impact on addressing those needs.

Therefore, one recommendation is for academic institutions and departments to place more value on the circulation and application of scientific knowledge. Metrics for tenure and professional performance should not only rely on peer-reviewed publications but could also incorporate outputs tailored for people outside of the academic community, such as technical reports, articles in trade journals, public research presentations, and the use of media and social media. As Hicks et al. (2015) point out, “Research that advances the frontiers of academic knowledge differs from research that is focused on delivering solutions to societal problems. Review may be based on merits relevant to policy, industry, or the public rather than on academic ideas of excellence” (430). A diversity of research metrics should be developed to determine academic accomplishment and impact. Another recommendation is that if researchers are engaging with society or partners outside of academia, they should publish more about the process

of these types of engagements including their methods, approaches, and techniques. Most scientists want their work to be used or useful in some capacity, but the processes of engagement and applying research in practice are typically messy and difficult.

Researchers can learn a lot from one another if we write more about not only successful outcomes, but also our shortcomings and failures.

A related recommendation relates to the fact that many academics support their research through externally funded grants. Most scholars then must demonstrate the value of their research in ways that are meaningful to their funders. Furthermore, many funding agencies do not support or value socially-engaged research, beyond superficial gestures. It is possible that through evaluation and through the subsequent communication of results back to funders, that the values funders place on broader research impact could change over time. For socially-engaged research projects, it is advisable to design evaluation into the project—implemented from the beginning rather than at the conclusion of the project—and for funders to grant time and resources for researchers to incorporate these evaluation efforts.

It is evident that researchers and practitioners have abundant information on how to implement, monitor, and evaluate adaptation activities. Research that builds theory, improves models, develops scenarios, and analyzes methodologies is important and will continue to inform climate change adaptation processes. However, if researchers want to address urgent global problems, they must also directly engage with practitioners and communities at risk to ensure that their work is usable and used. Furthermore, to improve adaptation practice, researchers should better document their engagement practices, use of their information, and outcomes of adaptation initiatives.

Reflections and study limitations

Limitations regarding my use of systematic review methods to understand climate change adaptation in the first paper (Appendix A) are important to acknowledge.

Systematic review methods provide useful and robust analyses for understanding trends in a subset of work. However, one issue is that they only capture a static moment in time. Since conducting my review in 2018, several new articles have been published regarding effective adaptation practices; their inclusion would likely impact my analysis. Another issue is that Web of Knowledge is partial to academic and peer-reviewed literature. While a large body of non-academic research on the evaluation of adaptation exists, there is no centralized database for this type of literature that provides an equivalent sample. My sample, therefore, includes only a few cases of non-peer-reviewed technical reports. A third issue is that by focusing on broader trends and patterns regarding adaptation outcomes, my systematic review temporarily removes the complex, underlying social, political, environmental, and economic contexts in which these adaptation initiatives occur. It is important to remember these contexts when determining adaptation success. No activity will be universally beneficial.

Another limit to my review of effective climate change adaptation initiatives was the difficulty in synthesizing and adequately representing the complexity of results in my dataset. In Appendix A, I was unable to fully report on how researchers evaluated other factors of success, beyond values of effectiveness and equity. In addition to these factors, I analyzed four other components of adaptation that have been identified in the adaptation research literature as important for evaluating success. These factors are sustainability, legitimacy, efficiency, and flexibility, which I briefly outline Table 1.

<i>Adaptation factors</i>	<i>Description of indicators</i>	<i>Percent of frequency in dataset</i>	<i>Types of activities in the dataset that indicated these components</i>
<i>Sustainability:</i>	Institutional, social, economic, or environmental resources to help adaptation actions continue, thrive, and evolve (Moser and Ekstrom 2010; Brooks et al. 2011)	50.9%	Natural resource-based activities; agricultural activities; information services and platforms; fisheries management
<i>Legitimacy:</i>	Extent to which adaptation processes and activities are acceptable, appropriate, and feasible in varied social and cultural contexts (Füssel and Klein 2006; Ford et al. 2013)	35.6%	Social learning and knowledge sharing activities; community-based activities; fisheries management
<i>Efficiency:</i>	Balance between costs of implementation and benefits of an activity, including financial, property, human resources, ecological impacts, aesthetic impacts, and services (Adger et al. 2005)	31.8%	Water storage, irrigation, harvesting systems; agroforestry; changing cropping patterns and dates
<i>Flexibility:</i>	Degree to which an activity can adjust to accommodate multiple decision contexts, regional conditions, timing constraints, and needs (Smit and Pilosofova 2001; Ford et al. 2010; Füssel 2008).	21.8%	Adaptive management; fisheries management

Table 1. Additional components of adaptation that have been identified in the adaptation research literature as important for evaluating success

Limitations regarding my evaluation of CLIMAS are also worth noting. A major limitation in evaluation work is establishing causality between activities, outputs, outcomes, and impacts. Without the use of a control group of people who did not interact with the CLIMAS program for comparison, outcomes cannot be definitively or solely attributed to CLIMAS activities. To negotiate this shortcoming, I focus on analyzing contributions rather than attribution. Another limitation points to the absence of CLIMAS

project partners and stakeholders in the evaluation process. Their inclusion is necessary for a fully-realized evaluation of socially-engaged research. In my initial research design for the evaluation, I included interviews with selected project collaborators outside of the CLIMAS research team. However, I was unable to complete these interviews for all projects. Engagement with project partners is more prominent in the current cycle of CLIMAS evaluation (2017-2022), which I describe in the section on future research below. Finally, it is worth mentioning my positionality as a CLIMAS-funded researcher and evaluator and its impact on my research outcomes. My evaluation and analyses are driven by my own assumptions—which also form the basis of the CLIMAS program theory—that socially-engaged science can and will inform societal and environmental change. An evaluator who operates under a different assumption, and/or outside of the CLIMAS research team, might produce different evaluation results.

Future plans and research

Through the course of my dissertation process, I learned several things that will inform my future research projects. These lessons apply mostly to improve the design of the CLIMAS program evaluation and to encourage better socially-engaged research practices within academia. During the last round of evaluation, I only participated as an evaluator but not as an evaluatee. Therefore, I did not investigate or challenge my own implicit assumptions about the impact of my research in practice. Starting in the fall of 2019, I have a CLIMAS-funded research project regarding climate adaptation and food security in the Southwest. I look forward to the opportunity to put my socially-engaged research through the same scrutiny as my CLIMAS colleagues.

The 2012 through 2018 CLIMAS program evaluation inspired new metrics and data collection techniques that I have applied to the current evaluation cycle. For example, while monitoring progress towards outputs, outcomes, and impacts still remain key components, I am prioritizing monitoring of individual and institutional relationships, specifically in regard to how they are built, maintained, strengthened, or lost over time. A recently developed database will help document the variety of interactions between CLIMAS investigators, information users, and project collaborators. By tracking changes in relationships over time, I aim to better understand how iterative social interactions provide pathways to more useful climate-related research and improved adaptation strategies.

I am also working to ensure that my evaluation indicators better mirror the practices of socially-engaged and transdisciplinary research. As noted above, the 2012 through 2018 evaluation centered CLIMAS researchers. The 2017 through 2022 evaluation cycle incorporates annual interviews with non-academic research partners and tracking the roles they play within projects. One aim of these interviews is to develop evaluation metrics and indicators that are important to the research partners and reflect their own individual and/or institutional objectives. Another aim is to incorporate their perspectives on project design, outputs, and outcomes.

I learned that flexibility is a key attribute for organizations and individuals involved in climate adaptation and resilience. Therefore, it is important to incorporate flexibility into the evaluation design by documenting researchers' and project collaborators' responses to unexpected changes, barriers, and exogenous influencing factors that impact project relationships and outcomes. The logic model narratives that

we use should be more flexible documents. Instead of creating a logic model at the beginning of a project and revisiting it at the end, each year I plan to review the logic model with CLIMAS researchers and project collaborators and revise it as necessary. A more flexible approach to evaluation may create more opportunities for researchers to identify, address, and adjust to unexpected challenges that often arise during socially-engaged research projects. This process may also yield more precise indicators and ways to understand the program's contributions to increasing the adaptive capacity and resilience in the Southwest.

To encourage better socially-engaged research practices in academia, I will discuss my CLIMAS evaluation findings with the researchers who participated. In addition, I will deliver results to our funders at NOAA-RISA and discuss ways to inform better evaluation practices and synthesize results across other NOAA-RISA research organizations. I also hope to design an online course regarding evaluation for socially-engaged research projects and programs.

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APPENDIX A: WHAT MAKES CLIMATE CHANGE ADAPTATION EFFECTIVE? A SYSTEMATIC LITERATURE REVIEW

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Abstract

Increased understanding of global warming and documentation of its observable impacts have led to the development of adaptation responses to climate change around the world. A necessary, but often missing, component of adaptation involves the assessment of outcomes and impact. Through a systematic review of research literature, I categorize 110 adaptation initiatives that have been implemented and shown some degree of effectiveness. I analyze the ways in which these activities have been documented as successful using five indicators: reducing risk and vulnerability, developing resilient social systems, improving the environment, increasing economic resources, and enhancing governance and institutions. The act of cataloging adaptation activities produces insights for current and future climate action in three main areas: understanding the common attributes of effective adaptation initiatives; identifying gaps in adaptation research and practice that address equality, justice, and power dynamics; and establishing priorities for evaluating adaptation initiatives.

1. Introduction

In 2007, the Intergovernmental Panel on Climate Change (IPCC) produced its fourth assessment report. Besides documenting observable changes in climate and its associated impacts, this report brought new awareness to the need for climate change adaptation (Ayers and Dodman 2010). In the past two decades, there has been rapid growth in the development of adaptation responses to climate change around the world (Moser 2009; Arnott et al. 2016). More funding opportunities, better scientific understanding, and increasing public awareness helped launch a wide variety of adaptation initiatives carried out by government, international development, non-profit, and community organizations. Adaptation initiatives include those aimed to influence human behavior and decision-making (e.g., Bowen et al. 2014; Vaughan and Dessai 2014); innovate new technologies and infrastructure (e.g., Hill 2015; Schenk et al. 2016); implement management, governance, and institutional policies (e.g., Okereke et al. 2009; Henstra 2016); improve people's access to resources (e.g., Adger 2006; Ribot 2010); and reduce exposure to environmental risk (e.g., Jordan 2015; Jost et al. 2016). These initiatives are focused on sectors that include agriculture, coasts, ecosystems, health, water, and urban systems.

There is little consensus on what counts as effective adaptation in practice. One reason is that initiatives are often proposed and planned but rarely implemented (Bierbaum et al. 2013; Mimura et al. 2014); academic literature has tended to focus on these proposed activities. Barriers that routinely impede adaptation efforts include insufficient resources, prohibitive policies, competing or conflicting priorities for action, and uncertainty about future changes (Moser and Ekstrom 2010; Biesbroek et al. 2013).

Adaptation efforts are often shaped by unique and localized combinations of underlying contexts, such as politics, funding, motivation, power dynamics, and cultural values. Initiatives embedded in the context of one community will produce different outcomes in another. Finally, it can be difficult to distinguish climate adaptation from related activities, such as reducing risk to environmental disasters or alleviating poverty, which complicates attribution of successful adaptation efforts. The IPCC, for example, claims that incorporating climate adaptation into sustainable development strategies will result in win-win solutions (Roy et al. 2018). While efforts to mainstream climate adaptation may appear efficient, actions that address present development issues may conflict with actions that address future climatic risks or vice versa (Barnett and O’Neill 2010; Roy et al. 2018). These factors make it difficult to disentangle a simple understanding of adaptation in practice.

The research literature has largely focused on critical analyses that draw attention to the failures and negative consequences of adaptation (Eriksen et al. 2011; Wise et al. 2014), the unjust burdens of adaptation that fall on more vulnerable populations (O’Brien and Leichenko 2000; Shi et al. 2016), and the inequality surrounding who benefits from adaptation and who does not (Bohle et al. 1994; Bäckstrand and Lövbrand 2006). In other words, there is evidence that climate change adaptation activities frequently do not work as intended. There is even less insight into what constitutes effective practices.

One way to analyze success is to include routine evaluation into the adaptation process (Adger et al. 2005; de Coninck et al. 2018) and several scholars and practitioners have developed frameworks to guide evaluation design for adaptation (e.g., Eriksen et al. 2011; PROVIA 2013; GEF 2016; Vogel et al. 2017). Three main factors challenge its

implementation as standard practice: uncertainty, lack of agreement, and attribution (de Coninck et al. 2018: 386). The first factor—uncertainty in actions and objectives that constitute adaptation practices—is introduced above. The second factor is the lack of agreement about the best methods for collecting robust and longitudinal data and determining the right indicators to monitor. Agencies like the United Nations Framework Convention on Climate Change (UNFCCC) have tried to establish common metrics to compare adaptation outcomes across projects and scales, while others have developed flexible sets of metrics and indicators to show accountability and effectiveness within projects (e.g., Hicks et al. 2016; GIZ 2017; Christiansen et al. 2018). A third factor that challenges effective implementation is the difficulty of attributing successful outcomes to specific adaptation activities. Many studies do not establish baselines or compare outcomes to cases that do not include climate adaptation. Evaluation practices aim to demonstrate linear connections between activities and outcomes; however, adaptation is a cyclical process, with no distinct end point (Smit and Pilifosova 2001). It is unlikely that society will ever become fully adapted. Therefore, evaluation practices and the notion of success must incorporate the state of adaptation as a continuous and circular process.

While the challenges surrounding the implementation and measurement of effective adaptation are multiple, progress has been made within the adaptation community⁶ regarding these challenges. In this paper I conduct a systematic review of research literature, to identify adaptation initiatives that have been implemented and show some degree of success. The act of cataloging offers a snapshot of adaptation in practice around the world and in different social, political, and environmental contexts. I analyze

⁶ In this paper, I define the adaptation community broadly to include anyone involved in theorizing, designing, planning, implementing, or evaluating adaptation initiatives.

how these adaptation cases are evaluated for effectiveness using five indicators: reducing risk and vulnerability, developing resilient social systems, improving the environment, increasing economic resources, and enhancing governance and institutions. My results produce insights for current and future climate action including: a) common attributes of effective adaptation initiatives, such as resource sharing, collective decision-making, and mutually beneficial outcomes; b) gaps in adaptation research and practice regarding equality, justice, and power relations; and c) suggestions for evaluation priorities in adaptation.

2.1 Defining adaptation

On a fundamental level, adaptation seems simple—adjusting behaviors, actions, and decisions within biological, social, and built systems in response to climatic changes (Smit and Pilifosova 2001). Adjustments can be reactive to events that have occurred or anticipatory in response to future events or conditions (Smit et al. 2000). However, in practice, adaptation suffers from a lack of clarity in its definition (IPCC 2014).

Adaptation is always contingent upon the events or conditions to which it is reacting or anticipating. For example, adaptation to climate change is often conflated with adaptation to environmental disasters or climate variability. While the field of climate change adaptation is relatively new, it stems from decades of research about responses to environmental change (Liverman 2015) and was formulated as a fundamental concept in hazard and risk studies (Bassett and Fogelman 2013) and cultural ecology (Head 2010) in the latter part of the 20th century.

Understanding current applications of adaptation hinges on the multiple and intersecting ways in which people know, experience, and deal with climate change. Goldman et al. (2018) argue that at the heart of this complexity lie the pluralities of how people know the world (different epistemologies) and the pluralities of understanding what the world is (different ontologies). They write, “Such an approach challenges an assumption that most of us hold dear: that there is one reality out there, about which we can explore different perspectives” (2018: 3). People have diverse conceptualizations of reality and multiple ways of understanding those realities. This philosophical shift implies that the adaptation community must grapple with coexistent realities of, experiences with, and ways of gaining knowledge about climate change. For example, Goldman et al. (2018) discuss how climate change for Maasai pastoralists in Tanzania means the extension of the cold season from one month (July only) to four months (June through September). The Maasai’s fundamental conception of what climate change is differs from that of Inuit harvesters in Canada who experience changes in sea ice conditions due to Arctic warming trends (Ford et al. 2013). By extension, there are multiple ways to adapt behaviors in response to different ways of understanding and experiencing climatic changes.

The contested nature of adaptation in practice is further demonstrated through the challenge of defining its basic goals. One goal of adaptation is to increase adaptive capacity, or the ability to respond effectively to changing stresses and shocks to manage or reduce risk (e.g., Engle 2011). A second goal is to increase resilience, or the ability of a social or ecological system to continue functioning when confronted with shock and stress (e.g., Nelson et al 2010). A third goal is to reduce vulnerability, or the

susceptibility to harm when exposed to an external hazard (e.g., Yamin et al. 2005). The origins of these three goals come from a variety of disciplines, such as ecology, human geography, sustainability science, risk management, and development, and have converged under the umbrella of adaptation research (Goldman et al. 2018). Often, as Smit and Wandel explain, the goals of adaptation are interconnected (2006). A system with more capacity to adapt should be less vulnerable to harm, thereby more resilient and able to cope when faced with risk. Residents of the Pacific Islands, for instance, have strengthened their adaptive capacity and reduced vulnerability by developing systems to share resources and labor, which has helped communities prepare for and recover from drought and cyclones (de Coninck et al. 2018: 360).

With myriad ways to define these adaptation goals, they can become overly generic when applied without context. Vulnerability, for instance, is often understood as biophysical and/or socioeconomic exposure to risk (Fussler 2007). But, as Dooling and Simon argue, conditions of exposure to risk are actively created by past and current political, economic, environmental, and social processes (2012). An example from Bellante illustrates these points (2017). Subsistence corn farmers in Mexico are plagued by extreme weather events and increased pest populations—impacts connected to climate change. Adaptation options to reduce exposure to these biophysical risks include applying new pesticides and using irrigation. Farmers who cannot afford to invest in pesticides or irrigation may adapt by selling their land. In addition to extreme weather and pests, global economic trade agreements have created conditions for international corporate producers to export cheap food products to Mexico. Local food consumption preferences have thus shifted from local to imported goods, thereby creating precarity for

farmers who do not have resources to compete. Their underlying exposure to climate risk is politically, economically, and culturally produced through the convergence of international trade decisions, economies of scale, and individual food choices. This case demonstrates what O'Brien and Leichenko (2010) term "double exposure," as farmers must confront the impacts of climate and globalization simultaneously.

To address biophysical, socioeconomic, and underlying risks, the Mexican farmers developed a local cooperative association to improve access to markets and fair crop prices. If the farmers chose only to address the impacts of pests and extreme weather, their crop yields may have improved; however, their adaptation would ultimately be ineffective if crop prices were low and there was no place to sell the corn. Therefore, adaptation initiatives may not effectively reduce vulnerability if they solely focus on addressing exposure to risk—the symptoms of vulnerability—without also addressing the underlying systemic issues—the root causes of vulnerability (Bankoff et al. 2004; Dooling and Simon 2012). This example underscores the importance of articulating both the tangible and epistemological goals of adaptation initiatives, as they can lead to various choices and outcomes.

Of course, consensus from the adaptation community regarding the definitions and objectives of adaptation, capacity, vulnerability, or resilience may not be necessary for adaptation initiatives to be effective. Explicitly articulating these ideas within the context of each initiative, however, is key. As demonstrated above, their conceptualization shapes the rest of the adaptation process, including the selection and implementation of activities, and how success is determined.

2.2 Challenges for evaluation in climate change adaptation

Given the complexity of conceptualizing adaptation and its objectives, measuring adaptation success is also complicated. The field of evaluation provides practical methods to monitor progress and change. Two functions of evaluation are useful for adaptation: formative (focusing on process) and summative (focusing on outcomes) (Pringle 2011; van Drooge and Spaapen 2017). Formative evaluation focuses on learning about the adaptation process itself and provides guidance for improving adaptation efforts. Summative evaluation focuses on adaptation outcomes and analyzes progress and accountability. Establishing both formative and summative evaluation processes when beginning adaptation initiatives will ideally produce plans, strategies, and activities that are more effective, efficient, reliable, and equitable and reduce the incidence of misguided or maladaptive practices.

Evaluation regularly relies on quantitative and qualitative metrics or indicators to illuminate relationships between observable impacts of adaptation initiatives. However, as the IPCC notes, determining the right metrics and indicators to monitor progress across adaptation initiatives is not straightforward, in part because different people and agencies have substantially different uses for evaluation (2014). Economic motivations prompted initial calls for evaluating climate adaptation projects; funders desired standard metrics to compare outcomes across projects worldwide to decide which projects to finance (Ford et al. 2013; Möhner 2018). This desire is still a powerful driving factor, although evaluation can be used to assess much more than economic efficiency; evaluation can also help people and organizations understand if and how activities are helping them adapt as well as who is benefiting. For example, evaluation can help fisheries managers determine how

adaptation policies improve aquatic health and sustain operations while also helping fisheries workers and coastal communities understand how these policies impact their livelihoods and local food security (Castrejon and Defeo 2015). Meaningful indicators and metrics that demonstrate impacts will vary based upon different values and goals; within a project, the goals and values of community members may not match those of funding organizations. Evaluation frameworks must balance, or at least acknowledge, these competing needs for information.

Another practical challenge for evaluation research is attribution or establishing causality between actions and outcomes. Impacts can be simultaneously underlying and acute, direct and indirect, and “cascading, cumulative, synergistic, connected, and distributional” (Moser and Boykoff 2013: 17). Contextual factors, such as poverty levels, development interventions, or management policies, are constantly in flux, making it difficult to connect improved conditions directly to a specific adaptation activity. Without having multiple controlled experiments for comparison, the impact of a singular activity remains uncertain. Furthermore, quantifying direct impact is not always feasible or even meaningful (Christiansen et al. 2018). To address the issue of attribution, the adaptation community can learn from a breadth of other evaluation practices, like those in global development, environmental management, and agricultural extension programs. The United Nations Development Program (UNDP 2019), for example, frequently conducts outcome and project evaluations to assess contributions towards achieving specific objectives. The UNDP also conducts impact evaluations, albeit rarely, which consider all of a project’s long-term effects, both intended and unintended. In most cases, the UNDP

notes, it is unrealistic to isolate the effect of one development initiative from other influencing factors (2019).

An additional challenge for evaluating adaptation is that climate change operates on longer timescales than most other types of projects. Outcomes may not be revealed for years or decades, if at all. As Moser and Boykoff (2013) note, “publicly perceived success is achieved when an anticipated problem or impact does not occur—deaths prevented, damages avoided—yet proving this is the result of a policy or management intervention is often difficult” (18). In the case of adaptation success, it is important to remember that correlation does not imply causation.

However, the challenges of evaluating adaptation are not insurmountable. Instead of attribution, for example, evaluators often find it more practical to focus on tracking an activity’s contributions towards a broader goal. Mayne (1999) suggests reassessing “what measurement can usefully mean. Measurement in the public sector is less about precision and more about increasing understanding and knowledge. It is about increasing what we know about what works...and thereby reducing uncertainty” (50). Evaluation measures are likely to be more useful in assessing, refining, and improving adaptation processes, rather than definitively calculating the extent to which an activity produces an outcome. Contribution analysis (Mayne 1999; Mayne 2008) outlines methods to: assess whether or not anticipated results occurred; whether or not a particular activity or process produced those results; identify additional factors that influenced results; or reveal other explanations for why results occurred (see Belcher et al. 2017). In any case, the process of systematic evaluation increases clarity of understanding the connections between activities and outcomes.

A growing cluster of scholars are analyzing adaptation initiatives, including planning, implementation, and outcomes (e.g., Albert et al. 2012; Hughes 2015; Vogel et al. 2017). Results from these studies establish several components for good adaptation practices: strengthening institutional partnerships; engaging local individuals and communities in adaptation design, research, and implementation; promoting strong leadership; and facilitating social learning. Results also outline primary barriers to adaptation, which include lack of policies, human and financial resources, and institutional capacities to support the adaptation process (e.g., Bierbaum et al. 2013). An opportune moment exists for the adaptation community to infuse new insight into existing evaluation practices. Critical assessments are necessary to examine how success is defined—for whom and by whom.

In this paper, I examine the ways that the adaptation community currently analyzes success and effectiveness using a meta-analysis of published studies. To do so, I temporarily suspend the various a priori ontological and epistemological frameworks and underlying social, political, and environmental contexts to gain a clearer sense of the activities that constitute effective adaptation in current practice as they emerge from published studies.

3.1 Research Design

This study is guided by methods for systematic literature reviews, which provide rigorous ways to gather data from and show patterns within a set of literature or reports (Berrang-Ford et al. 2015). These methods have been used by scholars to demonstrate trends in climate change adaptation. For example, Preston et al. (2011) analyzed 57

adaptation plans from Australia, the United States, and the United Kingdom and found that most plans were underdeveloped and inadequate to effect change. Approximately three-quarters of the plans promoted low-risk capacity-building efforts such as gathering and sharing information over tangible or specific actions to reduce vulnerability such as installing new infrastructure or adjusting behaviors. Berrang-Ford et al. (2011) expanded the understanding of the adaptation process by reviewing 39 peer-reviewed articles documenting adaptation initiatives implemented in developed nations. This study found that most adaptations were implemented at the municipal level and most commonly occurred in the transportation, infrastructure, and utilities sectors. Other systematic literature reviews have shown the use of scientific knowledge and political power in adaptation governance (Vink et al. 2013), household adoption of adaptation activities in the United Kingdom (Porter et al. 2014), the state of adaptation practices in Australia (Pearce et al. 2018), and impacts of adaptation for livestock management (Escarcha et al. 2018).

This paper builds on these studies by systematically analyzing the research literature on adaptation effectiveness or success—a task not yet undertaken to date. The following section details parts of the data selection and analysis process. Full methodological details and resulting data are available online in supplementary materials.

After several rounds of refining my search criteria, I used Web of Knowledge⁷ to find articles published since the IPCC 4th Assessment Report (2007—2018) that included variations of the following terms: climate, change, adapt, success, effective, evaluate, monitor, indicator, and metric. These searches resulted in 3069 articles, of which 719

⁷ The systematic literature reviews I consulted for developing my search methods used Web of Knowledge as their data source and found it to be representative of literature across social and physical sciences.

were duplicates. I reviewed the abstracts of the remaining 2350 articles for the following inclusion criteria: discussion and evidence that an adaptation activity a) was implemented beyond the processes of planning, gathering information, or raising awareness; b) responded to a combination of social, environmental, and climatic changes; and c) was at least partially effective. Genetic or behavioral adaptations in plant or animal species without connection to broader socio-ecological impacts or management practices were not included. Following Adger et al. (2005), I defined effectiveness as achieving one or more expressed goals or outcomes. This initial review resulted in 780 selections. As I scanned through these articles, I removed them from the study if they did not provide concrete evidence of my inclusion criteria. After a series of increasingly in-depth reviews, 94 articles met the full inclusion criteria. Some articles contained multiple, distinct cases of effective adaptation activities, leading to a total of 110 case studies included in this review.⁸

Several issues regarding the use of systematic review methods to understand climate change adaptation are important to consider. This paper takes one subset of work at a moment in time and uses one method applied by one person to analyze the content within this body of literature. It is not comprehensive; however, it is replicable and robust. Web of Knowledge is partial to academic literature and at present no parallel database for non-academic research exists to provide a broad, representative sample. The resulting set of literature includes only a few cases of non-peer-reviewed technical reports. Not all articles included in this sample had evaluation explicitly integrated into

⁸ Articles that were rejected for full review in this study were stored in a separate Excel spreadsheet documenting the reasons for their rejection. The codebook for rejected articles is included as supplementary data.

the adaptation activity; several assessments were conducted after the activity occurred or were conducted independently. Finally, this systematic review temporarily removes the interacting and underlying social, political, environmental, and economic contexts of a particular place and time to focus on broader trends and patterns regarding adaptation outcomes. However, these contexts are extremely important to consider when determining success—no activity will be universally beneficial.

3.2 Coding and data analysis

Articles were entered into MAXQDA software for content analysis. I created a codebook to categorize adaptation activities and measures of effectiveness. For adaptation activities, I began with those identified in the IPCC's *AR5 Climate Change 2014: Impacts, Adaptation, and Vulnerability Report* and adapted it as needed based on activities in the literature sample. The IPCC divided activities into three overarching groups: a) institutional actions that structure programs, policies, regulations, and financial incentives; b) social actions and behavioral changes that improve human wellbeing and social vulnerabilities; and c) physical or structural actions that shape infrastructure and ecosystems or lead to technological advancements. Each of the three overarching groups were further divided into 82 subcategories that were modified from the IPCC AR5 list of adaptations (see Table 1). To meet the inclusion criteria for this study, the planning or building capacity stages of an adaptation activity had to be completed. Therefore, certain activities considered adaptations by the IPCC (i.e., developing an adaptation plan or raising awareness around a particular climate issue) were not included in this assessment unless they were performed in conjunction with another implemented activity. I created

new subcategories when activities described in the literature did not match any of the subcategories in the IPCC AR5 list. I sorted 110 case studies into their most appropriate categories of adaptation activities. I developed new sub-categories when an adaptation activity fell outside the scope of those in the IPCC AR5 list. All cases included multiple adaptation activities.

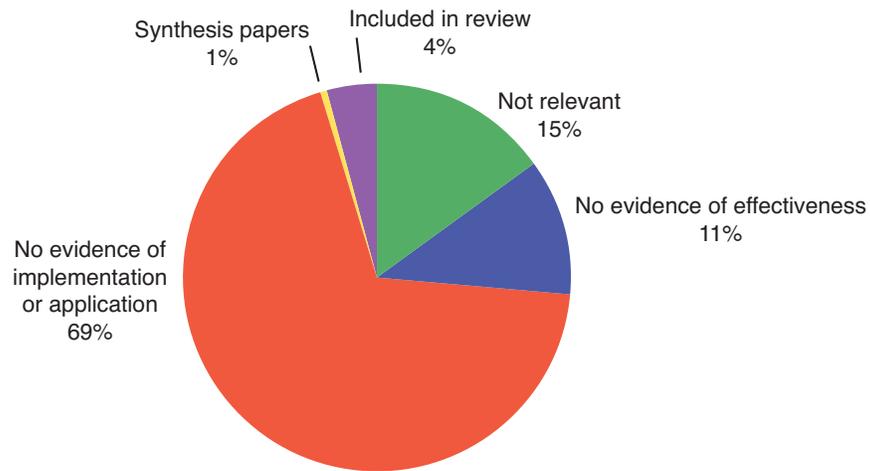
I coded outcome success using five categories of effectiveness: a) reducing risk and vulnerability to climate change impacts; b) improving the environment or natural resources; c) enhancing social well-being for individuals or communities; d) increasing access to economic resources; and e) strengthening institutions, policies, or governance structures. I devised and refined these codes inductively from evidence in the articles. I also coded for qualitative evidence of distributional (e.g., Rawls 1971) and procedural (e.g., Sen 2009) justice in the adaptation cases. Justice, as defined in this context, is based on notions of equity and fairness and is considered a key component of effectiveness (Adger et al. 2005). It considers the fairness of distribution of benefits from the adaptation activity, as well as patterns of decision-making power and representation during the adaptation process (Adger et al. 2005; Brooks et al. 2011). Data from the coding process were entered into a FileMaker Pro Advanced database and into IBM SPSS for quantitative and qualitative analysis.

4. Results

4.1 Rejected articles

A total of 2294 articles were reviewed for this study. Ninety-four articles were included and 2200 were excluded (see Figure 1). A small portion of excluded articles

described implemented adaptation initiatives but did not clearly substantiate effectiveness. Several others were not relevant because they did not address climate change adaptation, were incomplete, or could not be translated into English. Literature reviews or synthesis papers about adaptation were not included. Most articles were excluded because they did not provide discussion or evidence that initiatives were actually implemented. Of these rejected articles, most theorized planning and potential implications of adaptation strategies, constructed models or developed scenarios of future conditions, or uncovered biological adaptations of plant and animal species (Figure 1).



Types of articles that had no evidence of implementation or application

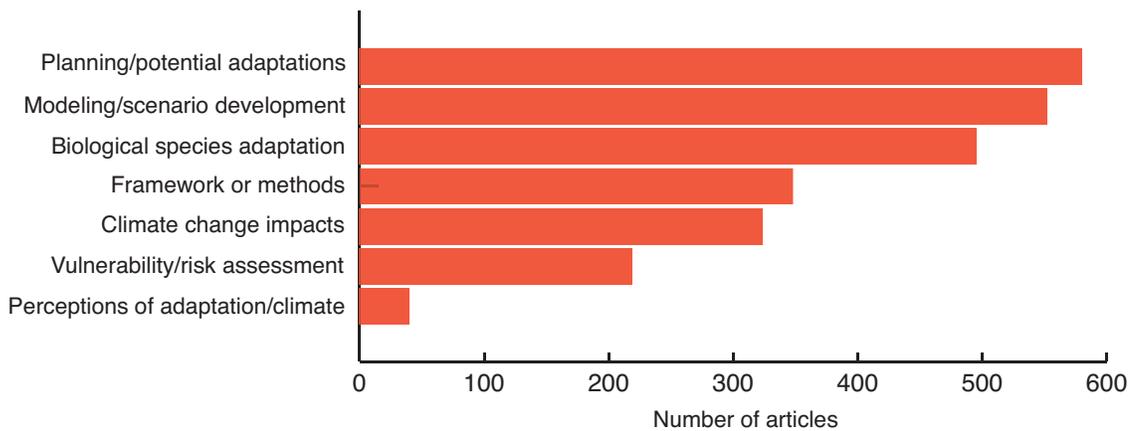


Figure 1. Percent of all articles included and excluded in review (n=2294). Breakdown of the types of articles that showed no evidence of implementation or application to real-world adaptation initiatives (n=1580)

4.2 Adaptation case studies

The majority of articles in this study were published between 2013 and 2018. Only seven articles were published between 2007 and 2012. The 110 case studies were diverse in regional focus, occurring most frequently in Asia (38.2%) and North America (30.9%), but also occurred in Africa (13.6%), South America (10.0%), and Australia and Europe (6.4% each).⁹ The United States was the most frequent country in the sample (15.5%), followed by China (9.1%), India (8.2%), and Bangladesh, Canada, Mexico, and South Africa (5.5% each).

Case studies were wide ranging in terms of approach, objective, and content. Some initiatives involved concrete actions (e.g., building a coastal sea wall) and others described an approach to conducting activities (e.g., adaptive management). All cases combined multiple adaptation activities, ranging from 2 to 24 types with an approximate average of 8. Most case studies (80%) combined activities across the three top-tier categories of adaptation activities: 1) social, 2) institutional, and 3) physical and structural (see Table 1). Social activities were further divided into educational, informational, and behavioral subcategories. Institutional activities were broken down into economic options, laws and regulations, and policies and programs. Physical and structural activities were further categorized as engineered and built environments, technological innovations, ecosystem-based adaptations, and services.

⁹ Some adaptation initiatives took place in more than one country; hence these percentages add up to more than 100%.

Social Adaptation Activities (404)		
Educational (114)	Informational (119)	Behavioral (171)
<ul style="list-style-type: none"> • knowledge sharing and learning platforms (43) • sharing local and traditional knowledge* (17) • awareness raising* (16) • extension services (16) • social learning* (11) • communication through media* (6) • integrating education into adaptation planning* (2) • participatory action research* (2) • gender equity in education* (1) 	<ul style="list-style-type: none"> • systematic monitoring and remote sensing* (44) • decision support tool (17) • developing an information sharing network (17) • using or developing longitudinal data sets* (17) • climate services (7) • early warning and response systems (6) • participatory scenario development* (5) • hazard, vulnerability mapping* (3) • integrating indigenous climate observations* (3) 	<ul style="list-style-type: none"> • crop switching (32) • crop patterns and dates (30) • soil, water conservation (22) • livelihood diversification (21) • changing livestock and aquaculture practices (19) • fertilizer and compost use (15) • reliance on social networks* (15) • accomodation* (10) • household evacuation, retreat, migration* (2) • human reproduction shifts (1)

Institutional Adaptation Activities (273)		
Economic Options (61)	Laws and Regulations (45)	Policies and Programs (177)
<ul style="list-style-type: none"> • subsidies, taxes, and financial penalties (19) • developing cooperative organizations (17) • marketing platforms (13) • microcredit and microfinance (7) • collective and revolving funds, savings groups (3) • insurance (2) 	<ul style="list-style-type: none"> • protected areas (15) • water regulations and agreements (8) • fishing and hunting quotas (5) • land easements and zoning (4) • technology transfer (3) 	<ul style="list-style-type: none"> • ecosystem-based management (41) • community-based programs (36) • adaptive management (18) • landscape and watershed management (17) • water management programs (16) • co-natural resource management (15) • disaster planning and preparedness (10) • fisheries management (10) • urban adaptation programs (6) • integrated coastal zone management (5) • adaptation plans, mainstreaming* (3)

Physical and Structural Adaptation Activities (241)			
Engineered and Built Environments (61) <ul style="list-style-type: none"> • water supply and irrigation systems (18) • water and pump storage (9) • storm, drainage, and wastewater management (9) • rainwater harvesting structures (8) • coastal protection (5) • sustainable roofs and buildings (4) • power plants and electricity grids (3) • road infrastructure (3) • flood and cyclone shelters (2) 	Technological Innovation (51) <ul style="list-style-type: none"> • genetics: crop/animal varieties (15) • information and communication technology (13) • conservation agriculture (6) • water saving/harvesting technologies (7) • renewable energy and biofuels technology (5) • traditional technologies (3) • food storage, agricultural equipment (2) 	Ecosystem-Based Adaptations (111) <ul style="list-style-type: none"> • ecological restoration (34) • increasing biological diversity (21) • agroecology and agroforestry (13) • erosion control (13) • shade trees, natural infrastructure (11) • controlling overfishing for the ecosystem (8) • ecological corridors (6) • ex-situ conservation (3) • fire reduction (2) 	Services (18) <ul style="list-style-type: none"> • emergency and health services (6) • municipal services (5) • social safety nets* (3) • cooling station (2) • food banks (1) • international trade (1)

Table 1: List of adaptation activities and amount of frequency in the dataset, divided into categories and subcategories based on the IPCC AR5 Report.

Of the three overarching categories, social adaptation activities occurred most often. Behavioral adaptations were frequently connected to changing agricultural practices, such as switching to new crops, modifying crop planting and harvesting behaviors, and implementing soil and water conservation measures. Other common social adaptation activities involved the provision of informational and educational support, such as working with extension services, developing decision support tools, and creating knowledge sharing platforms. The elevated number of social adaptation activities relates to the prevalence of agricultural practices in the sample, but also to the fact that the provision of information and education build capacity for other adaptation activities. For example, Serrat-Capdevila et al. (2009) outline a collaborative process to develop a decision support system for a river basin that spans the U.S.-Mexico border. This

initiative combined social adaptation activities—raising awareness, information networks, and scenario development—to inform institutional adaptation activities—landscape and watershed management and natural resource management programs. This process led to the approval of an Arizona State Legislature bill that gave regulatory powers to a local water district to influence land-use plans.

Institutional actions most often occurred within the policies and programs subcategory. These activities represented overarching approaches to adaptation, such as ecosystem-based management, adaptive management, resource management, and community-based programs. In a Colombian biosphere reserve, for instance, residents tested and implemented several agricultural, ecosystem-based, and infrastructural adaptation activities that were guided by community-based and collaborative natural resource management policies and programs (Borsdorf et al. 2013). These management approaches provided support for other tangible adaptations. Within the economic subcategory, financial incentives and penalties were the most common, along with the development of community cooperative associations and people's increased use of marketing strategies.

Physical and structural adaptations consisted of a diverse set of subcategories, among which ecosystem-based activities were most frequent. While general ecological restoration and conservation activities occurred most often, they were typically accompanied by more specific ecosystem-based activities. For example, Favretto et al. (2018) describe two thicket ecosystem restoration initiatives in South Africa using spekboom, a native succulent plant. In this case restoration efforts supported two other ecosystem-based activities: increasing biological diversity and improving land

degradation through erosion control. Other common activities in the physical and structural category included building water provision and infrastructure systems within the engineered and built environments subcategory and developing new information and communication technologies within the technology and innovation subcategory.

Dividing adaptation initiatives into categories is helpful in showing patterns among commonly effective activities. However, no activity occurred in isolation and 71.8% of all case studies combined activities across the three main categories.

Agricultural activities in the social category were often affiliated with the creation of cooperative associations and improved access to markets and marketing strategies in the institutional category and implementing agroecological practices and developing new crop varieties in the physical and structural category. Likewise, information networks, decision support tools, extension services, and knowledge sharing platforms (social) frequently occurred in conjunction with community-based management programs, cooperative organizations, and marketing strategies (institutional). Ecosystem-based, landscape and watershed, and water management programs (institutional), occurred together with collecting monitoring and remote sensing data (social) and ecological restoration and increasing biological diversity (physical and structural) (see Figure 2). Some adaptations built on the foundations of prior activities and others laid the groundwork for future activities. All of them contributed towards the effectiveness of a particular initiative in a given space and time.

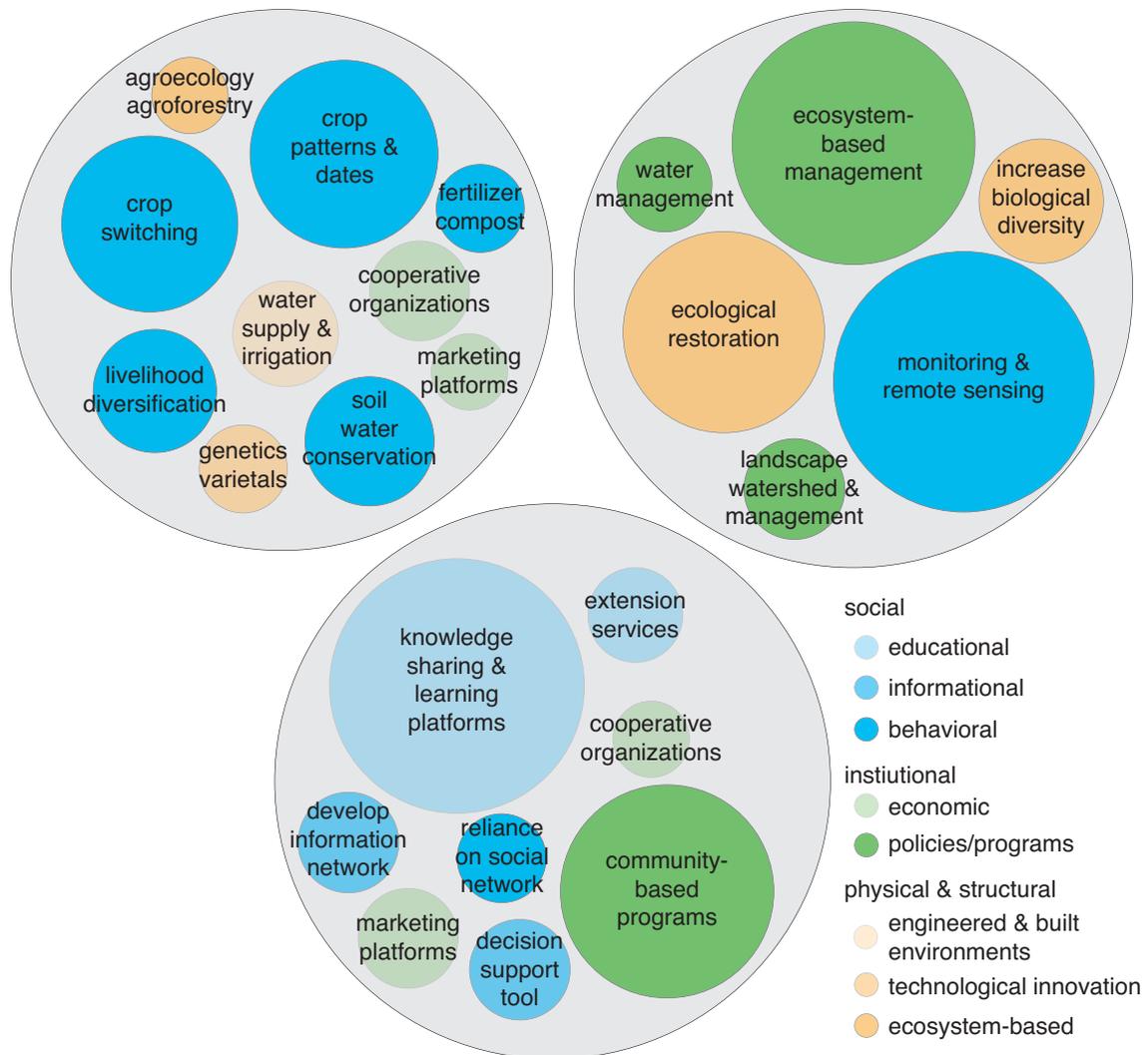


Figure 2. Sample clusters of adaptation activities that often occurred together. Activity circles are color coded based on adaptation categories and are sized relative to their prevalence in the dataset.

Several activities indicated in the original IPCC list never appeared in this dataset. These included disaster contingency funds, laws defining building standards, technologies for building insulation and cooling systems, assisted migration, and vaccinations. Other activities occurred only once or twice such as the use of climate or weather insurance, retreat and migration, flood/cyclone shelters and cooling stations, and fire reduction techniques. Their infrequency does not necessarily imply ineffectiveness; it may instead indicate that these activities have yet to be implemented and evaluated or

that researchers did not categorize them as climate change adaptation. Both factors would exclude them from this study.

4.3 Effectiveness

Indicators of effectiveness were based on improvements in elements of resilience, vulnerability, capacity, and/or preparedness, in one or more of the following ways: a) reducing risk to climate change impacts; b) enhancing social relationships and community well-being; c) improving ecosystem health, environmental quality, and natural resources; d) increasing people’s income and access to economic resources; and e) strengthening institutional connections, influencing policies and improving governance practices (see Figure 3 and Table 2). More than three-quarters of cases revealed effectiveness across multiple indicators. Some case studies showed indicators of effectiveness using quantitative measures and others used qualitative descriptions of improvement. I counted both types of indicators equally.

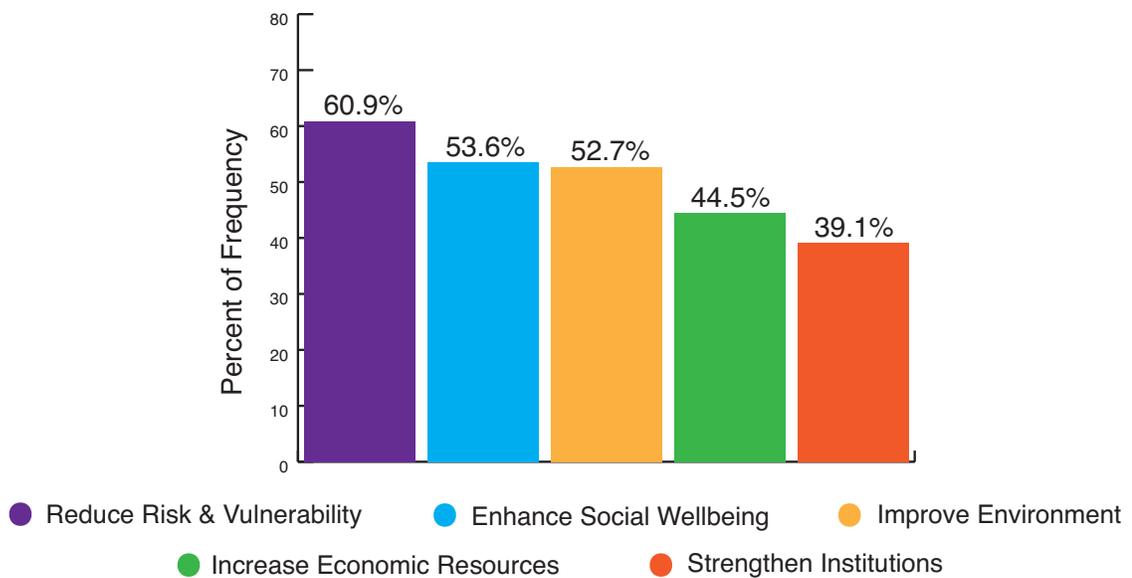


Figure 3. Percent of frequency for the five indicators of effectiveness

<i>Type of effectiveness</i>	<i>Indicators addressed</i>	<i>Examples of activities</i>
<i>Reduce risk and vulnerability</i>	biophysical and social vulnerability to potential climate hazards	new reservoirs and irrigation systems; efficient water use; rainwater harvesting; information and communication technologies; knowledge sharing platforms; early warning systems
<i>Enhance social wellbeing</i>	relationships, community building, collaboration, improved access to resources and information	cooperative associations; financial incentives; information sharing; social networks; changes in agricultural practice
<i>Improve environment</i>	ecosystem health, environmental quality, natural resources	ecosystem-based adaptations and policies, erosion control, restoration and conservation, adaptive management, fisheries management, biodiversity
<i>Increase economic resources</i>	income levels, access to economic resources	changes to agricultural, aquacultural, or livestock practices; livelihood diversification; cooperative associations; agroecology and agroforestry
<i>Strengthen institutions</i>	institutional policies, governance structures and practices, partnerships, conflict resolution	decision support tools, building information networks, fisheries co-management, community-based natural resource management

Table 2. Description of the five types of indicators of effectiveness and associated examples.

Most cases demonstrated effectiveness by *reducing risk to climate change impacts* (60.9%). Indicators of risk reduction involved addressing factors associated with vulnerability to potential climate hazards. Activities that regularly demonstrated risk reduction dealt with increasing availability of water resources by building new reservoirs and irrigation systems, using water more efficiently, and implementing rainwater harvesting. In China, for example, Li et al. (2018) showed that direct subsidies from the

Beijing government for water reservoirs and storage systems helped farmers reduce their exposure to drought. Another frequent set of risk reduction activities involved investing in information and communication technologies, knowledge sharing platforms, and early warning systems. Eakin et al. (2015) demonstrated that an early warning system in Chile alerted potato producers to protect their crops from potential pest hazards and disease outbreak. This form of information and communication technology had several positive effects including reducing the risk of potato blight.

Slightly more than half of the case studies demonstrated *enhancements in social relationships and community wellbeing* (53.6%). Indicators included an increase in cooperation, sharing resources, or improved access to resources associated with human wellbeing like food, water, land, and shelter. For example, in Pakistan, Sterrett (2011) demonstrated how structural adaptations increased food security for 50 village households, increased access to safe drinking water, reduced the workload of women who had to walk long distances to retrieve household water, and decreased the number of lives lost during a cyclone. Adaptations that Sterrett highlighted included enlarging water reservoirs, installing solar-powered water pumps for irrigation, establishing a plant nursery, and building an emergency shelter. Cooperative development practices and financial incentives also played substantial roles in improving social relationships. In Bolivia, local agricultural cooperatives provided farmers access to informational and physical resources to help them shift from monocultural farming to agroforestry involving cocoa trees (Jacobi et al. 2013). This adaptation created better working conditions (e.g., working in the shade rather than the sun and reduced chemical fertilizer

and pesticide use) and led to increased levels of self-organization among farmers who established their own extension and agricultural education service.

Improving ecosystem health, environmental quality, and natural resources also occurred in slightly more than half of the cases (52.7%). Indicators included halting land degradation, improving soil and water quality, restoring ecosystem functions, and increasing biodiversity. Unsurprisingly, ecosystem-based adaptations and policies were the most common in addressing environmental issues, such as erosion control, environmental restoration and conservation, adaptive management, and fisheries management. Ryan and Elsner (2016) for instance, showed that sand dams, a type of rainwater harvesting system, helped vegetation recover more quickly after periods of drought in Kenya. McCoy et al. (2018) showed that several water agreements in the Columbia River Basin in the United States reconnected multiple tributaries that helped restore fish habitat, resulting in increased Chinook salmon populations. Another case explained how a fishery on the western coast of the United States implemented co-management procedures that reduced the risk of overfishing seven groundfish species, as demonstrated by rising population numbers (Lubchenco et al. 2016).

Increasing people's income and access to economic resources occurred in slightly less than half of the activities (44.5%). Changes to agricultural, aquacultural, or livestock practices and livelihood diversification frequently led to economic benefits. In Brazil, a community-based fishing management structure was implemented in two aquatic reserves in the Amazon Basin. Freshwater fish populations more than doubled, leading to increased household income in surrounding communities over a period of five years (Oviedo et al. 2015). In the Philippines, Furoc-Paelmo et al. (2018) showed how the

introduction of a rubber-based agroforestry system increased household income in two farming areas. Part of the success stemmed from farmers' membership in organizations that helped them access credit, discounts on goods, and insurance.

Strengthening institutional connections, influencing policies and improving governance practices occurred least often (39.1%). Indicators included the creation of new partnerships, improved institutional relationships, conflict resolution, increased local participation and autonomy, and changed governmental structures. Activities in this category commonly relied on collaboration between people from different institutional and cultural backgrounds, such as developing user-friendly decision support tools, building an information network across organizations, or implementing community-based fisheries and natural resource management strategies. For example, a co-management approach to mangrove restoration in Vietnam led to the formal recognition of a group of local resource users who were able to negotiate an agreement to secure their own land use and protection rights (Schmitt 2013). In St. Vincent and the Grenadines, a network of several institutions and community organizers was strengthened through efforts to fund and build a solar-powered desalination plant to increase local freshwater availability and future water security (Jaja et al. 2017).

Which adaptation initiatives were the most effective? Eleven activities occurred more frequently than average in the dataset (greater than 11 occurrences) and had higher than average rates of effectiveness across three or more indicators (see Figure 4). Several of these activities were related to the exchange of information and social resources, including the development of cooperative organizations, extension services, reliance on social networks, community-based adaptation programs, and sharing traditional and local

knowledge. Other adaptations were connected to economically-based activities, including increased access to markets and marketing strategies for products and services, diversifying livelihood and sources of income, and implementing financial incentives and penalties. Still others were connected to agricultural practices, such as implementing new agroecology and agroforestry techniques, building new water supply and irrigation systems, and changing fertilizer and compost strategies.

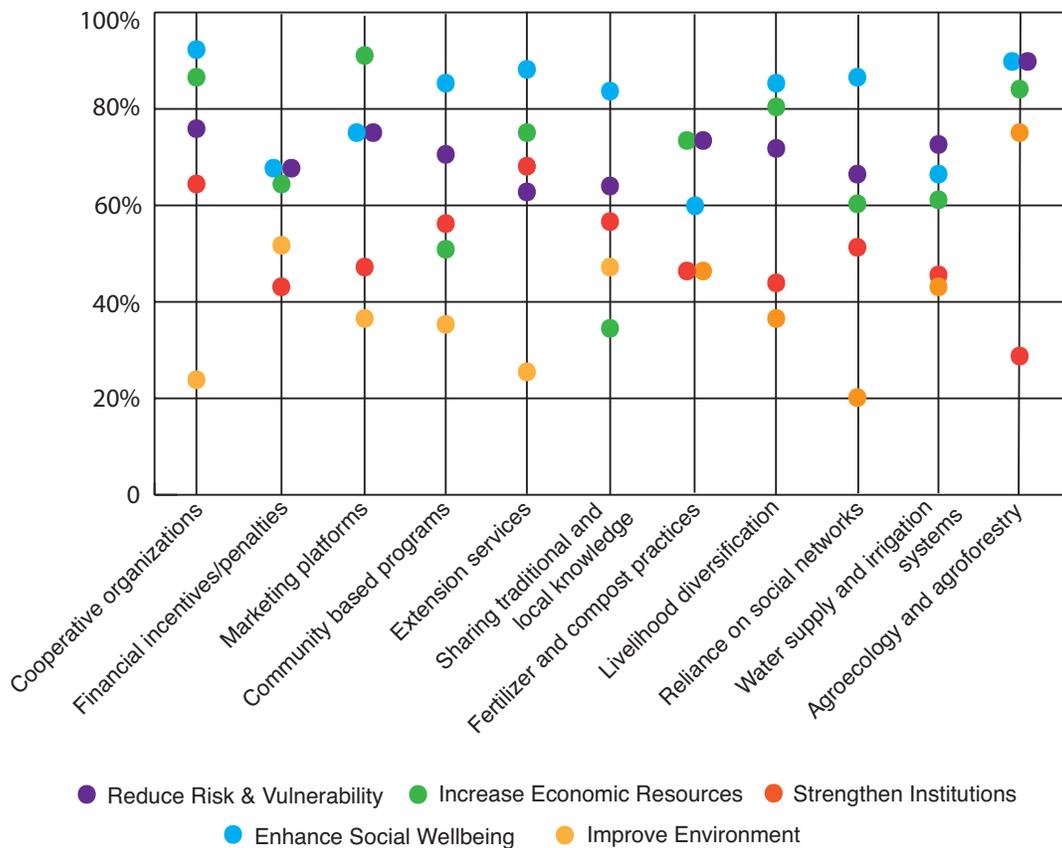


Figure 4: Most effective adaptation activities in the dataset. Activities occurred more frequently than average (>11 occurrences) and had higher than average rates of effectiveness across three or more indicators.

Two activities demonstrated high effectiveness across four indicators: developing cooperative organizations and implementing agroecology and agroforestry practices.

Developing cooperative organizations were highly effective in risk reduction and enhancements in institutional, social, and economic factors. In Uganda and Kenya, for example, Ombogoh et al. (2016) found a positive relationship between farmer cooperatives, collective action, and increased adaptive capacity. Members of the farmer cooperatives met regularly to share their knowledge and skills regarding agricultural production technologies, soil and water conservation, and agroforestry techniques. They often pooled their resources to buy fertilizer and seeds, which helped farmers who could not afford these inputs at the beginning of a planting season. Another form of support was labor-sharing during intense planting and harvesting seasons.

Agroecological and agroforestry techniques were highly effective at reducing risk and improving social, economic, and environmental conditions. Furoc-Paelmo et al. (2018), for example, demonstrated how rubber-based agroforestry practices in the Philippines, such as intercropping fruit trees with rubber trees, reduced the occurrence of pest and disease outbreaks, increased yield of latex, diversified sources of income, and improved soil quality. These activities illustrate the potential of adaptation activities to address multiple issues simultaneously.

Regarding justice, approximately one-third of authors in this review noted that fairness of outcome distribution or in representation, autonomy, or decision-making authority during the adaptation process were important components of effectiveness. For example, authors identified the need to demonstrate: diversity of voices and representation in decision-making processes (Schmitt et al. 2013); institutional and governmental policies to help those who were resource-constrained (Abid et al. 2016); equitable distribution of outcomes across populations (Lubchenco et al. 2016; Acevedo-

Osorio et al. 2017; Diedrich et al. 2017); remedies for unbalanced and unfair power relations (Ford et al. 2013; Phuong et al. 2018); and increased representation of multiple types of knowledge and expertise used to guide activities (Schmitt et al. 2013; Schemmel et al. 2016; Jaja et al. 2017).

However, only 14 case studies (12.7%) provided qualitative or quantitative evidence of justice. Of these 14 cases, the majority occurred when activities were community-based efforts and incorporated knowledge sharing platforms or information networks. Indicators of justice included diversity of representation in project management and design (e.g., Osbahr et al. 2010; Alessa et al. 2016); equitable access or fair distribution to resources (e.g., Padulosi et al. 2013; Ombogoh et al. 2016); mechanisms to ensure a diversity of opinions were expressed (e.g., Barrios et al. 2009; Butler et al. 2016); and local ownership of resources and data and leadership in decision-making institutions (Osbahr et al. 2010; Cao et al. 2018). In one case, Cao et al. (2018) compared two grassland management patterns that had evolved in China to determine which would lead to a more resilient socio-economic system. One pattern was a multi-household management plan (MMP), where grasslands were jointly managed by one or more households. The other was a single-household management plan (SMP), in which one household was in charge of an often-fenced area of grassland. Informal institutions arose among and between MMP household members. Often, these institutions helped provide flexible regulatory structures and resources to implement locally appropriate sustainable management practices, both of which led to improvements in the grassland ecosystems. These institutions helped provide more equitable and fair access to grassland resources, especially for raising livestock. In addition, these informal groups ran efficiently and did

not require much input in terms of time or labor resources. Plant and soil conditions under the multi-household management plan were shown to be more sustainable for future use than under the single-household management plan. In this case, diversity of representation and a focus on equitable resource access were factors that lead to effective adaptation strategies.

5. Discussion

Taking steps to implement climate change adaptation is urgent and necessary. Scientific consensus clearly indicates three key messages: 1) climate change is happening and becoming worse; 2) the impacts are costly, not only economically, but in terms of damages to ecosystem functioning and human wellbeing; and 3) technology, science, and policy innovations can help society mitigate carbon emissions and adapt to change (IPCC 2018; USGCRP 2018). Adaptation activities enacted now can have immediate and gradual impacts on social, economic, political, and environmental systems. In this paper, I take current stock of effective adaptation initiatives documented in the research literature. This exercise illuminates several attributes that aid and hinder effectiveness of adaptations and points to themes for further investigation. The following discussion delves further into lessons learned about adaptation from the activities in this study and guidance to help move the field of evaluation for adaptation forward.

5.1 Practicing adaptation

Given the confusion regarding what constitutes adaptation, the act of categorizing effective examples in practice can be clarifying. Adaptation activities that were most

frequently represented in this systematic review were community-based programs, ecological restoration, knowledge sharing and learning platforms, and changing crop types and planting and harvesting practices. While these activities demonstrated improvement in at least one category of effectiveness (that is, they reduced risk and vulnerability, developed resilient social systems, improved the environment, increased economic resources, or enhanced governance and institutions), several activities indicated effectiveness across multiple categories. Agroecology and agroforestry practices enriched soils, conserved water resources, and improved livelihoods and working conditions (Jacobi et al. 2013; Furoc-Paelmo et al. 2018). The development of local cooperative associations improved individual and community access to resources, improved livelihoods through offering financial assistance and increasing income levels, and facilitated learning and knowledge sharing within and across communities (Magombeyi and Taigbenu 2008; Phuong et al. 2018). Fisheries management, particularly fisheries co-management practices, improved institutional relationships, increased income, enhanced local community networks and resource access, and restored fish populations (Castrejon and Defeo 2015; Schemmel et al. 2016). Agricultural extension services increased crop and livestock yields and provided platforms for sharing knowledge about planting, production, and harvesting techniques (Padulosi et al. 2013; Elahi et al. 2018). New livestock and rangeland practices resulted in ecological restoration and improved relationships between organizations and individuals involved in land management (Cai et al. 2015; Cao et al. 2017). Central components of these activities draw attention to joint or collective decision-making; community-based and institutionalized techniques for sharing physical, financial, and informational resources; and techniques that aim to

improve human wellbeing, institutional relations, and environmental security. These examples suggest that adaptation activities can—and should aim to—achieve multiple objectives simultaneously.

The act of categorizing activities and their effectiveness also brings clarity to the choices researchers make when analyzing success and highlights the factors they omit. For example, several authors in this study considered a reduction in biophysical risks to climate change successful but ignored the systemic factors that produce underlying vulnerabilities. In coastal Bangladesh, Chow (2018) showed how a mangrove rehabilitation effort aided shoreline stabilization and helped control erosion, which reduced the risk and vulnerability faced by rural, coastal populations. Land stabilization helped these communities maintain their livelihoods and everyday practices. However, in this particular case, the author did not demonstrate how stabilization practices will mediate other factors that caused coastal erosion in the first place. Mangrove rehabilitation may become ineffective if the processes that cause erosion are not also addressed. Schmitt et al. (2013) also evaluated mangrove restoration practices but considered the causes of land erosion as well. They illustrated how the practices of a clam cooperative located along one part of the coast in Vietnam intensified land erosion in another community. Coastal resource users designed and implemented a co-management strategy with the clam cooperative in which the cooperative hired members of the community to rehabilitate and maintain a mangrove forest that would buffer erosion. This strategy stemmed the cause of land erosion, improved ecosystem function, allowed the clam cooperative to continue operations, and diversified income streams for hired community members. Effectiveness, therefore, can be measured in multiple ways. Some

adaptation initiatives in this study are only effective at addressing the symptoms of climate change but ignore other root causes of risk, vulnerability, and exposure. Others demonstrate solutions to address the symptoms and the root problems themselves.

Caution must be taken in how success is measured and determined.

Furthermore, it is important to remember the fluctuating and cyclical nature of adaptation. As Ford et al. (2013) illustrate, risk and vulnerability shift through time and space. Effectiveness in one moment of time does not signify long-term success, just as effectiveness in one community does not indicate success in a different community. Several authors identify the need to incorporate long-term monitoring and data collection into evaluation to understand how multiple stresses interact temporally. Fidel et al. (2014) showed how an adaptive co-management program designed to regulate walrus hunting practices in Alaska was “born from a history of conflict” between an indigenous community, the United States Fish and Wildlife Service, and the Alaska Department of Fish and Game (63). Local representatives from these organizations said the system has shown promise, although they recognize that this success is predicated on communication between organizations remaining open and the continued equal representation of all parties. Activities frequently represented in the present study such as resource co-management, cooperative development, and agroecology techniques do not guarantee the reduction of future risk or vulnerability nor will they be effective in every instance.

Finally, my analysis reveals important gaps and shortcomings within current adaptation practices in regard to justice in terms of distribution of benefits and empowerment within adaptation processes. An emerging theme in this literature calls for diversity in representation of the knowledge and expertise used to guide adaptation

initiatives. For example, Alessa et al. (2016) showed how indigenous observing networks—sets of human observers who monitor environmental variables in the Arctic—were collaboratively developed across communities in the region, to ensure that the collected data was relevant, and the methods were culturally appropriate. Data from these networks have informed more equitable natural resource management policies. Another theme considers the fair distribution of beneficial outcomes across populations. In Uganda and Kenya, Ombogoh et al. (2016) show how members of farmer cooperatives pooled their resources to buy fertilizer and seeds, helping those who could not afford these inputs at the beginning of a planting season. Cooperative members also initiated labor-sharing pools during intense planting and harvesting seasons. These activities helped ensure a balanced distribution of community resources. A third theme examines unbalanced power dynamics. On the central coast of Vietnam, farmer-to-farmer learning platforms generated improvements to poultry production practices (Phuong et al. 2018). These platforms were propelled by local expertise and customs and disrupted “hierarchies of knowledge” and “moderated imbalances of power” (892). Several articles in this study demonstrate awareness of issues relating to justice in adaptation, but only a few offer solutions to address them.

Acknowledging the role justice and fairness in adaptation and evaluation is only the first step. As Ford et al. (2013) argue, “issues of scale, power, and colonialism are central to vulnerability research,” which underpins and guides many adaptation initiatives (1196). Uncovering these underlying influences points to avenues for further research and action. In the field of evaluation, several indicators could help monitor trends regarding adaptation justice. These indicators could uncover patterns in: leadership; decision-

making processes; exclusion from leadership or decision-making; communication and accessibility; the types of knowledge used and considered valid; and the equitable of distribution of benefits.

5.2 Improving the practice of evaluation for adaptation

Evaluation should be recognized as an inherent part of the adaptation process. While there is general agreement about this statement within the adaptation community, agencies including the UNFCCC and the IPCC continue to express hesitancy; they state that they do not know the right indicators and metrics to measure success. Based on established evaluation practices in the fields of international development, ecology, and extension services, as well as the growing number of frameworks from within the adaptation community, there is enough information to guide appropriate design for formative evaluations that aim to improve adaptation efforts. Every case in this study shows that lessons learned from evaluation can guide future initiatives. Incorporating summative evaluation to demonstrate progress and accountability is also an attainable objective. Hicks et al. (2016), for example, aggregated a selection of promising qualitative indicators that can indicate progress within the realms of well-being, fundamental human rights, agency, power, and equality. Other scholars have developed numerous quantitative metrics to demonstrate effectiveness at multiple scales and across economic sectors and agencies (see Christiansen et al. 2018).

What remains unestablished—and adds to the IPCC and UNFCCC’s hesitancy—are agreed upon indicators and metrics to compare outcomes across adaptation initiatives (Bours et al. 2013; Arnott et al. 2016). While many adaptation organizations desire

standardized indicators and metrics to guide funding and policy decisions, the feasibility of standardizing evaluation is questionable (Christiansen et al. 2018). Given the multiplicity of definitions, objectives, approaches, ontologies, and epistemologies inherent within adaptation shown in this study, there is currently little evidence to support the practicality, usefulness, or need for standardized evaluation. Rather, metrics, indicators, and frameworks should be flexible enough to fit various social, environmental, and political contexts. Design and methods should be grounded in the expertise and needs of those involved in the adaptation initiative. Metrics and indicators should be culturally appropriate and meaningful to local participants. In addition, adaptation practitioners must consider the realistic time, funding, and technological capacities required for monitoring data collection and analysis. Within the evaluation process, the complexities of adaptation should be embraced, not erased.

This discussion confirms the importance of understanding different motivations for using evaluation in adaptation. Standardization commonly stems from a desire to compare economic efficiency across projects and can be tied to a universal monetary value, with the goal of guiding funding and policy decisions (Ford et al. 2013; Möhner 2018). Using standardized metrics and indicators to compare degrees of reduced risk and vulnerability or increased resilience and capacity across projects is more difficult. Each of these adaptation goals draw on heterogeneous cultural, social, values that are highly contextual and not universal. Evaluation encourages accountability by making people delineate connections between their intentions, actions, and outcomes. Adaptation researchers and practitioners are doubly accountable—both to funders (in terms of demonstrating economic value) and to the communities and systems at risk (in terms of

demonstrating tangible social and environmental improvements). Due to the growing urgency of climate hazards threatening human and environmental systems, evaluation should prioritize the values and needs of the people and systems at risk before generating standardized values. In addition, adaptation policy-makers and funders could place more value on tangible demonstrations of social and environmental improvements to guide their funding and policy decisions. Perhaps over time and through the routine practice of evaluation, appropriate methods, indicators, and metrics will emerge that make sense for standardized use in adaptation policy.

6. Conclusion

The research literature clearly outlines the complexities and challenges of defining adaptation, outlining its objectives, and demonstrating progress toward meeting those goals. The plurality of overlapping frameworks, contexts, and definitions can be overwhelming. But, as Schipper and Langston (2015) emphasize, these complexities should not lead to paralysis of action. While there is no standardized or single best method to frame adaptation, implement action, or approach evaluation, researchers and practitioners can work with the multiplicities inherent to adaptation by making their assumptions, values, and notions of progress explicit and balancing those conceptions with other ways of knowing and understanding. This paper takes stock of adaptation initiatives in practice and presents a snapshot of how effectiveness is currently documented. My analysis offers clarity on what constitutes effective adaptation, identifies emerging research gaps, and suggests ways to establish routine evaluation in practice.

Common attributes of activities that were effective across multiple indicators include collaborative decision-making; approaches for sharing physical, financial, and informational resources; and techniques that simultaneously enhance human wellbeing, institutional relations, and environmental security. Effective adaptation activities tend to be synergistic and build upon each other; no single activity is successful in isolation. Additionally, effectiveness can be measured in multiple ways. Adaptation objectives should ideally address the root causes of climate risk, vulnerability, and exposure, in addition to addressing climate impacts. Longitudinal monitoring and data collection will reveal differences in effectiveness through space and time.

Regarding emergent research needs, scientists who claim to inform climate change adaptation must engage more directly with other members of society and document this engagement in the research literature. To address pressing issues, it is no longer good enough to just produce strong science. Researchers need to follow through and show evidence of how their information used. Additional research gaps that emerged from this analysis call attention to issues of justice, including representation of diverse types of knowledge and expertise, fair distribution of adaptation benefits, and imbalanced power relationships within the adaptation process. Evaluation offers techniques to reveal issues in leadership, decision-making, access, and profit and to monitor progress towards developing more equitable adaptation practices. While evaluation is useful for adaptation funding and policy decisions, it should also be used to prioritize the needs and adaptation objectives of communities at risk.

Climate change is clouded in uncertainty—no one can currently pinpoint what will happen, when, or to whom. However, human society does have the scientific

understanding, technological capacity, and financial means to address climate change (IPCC 2018). Countless ideas, techniques, and opinions regarding how to address global and regional change exist, each based on multiple ways of knowing and being in the world, as well as different desires for the future. Systematic evaluation can help incorporate this diversity into well-informed, better planned, and more successful adaptation outcomes. Climate change demands society's immediate attention. Systematic evaluation can help regulate adaptation processes by tracking progress, seeking accountability, and guiding future actions.

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Supplementary Materials

1. Web of Knowledge Search Results

Inclusive dates: 2007-2018

climat* chang* adapt* effective* evaluat* = 991

climat* chang* adapt* effective* monitor = 489

climat* chang* adapt* effective* indicator = 346

climat* chang* adapt* effective* metric = 108

climat* chang* adapt* success* evaluat* = 532

climat* chang* adapt* success* monitor = 342

climat* chang* adapt* success* indicator = 193

climat* chang* adapt* success* metric = 68

Total citations returned = 3069

Duplicate citations returned = 719

Citations included in study = 94

2. Primary Inclusion Criteria:

- a. Evidence that an adaptation activity was implemented beyond development stages such as planning, information gathering, or analyzing potential options.
- b. The activity was implemented in response to climate change, at least partially.
- c. Quantitative or qualitative evidence of effectiveness or success as defined by the article authors.

3. Reasons for Exclusion:

- a. No evidence of application or use in climate change adaptation. No evidence of communication of information. No evidence that adaptation action was implemented beyond planning, assessing, modeling.
- b. Plant, animal, biological species, or genetic adaptation.
- c. Potential climate change adaptations discussed, such as planning, strategies, proposals. Implications of different adaptation options. No evidence of implementation.
- d. Decision support, projections, models, scenarios – potentially useful tools for planning adaptation. No evidence of implementation.
- e. Framework for best practices of adaptation, lessons learned, review of methods, reflections on adaptation process. No evidence of implementation.
- f. Climate change impacts – present or modelled description of climate change impacts. No adaptation action implemented.
- g. Vulnerability, risk, or other needs assessment. No adaptation action implemented.
- h. Perceptions of climate change or adaptation. Studied different perceptions about adaptation options or perceptions of impacts or risks. No adaptation action implemented.
- i. Evaluation developed, conducted, or ongoing regarding adaptation process. No clear evidence of outcome.
- j. Success of adaptation process only. No outcomes of implemented adaptation.
- k. Barriers to adaptation, not successful, or no clear evidence of success.
- l. Mitigation or climate dynamics only. No adaptation.

- m. Archaeological, paleological, or historical context only – not related to current climate change issues.
- n. Miscellaneous issues with article: no reliable translation, full article not available, technological patent, not related to climate change.

4. *Codes for outcome effectiveness/success*

- a. *Reduced vulnerability or risk*: demonstrated qualitative or quantitative reduction in vulnerability, exposure, or risk to impacts; avoiding danger, promoting security; reduced sensitivity to climate-related threats; increased adaptive capacity or preparedness
- b. *Environmental improvements*: increased environmental health, services, quality, resources, qualitative or quantitative
- c. *Social improvements*: community/individual development and wellbeing; strengthened relationships and cohesion; access to health services, food, water, education, and housing
- d. *Economic improvements*: measurable increases to income, diversity of livelihood, employment, access to economic services, reduction in poverty
- e. *Institutional, political improvements*: policy improvements; strengthening institutional relationships or cohesion; establishment of governance, political infrastructure, leadership, decision-making techniques

5. *Code for evidence of equity in adaptation outcomes*

Equity considers the equality of distribution of benefits from the adaptation activity, as well as distributions of decision-making power and representation during the adaptation process (Adger et al. 2005; Brooks et al. 2011). Examples include:

- a. Fairness of the rules by which decisions are made
- b. Distributional consequences and benefits of environmental decisions
- c. Aim to alleviate underlying and systemic vulnerabilities
- d. measures to reduce poverty and increase access to resources can reduce present-day vulnerability as well as vulnerability to climate
- e. Provision of greater degree of assistance to populations with high poverty rates.
- f. Ensuring that initiatives do not result in further marginalization or increase inequality.
- g. Aims to benefit populations or countries with low historical responsibility for anthropogenic climate change

6. *Full List of Adaptation Activities from IPCC 2014 Report (see Mimura et al. 2014) – My additions are noted*

Social Adaptation Activities

Educational: knowledge sharing and learning platforms; sharing local and traditional knowledge; awareness raising; extension services; social learning; communication through media; integrating into adaptation planning; participatory action research; gender equity in education

Informational: systematic monitoring and remote sensing; decision support tool; developing an information sharing network; using or developing longitudinal data sets; early warning and response systems; health early warning systems; participatory scenario development; hazard and vulnerability mapping; integrating indigenous climate observations; downscaled climate scenarios; community driven slum upgrading; community based adaptation plans.

Activities added: climate services

Behavioral: crop-switching; changing cropping practices; soil and water conservation; livelihood diversification; changing livestock and aquaculture practices; fertilizer/compost use; reliance on social networks; accommodation; silvicultural options; household preparations and evacuation planning; human reproduction shifts; retreat and migration

Institutional Adaptation Activities

Economic and Financial Incentives: taxes or subsidies; microfinance; penalty payments; insurance; payments for ecosystem services; revolving funds; savings groups; cash transfers; catastrophe bonds; disaster contingency funds; water tariffs

Activities added: developing cooperative organizations; marketing platforms

Laws and Regulations: protected areas; water regulations and agreements; fishing/hunting quotas; easements; technology transfer; land zoning; building standards; defining property rights and land tenure security; laws encouraging having insurance; laws supporting disaster risk reduction

Policies and Programs: community-based adaptation; water management programs; integrated water resource management; municipal water management programs; ecosystem-based management; integrated coastal zone management; adaptive management; landscape and watershed management; disaster planning and preparedness; community disaster management; fisheries management; urban adaptation programs; mainstreaming climate change; adaptation plans; urban upgrading programs

Physical and Structural Adaptation Activities

Engineered and Built Environment: water supply/irrigation systems; water and pump storage; rainwater harvesting structures; coastal protection structures; drainage; flood levees and culverts; storm or wastewater management; beach nourishment; power plants or electricity grids; road infrastructure; roof tops; flood/cyclone shelters; sewage; sustainable houses; building codes; floating houses

Technological Innovation: new crop/animal varieties; information and communication technology; conservation agriculture; renewable energy technology; water saving/harvesting technologies; efficient irrigation; genetic improvements; traditional technology use; biofuels; food storage and preservation facilities; new agricultural equipment; building insulation; cooling systems; early warning systems technology; hazard mapping and monitoring technology

Ecosystem Based Adaptations: ecological restoration; wetland conservation; afforestation and reforestation; conservation of mangroves; increasing biological diversity; erosion control; shade trees; controlling overfishing for ecosystem purposes; ecological corridors; ex situ conservation/seed banks; bushfire reduction and prescribed fire; green roofs; assisted migration; fisheries co-management; community-based natural resource management; adaptive land use management

Activities added: Agroecology and agroforestry

Services: municipal services; health services; enhanced emergency and medical services; social safety nets; cooling station; food banks and distributions of surplus; international trade; vaccination programs

7. Articles included in review

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APPENDIX B: CONTEXTUALIZING CLIMATE SCIENCE: APPLYING SOCIAL LEARNING SYSTEMS THEORY TO KNOWLEDGE PRODUCTION, CLIMATE SERVICES, AND USE-INSPIRED RESEARCH

Owen, Gigi, Daniel B. Ferguson, and Ben McMahan. 2019. Contextualizing climate science: applying social learning systems theory to knowledge production, climate services, and use-inspired research. *Climatic Change*. DOI: 10.1007/s10584-019-02466-x

Abstract

Scientists need to acknowledge the inherent social contexts that drive the scientific process if they want their research to improve complex societal problems such as vulnerability to climate change. Social interactions and relationships are essential elements for conducting use-inspired research, creating usable knowledge, and providing climate services. The Climate Assessment for the Southwest (CLIMAS) program was founded on theories of use-inspired research and co-producing knowledge with non-academic partners. A recent program evaluation illuminated gaps in these underlying program models and led to the inclusion of social learning systems theory and communities of practice. Using grounded examples, we demonstrate the CLIMAS program's ongoing role in fostering, maintaining, and expanding a climate resilience social learning system in the U.S. Southwest. Broader implications from the evaluation focus on the importance of establishing and maintaining relationships, increasing institutional and individual flexibility in response to change, and improving the practice of transdisciplinarity. These findings inform new program evaluation metrics and data collection techniques. This paper contributes to current theory and practice of use-inspired science and climate services by identifying and demonstrating how social interactions inform climate knowledge production. The reconceptualization of the CLIMAS program as part of a growing regional social learning system serves as an

example for similar types of programs. We encourage climate services and use-inspired research programs to explore applications of this framework to their own operations.

Keywords: social learning systems, communities of practice, climate services, use-inspired research, evaluation

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1. Introduction

Seasonal and annual climate variability, extreme weather events, and long-term climate change present complex challenges to society. As climate problems have grown more acute—including increased risk of floods, droughts, sea level rise, and wildfires—subsets of the climate research community are focused on ways to make their research more responsive to societal needs. These efforts show that addressing complex problems requires re-thinking conventional modes of knowledge development. The standard linear model of science assumes that scientists will develop a wellspring of knowledge to advance social goals, while remaining isolated from specific applications of their work (Guston 2000). In contrast, value-laden problems like climate change call out the need for socially-engaged research processes to generate “use-inspired” (Stokes 1997) knowledge

that is useful-for and usable-by society to confront these so-called wicked problems (Head 2008).

Several scholars have outlined overlapping theories, approaches, and processes for conducting useful research and providing effective climate information services (e.g., McNie 2013; Kirchoff et al. 2013; Wall et al. 2017). Broadly defined, climate services are climate data and information products designed to support decision-making and planning (Hewitt et al. 2012). Climate science is rapidly advancing, but as Miles et al. (2006) note, its use in planning and decision-making has not kept pace—an observation that continues to be relevant today. Likewise, Lemos et al. (2012) refer to a “persistent gap between knowledge production and use” (789). Brasseur and Gallardo (2016) identify several critiques of climate services practice: stakeholder diversity remains unrecognized; products often do not meet user needs; and uncertainty in climate data presents particular challenges for their use. To be more effective, climate services and use-inspired climate research need to be better defined, monitored, and evaluated (Vaughn and Dessai 2014; Lourenço et al. 2016).

In 2012, the Climate Assessment for the Southwest (CLIMAS¹⁰)—a regional climate research and services program—initiated a long-term monitoring strategy to better understand the program’s impact on climate adaptation and resilience. This evaluation has led to: 1) an evolution of CLIMAS’s underlying program theory to include social learning systems theory; 2) articulation of the specific roles CLIMAS plays in a social learning system for regional climate resilience; and 3) improved monitoring practices to better assess the CLIMAS program’s value and impact.

¹⁰ All authors of this paper are members of the CLIMAS team and receive funding from the CLIMAS program through the Climate Program Office at the National Oceanic and Atmospheric Administration.

In this paper, we first review the theoretical principles of use-inspired research upon which the CLIMAS program was founded. Drawing on our program evaluation and literature about social learning systems and communities of practice, we offer a revised conceptual model of CLIMAS's program theory. We illustrate this new framework by translating its theoretical principles into practice. Using five examples, we show how the CLIMAS program actively participates in a social learning system for regional climate resilience. We indicate how our evaluation findings and application of social learning systems theory can inform other use-inspired research and climate service programs through increased emphasis on relationship-building, institutional and individual flexibility, and transdisciplinary practices. Finally, we reinforce the need to establish routine monitoring and program evaluation to advance social learning systems theory and create effective communities of practice.

1.1 Use-inspired research and knowledge production

Scholars from several fields have pushed beyond the idea that research meant to confront complex climate-related problems should simply be informed or inspired by potential use. A mature literature describes multiple pathways for achieving usable science (e.g., Dilling and Lemos 2011), actionable science (e.g., Beier et al. 2017), or usable knowledge (e.g., Clark et al. 2016). These pathways originate in the field of science and technology studies wherein researchers conceptualize interactions between science and society (e.g., Jasanoff et al. 1995; Biagioli 1999).

In the 1990s, several theories addressed the evolution of science in response to rising social and environmental issues. Funtowicz and Ravetz (1993) formulated the

concept of post-normal science, which was issue-driven and aimed to impact decisions and policy. Post-normal science required new methodologies, the legitimization of multiple forms of expertise, and stood in contrast to basic research, defined by Funtowicz and Ravetz as curiosity-inspired. Gibbons et al. (1994) identified a new form of knowledge production (Mode 2) that emerged from traditional scientific practice (Mode 1). They described Mode 1 research as conducted for the pursuit of knowledge itself and housed within traditional academic disciplines. Mode 2 was driven by societal context and characterized by transdisciplinarity and multiple sites of knowledge production. Like post-normal science, Mode 2 included a diversity of people and types of research in knowledge production (Nowotny et al. 2001). Other scholars further developed these models into interactive research frameworks for social and environmental sciences (e.g. Caswell and Shove 2000; Woolgar 2000). These ideas matured in tandem with rising societal and environmental problems of the era—a time period that coincided with the development of federally-funded research programs designed to inform climate policy and decision-making.

In traditional models of U.S. government-funded science, conceptual boundaries between research and application help ensure that science is not captive to political interests (Guston 2000). Over time scholars and practitioners have described permeable boundaries as a more apt metaphor when considering problem-oriented research (Cash et al. 2003; Agrawala et al. 2001). The concept of boundary organizations (Guston 2001) emerged as a structural means for better connecting science and society. For climate services and research organizations, Agrawala et al. (2001) described these connections

as an “end-to-end system running from climate researchers to consumers of climate information, and back again” (459).

Other constructivist ideas about science and society informed the development and ongoing evolution of climate service and research programs. Knowledge co-production (Lemos and Morehouse 2005; Meadow et al. 2015)—or processes that involve researchers and nonacademic partners working toward shared goals of producing robust, novel, and useful knowledge for real-world applications—remains an important touchstone. Similarly, repeated and sustained interaction between scientists and non-academic partners is important to maintaining healthy relationships that allow use-inspired science to occur (Lemos and Morehouse 2005; Gibbons et al. 1994).

Transdisciplinarity has emerged more recently in the U.S. as a framework for connecting research to societal challenges (Jahn et al. 2012; Mauser et al. 2013; Weichselgartner and Truffer 2015). Transdisciplinarity attempts “to link two processes of knowledge production: 1. a societal process, in which actors try to understand and tackle a particular societal issue, and 2. a scientific process, in which scientists design and conduct research on the societal issue” (Pohl et al. 2017: 44). These theories help contextualize the evolution of science for societal applications and have shaped the development of the CLIMAS program’s theory and practice for creating usable knowledge.

1.2 Historical Context of the CLIMAS program

In the mid-1990s, the U.S. National Oceanic Atmospheric Administration’s Regional Integrated Sciences and Assessments (RISA) program was established with a mission to improve the nation’s capacity to adapt to climate variability and change. RISA

supports climate research that encourages inter- and transdisciplinarity; is regionally-focused; encompasses climate variability and long-term climate trends; and emphasizes institutional learning and innovation (Meadow 2017). A fundamental tenet of the program recognizes that for societies to adapt to climate variability and long-term change, researchers must gather “knowledge about behavior, policy, institutions, and decision contexts because these aspects often affect the ability of society to respond to and incorporate climate knowledge” (Simpson et al. 2016: 3).

CLIMAS was established in 1998 as the second RISA-funded research team. The initial proposal—written by social and physical scientists at the University of Arizona—articulated a regional assessment program focused on “collection, interpretation, valuation, and communication of information of relevance to decision-makers, resource managers, and other interested individuals” in the U.S. Southwest (Bales et al. 1997: 3). CLIMAS has continuously evolved in terms of research questions, team composition, and approaches to conducting a sustained regional climate assessment. However, it has remained connected to two core principles about developing use-inspired knowledge established at the program’s outset: 1) “sustained interaction with stakeholders” and 2) “modifying science agendas in response to stakeholder needs” (Bales et al. 2004: 1728). Since the program’s inception, several CLIMAS researchers have articulated various methods, approaches, and concepts used in use-inspired, co-produced, and transdisciplinary work and reflected upon the effectiveness of these principles in practice (see Liverman and Merideth 2002; Lemos and Morehouse 2005; Guido et al. 2013; Meadow et al. 2015; Ferguson et al. 2016).

2. Program monitoring and evaluation

Investigating how these theoretical concepts work in practice is a worthwhile endeavor. Substantiating how use-inspired research, climate assessments, and climate services translate into demonstrable progress towards addressing climate-related challenges is becoming increasingly relevant (Corell et al. 2014). Scholars have described or tested evaluation frameworks and methodologies to measure progress towards climate change adaptation (e.g., Preston et al. 2009; Moser and Boykoff 2013); use-inspired climate research programs (e.g., McNie 2008; Ferguson et al. 2016); knowledge co-production (e.g., Fazey et al. 2014; Wall et al. 2017); and climate services (e.g., McNie 2013; Vaughn and Dessai 2014).

In 2012, CLIMAS implemented evaluation as a core component of the program, using a theory-based evaluation framework (Funnell and Rogers 2011). This approach entails defining a “theory of change” that connects a program’s actions to desired outcomes. Action-logic models are often the mechanism used to establish theories of change. Between 2012-2017, we identified 23 projects to include in the evaluation. Selection criteria included projects that engaged nonacademic partners and allowed for annual monitoring and data collection. Aided by our CLIMAS co-investigators, we designed evaluation research plans for each project using a series of action-logic models to articulate how program activities and outputs could lead to measurable outcomes (Ferguson et al. 2016). This process included defining contexts, research inputs, expected outputs, short-to-medium term outcomes, and broader impacts. Data measuring progress towards outputs and outcomes were collected via periodic semi-structured interviews with CLIMAS investigators in 2012 (15 interviews), 2014 (12 interviews), and 2017 (11

interviews), and annually through project reports between 2012-2017. In addition, two projects used online pre- and post-surveys (distributed between 2013-2017) and a follow-up survey (2018) in to collect data from 51 students who participated in annual CLIMAS training programs in conducting use-inspired science.

3. Evolving the CLIMAS program model by incorporating a social learning systems framework

The CLIMAS program evaluation revealed that our underlying theory about how the program functioned needed updating. The impact of the CLIMAS program could not be demonstrated using evaluation methods that characterized the program as a boundary organization, a one-time intervention, or a singular source of climate data. In the context of a regional climate program, improved technology for collecting, visualizing, and sharing information; observable impacts attributed to climate change and variability; and escalated public and private concern have contributed to an expanding network of people and institutions connected by climate-related problems. Network growth and iterative social interactions have led to increased knowledge usability and multiple sites of academic and non-academic knowledge production (Dilling and Lemos 2011). By creating new network connections, institutional boundaries become perforated and the need for a singular organization to pass information back and forth from end-to-end between science and society is no longer necessary. In this evolved context, organizations dedicated to increasing density of communication (Gibbons et al. 1994), expanding research participation to peer communities (Funtowicz and Ravetz 1993), and fostering iterativity and interaction (Dilling and Lemos 2011) are crucial. To harness diversity in

multi-sited knowledge production, CLIMAS researchers have embraced methods that move toward social learning¹¹ (Wenger 2000) and building knowledge systems (Van Kerkhoff and Szlezák 2006; Cornell et al. 2013) that support regional climate resilience.

A social learning system connects diverse ways of knowing to collectively evolve practice and thought (e.g., Wenger 1998; Pahl-Wostl and Hare 2004). These systems identify and respond to complex problems through social engagement and knowledge sharing. Learning occurs through shared interactions within communities of practice, which “are the basic building blocks of a social learning system because they are the social 'containers' of the competences that make up such a system” (Wenger 2000: 229). Communities of practice organize around emergent problems, interests, identities, and skills (Wenger 1998; Pahl-Wostl and Hare 2004). Membership is flexible, spanning across boundaries such as geographic location, academic discipline, or economic sector. Social learning occurs through iterative engagement within and across communities of practice. People share knowledge, expertise, and information needs, while learning from others’ expertise and about their needs.

These ideas have shaped the latest iteration of CLIMAS program theory, which is: repeated interactions between physical, natural, and social scientists and non-academic partners contribute to a flourishing social learning system comprised of researchers and practitioners who collaborate to address climate-related issues important to the U.S. Southwest. These interactions lead to three primary outcomes: 1) new use-inspired knowledge; 2) increased likelihood that this knowledge is useful and usable for decision-

¹¹ Wenger’s conceptualization of social learning systems and communities of practice emerges from information science and anthropology, but has been applied in several fields, including health, education, and business management.

making; and 3) enhanced capacity to develop usable climate knowledge and to utilize that knowledge. We refer to this conceptual model as a *climate resilience social learning system for the Southwest* (Figure 1).

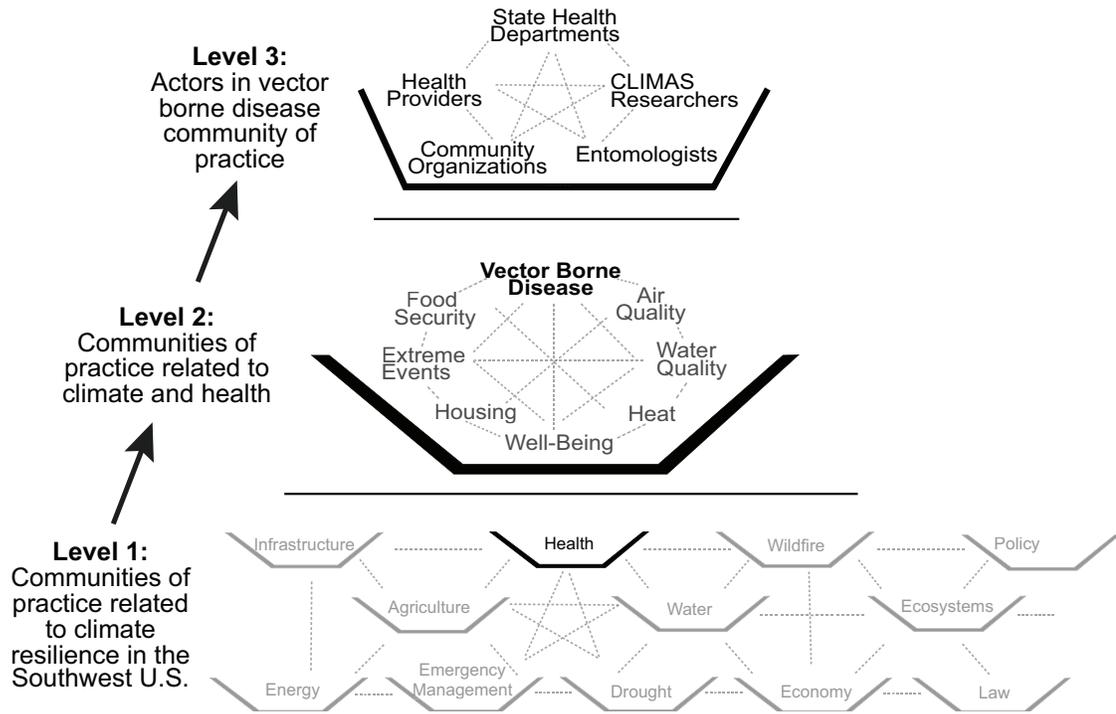


Figure 1. Conceptual model of a climate resilient social learning system in the Southwest U.S. Social learning occurs based on relationships and interactions within and across different communities of practice; level 1 illustrates a sample network of communities of practice working to address regional climate resilience issues; level 2 focuses on the health and climate community of practice, revealing eight more communities of practice, each addressing a specific human health issue; level 3 identifies groups of actors who work within a regional vector borne disease community of practice.

This social learning system is embedded in an extended network of individuals, groups, and organizations that aim to build regional climate resilience. Within the system, communities of practice cohere around climate-related challenges. Participation manifests in several ways, including funding projects, collaborating on research, and contributing or receiving climate information. Membership is dynamic and activity waxes

and wanes depending on stakeholder interests and needs. The social learning system provides a solid base that retains enough flexibility to respond to urgent information needs, emergent research priorities, novel funding opportunities, and policy decision frameworks. It works to connect diverse ways of knowing and producing knowledge within the network, to incorporate multiple viewpoints, enable new partnerships, and create space for transformation.

The climate resilience social learning system for the Southwest is not bounded. Social learning systems are simultaneously communities of practice themselves and nested “constellations of interrelated communities of practice” (Wenger 2000: 229). Shared practices, resources, tools, routines, language, interests, and histories create boundaries for each community of practice. These boundaries are negotiable and “rather fluid” (Wenger 2000: 232). Learning occurs through interactions within a community of practice (e.g., a deep dive into a particular way of thinking), and across these boundaries (e.g., as people are challenged to recognize new points of view, new approaches, and new problems).

A social learning system cannot be run by any particular organization—the CLIMAS program is one organization among many in the regional climate resilience social learning system. However, CLIMAS performs several functions within the system, carried out by the program’s researchers, including: fostering interaction within and across communities of practice; encouraging network growth; providing academic expertise and scientific information; and facilitating use-inspired research. CLIMAS also supports the system’s evolution by maintaining, analyzing, evaluating, and conceptualizing it as a whole. The rest of this paper further illustrates these functions by

drawing on examples from the program evaluation and tying them to social learning systems theory.

4. Social learning systems in practice: examples from the CLIMAS program

A social learning system framework illustrates pathways towards more useful research and climate services. Pahl-Wostl et al. (2007) note that “Bridging institutions play a major role in strengthening the generation of social capital and creating new opportunities and multilevel cooperation and learning. The question arises of how these characteristics are developed and sustained” (6). Clear demonstrations of the structural mechanisms that encourage the social interactions that inform knowledge production are needed (Kirchhoff et al. 2013). The primary purpose of the CLIMAS program is generating scientific knowledge. Here we describe five additional core functions that CLIMAS performs within the social learning system: communicating, convening, consulting, collaborating, and training.

4.1 Communicate

Communicating information to members of the regional social learning system is an essential component of CLIMAS. Every project in our evaluation (23/23) disseminates information such as research results, regional climate conditions, or seasonal outlooks. CLIMAS investigators aim to improve general climate knowledge, increase comprehension of specific climate issues, and inform decisions, planning, or policies. Communication and outreach often represent the initial social interactions people have

with CLIMAS and typify how the majority of people connect with the program (Ferguson et al. 2016).

Communication approaches include presentations and authoring technical reports, white papers, and peer-reviewed journal articles. Although journal articles are highly valued within academia, CLIMAS investigators produced 25% more technical reports and white papers than journal articles in the projects assessed. Scientific knowledge production is important, but a priority for CLIMAS investigators is providing information to people who will use it in practice—people for whom academic journals are not often accessible. CLIMAS communication approaches aim to reach broader portions of the social learning system using online communication platforms such as email list-servs, recurring newsletters, podcasts, blogs, websites, interactive data tools, news media, and social media.

Four CLIMAS projects focus on climate communication. Their central purpose is to distribute useful and usable information at intervals that mirror seasonal-to-interannual climate patterns. One such product is the *Southwest Climate Outlook (SWCO)*, a monthly newsletter focused on recent and future regional climate conditions. With approximately 1,600 subscribers, *SWCO* has helped establish the CLIMAS brand across the Southwest (Guido et al. 2013; Ferguson et al. 2016). *SWCO* stems from a project relatively early in CLIMAS history. Beginning with persistent drought conditions in the Southwest in 2002 and an interest in understanding and fulfilling regional needs for climate information, CLIMAS researchers collaborated with potential readers to design a monthly newsletter. The newsletter contained information on recent conditions, climate forecasts, and explanatory articles about the climate of the region. Since then, *SWCO* has evolved in

format and content by responding to reader feedback, advancements in technology, and increased online access. It has expanded into other forms of outreach including a monthly podcast, a series of online information hubs and a blog on the CLIMAS website, and a bilingual monthly outlook for the Rio Grande/Rio Bravo river basins.

Wenger (2000) identifies the need for artifacts (such as tools, models, and documents) and the importance of common language and knowledge to help maintain social learning systems. Our evaluation does not comprehensively measure the impact of *SWCO* and other CLIMAS communication efforts, but it provides evidence regarding how these communication products work to engage others, incite action, and reach new audiences within the regional social learning system for climate resilience.

Google and social media analytics show constant interest in *SWCO*, the blog, podcasts, and website content based on unique views, with spikes of interest leading up to annual climate events. Viewership intensifies in May, June, and July with the onset of seasonal extreme heat, the annual monsoon, and regional wildfires. Spikes also occur during occasional events such as the 2015-2016 El Niño. Regional journalists use CLIMAS communication tools to inform their work. Michael Crimmins, CLIMAS investigator and co-host of the Southwest Climate Podcast, has received an increasing amount of media requests, especially since the 2015-2016 El Niño. He says, “Weather has become the number one click-bait, so local newspapers have really stepped up their weather reporting. Some [reporters] listen to the podcast and then follow up based on some of the stuff we’ve talked about to help drive their writing and frame their interview questions” (personal communication, M. Crimmins, April 2017).

Key climate messages from these tools are redistributed by other members of the social learning system through their own social media or in presentations. For example, one user states, “I have used CLIMAS products since...2006. I have always found the *Southwest Climate Outlook* to be extremely informative, and a useful tool to communicate climate issues in the Southwest with our stakeholders. I’ve used the graphics in frequent presentations. I recently started listening to the podcast and have enjoyed that as well. CLIMAS is a great resource for distilling global and national products to services that impact the Southwest.”

CLIMAS communication products also inform decision-making about regional climate and impacts. For instance, members of the New Mexico Office of the State Engineer and the Interstate Stream Commission use *SWCO*’s diagrams of regional reservoir levels in presentations to the New Mexico State Legislature. They requested adding the Ute Reservoir along the Canadian River to the diagram because it was important to their policy discussions. *SWCO* also sparks engagement within the climate resilience social learning system. A phone call about inaccurate depictions of drought in the Four Corners region sparked a new CLIMAS research project, for example.

These outreach and communication tools serve as a form of engagement within the climate resilient social learning system. They maintain, align, and improve people’s knowledge of regional climate by providing information on a regular and expected basis and builds CLIMAS’s reputation for providing pertinent, timely, and reliable information.

4.2 Convene

CLIMAS connects people and organizations whose interests relate to climate. By creating opportunities and spaces for people and organizations to connect (online and in-person), convening activities facilitate social learning by “enabling a rich fabric of connectivity among people” (Wenger 2000: 232). Regular convening activities assist communities in developing a sense of joint initiative, accountability, and trust, as well as shared resources such as tools, languages, and projects. Approximately half of the projects included in this assessment (14/23) have a specific convening function such as network building or hosting events. CLIMAS acts as a connector between organizations and individuals, with the intent of maintaining a relationship or partnership beyond the life of a workshop or project.

One example comes from a project involving agricultural producers in southeast Arizona who wanted better tailored climate forecasts for their region. Their crops are sensitive to weather and climate extremes like freezes, hail storms, wind, floods, and drought. Forecasts can help growers prepare for these events, but the information is not always readily available or accurate enough. In 2014, the Tucson Weather Forecast Office of the National Weather Service (NWS) approached CLIMAS researchers and University of Arizona Cooperative Extension specialists to help build a stronger partnership with this agricultural community. These agencies convened a working group to assess information needs, provide training opportunities, and develop decision-support tools. Outputs included an email list-serv (which jumped to 100 subscribers in the first year and is now at 150) and new forecast visualizations for frost and freeze events.

The email list-serv maintained and facilitated by CLIMAS remains a linchpin of this working group, enabling direct discussions between NWS, growers, and resource managers about regional weather and climate briefings. Interactions are regular but fluctuate seasonally with regional climate events including spring frosts, fall heat waves, winter precipitation, and the summer monsoon. In-person and online feedback has improved forecasts and advanced notifications for freeze events are now timelier. The simple technology of the email list-serv has encouraged new relationships to develop.

Evaluation of this project shows how CLIMAS investigators helped build a community of practice around the need for accurate agricultural forecasts. A federal policy enacted in 1991 prevented NWS employees from providing tailored forecast services to specific sectors or individuals. A CLIMAS investigator notes that many regional agricultural producers said that this policy hurt their relationships with the NWS—they felt abandoned by their local offices (J. Weiss, personal communication, March 2018). When this policy changed in 2006, the NWS mission shifted toward increased engagement with sector representatives. The local NWS offices wanted to reestablish trust and communication with growers in southeast Arizona and asked to leverage CLIMAS's relationships and reputation with this community. Without this connection, NWS representatives would have had to build these relationships from scratch and would have had to find a different means of communication.

CLIMAS researchers participated in the working group primarily as a means to catalyze further partnerships, discussions, and interactions. By facilitating engagement, they helped to rebuild trust, a key component of a functional social learning system (Wenger 2000: 229). Agricultural growers now have a better working relationship with

local NWS representatives, who listen to agricultural needs and provide resources to help them deal with regularly occurring climate issues.

4.3 Consult

Almost all evaluated projects (21/23) incorporate consulting by providing tailored, expert advice for targeted audiences. Organization representatives identify information needs and seek expertise from CLIMAS investigators, who collect data and deliver findings, often as written reports or presentations. Investigators make their research skills and ties to academia available to others within a community of practice, who may not have the same time, data access, specific knowledge, or funding.

The length, breadth, and depth of consultations vary and interactions may extend to larger research collaborations beyond original requests. Consultation needs are generated through formal assessment activities including surveys, interviews, or facilitated group discussions, and informally through personal conversations. While the information produced is designed for a specific purpose, lessons from these exchanges are often transferable to people and organizations facing similar issues.

In 2014, CLIMAS investigators convened a workshop on public health and climate, which included representatives from the Arizona Department of Health Services (ADHS). ADHS was partnering with other researchers on extreme heat risk and exposure but expressed their need to know about other climate change impacts to health. CLIMAS researchers offered to assess potential health risks and to model projections of vector-borne diseases and Valley Fever in Arizona. For example, projections showed how increased seasonal temperatures would impact mosquito populations that transmit West

Nile Virus, but that these impacts would vary differentially by altitude (Roach et al. 2017).

ADHS representatives outlined their information needs, informed research questions, and verified emerging results from the health risk assessment and vector projections. CLIMAS researchers published their findings in academic journals (Brown et al. 2017; Lega et al. 2017) and co-authored public reports with ADHS representatives (Brown et al. 2016; Roach et al. 2017). ADHS representatives disseminated research findings within their organization and included them in statewide adaptation plans to address future health risks.

Within public health there are several established communities of practice. “I am in the engagement, vector-borne diseases and methods communities of practice—I don’t even know how many of these there are,” explains one CLIMAS researcher. “They are made up of your peers who are doing similar work in different places. Being an academic in this space is rare. Being an academic is a service in this case, in support of the work others are doing” (H. Brown, personal communication, April 2017). Consulting builds trust and confidence between members of a social learning system through an iterative practice of building shared knowledge for a particular purpose. In this case, members of a community of practice focused on human health invited CLIMAS investigators to help meet specific information needs. By following through on these research and information requests, CLIMAS investigators showed that they brought an added value to an already established community of practice.

4.4 Collaborate

Over half of the projects evaluated (16/23) are research collaborations between CLIMAS researchers and representatives from other organizations, agencies, and communities in the regional social learning system. Collaborations occur when “communities of practice deepen their mutual commitment” and include “exploring the knowledge domain, finding gaps in community practice, and defining projects to close these gaps” (Wenger 2000: 232). Collaborative projects are designed to generate mutually useful and usable research. Iterative and sustained collaboration between CLIMAS researchers and project partners provides opportunities for communication, feedback, and discussion. Collaborative research aims to produce information that impacts decision support, planning, policymaking, education, or awareness.

The lifespan of a collaborative project includes many stages from beginning-to-end. In these 16 projects, CLIMAS researchers were involved in all stages, while non-CLIMAS collaborators were involved in beginning stages (e.g., project brainstorming and developing research priorities) and/or later stages (e.g., co-authoring reports and papers and disseminating findings). Collaborators were typically less engaged during the research itself, such as research design, data collection and analysis, testing results, or evaluation. Project collaborations develop over time and often originate from previous interactions, including communication, convening, or consulting activities. Together, project collaborators learn about one another, build trust, determine the most useful products or research, and set realistic project outcomes.

In 2011, Federal Emergency Management Agency Region 9 (FEMA-R9) relied on weather forecasts to prepare for emergencies but recognized that climate forecasts

could help them identify potential disaster risk (Meadow et al. 2016). Representatives communicated with the Western Region Headquarters of the National Weather Service (WR-NWS) who contacted CLIMAS, sparking collaboration between these three organizations to develop a climate information tool for disaster preparedness. Through an assessment of information use and distribution within FEMA-R9 operations, the Watch Standers Office became the target audience for this climate service—they consolidate several sources of information about potential disasters and coordinate emergency response. Watch Standers outlined a product that synthesized climate trends and forecasts but did not know what specific information would be most useful. “It took a lot of discussion to figure out what kinds of decisions they wanted to make with this product, and why the 30-day forecast period was so important. There was a lot of back and forth” (A. Meadow, personal communication 2014). Together, CLIMAS, FEMA-R9, and WR-NWS developed a hydro-climate information dashboard with historical data, current conditions, future outlooks, and potential risks.

While the project established relationships across the three institutions, enhanced the usability of climate information, and improved climate awareness, the usefulness of the product remains unclear. As Watch Standers began to incorporate climate information, it appeared the dashboard did not match their needs. A better product would show analogies between current climate conditions and climate conditions that led to past emergency situations. “Unfortunately by then, it was too late. We were running on fumes of money and a wholesale revamp wasn’t possible” (A. Meadow, personal communication 2017). This project aimed to design a climate service by balancing the needs, capacity, and expertise of each organization. However, more time, interaction, and

product development were necessary. This example underscores the need for long-term, sustainable institutional relationships and flexible approaches to manage unexpected barriers. Nevertheless, results from this project have informed new collaborations with regional emergency managers.

4.5 Train

As a university-based program, CLIMAS seeks to build capacity to conduct use-inspired research. The program helps train current and future generations of researchers to apply interdisciplinary and transdisciplinary theory in practice. For graduate students, CLIMAS provides classroom and experiential opportunities including: a seminar presenting theory and case studies that connect science and decision-making; research assistantships on CLIMAS funded projects; and fellowships for students to conduct their own use-inspired research. Between 2012-2017, CLIMAS researchers taught 63 seminar students, hired 46 research assistants, and funded 16 fellows.

Many academic programs focus their training on preparing graduate students for academic careers, even though the job market for those who hold PhDs has diversified beyond the faculty track. Approximately 40% of current U.S. PhD graduates ever hold tenure track positions, but student training has remained relatively unchanged over the last several decades (NASEM 2017). These findings are reflected in our survey results that indicate most CLIMAS seminar students (90.5%) and fellows (93.8%) are not solely seeking academic positions after graduation, but are also interested in positions at non-profit, government, or other non-academic organizations. CLIMAS training efforts stem from the following principle—if students want to make their research useful and usable

outside of university settings, they must build disciplinary competence but also develop the skills to work with multiple kinds of experts and practitioners. Training focused on use-inspired climate research and services helps maintain and secure the longevity of the social learning system.

Disciplinary training is a necessary component of graduate and faculty development, however creating useful knowledge for social applications requires additional interdisciplinary training (e.g., training physical scientists in ethnography, discourse analysis, or survey administration); technical training (e.g., facilitating meetings or communicating to general audiences); and transdisciplinary training (e.g., assisting organizations on their research projects or seeking expertise from non-academics). These efforts consume time and compete with other expectations for graduate students and tenure-track faculty. Even after collaborations have been established, a partner's needs may not fit a university researcher's timelines, funding, or disciplinary interests. CLIMAS prioritizes interdisciplinary and transdisciplinary research and training opportunities that are not often present within traditional disciplinary boundaries.

The Climate & Society Fellowship was created in 2013 for graduate students to conduct use-inspired research and to develop science communication skills. Funded projects address research needs expressed by non-academic partners. For example, a project to quantify climatic drivers of forest growth grew from a partnership between a graduate student who studied paleoclimate and the Navajo Nation Forestry Department (NFD). The NFD wanted to know how regional climate and projected tree-growth would affect forests in the Chuska Mountains so they could develop a 10-year management

plan. The graduate fellow and NFD representatives collaborated on research questions and design, data collection, and production of a tree-ring and climate records database. One finding revealed that observed extreme drought conditions experienced over the past 1000 years represent expected average drought conditions by 2050 (Guiterman 2014). This project laid the groundwork for ongoing research collaborations and has resulted in additional funding from the U.S. Environmental Protection Agency, the Bureau of Indian Affairs, and the Navajo Nation.

In a recent follow-up survey, the majority of past research fellows indicated that lessons they learned about conducting use-inspired science, engaging stakeholders, communicating science, and collaboration have influenced their current career and research trajectories. Past fellows have collectively received approximately \$500,000 in grants to extend their work beyond their original one-year projects.

5. Implications of adopting a social learning systems framework

The CLIMAS program evaluation led us to re-frame our conceptual model for conducting use-inspired research and providing climate services. Instead of assessing the program as a singular institution, we have come to view the program as inseparable from the larger knowledge system. While CLIMAS cultivates, maintains, and benefits from a social learning system, it does not drive the system. Several organizations, individuals, and communities of practice within the system symbiotically influence and motivate one another; therefore, the outcomes and outputs are not tied solely to the efforts of CLIMAS but to the efforts of several people and institutions involved. The following discussion

explores broader implications of the social learning system model to inform similar programs that conduct use-inspired research and produce climate services.

5.1 Increasing flexibility

Climate service and research organizations should aim to become more flexible regarding their desired goals and outcomes. CLIMAS projects in this evaluation were designed to develop useful research and products using explicit co-produced and transdisciplinary processes, however, several researchers noted that they did not achieve all their project goals. As one researcher states “You can have the most perfect process and it still doesn’t work out” (A. Meadow, personal communication, April 2017). Falling short of project objectives does not always equate to failure or signify that products or research outcomes are not useful or usable. A social learning system is dynamic—it is constantly shifting as new knowledge is developed, artifacts are produced, and social relationships deepen (Wenger 2010). Researchers must negotiate changes such as expected length of time to reach a goal, personnel changes within partner institutions, or sudden revisions to project funding and governmental policies. Political, social, economic, and environmental factors can unsettle the best laid plans. Project goals, products, or processes must be dynamic to accommodate these evolving contexts.

Increasing flexibility can be implemented at both organizational levels (McNie et al 2016) as well as personal levels (Lemos and Morehouse 2005). McNie et al. (2016) argue that becoming more responsive to “users’ needs, developing problems, and emerging research windows of opportunities requires higher degrees of organizational flexibility” (890). Use-inspired research and climate service programs should provide the

time, space, and economic resources to allow researchers to change course as necessary, in response to shifting user needs, unexpected challenges, and windows of opportunity. Individual researchers should be encouraged to reflect upon and learn from unmet project goals to improve future research processes and objectives. Within the context of climate resilience and adaptation, projects, people, and institutions must themselves be flexible, resilient and adaptable to change.

5.2 Establishing and maintaining relationships

Social learning systems emphasize the importance of relationships. Gibbons et al. (1994) argue that knowledge production “is above all embodied in people and the ways they are interacting in socially organized forms” (17). Organizations in the field of use-inspired research and services must develop and maintain relationships that are grounded in trust and accountability. This evaluation shows how the CLIMAS program establishes, maintains, and improves relationships with individuals and climate-related organizations in the Southwest. These relationships form the foundation of an effective use-inspired research or climate services practice.

Relationships can be individual as well as institutional. Folke et al. (2005) indicate that one role of organizations is to store collective memory and mobilize these experiences to address new challenges, future uncertainties, and changes. CLIMAS and similar organizations accumulate collective experiences through their research, relationships, and institutional credibility. As shown in section 5.2 with agricultural producers and the NWS, other institutions leverage the CLIMAS program’s reputation as

well as individual relationships to enhance present and future projects and tool development.

Through relationship building and sustained collaboration with communities of practice, climate service providers learn about information needs while integrating themselves as members of those communities. This process increases adaptive capacity (Pahl-Wostl et al. 2007) and encourages climate service providers to seek out diverse expertise and technical capacities (WMO 2018). Building trusted relationships also has several institutional barriers, is time consuming, and does not guarantee success. As demonstrated above, CLIMAS, FEMA-R9 and WR-NWS were unable to create the ideal climate information product within timing and funding constraints. However, their interactions formed a new community of practice combining emergency management and climate information, which has informed new projects. Relationship building is a main component in building successful communities of practice. These connections are integral to developing a shared set of instruments—languages, practices, tools, websites, and products (Wenger 2000)—that make a partnership more effective (Hewitt et al. 2017).

5.3 Practicing transdisciplinarity

A social learning system reflects a distributed, transdisciplinary network, and situates climate research and service organizations within multiple practices, knowledges, and forms of expertise. If scientists want their research to inform problems with societal implications, it is important that research processes incorporate multiple types of expertise and knowledge. This nonlinear process requires building personal and

institutional relationships over time, establishing trust and credibility, developing avenues for ongoing communication, and integrating these interactions into research and practice.

The concept of transdisciplinarity predates CLIMAS (e.g., Funtowicz and Ravetz 1993; Gibbons et al. 1994), however practical methods to accomplish it were not well developed during the program's initial formation. Stakeholder engagement was expressed as multidisciplinary and interdisciplinary interactions among the research team, which was somewhat novel for climate research at that time (Bales et al. 2004). The embedded social learning system model pushes CLIMAS program theory and practice towards transdisciplinarity by incorporating and valuing diverse forms of expertise and participation beyond academic knowledge.

A transdisciplinary approach calls out the power relations within knowledge production that “assume some forms of climate knowledge are more relevant than others” (Serrao-Neumann and Coudrain 2018: 4) and create hierarchies of value, use, and trust. Pahl-Wostl et al. (2007) argue, “An obvious consequence of the establishment of [collaborative] platforms is a change in power relationships” (14). Within a well-functioning social learning system, academic knowledge and expertise should not hold higher positions of power or value. While formal disciplinary knowledge, training, and expertise are valuable, their decentralization serves to prioritize and promote other types of expertise and ways of knowing. The social learning system framework displaces earlier descriptions of organizations like CLIMAS as a pivotal mediator on a boundary between science and society. These models have proved useful to identify specific roles CLIMAS can play within a system (e.g., Feldman and Ingram 2009; Kirchhoff et al. 2013), but do not adequately capture the program's function and purpose.

Climate resilience viewed through a social learning system framework clarifies how use-inspired research and services programs can encourage transdisciplinary research practices. One way is to connect diverse sites of knowledge production by supporting researchers who collaborate within and across communities of practice. Within these networks, academic and climate researchers play an important role, among the many roles that others also play (see section 5.3 regarding the public health community of practice). While CLIMAS projects do not always practice transdisciplinarity, the social learning system model guides programmatic operation and research decisions towards it. Furthermore, it is likely that transdisciplinarity does not represent the final form in an evolution of conducting use-inspired research—like interdisciplinary practices, transdisciplinary approaches will eventually evolve into new ones. However, the decentralization that occurs through the social learning system model depicts one evolutionary step towards practicing transdisciplinarity.

5.4 Designing new evaluation practices

To be continually innovative and successful, use-inspired research and climate service organizations must reflect upon the work they produce as well as the processes used to produce that work (McNie 2013; Vaughn and Dessai 2014). Several conceptual frameworks now exist to guide organizations in applying monitoring and evaluation practices (e.g., Vogel et al. 2007; McNie 2008; Wall et al. 2017), but no one-size-fits-all model exists. In our case, the social learning system concept helped us organize CLIMAS program activities—beyond its primary function of producing new knowledge—into five categories: communicating, convening, consulting, collaborating, and training. These

categories have revised our understanding of the program’s objectives and impact, revealed gaps in our previous evaluation design, and identified areas for improvement. By uncovering the underlying processes of the CLIMAS program, we hope to better understand and articulate the usefulness and impact of the program’s research and services. Our 2012-2017 program evaluation has inspired new metrics and data collection techniques for the 2018-2022 program evaluation.

While monitoring progress towards outputs, outcomes, and impacts remain important components of our evaluation, we are now prioritizing tracking individual and institutional relationships, specifically how they are built, maintained, strengthened, or lost over time. As one CLIMAS investigator points out, “We have relationships with people. They call us, and we call them when something arises. While it’s squishy and low level, it does make a difference. [An interaction] with us may have turned into something that other people did and now they are better off—but it actually started with us. How do we put better values on these social components?” (M. Crimmins, personal communication, April 2017). To monitor how relationships develop through the practices of communication, convening, consulting, collaboration and training, we recently developed a database to document the variety of interactions between CLIMAS investigators, information users, and project collaborators. By tracking this information over time, we aim to better understand how these commonplace, but sustained, interactions provide pathways to better climate service products and more useful research. Through this process we intend to better articulate the value of these underlying social components.

Because we strive to do transdisciplinary work, our evaluation metrics should better mirror the practices of transdisciplinarity. Our 2012-2017 evaluation revolved around data collection from CLIMAS investigators. The current evaluation focuses more on non-academic partners and tracking the roles they play within projects. Partners and climate information users will be directly involved in the evaluation process through annual interviews. We aim to include metrics that demonstrate progress towards their own individual and/or institutional goals. Involving partners in the evaluation process will help establish adaptable project outputs and outcomes. In addition, we aim to better explain if and how a transdisciplinary approach leads to more effective outcomes.

Finally, we are incorporating flexibility into our evaluation design by documenting responses to unexpected changes, barriers, or other outside factors that impact relationships and project outcomes. Several scholars have identified flexibility as a key attribute for organizations and individuals involved in climate adaptation and resilience (e.g., Nelson et al. 2007; Adger et al. 2011; Amaru and Chhetri 2013), however, more empirical evidence is needed to demonstrate how a flexible approach leads to more useful climate research and services. To monitor flexibility, our evaluation-related interviews now include in-depth questions regarding the political, economic, social, historical, and environmental contexts surrounding particular projects. Questions interrogate how responses to sudden or external changes in a project leads to improved relationships, outputs, and outcomes.

In a similar respect, the ways we monitor project outcomes should be less rigid and more flexible themselves, to acknowledge information use at varying timescales and diverse decision-making practices. Climate information use does not always occur in a

linear fashion; it is rare that an information product is made and immediately used to make a decision, for example. As a CLIMAS researcher notes, “You often have to look at much more nebulous, conceptual uses of information... It may take longer to layer these conceptual uses, but over time people start to understand the information better. They trust it more because they are hearing the same kinds of information from a bunch of sources. Next time they have to make a decision, they might use that information...but we don’t know how long that takes” (A. Meadow, personal communication, April 2017). To better understand these more circuitous and layered uses of climate information, our evaluation process will extend beyond the “end” of a project. We will continue to interview CLIMAS researchers and partners after project funding runs out to record information use or project outcomes. Similarly, our interviews will include questions about the historical context of how project start and why it was needed.

6. Conclusion

In this paper, we use a social learning systems model to demonstrate a programmatic evolution of theory and practice for use-inspired research and climate services. Developing the appropriate knowledge to address complex issues such as climate change, requires approaches that situate science within the social context of these problems. Social learning systems theory provides one way to understand the process of contextualizing science. This model decentralizes traditional sites of knowledge production and empowers communities of practice to determine how knowledge is produced, communicated, and valued. Communities of practice provide a foundation for establishing relationships and creating opportunities for learning and innovation across

different forms of expertise. Actors within communities of practice must actively maintain these relationships and opportunities, which requires practice and skill, especially when maneuvering through institutional, political, and economic barriers.

A climate resilience social learning system in the Southwest provides a solid theoretical transdisciplinary framework for conducting use-inspired research and creating usable knowledge. While the CLIMAS program has roots in engaged, use-inspired research, we find the social learning systems framework supplies a missing theoretical component in understanding how the program operates. Social learning systems theory has been used to analyze projects based in adaptive and community-based resource management (e.g., Pahl-Wostl et al. 2007; Fernandez-Gimenez et al. 2008; Berkes 2009) and climate change adaptation (e.g., Pelling et al. 2008; Collins and Ison 2009; Wilder et al. 2010), but has not been explicitly incorporated into guiding theories and frameworks for use-inspired research and climate services programs. Understanding the CLIMAS program as one piece of a larger social learning system comprised of multiple communities of practice reveals the importance of developing and fostering different types of social interactions for knowledge production. Our findings are not prescriptive or formulaic—not all climate service and use-inspired research programs should operate under the social learning systems framework. However, we encourage programs that aim to produce useful and usable knowledge to explore how social learning systems theory could apply to their programmatic objectives.

Social learning systems theory is well described in academic literature but more evidence of social learning systems in practice is needed. Routine and deliberate monitoring and evaluation will improve use-inspired research and climate services, while

also informing theories of knowledge production. By documenting incremental steps, such programs can make adjustments that strengthen a social learning system over time. Systemic change, or lack of it, will be noticeable by collecting this data over several years. Through practice, reflection, and documentation, we can understand how social learning systems evolve, are maintained, and work towards climate resilience.

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APPENDIX C: EVALUATING CLIMATE RESEARCH: SCIENTISTS' VISIONS OF A CLIMATE RESILIENT U.S. SOUTHWEST

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Abstract

Socially-engaged science and collaborative research practices offer promising ways to address complex environmental and societal problems like climate variability and climate change. However, it is unknown if and how these types of collaborative knowledge production result in tangible, real-world impacts. Drawing from a six-year evaluation, I investigate the outcomes and contributions of ten socially-engaged research projects supported by a federally-funded climate research program in the U.S. Southwest. Based on a series of logic-model narratives that outline research objectives, project outputs, and anticipated outcomes, I compare anticipated outcomes to researchers' perceptions about the outcomes they achieved. Quantitative and qualitative results indicate several contributions that the program has made toward raising awareness about climate issues in the U.S. Southwest, increasing capacity within the region to adapt to climate change and climate variability, and building lasting collaborative relationships. However, researchers sometimes envisioned the instrumental impacts of their work, such as informing policy, planning, and decision-making, to be different than what occurred within the six-year evaluation timeframe. Further exploration of these results reveals implicit assumptions in understanding how scientific information is applied to policy, planning, and decision-making. Evaluation results have led to functional changes within the research program and have informed individual researchers' approaches to future projects. This paper

provides an example for socially-engaged research organizations who are considering conducting program evaluations.

1. Introduction

The Southwest region of the United States is highly variable climatically, subject to extremes such as drought and heat, and vulnerable to the impacts of climate change. Already well-known for its arid desert climate, this region is quickly becoming hotter and drier (Gonzalez et al. 2018). Since 1970, average temperatures have risen more than 3 degrees Fahrenheit in New Mexico and Arizona, making them the second and third fastest-warming states in America (Climate Central 2019). Increased temperatures have intensified drought conditions across the Colorado River and Rio Grande basins (Gonzalez et al. 2018). In addition to large-scale climatic changes, the Southwest experiences monthly, seasonal, and annual variability in rainfall and temperature caused by the El Niño–Southern Oscillation and other global atmospheric circulation patterns.

The impacts of climate change and climate variability on the Southwest are wide-ranging. Given current and predicted climatic conditions, the region faces several sustainability crises. For example, approximately 40 million people in the western U.S. and northwestern Mexico rely on Colorado River water for domestic, industrial, and agricultural uses (U.S. Bureau of Reclamation 2012). However, increased temperatures have already reduced streamflow in the upper portion of the Colorado River basin by seven percent (McCabe et al. 2017). Climate model-based temperature projections indicate Colorado River streamflow reductions of 20 percent by 2050 and 35 percent by 2100 (Udall and Overpeck 2017). In addition, human health and safety are currently at

risk due to increased severity of heat extremes (Garfin et al. 2017), higher incidences of West Nile virus and valley fever (Brown et al. 2015; Roach et al. 2017), and higher frequency of respiratory problems caused by dust and windstorms (Roudopoulou et al. 2014). Combined, these impacts of climate change and climate variability could cause a cascade of social, economic, and environmental problems (Leroy et al. 2016).

While these studies paint a picture of doom and gloom for the Southwest, there are numerous ways that people are planning and preparing for climate-related challenges. The City of Flagstaff, AZ has implemented an adaptation action plan informed by customized reports that address city-specific climate impacts (Meadow et al. 2018). Farmers in Yuma, AZ have adopted more efficient irrigation technologies, agricultural infrastructure, and production practices to conserve water (Frisvold et al. 2018). Riparian environments are springing back to life due to increased streamflow allotments for ecological restoration (Kerna et al. 2017). Irrigation districts, farms, tribes, and other organizations in Arizona and New Mexico have volunteered to enter water trading agreements to reduce the economic impacts of regional water shortages and extreme drought (Colby 2017). State agencies are planning for increased public health issues related to climate such as extreme heat and vector-borne diseases (Roach et al. 2017). For many people, these types of activities inspire hope that the Southwest will be resilient and adapt to climate change and climate variability.

These examples are associated with studies conducted by social and physical science researchers affiliated with the Climate Assessment for the Southwest (CLIMAS) program. CLIMAS is part of a national network of 11 university-based climate research programs funded through the U.S. National Oceanic Atmospheric Administration's

Regional Integrated Sciences and Assessments (NOAA-RISA) program. This federally funded program was officially established in 2001 and supports research related to the science and impacts of regional climate variability and change. The CLIMAS research agenda centers the climate information needs of individuals, communities, organizations, and institutions in Arizona and New Mexico, with the aim of improving people's understanding about climate variability and climate change and informing their climate-related planning or policy decisions. CLIMAS researchers collaborate directly with representatives from regional groups to coproduce knowledge and information that is potentially useful (based on researchers' assumptions of the knowledge and information that people need) and usable (based on people's perceptions of their own knowledge and information needs) for planning, policy, and decision-making processes (Dilling and Lemos 2011; Ray and Webb 2016).

The theoretical underpinnings of the CLIMAS program are grounded in socially-engaged approaches to research, which combine scientific and practical forms of knowledge to address complex global challenges. Engaged research, explains Van de Ven (2007), is a "participative form of research for obtaining the advice and perspectives of key stakeholders (researchers, users, clients, sponsors, and practitioners) to understand a complex social problem" (ix). Ideally, stakeholders and scientists define the problem and research questions, design and conduct the study, and apply research findings (Van de Ven 2007). This type of participatory engagement is not typical of conventional science methodologies. Instead, U.S. scientific practice and policy has largely reflected a "loading-dock" model in which researchers create a stockpile of information that they assume will be used to advance societal goals (Cash et al. 2006). The approach gives

little attention to how research findings actually respond to, inform, and improve societal challenges.

Several scholars agree that engaged and participatory research approaches are better suited to improve societal and environmental issues than traditional models of science (e.g., Kates et al. 2001; Nowotny et al. 2001; Cash et al. 2003; Lemos and Morehouse 2005; Pahl-Wostl et al. 2007). However, it is still unclear if and how collaborative knowledge production results in societal improvement (Zscheischler et al. 2018). In addition, scientists' expectations of the outcomes of collaborative research (e.g., societal and environmental change) are often much more optimistic than what occurs in reality (Lang et al. 2012). There is a need to demonstrate and evaluate the outcomes of socially-engaged research.

To address this gap, I present results from a six-year evaluation of the CLIMAS program. This evaluation offers information about 1) the theoretical frameworks applied by CLIMAS researchers to conduct socially-engaged research and deliver climate services; 2) how CLIMAS projects, information, and services have contributed—and failed to contribute—to societal and environmental change; and 3) how real-world outcomes of socially-engaged research compare to researchers' visions for the impact of their work. The first topic is discussed in Owen et al. 2019, which describes the evolution of the theory and practice of use-inspired and transdisciplinary climate research within the CLIMAS program. This paper focuses on the latter two topics.

In this paper I briefly review socially-engaged frameworks for knowledge production and research evaluation techniques. Then, I detail the process of developing the CLIMAS program evaluation. This process involved coproducing a series of

narratives with CLIMAS researchers to define their anticipated outcomes and their visions for achieving those outcomes. These narratives, sometimes referred to as logic models (Funnell and Rogers 2011), reveal how researchers envision the connections between their research activities, their research outcomes, and their contributions to societal change. I compare project outcomes anticipated by researchers to project outcomes that researchers perceived to be achieved in a six-year period. Quantitative and qualitative results indicate several contributions of the CLIMAS program toward increasing regional climate resilience and adaptive capacity. An in-depth qualitative review of one CLIMAS project shows how the evaluation process encourages researchers to reflect upon and learn from the successes and failures of their projects.

This evaluation aims to improve internal CLIMAS program management and the practice of socially-engaged research. Findings provide a baseline of information regarding program outcomes and approaches to socially-engaged research, which will be useful for comparison to future CLIMAS program evaluations. This paper provides an example for socially-engaged research organizations who are considering conducting program evaluations.

2. Socially-engaged research practices and evaluation

Scientific research has among its goals the improvement of society. Current U.S. science policy and most university-supported research is based on a model of scientific “freedom of inquiry” in which scientists “are free to pursue the truth wherever it may lead” (Bush 1945). This vision of science policy was originally developed to maintain scholarly independence from government or corporate influence (Dennis 2015). It

assumes that discoveries made by academic experts will be delivered to societal members who will use the results to inform policy, practice, and technology (Cash et al. 2006; Van Drooge and Spaapen 2017). However, the model does not explain *how* scientific results will be delivered, consumed, or used. This linear conceptualization of science for society has been shown to be of limited use when addressing highly complex, systemic problems such as environmental change, climatic shifts, and other global sustainability issues (Nowotny et al. 2001; Cash et al. 2003; Wiek et al. 2012). In response, a rich literature has emerged to describe a different model for scientific production that can be broadly categorized as socially-engaged research. Various ideas within this vein include post-normal science (Funtowicz and Ravetz 1993); Mode 2 knowledge production (Gibbons et al. 1994; Nowotny et al. 2001); boundary work (Guston 2001; Cash et al. 2003); knowledge coproduction (Jasanoff 2004; Lemos and Morehouse 2005); transdisciplinarity (Pohl 2008; Jahn et al. 2012); transformational sustainability science (Kates et al. 2001; Wiek et al. 2012); social learning (Wenger 2000; Pahl-Wostl et al. 2007); and useful science or usable knowledge production (e.g., Dilling and Lemos 2011; Clark 2016; Beier 2017) (see Table 1 for brief descriptions). These frameworks converge and diverge in terms of agenda and approach. However, they all make one thing clear: physical and social scientists must collaborate with people outside of the academic realm if they want their research to inform policy or create societal and environmental change.

<i>Research concepts</i>	<i>Description</i>	<i>Exemplary citations</i>
<i>Post-normal science</i>	Motivated by societal issues and needs rather than researcher curiosity. Relies on participation of a ‘peer community’ that extends beyond scientists.	Funtowicz and Ravetz 1993
<i>Mode 2 knowledge production</i>	Contextualized by the societal factors surrounding a particular issue and characterized by the inclusion of multiple types of knowledge and research partners.	Gibbons et al. 1994; Nowotny et al. 2001
<i>Boundary work</i>	Aims to solve real-world issues through dialog and collaboration across the ‘boundaries’ between scientific experts and decision makers.	Guston 2001; Cash et al. 2003
<i>Knowledge coproduction</i>	Iterative engagement between researchers and nonacademic partners will produce innovative, scientifically-robust, and useful knowledge for real-world applications.	Jasanoff 2004; Lemos and Morehouse 2005
<i>Transdisciplinary research</i>	The integration of multiple types of expertise and knowledge is necessary to address a common issue.	Pohl 2008; Jahn et al. 2012
<i>Transformational sustainability science</i>	Incorporates knowledge from outside academia into research processes to support the creation of sustainable social systems.	Kates et al. 2001; Wiek et al. 2012
<i>Social learning</i>	Social processes help create mutual understandings between two or more parties, through which individual and societal transformations can occur.	Wenger 2000; Pahl-Wostl et al. 2007
<i>Useful science, usable knowledge</i>	Research conducted to produce knowledge that is useful, usable, and actually used by societal members.	Dilling and Lemos 2011; Clark 2016; Beier 2017

Table 1. Descriptions of socially-engaged research concepts

Approaches to socially-engaged research are helpful in framing ideal scenarios for how scientists can collaborate with others to address societal problems. However, the outcomes of socially-engaged research more often remain aspirational and theoretical than fully realized in practice (Lang et al. 2012). The nature of working across disciplinary and social boundaries can be messy and unpredictable. Several scholars highlight the complexities and realities of conducting socially-engaged research. External factors like inconsistent political, public, and financial support and sudden shifts in

institutional operations or personnel impede the progress of socially-engaged research projects (e.g., Meadow et al. 2013; Polk 2015; Wall et al. 2017). Internal social dynamics like poor communication techniques, lack of leadership, personality conflicts, and inequitable processes for decision-making within collaborative projects can also challenge momentum (e.g., Jakobsen et al. 2004; Pohl 2005; Hollaender et al. 2008).

Regarding transdisciplinary research in particular, Felt et al. (2016) argue for a “careful investigation of the concrete intertwinements of imaginations, expectations, structures (institutions, programs, careers, etc.), people, and values” (737). Although transdisciplinarity upholds the importance of opening the research process to multiple forms of expertise, it still relies on established systems of governance, policy, and administration. These systems, according to Meehan et al. (2018), “reflect implicit logics of accountability and imaginaries of social impact that shape program design, collaboration, and the very conditions for knowledge mobilization” (760). For example, research funding for transdisciplinary programs is typically channeled through universities or other science-based institutions, in which scientists manage the research agenda. As Felt et al. (2016) illustrate, it is typical for these programs to center the legitimacy of scientific logic and expertise and only be *informed by* other types of knowledge, rather than fully engage them in research design and activities. This power imbalance exemplifies one mismatch between the theory and common practices of socially-engaged research.

Within socially-engaged research models lie several assumptions about how knowledge is mobilized for use, by whom, and for what objectives. Both Felt et al. (2016) and Meehan et al. (2018) employ the concepts of imagination and imaginaries as

important epistemological drivers of socially-engaged knowledge production; specifically, they draw on Jasanoff and Kim's concept of the socio-technical imaginary (2009). Jasanoff (2015) defines socio-technical imaginaries as "collectively held, institutionally stabilized, and publicly performed visions of desirable futures, animated by shared understandings of forms of social life and social order attainable through and supportive of advances in technology" (4). This constructivist viewpoint argues that scientific solutions to complex social problems are directly intertwined with individual and collective visions of modernity, progress, and a better future world.

National science policies are a main driver of sociotechnical imaginaries. Meehan et al. (2018) show how researchers' experiences in the Fulbright-NEXUS program—a transdisciplinary program jointly sponsored by the U.S. and Brazilian governments for researchers from the Americas to produce science to inform policy—stood in contrast to the processes of social-engagement they imagined would occur. In preparation for their research projects, most of which aimed to promote climate change policy in Latin America and the Caribbean, participants were trained by Fulbright staff on the benefits of producing useful science for society. However, as researchers worked with politicians to understand how science would be useful to developing climate policy, they found that politicians saw them as "mere 'consultants' for market innovation and political will" rather than research partners (Meehan 2018: 771). In this case, researchers realized that their science might be useful only if it promoted national policy priorities and development agendas; if not, research results may be ignored or rejected.

An individual researcher's objectives and project design are situated within a variety of collective imaginaries; simultaneously, a researcher's findings can contribute

to or contest the proliferation and maintenance of these imaginaries. What has not been sufficiently examined in this literature are the roles that individual scientists play in maintaining, performing, and contesting sociotechnical imaginaries and visions of societal progress. The notion of imaginary draws attention to the epistemological framings that comprise how researchers envision societal progress, how their research supports that vision, and how collaborative knowledge production frameworks guide that vision. Despite the profound influence of these individual and collective imaginaries, researchers' visions of their own socially-engaged research processes usually remain implicit and unquestioned.

Evaluation methods offer ways to untangle and define scientists' implicit visions and assumptions, in addition to other components of knowledge production such as outcomes and impacts. Scholars have used evaluation frameworks and methodologies to measure the contributions of transdisciplinary knowledge (e.g., Roux et al. 2010; Belcher et al. 2016), use-inspired knowledge (e.g., McNie 2008; Ferguson et al. 2016), and co-produced knowledge (e.g., Fazey et al. 2014; Wall et al. 2016). Of these evaluation frameworks, program theory-based evaluation has proven helpful in demonstrating how research makes tangible contributions to addressing societal issues (Funnell and Rogers 2011). This approach argues for the development of an underlying program theory, or an explicit declaration of the changes that will occur and how these changes will occur. Some evaluators elaborate upon these underlying program theories using theories of change.¹² Belcher et al. (2017) describe a theory of change as “a comprehensive

¹² Funnell and Rogers (2011) among other evaluators note that there are no standard definitions for program theory, theories of change, or logic models. These terms and methods are relative to the social and political contexts of the program being evaluated.

description and illustration of how and why a desired change is expected to happen in a particular context” (3). The logic model is a related, but more simplified, evaluation tool that facilitates the articulation of a logic, or causal narrative, that links activities to outputs, outcomes, and impacts. In terms of evaluating research, theories of change and logic models invite researchers to explain their visions for what they want their research to accomplish and how. They must communicate their visions for research design, potential challenges, deliverable products, and end results. In doing so, researchers’ assumptions about how their research will achieve these visions also become explicit.

The theory of change model also provides ways to examine research effectiveness and outcomes. By articulating logic model narratives, researchers develop criteria to determine if and how their scientific work contributes to a sustainable, adaptable, and resilient society. As a research project concludes, researchers recall their initial visions and objectives. Researchers can examine the project’s successes and failures by comparing their anticipated goals to those they accomplished. This examination often reveals multiple challenges encountered and advantages received during the research process. It also encourages researchers to investigate their own roles in the research process. This self-reflection can help researchers improve and refine their approaches to future socially-engaged research endeavors.

There are some limitations to the theory of change approach. One limitation is establishing causality between actions, outcomes, and impacts (Stufflebeam 2001; Lang et al. 2012). Rather than definitively calculating the extent to which an activity produces an outcome, evaluation measures are likely to be more useful in assessing, refining, and improving adaptation processes. For example, contribution analysis (Mayne 1999; Mayne

2008) aims to: assess whether or not anticipated results occurred; whether or not a particular activity or process produced those results; identify additional factors that influenced results; or reveal other explanations for why results occurred (see Belcher et al. 2017). The process of systematic evaluation increases clarity in understanding the connections between activities and outcomes but does not always indicate direct causation. Another limitation is that theories of change can sometimes be wrong or misguided. For example, a project that turns out to be unsuccessful could reveal problems with the underlying theory of change rather than with the implementation of the project. In such a case, theories of change can and should be revised.

2.2 Overview: CLIMAS Program

In the 1980s, scientists and staff in the U.S. National Oceanic Atmospheric Administration (NOAA) began to outline ways to connect climate observations to national-scale policy and decision-making. In their early designs for a national climate program, they recognized the need to incorporate not only scientific observations, but also to understand the people who would use climate information (Meadow 2017). Ultimately, they decided, a functional climate information system must be inspired by the real-world and regional applications of that information. In the late 1990s, these early framings informed the development of the NOAA Regional Integrated Sciences and Assessments program (NOAA-RISA). This federal program has since evolved into 11 currently-funded research programs distributed throughout the United States that practice use-inspired and socially-engaged methods of knowledge production. A recent ethnography of NOAA-RISA “revealed a deeply held belief in the power of knowledge

about climate patterns and changes—when developed in optimal ways—to make tangible positive impacts on the lives of people around the world” (Meadow 2017: 13). While individual NOAA-RISA programs vary in form, function, and focus, they all operate within this ideology.

Founded in 1998, CLIMAS is the oldest currently-funded NOAA-RISA program. CLIMAS projects are based in Arizona and New Mexico, but activities and outcomes often extend to other states in the U.S. Southwest region. While the program has fluctuated in size and composition over the years, it is comprised of 10 to 15 physical and social scientists at the University of Arizona in Tucson and New Mexico State University in Las Cruces. Research projects focus on regional climatic and environmental issues and topics shift based on the needs of project partners and stakeholders. A core office, consisting of a program director and two or three additional research staff, manages routine program operations and interactions with the federal NOAA-RISA program. The underlying vision and mission have not significantly changed since the early program days: CLIMAS aims to improve the Southwest’s ability to respond sufficiently and appropriately to climatic events and changes by creating usable knowledge with and for non-academic partners. As the program evolved, researchers increasingly shifted away from traditional research models and moved toward transdisciplinary research and social learning systems that support regional climate resilience (Owen et al. 2019).

3. CLIMAS Program Evaluation Process and Methods

Throughout the years of CLIMAS’s existence, program leaders have reflected on the program’s achievements through periodic reviews. The current evaluation design,

which I developed drew upon results and information from prior assessments. Occasional interviews and surveys with past team members and project partners were conducted between 2004 and 2011, which helped guide programmatic directives and funding choices. In 2007, the CLIMAS program manager (and now the current program director) implemented a survey (n=59) to better understand stakeholder perceptions of and interactions with the program. One result was a conceptual model of stakeholder-program relationships (Ferguson et al. 2016). Four primary roles of CLIMAS were identified: 70% of respondents said that the program acted as a broker for climate information; 53% said that they used program researchers as informal consultants for expert advice; 37% said that they partnered with a program researcher for a short-term project or event; and 17% said that they considered themselves long-term collaborators.

The program manager decided to coordinate a program-wide evaluation as part of a new CLIMAS funding cycle that ran from 2012 to 2017. In deciding whether to conduct an internal evaluation or hire an external evaluator, the program manager considered a) available resources and b) the evaluation's purpose. He wanted to use evaluation results to guide program management decisions and contribute to an improved understanding about socially-engaged research processes; he did not aim to definitively demonstrate the program's value in objective terms. Internal evaluation can facilitate learning and increased understanding about a program's function; external evaluation is often used when the goal is to demonstrate accountability (Conley-Tyler 2005). Guided by evidence that organizations seeking to improve management and performance generally use internal rather than external evaluators (e.g., Owen 2006), he decided that an internal evaluation was appropriate. As a social scientist and member of the core team,

I was tasked with managing and implementing the process. As an internal evaluator, it was relatively easy to schedule and conduct multiple interviews with individual researchers over several years, and to gather data via participant observation during team meetings and other program-related events.

The program manager and I co-developed the initial research design. Our objectives for the evaluation were to 1) demonstrate the program's contributions to building adaptive capacity in the Southwest; 2) develop methods to evaluate the CLIMAS program; 3) feed evaluation results back into program operations and funding decisions; and 4) develop a better understanding of the impact of socially-engaged research. These goals aimed to understand the program's effectiveness and to improve the process of socially-engaged research evaluation.

When designing this research in 2011 and 2012, we chose theory-based evaluation as outlined by Funnell and Rogers (2011), to structure the CLIMAS evaluation. The descriptions of the evaluation process, design, and methods for data collection and analysis fit our objectives and also fit the financial and human resources available to the CLIMAS program at that time. Following this type of evaluation design, the program manager and I first generated an underlying theory of change for the CLIMAS program. Using the CLIMAS mission statement as a starting point, we constructed the following theory of change: *Engaging with existing and potential climate stakeholders in the Southwest results in usable knowledge. These interactions and information products expand people's capacities to adapt to climatic shifts and changes.* A theory of change, as Van Drooge and Spaapen (2017) note, "invites stakeholders to articulate how an impact will be generated" (7). In this case, CLIMAS-funded researchers

were our stakeholders.¹³ Together, we further elaborated the program's theory of change through a series of semi-structured interviews and focus groups between 2012 and 2014. This iterative process allowed us to understand how each individual researcher applied the CLIMAS program theory of change in their own work.

In the summer of 2012, I interviewed 11 investigators to understand how, in a broad sense, they imagined their research impacting society and increasing the adaptive capacity of the Southwest. An important part of this interview was to understand not only what researchers sought to accomplish, but why they wanted to accomplish certain goals. Friedman et al. (2006) argue that project goals tend to reflect a researcher's implicit values and desires; asking the researcher why their goals are important and why they want to accomplish them helps reveal these values and desires. Following this reasoning, I asked CLIMAS investigators to identify why their goals were important to them. All 11 answers came down to slight variations of a singular narrative: science has shown that climate change and climate variability threaten current and future populations in the Southwest in several interconnected ways; socially-engaged science can help people anticipate and prepare for these risks, thereby reducing the amount of human and environmental damage incurred. Underlying values rooted in this narrative were the importance of cooperation and mutual understanding, a desire to solve real-world

¹³ I recognize the absence of project partners and stakeholders in the evaluation process. Their inclusion is an important and necessary component of a fully realized evaluation of transdisciplinary research. Our initial research design included interviews with project partners or stakeholders beyond the CLIMAS research team. However, due to timing and logistical constraints during this funding cycle, I was unable to include interviews with project partners beyond the CLIMAS research team for all projects. Without these interviews, I cannot speak to their perceptions of the research process, how new knowledge and other project outputs were produced, or how new knowledge and other project outputs were used. Therefore, this first round of program-wide evaluation focuses on researchers' perceptions of outputs, outcomes, and impacts and serves as a baseline test of the assessment process. The subsequent funding cycle that runs from 2017 to 2022 engages project partners outside of CLIMAS in the evaluation design and implementation.

problems, and a vision for a resilient and flourishing Southwest region. Ultimately, the team’s objectives were to improve human well-being and influence social and environmental change (see Figure 1). CLIMAS researchers envisioned achieving these objectives by informing urban and rural planning, providing decision support, improving people’s understanding of climate, informing policy, and producing original, use-inspired knowledge.

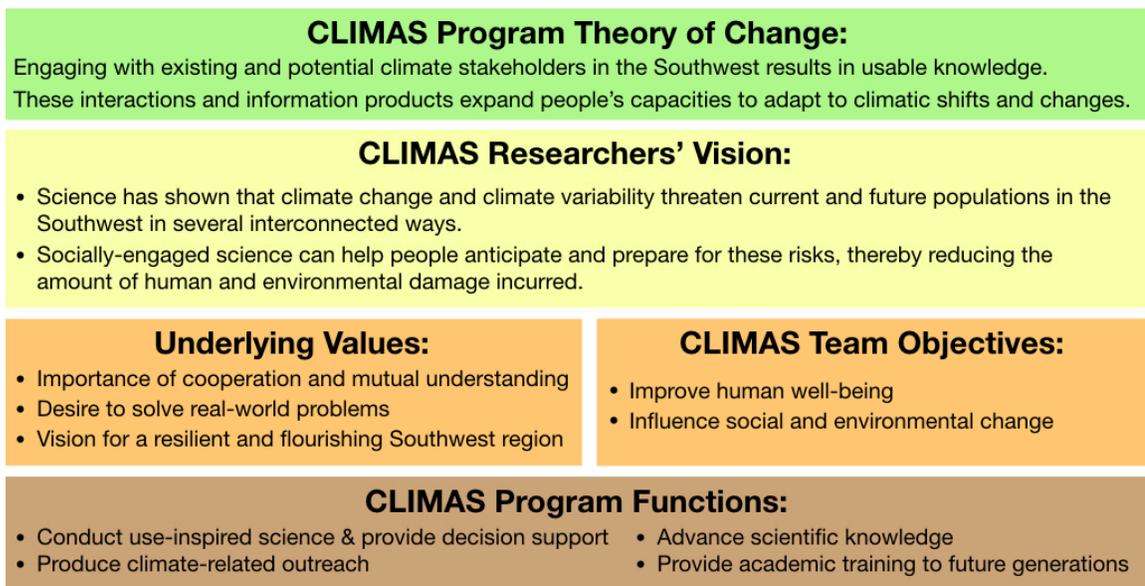


Figure 1: Diagram of CLIMAS program theory of change, visions, values, objectives, and activities

Understanding the team’s visions, values, and broad objectives allowed us to then articulate how socially-engaged research projects enact those values and fulfill those visions and objectives. In the fall of 2012, we organized a focus group with 13 CLIMAS investigators. In the focus group, we collectively identified four programmatic functions: 1) to conduct use-inspired science and provide decision support, 2) to produce climate-related outreach, 3) to advance scientific knowledge, and 4) to provide academic training to future generations of scholars. This paper focuses on understanding the first identified

function of CLIMAS, which is to produce research that is useful and to provide support to people making climate-related decisions in the Southwest.

I included a total of 10 CLIMAS projects for evaluation of this function. Logic model narratives for each project were designed via a team focus group in 2013 (n=11) and individual interviews with investigators in 2014 (n=11)¹⁴, which provided the basis for understanding how researchers imagined their work bringing about desired change. The components of these logic narratives included: the *assumptions* and *context* in which the project occurred; *inputs*, or the human, financial, and institutional resources needed; *outputs*, or the actions taken and direct products of these actions; *outcomes*, or specific changes in behavior, attitudes, knowledge, relationships, capacities, policies, or operations; and *impacts*, or broader changes that occur within communities, regions, or systems as a result of program activities (See Figure 2).



Figure 2: Basic components of a logic model.

From 2012 through 2014, I conducted a total of 22 interviews and two focus groups with research team members about evaluation design, project outputs, and project

¹⁴ CLIMAS investigators often collaborate on projects, hence the mismatch between the number of projects (10) and the number of investigators involved (11).

outcomes. During individual interviews, I co-developed logic models with each researcher for their project. In 2016 and 2017, I conducted 13 more interviews with investigators regarding project outputs and outcomes. In addition, I collected annual progress reports from 2012 to 2018 from each investigator; the annual progress reports outlined project outputs, recorded events, announced new partnerships, and provided other updates.

Information from interviews and reports were entered into a FileMaker Pro database for content analysis. I categorized anticipated and unanticipated outputs by type, such as reports for project partners, models or data analyses, workshops, presentations, or information tools. I also documented several types of project outcomes, or changes, that happened as a result of the research process. I used researchers' perceptions of project outcomes based on interview data, however, outcomes were only counted when researchers supplied or I found supplemental documentation of, tangible evidence that these outcomes occurred. To categorize these outcomes, I used a conceptual typology adapted from Meagher and Martin (2017) and Meagher and Lyall (2013). These researchers identified five types of outcomes:

- *capacity building outcomes*: developing collaborations or providing the information and training necessary to engage in a particular activity;
- *instrumental outcomes*: direct influence or use in policy, practice, or decision-making;
- *conceptual outcomes*: changes in thinking, raising awareness, or improving understanding of an issue;

- *enduring connectivity outcomes*: relationships lasting beyond the course of a particular project or activity; and
- *attitudinal or cultural shifts outcomes*: changes in institutional, group, or individual attitudes regarding issues or toward engaging in collaborative activities or knowledge exchange.

For both outputs and outcomes, I compared project goals to project results. This comparison comprises the basis of my evaluation findings.

4. Evaluation Results and Analysis: Outputs and Outcomes

Project outputs encompass the tangible ways in which CLIMAS researchers share their research results with scientists, research partners, and the broader public. Most outputs produced were written (e.g., technical reports, data analyses, and peer-reviewed publications) or orally delivered (e.g., presentations to project partners, academic audiences, or the public). CLIMAS researchers completed and delivered most of the outputs they identified at the project outset and tended to produce more items than anticipated. In total, only four anticipated outputs did not materialize by 2018; these were two academic papers, a suite of outreach materials regarding public health, and a tool to enhance adaptive capacity in the Southwest. See Figure 3 for a further breakdown of project outputs.

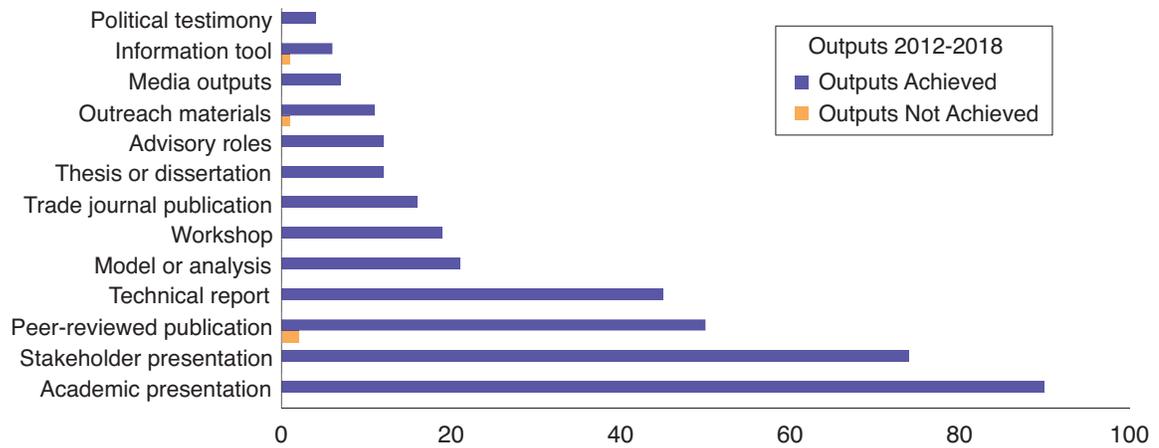


Figure 3. CLIMAS project outputs achieved and not achieved between 2012 and 2018.

CLIMAS researchers achieved 61 outcomes in total, spread relatively evenly across the five outcome categories defined by Meagher and Martin (2017) and Meagher and Lyall (2013) (see Table 2). Capacity building outcomes were most frequent (26.2%), followed by instrumental outcomes (21.3%), conceptual outcomes (19.7%), and enduring connectivity outcomes (19.7%). The smallest number of outcomes comprised the attitudinal or cultural type (13.1%).

<i>Outcome Type</i>	<i>Description</i>	<i>Percent of Frequency</i>	<i>Example from a CLIMAS Project</i>
<i>Capacity Building:</i>	Developing collaborations or providing the information and training necessary to engage in a particular activity	26.2% (n=16)	Through an iterative research process, FEMA-R9 representatives identified potential uses for 30-day climate forecasts in their agency's operations. This collaboration led to the development of a climate information tool for disaster preparedness.
<i>Instrumental:</i>	Direct influence or use of research in policy, practice, or decision-making	21.3% (n=13)	The New Mexico Department of Transportation used CLIMAS research about the sources and patterns of dust storms to apply for federal funds for improved highway signs, warnings, and road markings. The approved funding was used to build new infrastructure along a stretch of the Interstate-10 Freeway.
<i>Conceptual:</i>	Changes in thinking, raising awareness, or improving understanding of an issue	19.7% (n=12)	Results from a paleoclimate project with the U.S. Geological Survey and water resource managers increased awareness and understanding of how temperatures impact streamflow and drought in the Colorado River basin.
<i>Enduring Connectivity:</i>	Relationships lasting beyond the course of a particular project or activity	19.7% (n=12)	An electric utility company in Tucson, AZ initiated a new project on carbon reduction with CLIMAS researchers a year after the initial project ended.
<i>Attitudinal or Cultural:</i>	Changes in attitudes toward engaging in climate research or knowledge exchange activities	13.1% (n=8)	Municipal government representative in Ciudad Juárez, Mexico shifted from participants to leaders in a collaborative heat and health initiative in the New Mexico/Texas/Chihuahua region.

Table 2. Percent of frequency and examples of the five outcome types.

CLIMAS researchers accomplished 16 capacity building outcomes. A common thread woven through all CLIMAS projects in this study is the prevalence of iterative interactions with project partners to develop and maintain collaboration. Regular (generally monthly to quarterly) phone calls, virtual meetings, and in-person meetings

formed the basis of interaction. Occasional workshops, trainings, and presentations provided more formalized mechanisms for interaction and capacity building. For example, representatives of the Federal Emergency Management Agency Region 9 (FEMA-R9) contacted CLIMAS researchers for help developing a climate information tool for disaster preparedness. Through multiple interactions, including in-person and virtual meetings, phone calls, interviews, and participant observation with FEMA-R9 personnel, connections strengthened between project collaborators. This iterative process helped FEMA-R9 representatives identify potential uses for 30-day climate forecasts in their agency's operations and resulted in a monthly graphical summary that depicted relevant historical data, current conditions, future outlooks, and potential risks.

Instrumental outcomes, which included instances of direct influence or use of CLIMAS research in developing policy, informing practice, or guiding decision-making occurred 13 times. Influence and use occurred in various ways. CLIMAS researchers gave testimony in state hearings on water supply and agricultural economics; project partners cited CLIMAS research information to support difficult resource management decisions; and research analyses were used to validate new government or institutional policies. One example involves dust storms, which have caused numerous human casualties on the Interstate-10 Freeway near Lordsburg, NM. The New Mexico Department of Transportation used CLIMAS research about the sources and patterns of these dust storms to apply for federal funds to improve highway signs, warnings, and road markings. Funding was approved and new infrastructure was installed in 2017 and 2018.

CLIMAS researchers achieved 12 conceptual outcomes. Conceptual contributions involved the creation of relevant physical and social science products that raise awareness, expand knowledge about regional climate dynamics and impacts, and increase people's understanding of managing climate risk. These products often manifest as standard academic outputs, such as peer-reviewed publications and presentations at academic conferences. To match the needs of project partners, they also take other forms such as tailored models and analyses, outreach materials, and technical reports. For instance, results from a paleoclimate project with the U.S. Geological Survey and water resource managers increased awareness and understanding of how temperatures impact streamflow and drought in the Colorado River basin. Researchers found that cool season precipitation is the primary driver of variability in streamflow. However, in drier years, temperature has a greater influence on streamflow variability than it does during wet years (Woodhouse et al. 2016). These findings have important implications for water management in the basin as regional temperatures are projected to increase. Research results were shared with water managers and other stakeholders through workshops, presentations, technical reports, fact sheets, and a public website.

Evidence of enduring connectivity between CLIMAS researchers and project partners occurred twelve times. Indications that relations lasted beyond the course of a project included continued research on the same topic together, designing and seeking funding for a new project, and multiple requests over time from partners to CLIMAS researchers for climate information. In 2015, CLIMAS and other University of Arizona researchers collaborated with an electric utility company in Tucson, AZ. Utility employees identified several regionally-specific climate and environmental risks that

could impact their operation; researchers provided data and analysis to address these specific concerns. This project ended in 2017. A year later, utility employees sought CLIMAS researchers' assistance to explore potential scenarios for carbon reduction.

Attitudinal or cultural changes toward engaging in climate research or knowledge exchange occurred eight times. Outcomes in this category, although somewhat similar to capacity building or conceptual outcomes, were more nuanced than others. In this evaluation, the distinction was based on evidence of a detectable shift in acceptance or a shift in project roles. In some cases, this shift occurred when project partners expressed a greater acceptance about the realities of climate change. In others, this shift occurred when project partners took on new roles in the research process or sought out new collaborations with other organizations to work on climate change and variability challenges. For example, a research initiative in the border cities of the Rio Grande—Bravo basin (El Paso, TX, Ciudad Juárez, Chihuahua, and Las Cruces, New Mexico) aimed to improve a regional early warning system for extreme heat conditions and associated health risks. In the beginning stages of this project, officials from the Oficina de Resiliencia in Ciudad Juárez participated in meetings and events. Over time, they became leaders within the initiative and developed a plan with El Paso to reduce urban heat island effects using green infrastructure.

Out of the 61 outcomes achieved, 16 were unanticipated by researchers at the beginning of their projects (Figure 4). They mostly fell into the enduring connectivity and instrumental types. In terms of enduring connectivity, eight unanticipated long-term relationships were established through new research avenues after the initial project concluded. This finding suggests that establishing long-term relationships are an

important outcome of CLIMAS research projects even though few researchers identified this outcome as an explicit project objective.

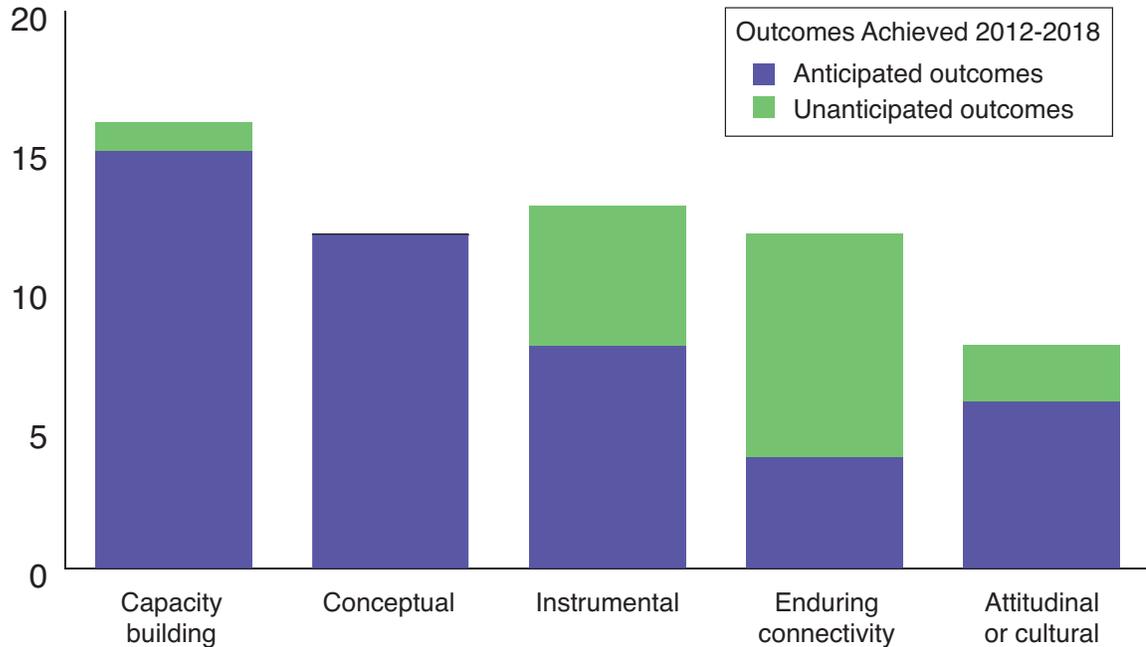


Figure 4. Total CLIMAS project outcomes achieved between 2012 and 2018, divided by outcomes that were explicitly anticipated at the beginning of a project and outcomes that were unanticipated.

Five instrumental outcomes occurred that were unanticipated. Two of these unanticipated outcomes stemmed from one CLIMAS project that involved investigating the use of resource management tools to increase water supply reliability. Water supply reliability tools can take many forms; this project focused on aquifer storage and recovery and voluntary water trading agreements. For example, aquifer storage and recovery (also called groundwater banking) uses underground reserves to store surface water during times of surplus water availability. This water can then be pumped for use during times of shortage (O'Donnell and Colby 2010). A CLIMAS researcher collaborated with the U.S. Bureau of Reclamation to assess the practicality and feasibility of water banking and

trading programs for the Lower Colorado River basin. She provided several economic models, guidebooks, and models. In 2017, the Central Arizona Water Conservation District approved over \$5 million (USD) for infrastructural improvements to increase underground water storage capacity for the City of Tucson, Town of Marana, and Town of Oro Valley. The water that accumulates in these reserves will now be stored for future use. The CLIMAS researcher explicitly stated her project objectives as raising awareness and increasing interest in water supply reliability tools in the evaluation logic model. She did not explicitly state the implementation of new infrastructure as an objective. She saw her role as providing information that *could* help inform water planning and policy but did not feel comfortable specifying that it *would*. CLIMAS researchers sometimes wanted to stay impartial when defining their intended research outcomes because they did not want their science to be viewed as biased.

Several anticipated outcomes (n=23) were not achieved by the end of the funding cycle in 2018 (see Figure 5). When envisioning the impact of their research, CLIMAS researchers were able to articulate realistic conceptual outcomes such as improving people's awareness and understanding of an issue. All anticipated conceptual outcomes were achieved, and none were unanticipated. Researchers were less precise in defining the instrumental outcomes of their work in comparison to the other four outcome types. Out of the 22 instrumental outcomes initially identified as project goals, only eight actually occurred. This result suggests that CLIMAS researchers had more difficulty accomplishing the types of instrumental outcomes as originally envisioned. Researchers generally envisioned the instrumental impact of their work—informing policy, planning, or decision-making—to be greater than what occurred within a six-year timeframe.

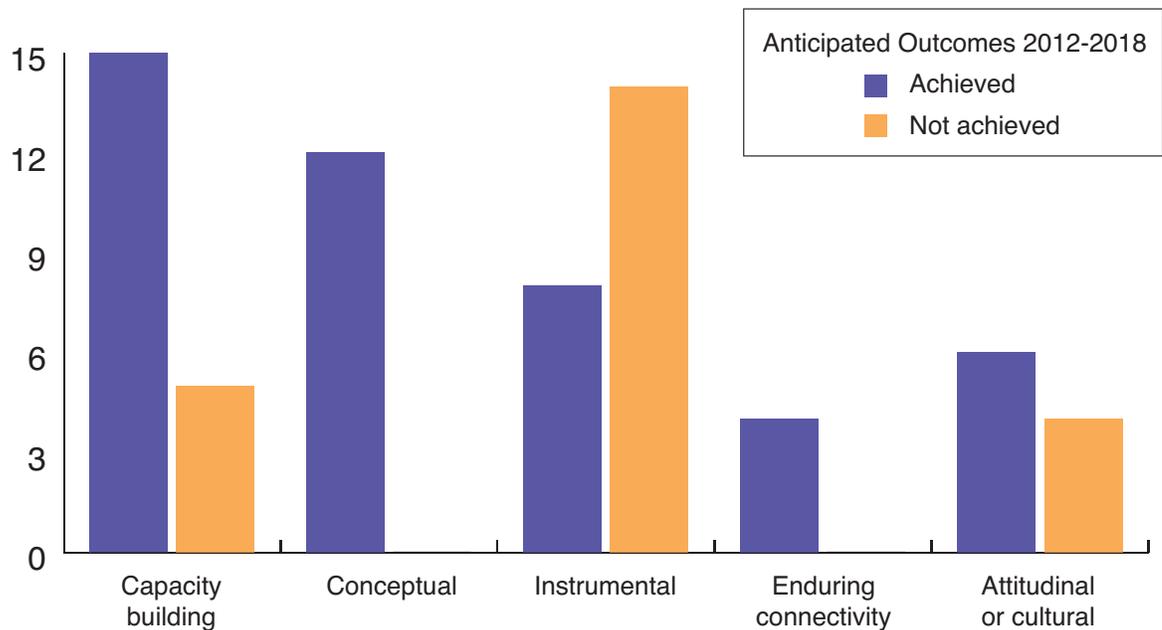


Figure 5. Explicitly anticipated CLIMAS project outcomes that were achieved and not achieved between 2012 and 2018.

Researchers' visions for how their work would be used by project partners and stakeholders did not always manifest as intended. Sometimes, unexpected factors such as changes in political, economic, and environmental conditions or shifts among the research team impeded the path to instrumental outcomes as envisioned by researchers in their logic models. It is important to uncover and understand these challenges in order to improve the practice of socially-engaged research. In the following section, I draw on qualitative findings from one project evaluation to illustrate some of the barriers CLIMAS researchers faced in achieving their objectives as anticipated, and in particular, outcomes involving instrumental applications. This review also shows how the evaluation process encouraged CLIMAS researchers to reflect upon project successes and failures, their approach to socially-engaged research, and improvements for future research practice.

5.1 Evaluation Case Study: Planning for Drought in the Warming and Drying Southwest: Supporting Tribal Decision Making in the Four Corners¹⁵

Native American populations have inhabited Southwest lands for thousands of years. The Four Corners region, where Arizona, New Mexico, Colorado, and Utah meet, is home to four Native Nations: Navajo, Hopi, Ute, and Zuni. Hopi people descended from populations who practiced dryland maize farming in this region since at least 700 AD (Ferguson et al. 2016b). Ranching practices began in the 1500s when Spanish colonialists introduced sheep and other livestock to the region; in the early 1900s, cattle became the primary choice for Hopi ranchers. Dryland ranching and rainfed farming practices remain prevalent on Hopi lands today. Underground aquifers supply most of the water for these and other consumptive purposes (Ferguson et al. 2016b).

In 2009, personnel from the Hopi Department of Natural Resources (HDNR) were seeking technical insight on how to monitor and respond to regional drought conditions. For the past 15 years, the Four Corners region had been experiencing severe to extreme drought conditions. Dust storms were increasing in frequency and intensity causing land erosion and the migration of sand dunes across rangelands and Hopi communities (Ferguson et al. 2010). Invasive species started to dominate the landscape as native vegetation died off. Ranchers faced drought impacts such as poor forage quality and dry water tanks for their cattle herds; the total number of reported cattle had fallen by 60 percent between 1994 and 2009 (Ferguson and Crimmins 2009).

¹⁵ This section draws on data from annual progress reports, research articles, and interviews with two CLIMAS researchers in 2012, 2014, 2016, and 2017 and one interview in 2017 with a social scientist from the Hopi tribe who was a hired member of this research team.

In 2000, Hopi Tribal Council hired an external consultant to develop a drought mitigation and response plan. The plan included a strategy for monitoring drought-related factors such as precipitation, temperature, and soil moisture. However, the strategy relied on indicators that necessitated access to technological equipment, human resources, and funding that the HDNR did not have. HDNR personnel wanted to change their drought plans to better respond to persistent regional drought conditions. In 2009, they contacted two CLIMAS researchers (Daniel Ferguson and Michael Crimmins) for guidance.

Over the next few years, Ferguson and Crimmins spent time with scientists, water managers, ranchers, farmers, and other Hopi community members to better understand local concerns about regional drought. One underlying issue stemmed from inadequate monitoring systems and inaccurate depictions of drought conditions in the Four Corners. For example, the U.S. Drought Monitor is the nation's premier drought monitoring product developed by the U.S. Department of Agriculture, NOAA, and the National Drought Mitigation Center. It combines several types of weather and hydrological data from a variety of sources and monitoring sites to show drought conditions across the country at weekly timescales. The range of drought indices vary in intensity between zero, abnormal, moderate, severe, extreme, and exceptional. One important use of the Drought Monitor is depicting which parts of the country are eligible for drought-relief funding (Ferguson et al. 2016b). However, as was the case in the Four Corners, the Drought Monitor has not always provided accurate pictures of local drought conditions (Steinemann 2014)

In 2008 and 2009, the Drought Monitor depicted no drought, or abnormal to moderate drought in the northeast corner of Arizona, but local conditions during these

times reflected severe, extreme, and exceptional drought. The Drought Monitor sourced its data from only 20 official National Weather Service monitoring stations scattered across Hopi and Navajo territory—a geographically diverse landscape that spans almost 30,000 square miles.¹⁶ Without a sufficient monitoring program and without accurate information about real-time drought conditions, HDNR personnel did not have enough data to plan for or respond to drought. They did not have the necessary evidence to show Hopi Tribal Council who could make management decisions or apply for drought-relief funds.

HDNR and CLIMAS researchers jointly developed a project to better understand the social impacts of drought in the region and to build a local drought information system that was feasible for HDNR to put into practice and provided useful data for the Hopi tribe. Over the course of the project, Ferguson and Crimmins spent several months working with HDNR in the Four Corners. They also hired a social scientist from the Hopi community to conduct an impact assessment survey and to work directly with HDNR personnel. The collaboration was driven by the desire to develop a set of drought indicators and a monitoring program that would inform a more useful plan to deal with extreme drought conditions. CLIMAS researchers envisioned that the outcomes of this project would empower HDNR personnel to manage Hopi lands differently for drought.

Through a series of interviews in 2012 and 2013, I co-developed a logic model with CLIMAS researchers to form a narrative that outlined project components consisting of goals, assumptions, context, outputs, and outcomes (see Figure 6). In 2016 and 2017, after the project concluded, I interviewed the two CLIMAS researchers and the

¹⁶ For comparison, Ferguson and Crimmins (2009) point out that South Carolina, which is similar in geographical size, has more than 100 NWS monitoring stations.

researcher from the Hopi tribe to capture their reflections on the process and to determine what was achieved.

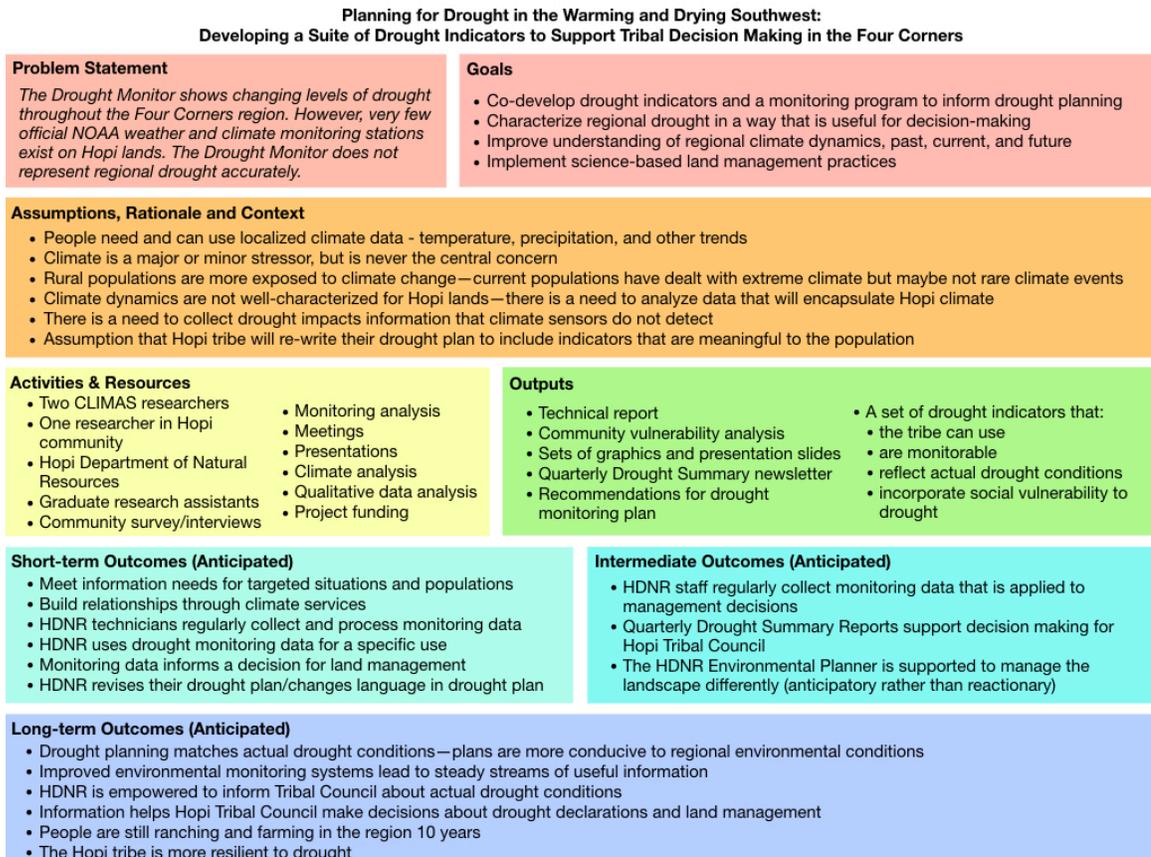


Figure 6. Project logic model.

By the end of the project, all of the anticipated outputs had been completed. However, only three short- or medium-term anticipated outcomes came to fruition. These outcomes included meeting informational needs for targeted situations and populations (building capacity), providing data to inform land management decisions (instrumental), and building relationships through climate services (enduring connectivity). Informational needs were met by providing a comprehensive report with climate information specific to the Four Corners and a two-page Quarterly Drought Summary

containing local climate and range conditions. Information in the summary was used to inform land management decisions. In October 2014, for example, the Hopi Tribal Council cited data in the Quarterly Drought Summary to support a decision to impound horse, sheep, and cattle grazing on land in poor condition—an action that caused controversy between the Council and local ranchers. Lasting relationships between tribal members and CLIMAS researchers were built during fieldwork and maintained through short visits, long stays, phone calls, and other personal interactions. CLIMAS researchers and HDNR personnel spent considerable time learning about one another. Since the project ended, Ferguson and Crimmins remain a source of climate and weather information for HDNR and have been invited to give presentations on several occasions. Overall, relationships remain intact between CLIMAS researchers and HDNR technicians and other Hopi members, with room for future collaborations.

Other short- and medium-term anticipated outcomes were not achieved as originally envisioned. A local drought information system and monitoring program was put into practice during the project; however, HDNR technicians did not continue regular collection of drought monitoring data. This information fed into the Quarterly Drought Summary, but that product was not published after the end of the project. HDNR have not yet used the monitoring program or data to revise their drought plan. For these reasons, CLIMAS researchers described feeling a sense of failure upon reflection of this project.

5.2 Reflecting on Project Outcomes

The evaluation process revealed insights about the project's successes and failures that may have otherwise been left unacknowledged or unexplored. CLIMAS researchers reviewed their original visions and objectives for the project and reflected upon what went right and what went wrong. The first point of reflection involved the changing nature of drought conditions and the fact that Hopi communities have survived several extreme drought events without scientific drought monitoring programs. When initial discussions between CLIMAS researchers and Hopi members began in 2008, drought conditions were relatively severe. By the middle of 2015, annual precipitation increased, which may have reduced the tribal council and HDNR's previous urgency to prioritize drought monitoring. "Things got progressively better drought-wise, so perhaps we had trouble articulating why they should do all this work," said Ferguson during an interview in 2016. "It no longer fit into an immediate need or specific decision that they needed to wrangle with at that moment, or even for multiple years."

Personnel changes within HDNR and tribal leadership also prompted reflection. For example, one anticipated outcome of the project was to support the HDNR environmental planner to manage the landscape differently—to act in anticipation of drought rather than in reaction to it. But the environmental planner left his position in 2014 and the position remained empty until 2018. "Externalities like a key, enthusiastic partner who is the champion for the project are crucial," said Crimmins (personal communication 2017). "It can be a single point of failure if they move out of their position." The HDNR environmental planner was instrumental in the initial stages of project design and implementation and possessed both the vision and expertise to drive

the project. “If there’s nobody to own this process it just doesn’t happen,” Ferguson shared (personal communication 2017).

The third point of reflection involved the researchers’ vision for how the project would function. CLIMAS researchers realized that they had assumed the process would be relatively straightforward, with a direct connection linking scientific information—in the form of monitoring data—to a more sustainable practice of land management. They also thought that co-developing a monitoring program with HDNR staff using readily available resources would lead to permanent implementation of this program. They assumed that rain and temperature data collected via monitoring would inform the Quarterly Drought Summary and that, in turn, HDNR and tribal council would consult it to make drought management decisions. However, as A. Masayesva, a Hopi social scientist, said “There’s no one in the [HDNR] office who is supposed to do this work. And the value of the summaries hasn’t been communicated back up to tribal leadership in a way that adequately promotes the idea” (personal communication 2017).

A compounding factor in this circumstance involved changes in executive tribal leadership. Over the course of the project, elections for a new chairman and vice-chairman were held twice. Therefore, leaders who initially approved the project and influenced project development were no longer in charge when the project ended. It is unclear how familiar new officials were with the project’s goals or outcomes. Without a directive from the chairman, vice-chairman or Hopi Tribal Council to continue monitoring and producing the summary and without someone inside HDNR to promote these activities, they simply ended.

Finally, CLIMAS researchers reflected on several exogenous political and economic factors that contextualized the backdrop in which the CLIMAS project occurred. In the fall of 2009, during the project's scoping and planning phases, Hopi Tribal Council banned the Sierra Club and other environmental and conservation groups from entering the Hopi Reservation (Hopi-Navajo Observer 2009). The Council's resolution was based on the Sierra Club's efforts to shut down the Navajo Generating Station, which purchased coal from the Kayenta coal mine, a major employer of and generator of revenue for tribal members. The Tribal Council stated that environmental groups "have manufactured and spread misinformation concerning the water and energy resources of the Hopi Tribe in an effort to instill unfounded fears into the hearts and minds of the Hopi public" (Hopi-Navajo Observer 2009). Being outsiders and working on an environmental issue, Ferguson noted that this announcement influenced their initial approach to "keep their heads down and focus on the task at hand" (personal communication 2017). The task was to improve access to and use of hydrometeorological data that could be used to inform the tribe's decisions. However, researchers were careful not to discuss their own opinions about these decisions or how the tribe would use this information.

About two years later another environmental controversy arose. In February 2012, U.S. Senators Jon Kyl and John McCain introduced Senate Bill 2109: The Navajo-Hopi Little Colorado River Water Rights Settlement Act of 2012. In exchange for "past, present, and future claims for water rights" from the Lower Colorado River (SB 2109), this settlement authorized three water projects that would bring drinking water to Navajo and Hopi communities (Shebala 2012a). Although the President of the Navajo Nation

avored the bill, councilmembers and citizens of both the Navajo Nation and Hopi Tribe had doubts. When Kyl and McCain came to discuss the proposed bill with Navajo leaders in April 2012 in Tuba City, they were met by more than 200 protesters who opposed the bill (Mountz 2012). Several public forums were held in Navajo and Hopi communities to hear their concerns. By summer, both the Hopi Tribal Council and the Navajo Nation Council rejected SB 2109 (Shabala 2012b; Thayer 2012). Even though the CLIMAS project did not deal directly with water supply, any issues surrounding water suddenly became a slippery topic of conversation. “It wasn’t our place to engage with the politics—to get into the middle of a battle that we didn’t understand the contours of,” D. Ferguson stated (personal communication 2016). “It was such a complex, constitutional landscape—our heads were swinging a bit, so we kept focused on the task at hand.”

These qualitative reflections provided researchers with the opportunity to learn from their successes and failures and bring those lessons into new transdisciplinary projects. “For example,” D. Ferguson explained, “we learned what actually happens in a drought impacted landscape as opposed to what you see from a dataset. We learned about the political and policy implications of drought and people trying to manage it. I have a better sense of what data sovereignty means. For future work I’m going to be much more thoughtful about who owns that data and information” (personal communication 2017). Crimmins added that “When you do physical science, you’re developing stuff for people. You think you should be able to do what you want and have access to the data you want. You assume it is going to be helpful” (personal communication 2017). These reflections help researchers uncover their implicit assumptions and serve to improve how researchers envision their research outcomes in future projects.

6. Discussion

The objectives for the CLIMAS program evaluation were to: 1) demonstrate the program's contributions to building adaptive capacity in the Southwest; 2) develop methods to evaluate the CLIMAS program; 3) feed evaluation results back into program operations and funding decisions; and 4) develop a better understanding of the impact of socially-engaged research. Regarding the first objective, the five types of outcomes adapted from Meagher and Martin (2017) and Meagher and Lyall (2013)—namely, capacity building, instrumental, conceptual, enduring connectivity, and attitudinal or cultural shifts—provide a means to quantify and show trends among the types of changes that researchers perceived to be achieved. Qualitative results offer a richer description of these contributions. For the second objective, the processes of developing a program theory of change and project logic models were valuable in developing qualitative and quantitative methods to show the contributions of CLIMAS research and the program. For the third objective, qualitative and quantitative results inspired researcher learning and reflection, which informed programmatic changes and influenced researcher's practice of transdisciplinary research. Regarding the fourth objective, the theories of change and logic models provided a way to investigate and better understand researchers' visions for the role of science as an effective tool for societal and environmental change. I addressed the first objective in the results section. The following discussion examines the other three evaluation objectives.

6.1. Objective: Develop methods to evaluate the CLIMAS program

Theory-based program evaluation provided helpful methods to demonstrate both scientific excellence as well as societal impact. The theory of change narratives allowed CLIMAS researchers to articulate how they imagined their research being useful or used and by whom. Logic models connected researchers' actions and outputs to their desired expectations and visions for societal and environmental change in the Southwest. Evaluation results were based on comparisons between anticipated outputs and outcomes that researchers identified in their logic models to outputs and outcomes that were achieved.

However, researchers' logic models were not all equally constructed. Some were relatively simplistic in their links between project actions and successful outcomes. As Belcher et al. (2017) notes, researchers' "understanding and ability to model knowledge translation, policy change, and social change generally is still not well developed" (11). Some CLIMAS researchers had very clear project objectives and outlined them in great detail while others left their objectives more open ended. For instance, one researcher identified two very broad short-term and intermediate outcomes regarding his research with agricultural communities in the Southwest; the researchers involved in the drought project in the Four Corners identified nine very specific outcomes. The agricultural researcher achieved both of his identified outcomes, whereas many anticipated outcomes were not achieved in the Four Corners. However, this result does not suggest that the agricultural project was more successful than the Four Corners project. Rather, it suggests that some researchers developed more detailed logic models than others. The purpose of this evaluation was not to tick boxes. Research evaluation strongly emphasizes self-

reflection and learning to conduct better socially-engaged research (Lang et al. 2012). A well-developed logic model with specific outcomes may have more instances of failure; however, these failures provide important learning opportunities.

The need to test, refine, and improve methods to assess the impacts of socially-engaged research remains. This round of program-wide evaluation focused on researchers' perceptions of outputs, outcomes, and impacts. However, the inclusion of project partners and stakeholders in the evaluation process is an important and necessary component of a fully realized evaluation of transdisciplinary research. The following funding cycle that runs from 2017 to 2022 engages project partners outside of CLIMAS in the evaluation design and implementation. Through this process I hope to gain understanding about CLIMAS research partners' perceptions of research processes, the production of new knowledge and other project outputs, or how they applied new knowledge and other project outputs.

As an evaluator, I gleaned important lessons to better facilitate the process of logic model development as part of the overall evaluation of the CLIMAS program and other socially-engaged research. For example, I will encourage researchers to specify more detailed visions regarding their research outcomes. In addition, the logic model should be a more flexible document. In the next evaluation cycle, instead of creating a logic model at the beginning of a project and revisiting it at the end, each year I plan to review the logic model with CLIMAS researchers and revise it as necessary. As Van Drooge and Spaapen (2017) point out, "In case the project or program develops differently than expected, the [theory of change] and the logical frame can be discussed and adapted" (8). A more flexible evaluation model may create more opportunities for

researchers to identify, address, and adjust to unexpected challenges that often arise in socially-engaged research projects (see Owen et al. 2019). This process may also yield more precise indicators and ways of understanding the program's contributions to increasing the adaptive capacity in the Southwest.

6.2. Objective: Feeding evaluation results into program operations and funding decisions

Embedding evaluation as a standard practice in the CLIMAS program lay the groundwork necessary to make evidence-based decisions for program operations, funding decisions, and future project design. Although there is little agreement in the evaluation literature on what classifies as an effective internal evaluation, there is general agreement that internal evaluation supports program management (Volkov 2011). My positionality as a CLIMAS-funded researcher, member of the core CLIMAS team, and program evaluator offered several advantages for feeding evaluation results into program operations.¹⁷ One benefit was my ability to conduct a longitudinal, in-depth evaluation that spanned several years. I co-designed project evaluations with CLIMAS researchers, conducted routine interviews with them over a six-year time period, collected annual progress reports, and attended team meetings where program management decisions were made. Another benefit was my institutional knowledge about the CLIMAS and NOAA-RISA programs, as well as knowledge about the University systems in which these programs were housed.

¹⁷ It is worth noting that my positionality as both evaluator and CLIMAS researcher can also be a disadvantage. For example, as a CLIMAS researcher and member of the core office, I subscribe to and maintain the underlying CLIMAS program theory, which assumes socially-engaged research can and will inform societal and environmental change. My research analysis is therefore driven by this assumption. An evaluator who operates outside of this assumption, or outside of the CLIMAS program, may produce different evaluation results.

As member of the core CLIMAS team, an additional benefit was my ability to easily communicate with the program director. Our discussions about preliminary evaluation findings informed programmatic changes. For example, underperforming projects were defunded and program personnel changes were made. One of the most profound operational changes occurred as the team designed a proposal for the subsequent CLIMAS funding cycle. This process began in early 2016. Preliminary lessons derived from the evaluation between 2012 and 2016 were used to redesign the program's approach to funding, research design, and project selection. In prior years, investigators each received funding for the full five-year grant cycle. Projects were typically defined and use-inspired but were often open-ended and exploratory in nature. Federal budget cuts for the 2017 to 2022 grant cycle meant that CLIMAS could no longer sustain this level of funding for each researcher; instead, researchers only received funding for two to three years each. Collaboration on projects was encouraged in order to share resources. To better evaluate research impact, projects that more explicitly defined their project goals, partners, outputs, and outcomes were included in the proposal. Those that relied on the old funding model were either asked to re-draft their project designs or were not included.

Due to a fairly steady federal funding stream, the CLIMAS program has had the opportunity to refine its approach to conducting socially-engaged science for almost two decades. This timeframe has allowed for the development of long-term institutional and personal relationships, which are necessary for social learning to occur and for mutual understanding regarding climate-related challenges to emerge. As we explain in Owen et al. 2019, this evaluation helped the program manager and the core office envision the

CLIMAS program as a contributor to a social learning system for climate resilience in the Southwest. While the CLIMAS program is not the center of the social learning system, it actively works to build and maintain it. Program activities involve developing science communication and outreach, convening and facilitating meetings and workshops, providing consulting services, collaborating with multiple partners on projects, and offering training for future academics. While projects may only last a few years, the long-term institutional framework of CLIMAS allows it to consistently provide scientific information and develop scientific partnerships, while remaining flexible to shifting needs over time.

6.3 Objective: Develop better understandings of socially-engaged research approaches

This evaluation has important implications for refining the practice of socially-engaged research. One implication emerges from the mismatch between anticipated and achieved instrumental outcomes. Fourteen out of the 22 instrumental outcomes that were initially identified as project goals did not occur as intended within the six-year timeframe.¹⁸ In developing their logic models, CLIMAS researchers generally described anticipated instrumental outcomes as the provision of scientific evidence to inform resource management decisions and planning efforts to reduce the risks associated with climate variability and climate change. As a whole, CLIMAS researchers envisioned their science-based analyses, information products, and decision support tools as being more useful or usable to their partners than what occurred in reality. While acknowledging the non-linearity of socially-engaged research processes, CLIMAS researchers still imagine a

¹⁸ It is possible that, given more time, some of these outcomes might still occur.

relatively linear pathway between the provision of science and achieving instrumental outcomes. This finding reveals an implicit assumption held by CLIMAS researchers about the role of science in solving societal and environmental issues. Although several CLIMAS projects are collaboratively designed with and led by non-academic research partners, to a degree all CLIMAS research projects assume that academic science and knowledge will, at least partially, provide answers to people's climate-related problems. Given the context of the CLIMAS research program, this assumption is not unreasonable. However, it points out that socially-engaged scientists typically center scientific ways of knowing and understanding. How, then, might a socially-engaged research program that centers other ways of knowing and understanding be structured and what might such a program accomplish?

A related assumption revealed through this evaluation is that the main barrier to a climate-adapted society is ultimately based on a lack of knowledge. Researchers believe that partners know the types of information they need or that this need can be ascertained. It is assumed that research partners, or other users of climate information, have the power and will execute that power to implement science-based decisions. Sometimes, science does fill an identifiable knowledge gap, in which case a linear link can be traced between the science and its application. However, in many cases, researchers find that external and internal factors impede a straightforward application of research. Politics, turnover in partner organizations, environmental changes, and shifts in partner interest present considerable barriers to linear applications of science. As a federally-funded research program housed in an academic setting and led by social and physical scientists, the centering of scientific knowledge production in the CLIMAS program is understandable.

However, even when scientific knowledge is coproduced with partners to meet their needs, it does not necessarily lead to societal change.

McNie (2012) draws attention to the need “to build relationships and tend to social systems” (25), a need that is mirrored in my research findings. The number of capacity building and enduring connectivity outcomes that CLIMAS researchers achieved reflect this call for relationship building. Delivering salient, robust, and relevant science is an important part of building trust and relationships with research partners; iterative and routine interaction and communication are also important. While the intensity of relationships tends to fluctuate over time—sometimes interactions are frequent and intense and other times they are sporadic and informal—the connections and relationships built through repeated interactions are crucial: partners learn from CLIMAS researchers and CLIMAS researchers learn from their partners. Through these interactions, researchers come to understand the unique blends of social, political, and environmental contexts in which a project is embedded. Over time, this knowledge helps make researchers’ expectations and assumptions about their impact more realistic. Through iterative interactions, research partners often gain a greater understanding about regional climate, the types of climate information available to them, and how they might incorporate this information into their operations.

Although CLIMAS researchers acknowledge the importance of relationship and collaboration, there was a mismatch between anticipated and achieved outcomes that demonstrate enduring connectivity. Only one third of achieved outcomes in this category were articulated in researchers’ logic models. Researchers (and research funders) should consider the establishment and maintenance of lasting connections as a worthy goal.

Several qualitative differences exist between newly established partnerships and partnerships that had time to develop. For example, mature partnerships promote mutual understandings of one another's needs, increase levels of rapport and trust, and strengthen participants' commitment to the project (Kothari et al. 2011). Researchers may not identify lasting connections as an outcome of research; for some, it may simply be assumed. Addressing this issue may be as simple as asking researchers specifically about their objectives related to developing partnerships (Meagher and Martin 2017).

While sometimes less tangible than instrumental outcomes like economic policies or operational planning decisions, social outcomes often lay the necessary groundwork for more tangible societal and environmental change. As CLIMAS researcher Crimmins noted, "Part of our role as CLIMAS winds up being tilling the ground. Sometimes planting the seeds, maybe we even harvest the crop. But sometimes we just till the ground" (personal communication 2017).

7. Conclusion

Scientific advancements have improved the understanding, attribution, monitoring, and prediction of climate variability and change. The promise of socially-engaged science offers the idea that collaborations between scientists and other members of society will produce outcomes that lead to societal and environmental change. The CLIMAS program's theory of change reflects this promise: *Engaging with existing and potential climate stakeholders in the Southwest results in usable knowledge. These interactions and information products expand people's capacities to adapt to climatic*

shifts and changes. This paper shows that in some cases this theory of change is sometimes true and sometimes inaccurate.

Results highlight instances in which CLIMAS research directly informed policy, planning, and operational decision making. They illustrate the importance of individual and institutional relationships that have been built through activities related to CLIMAS research. Analysis also reveals several research objectives that were not attained. In some cases, CLIMAS researchers envisioned their science-based analyses, information products, and decision support tools as being more useful or usable than what occurred. Exploration of these results reveal implicit assumptions in researchers' visions for how scientific information is used. One assumption maintains that the lack of scientific knowledge and information is a fundamental barrier to a climate-resilient society; therefore, provision of this knowledge and information will directly inform policy, planning, or operational decision-making. However, political, social, and economic challenges often present stronger barriers than the lack of knowledge and information.

CLIMAS research results in new knowledge that is always potentially useful—based on researchers' assumptions of the knowledge and information that people need—and is often used—based on people's application of this new knowledge. These collaborations and new knowledge can lead to demonstrable outcomes such as expanded adaptive capacity, increased awareness about climate, direct use in policy or decisions, long-lasting individual and institutional relationships, and increased willingness to engage on climate-related issues. However, research partnerships and new knowledge do not always lead to instrumental outcomes. The ways in which CLIMAS partners actually use scientific research and information often differs from how researchers envision their

partners making use of this research and information. This mismatch points to some implicit assumptions that researchers bring to their socially-engaged research projects. Making these assumptions explicit can help researchers develop more accurate objectives and expected outcomes for future research projects.

Routine evaluation is integral to understanding the impact of socially-engaged research. While improvements to the CLIMAS program's evaluation approach are necessary, the methods and results from this evaluation provide a baseline of data for comparison to future findings. Even rudimentary logic models provide data regarding researchers' visions for how and why they want to create societal and environmental change. Over time, as more data is gathered and the evaluation process refined, a clearer picture of the program's impact will emerge.

This evaluation has asked researchers to reflect on the intent and purpose of the CLIMAS program itself, as well as the research and information produced. Most researchers, however, have little-to-no experience with research evaluation. While scientists are often asked to connect their work to broader societal impacts, researchers are not typically expected, nor given the time or financial resources by their institutions, to actually reflect upon the societal impact of their research. Evaluation in this case, is less about demanding an audit of one's impact and more about maintaining and improving one's accountability to societal partners.

Theories of change and logic models help make researchers' assumptions and objectives explicit. In this context, concepts like the imaginary and envisioned futures aim to reveal what researchers think about the world, how they think about the world, and how they think the world should be. Socially-engaged research aims to bring these

visions into reality. This type of research demands purposeful examination into the process of effecting societal change. An extensive body of literature discusses the theoretical components of socially-engaged research and research evaluation. Only a small, albeit growing, number of empirical examples exist. There is much to be learned from the successes and failures of socially-engaged research practices.

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