Title
When borders interfere: Advancing adaptive management in the Anthropocene

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Publication Date
2019

Peer reviewed|Thesis/dissertation

UNIVERSITY OF CALIFORNIA,
IRVINE

When borders interfere: Advancing adaptive management in the Anthropocene

DISSERTATION

submitted in partial satisfaction of the requirements
for the degree of

DOCTOR OF PHILOSOPHY

in Social Ecology

by

Kristen Ann Goodrich

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Professor Richard Matthew, Chair
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2019

DEDICATION

In 2010, the death of two people due to flooding in Los Laureles Canyon helped to open my eyes to the inextricable relationship between the social and ecological in the Tijuana River Watershed and ask more questions.

This work is dedicated to you.

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ACKNOWLEDGMENTS

In 2009, I left a position that involved work on the 31-state Mississippi River Watershed with the naïve idea that environmental management in the Tijuana River Watershed would be simpler. Ten years later I am still as challenged, fascinated, and inspired by this bioregion as when I arrived. I am indebted to my colleagues at the Tijuana River National Estuarine Research Reserve (TRNERR) and Southwest Wetlands Interpretive Association (SWIA) who have supported my goal to become a "real" social scientist and immerse myself in academia, while still keeping one foot in the "field." I believe it made my research better. Ana Eguiarte, in particular, was by my side the entire ride, patiently making every idea come to life. She even tolerated my practice of the systematic observation method by tracking the movement of a discarded shoe over time through Los Laureles Canyon – one of my many ("ok…Kris") ideas. Together, we spent many years driving a rusted out van through unpaved roads while traversing potholes and gullies. Those memories will remain my fondest.

My advisor, Dr. Richard Matthew, created enormous opportunities for exploration and growth during my tenure at the University of California, Irvine (UCI). My committee members, Drs. Dave Feldman, Vickie Basolo and Nícola Ulibarrí encouraged me to find my own voice in this process of developing my dissertation, and for that hard nudge, I am grateful. Dr. Dan Stokols, instrumental in the establishment of the School of Social Ecology at UCI, inspired my application to the program and fed my curiosity about the nature of interdisciplinarity. Thanks to the National Science Foundation, I was able to live and breathe the practice by becoming a part of an interdisciplinary research team and work beside, learn from, and write with engineers (an outcome I never expected in pursuing a PhD in social science) including with a mentor in Civil and Environmental Engineering, Dr. Brett Sanders.

In 2016 the Switzer Foundation offered me a fellowship. Since, the Foundation has only grown to amaze me in its ability to cultivate a cohort of environmental leaders who inspire. As an interdisciplinary student, it can sometimes be lonely to not have a departmental "home" but with Switzer, I found a community. I gained close colleagues and lasting friends at UCI whose support and encouragement throughout some of the most difficult moments reminded me of my ability and worth. Interdisciplinarity requires collaboration and I'd like to acknowledge my research colleagues with whom I collaborated to develop this dissertation: the Flood Resilient Infrastructure and Sustainable Environments (FloodRISE) team (particularly the FloodRISE Research Impact and Integration team and Los Laureles Canyon survey enumerators), the Climate Understanding and Resilience in the River Valley (CURRV) team at TRNERR, Dr. Susanne Moser, Dr. Kyle Haines, Dr. John Bellettiere, Genia Nizkorodov, UCI Flood Hazard Scholars and UCSD Cross-border Initiative students.

My family, friends, and husband have patiently tolerated my late writing nights, distracted dinners, and less-than-graceful moments. I cannot measure my gratitude for the dedication of mother, Joan, who worked her entire life to create opportunity for my brother and me to pursue our education. She never bounded our learning. Mom, "climate change."

I received support from the National Science Foundation's Flood Resilient Infrastructure and Sustainable Environments (FloodRISE) project (NSF #133161), through the SedRISE project funded by the National Oceanic and Atmospheric Administration's (NOAA) Ecological Effects of Sea Level Rise (EESLR) program, UCI School of Social Ecology Dean's Dissertation Writing Fellowship and the Robert and Patricia Switzer Foundation Fellowship.

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ABSTRACT OF THE DISSERTATION

When borders interfere: Advancing adaptive management in the Anthropocene

By

Kristen Ann Goodrich

Doctor of Philosophy in Social Ecology

University of California, Irvine, 2019

Professor Richard Matthew, Chair

Adaptive management is challenging, even in the purest of circumstances. It requires experimentation and learning which is difficult to achieve in complex and constrained settings such as the U.S.-Mexico border region, particularly in the context of a changing and uncertain climate. This dissertation explores the limitations to adaptive management presented by both physical and psychological borders using the binational, bioregional, setting of the Tijuana River Watershed as a case study. It offers observations and evidence for opportunities to advance adaptive management through three studies: (1) an exploration of deficits in social capital to illuminate what underutilized social capital can be leveraged in adaptive management; (2) an examination of the process of collaborative community-based research as a method for improving tools for adaptive management; and (3) a characterization of the experiences of, and psychological impacts on, environmental professionals to suggest training and support to enhance their ability to adaptively manage in the Anthropocene.

INTRODUCTION

While adaptive management of environmental resources has proven difficult to achieve in many contexts around the world, there are few areas that present as clear and varied sets of challenges to creating the kinds of community capacity, shared institutions, and common sense of regional purpose that is needed for adaptive management at the borders of national sovereignty. Environmental security at borders present unique challenges for adaptive management: cultural-linguistic disconnect; susceptibility to changing domestic discourse; lack of continuity of binational programs and building institutional capacity; and the seemingly divergent emphases and approaches of environmental and human protection. The United States (U.S.)-Mexico border region, particularly the San Diego-Tijuana region, presents a unique case study of adaptive management at a historical geo-political moment in time. Increasingly, other, non-physical borders – the psychological toll, for example, on environmental professionals - present challenges to adaptive management as the perils of climate change offer unthinkable future scenarios of widespread natural disasters, human displacement, and species and habitat loss. The urgency of environmental management has intensified. If we don't improve, we face global catastrophe.

Adaptive management can be simply described as implementing policies as experiments while engaging learning (Holling, 1978). There are core elements of successful adaptive management: (1) natural resource decisions should be made and modified as a function of what we learn about natural systems (i.e., embrace social learning); (2) decisions should be modest in scope, scientifically sound, and reversible in impact; (3) decision-makers must learn from previous mistakes, monitor impacts, adopt mid-course changes, and reach consensus; and (4) collective decision-making (Blatter & Ingram, 2001; Feldman, 2008; Hass, 1990). Often more abundant than elements of success are failures (or barriers): (1) lack of agreement over purpose or visioning; (3) lack of stakeholder engagement; (4) experiments are difficult; (5) surprises are suppressed; (6) prescriptions are followed; (7) decision-makers are risk averse; (8) the process lacks leadership and direction; and (9) there is a focus on planning, not action (Allen & Gunderson, 2011; Feldman, 2008).

Borders, which in some cases can be productive regions for exchange, can also produce gross disparities in social and environmental realms, leading to significant challenges to adaptive management, especially for those adjacent to a border that divides developed and developing countries. Where borders create these divides, cooperation must transcend national boundaries in ways that challenge our accepted ideals of how collaboration plays out in environmental management paradigms. I examine the particular case of this binational bioregion, manifested in the deeply interconnected social and ecological goals of improving community capitals and environmental outcomes through adaptive management in the Tijuana River Watershed (Goodrich, Boudreau, Crooks, Eguiarte, & Lorda, 2018). In the context of a bioregion that contains one of the last remaining un-bisected coastal wetlands in Southern California adjacent to the busiest land border crossing in the world, debates about the problematic of environmental security come alive and offer ideas for improving social and ecological outcomes. It also asks for a definition of community that is reflexive and critical, not brittle, and provides a platform for studying this unique region, from which to situate.

This dissertation will demonstrate through its studies how the needs of communities that straddle the U.S.-Mexico border region require the disruption of established knowledge production and assess mechanisms for supporting communities, and the practitioners that support them, in adaptation to accelerating environmental degradation and climate change. It argues for an expanded conception of adaptive management, one that emphasizes community co-production of the scientific products that are developed to "benefit them" despite uneven and unjust consequences of contemporary environmental change. Though a lofty goal, considering the deeply institutionalized and centralized ways of creating knowledge that tend to benefit and spiral-up wealth and privilege, it is crucial to interrogate, particularly through the lens of environmental crises and other symptoms of global change in the Anthropocene, adaptive management and environmental security that contribute to the overall resilience of social-ecological systems.

A bioregional-orientation supports the thesis of this dissertation, that the lack of coordination between the two national communities means that meaningful sites of cross-border collective decision-making, a prerequisite for adaptive governance, are difficult to establish. Experimentation and application of policy at the border is complicated as is the national policy on which adaptive management and governance rely upon. Continuity of powers is absent, begging for cultivation of a regional consciousness. It also offers a challenge to treat borders less as talking points and domestic narratives of conflict and more as real places where societies coexist and intermingle.

Within this intermingling, opportunities for experimentation exist to test ways in which adaptive management and environmental security in this bioregion and beyond may be improved upon. Thus, through the research presented in this dissertation I propose the questions*, what are strategies for improving adaptive management in the San Diego-Tijuana bioregion and what role does a bioregional community have to play in this?* Also, *what are the consequences of failed adaptive management (and corresponding environmental outcomes) on those that engage with it and what are the data needs to address the gaps?*

I explore these research questions through the border region research site (San Diego/Tijuana) (Figure I.1) and posit that this site is significant to interpreting current challenges to adaptive management and social-ecological paradigms because it is situated in a space with unique geographical and geopolitical attributes. I do this specifically through assessing:

1. How deficits in community capitals play a role in vulnerability of residents to natural hazards such as flooding and erosion; and how by collecting information from those who are most vulnerable, purely physical understandings of drivers of these processes may be enhanced by elevating underutilized community capitals.
2. How collaborative community-based research can be implemented as a method and process for improving tools for adaptive management; and
3. How (moving beyond the bioregion), if the process of disruption of these systems (and ongoing environmental degradation/climate change impacts) takes a psychological toll on those who are called upon to adaptively manage; and what can be done to better support environmental professionals in an Anthropocene-future.

Adaptive Management in the Anthropocene

Human activity has impacted our planet's ecology at an unprecedented scale and rate, irreversibly altering fundamental biogeochemical cycles and ecosystem functions (Goodrich & Nizkorodov, 2016). As more is understood about ecological and human systems and novel stratigraphic signals cement the Anthropocene as a formally defined geological epoch, the scientific community has challenged assumptions about environmental management and the basic framework upon which an environmental management approach has been based (Walker & Salt, 2011).

Figure I.1. The Tijuana River Estuary (north of red line) and Los Laureles Canyon (south of red line) (red line depicts the U.S. - Mexico Border), a binational bioregion (Cruz, Forman, & Haines, 2018).

Human activity has impacted our environment in ways that are difficult, nearly impossible, to find a historical likeness. We have had such an impact on the nitrogen cycle that the nearest comparison is the origin of the major pathways of the modern cycle some 2.5 billion years ago (Canfield, Glazer, & Falkowsky, 2010). Lewis and Maslin (2015) discuss other troubling realities: contemporary recorded carbon levels have not been seen for at least 800,000 years to millions of years, delaying Earth's next glaciation event; ocean acidity, due to this release of carbon, is increasing at a rate that has not been exceeded in over 300 million years; we are nearing what is being called the Sixth Mass Extinction with species loss occurring 100–1,000 times higher than background rates; and we have transported species across oceans and altered landscapes, genetically modified organisms, and ostensibly reordered life and evolutionary outcomes. Technology and human activity appear to be moving along an unsustainable and perhaps catastrophic trajectory, where human populations expand, producing plastic debris that swirl in gyres the size of the state of Texas and hypoxic zones the size of Massachusetts.

Nir (1983) further classifies four factors — demography, history, economics, and socioeconomics — that affect the intensity, volume, and rate of human intervention in the environment. Humans have intervened against the force of gravity, decelerated and accelerated natural processes, focused energy, and altered or destroyed ecosystems in ways that are urging scientific and scholarly communities to rethink ways to mark this unprecedented period (Syvitski & Kettner, 2011).

There is scientific endorsement to define a new layer of geological time — the Anthropocene — as a "physical manifestation of the timescale" or a "unit in the rock record" ("All in good time," 2015, p. 129). It is anticipated that human impact will be observable in stratification material — rock, sediment or glacier ice — for millions of years to come. Strengthening the argument, in 2016, indicators (e.g., plastics, fly ash, radionuclides, metals, pesticides, reactive nitrogen, and consequences of increasing greenhouse gas concentrations) of the Anthropocene were found in lake sediments that were markedly different from Holocene signatures (Waters et al., 2016). Waters et al. (2016) argue that criteria available to recognize the Anthropocene are consistent with those used to define other stratigraphic units. The Holocene is different from its previous Pleistocene in the Geological Time Scale because it is one in which complex human societies have developed.

Additionally, Steffen and colleagues (2011) identify the Holocene as a stable, accommodating environment and the only one, which we can be sure, can support society as we know it. Those who argue that a new Anthropocene epoch is not required offer that the Holocene already incorporates the introduction of humans (Lewis & Maslin, 2015). However, the Holocene does not include any human derived markers in stratigraphic material, a critical point of for those proposing the naming of a new epoch (Lewis & Maslin, 2015). Additionally, key signals used to recognize the start of the Holocene epoch were not directly influenced by human forcing (Waters et al., 2016). This is considered a major distinction from the proposed Anthropocene.

Although the term has already been adopted among a variety of scholarly and environmental circles and widely among the social sciences, formalization of the Anthropocene as a stratigraphic entity equivalent to other formally defined epochs is recommended due to novel stratigraphic signatures[1] (Waters et al., 2016). Evidence has been accumulating and accelerating. For example, when looking back to 2011, geologists formally recommended that the term Anthropocene be adopted as a "powerful framework for considering global change and how to manage it" ("The human epoch," 2011, p. 254). As the Anthropocene Working Group of the International Commission on Stratigraphy is exploring the official geological recognition of the Anthropocene in stratigraphy, its informal use among scholars and practitioners has proved useful in launching a dialogue and drawing attention to an undeniable trajectory.

Dating the Anthropocene, until recent findings of an abrupt stratigraphic transition, had been incomplete and in flux (Ellis, Fuller, Kaplan, & Lutters, 2013; Waters et al., 2016). Waters et al. (2016) discusses indicators in recent lake sediments that are distinct from Holocene signatures and worldwide anthropogenic deposits. Several markers are offered ranging from the Pleistocene/Holocene boundary to the rise of agriculture in the mid-Holocene to the industrial

[1] Stratigraphic signatures include concrete, plastics, global black carbon, and plutonium fallout (radiocarbon concentration). Long ranging signals include nitrates and global temperatures (Waters et al., 2016).

revolution to the Atomic Age. Proposals primarily include (1) an "early Anthropocene" that begins with the spread of agriculture and deforestation; (2) the Columbian exchange of Old World and New World species; (3) the Industrial Revolution; and (4) the "Great Acceleration" of population growth and industrialization in the mid 20th century (Waters et al., 2016). However, two years, or Global Standard Stratigraphic Age (GSSA), have been suggested for the start of the Anthropocene epoch that have broad support - (1) the year 1610, the Orbis hypothesis, when the massive human population crash in the Americas during colonialism led to the a dip in CO^2 - the Orbis Spike[2] and (2) the year 1964 that is indicated by a peak[3] in ^{14}C - the bomb spike. The year 1610 represents the significant birth of the modern 'world-system' that is geologically embodied by the movement of species, atmospheric CO^2 decline, and global geologic deposits and linked driving human forces that include acceleration of technological developments, rapid human population growth, and increased resource consumption (Waters et al., 2016). The year 1964 is also proposed as a "global event horizon marker" with unambiguous stratigraphic deposits (Waters et al., 2016).

These deposits are accompanied by other potential auxiliary stratotypes including fossil deposits of genetically modified crops, lead isotopes in ice cores, and microplastics in marine sediment. These two years are being argued as the two strongest candidates among other years or events, each of which conform to the criteria of a Global Stratotype Section and Point (GSSP). GSSPs are also known as 'golden spikes', or a single manifestation of change recorded in a stratigraphic section, often reflecting a global-change phenomena. GSSPs exemplify

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[2] Lewis and Maslin (2015) suggest naming the dip in atmospheric CO2 the 'Orbis spike' and the suite of changes marking 1610 as the beginning of the Anthropocene the 'Orbis hypothesis', from the Latin for world, because post-1492 humans on the two hemispheres were connected, trade became global, and some prominent social scientists refer to this time as the beginning of the modern 'world-system.'

[3] An excess of ^{14}C started in 1954 and peaked at 1964 (Waters et al., 2016).

chronostratigraphic units, which unlike time units, are physical entities like rocks, sediments, and glacier ice (Waters et al., 2016).

The criteria for GSSP include (1) having a geological marker that reflects a global event in stratigraphic material; and (2) containing an "auxiliary stratotype" indicating changes to the Earth system (Lewis & Maslin, 2015). Thus examples, however socially significant, like early use of human fire, increasing fossil pollen from domesticated plants, and metal pollution are not globally widespread enough to count as a global GSSP primary marker. Lewis and Maslin (2015) even identify limitations in using the Industrial Revolution as a clear GSSP marker despite its historical significance. Changes to earth systems are not instantaneous or evenly distributed and this further complicates the efforts to mark events. As golden spikes are the preferred boundary markers, 1610 and 1964 are the least ambiguous years under consideration due to their clear, global synchronous geological markers on an annual or decadal scale, criteria required to define a GSSP for the Anthropocene.

However, both proposed years, 1610 and 1964, have their limitations. The Orbis hypothesis may not show large changes around 1600 in biological material from the transport of species because of the time lag in appearance in geological deposits. A radionuclide spike may be a good GSSP marker, but not considered an earth-changing event as past nuclear weapons tests have not transformed aspects of the earth's functioning. Lewis and Maslin (2015) further note the profound philosophical, social, economic, and political implications of choosing a year on our identification of the significance of human in both our geological record and our society. Formalizing the Anthropocene would represent not only the first epoch to be witnessed by advanced human societies, but to be onset by their own doing (Waters et al., 2016).

Although there is a disagreement among stratigraphers as to the exact start date of the Anthropocene, there is a consensus in the scientific community that human activities since the Industrial Revolution have resulted in a trajectory toward more hostile states from which we cannot easily return (Steffen et al., 2011). Several anthropogenic environmental phenomena — climate change, land-system change, biodiversity loss, and the alteration of biogeochemical cycles — are already approaching, if not exceeding, critical ecological thresholds (also called tipping points) of the planet (Rockstrom et al., 2009; Steffen et al., 2015). These issues are deeply interrelated, causing negative feedbacks, further aggravating already stressed regional and global systems.

If thresholds are not already exceeded, humankind is dangerously close to a tipping points (Steffen et al., 2015). A team of 18 international scientists at The Stockholm Resilience Center identified nine planetary boundaries, later translated into global priorities relating to human-induced changes to the environment (Rockstrom et al., 2009; Steffen et al., 2015). These planetary boundaries are not ecological thresholds, but rather serve as "early-warning signs" of decreased ecological resilience under changing conditions. Research indicates that four of these nine boundaries have already exceeded the operating 'safe' spaces of the planet: climate change, loss of biosphere integrity (biodiversity loss and species extinction), land-system change, and altered biogeochemical cycles (phosphorus and nitrogen) (Steffen et al., 2015). Both climate change and biosphere integrity are identified by Steffen et al. (2015) as core boundaries — they are highly integrated system-level phenomena that either regulate or provide planetary level overarching systems within which other boundary processes operate. The significant alteration of these two processes, these scholars argue, would "drive the Earth System out of the Holocene state" (Steffen et al., 2015, p. 8). Findings also indicate that while ocean acidification and freshwater use are below planetary boundary levels, current patterns of human behavior can push these indicators beyond boundary levels by the end of the century.

The significant system-level disruption of environmental processes has resulted in a growing concern that humankind is reaching its carrying capacity[4] and that we are pushing the environment past ecological thresholds. A calculation of humankind's global footprint[5] reveals that present day humanity uses the equivalent of 1.5 planets (Global Footprint Network, 2015). In other words, it takes the Earth one year and six months to regenerate what we use and degrade in a year. The United Nations Food and Agriculture Organization predicts that demand for food, feed and fibers could grow by 70% by 2050, resulting in a human ecological footprint of two planets by 2030 (World Wildlife Fund, 2012; Global Footprint Network, 2015).

Furthermore, humans have unequivocally transformed and managed landscapes that provide critical ecosystem services to the world's population (Goodrich & Nizkorodov, 2016); humans have become the "premier geomorphic agent" in sculpting Earth's landscape (Hooke, 2000, p. 843) (Table I.1). In coastal systems, these activities have modified floodplains, delta functions, and sediment dispersal. Widespread change in land cover resulting from urbanization is expressed through massive losses of pervious surfaces, and gains in engineered infrastructure (manifested as reservoirs, dams, seawalls, conveyances, and irrigation systems) can impair or

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[4] Lundquist, Anderton, and Yaukey (2015) define carrying capacity as the maximum population size within a given area that can sustain itself indefinitely without damaging its existing resources, given its technology and consumption patterns. An overshoot of 'carrying capacity' will result in high resource scarcity (e.g., food, water, land) and will lead to population collapse.

[5] Ewing et al. (2010) define global footprint as the amount of biologically productive land and water area required to produce all the resources the globe uses and to absorb the waste mankind generates, given prevailing technology and resource management practices.

eliminate functions of ecosystems, diminish human access to their services,[6] and in some cases, intensify disservices (Millenium Ecosystem Assessment, 2005).

Table I.1. Human Geomorphic Activity and Results

HUMAN GEOMORPHIC ACTIVITY	RESULT
Deforestation	Soil erosion; slope failure; downstream sedimentation
Farm animal grazing	Gully development; soil erosion
Agriculture (including tillage, terracing, irrigation systems, and subsurface water extraction)	Soil erosion; creep; siltation; subsidence
Mining	River channel and hill slope alteration; slope instabilities; subsidence
Transportation	Gully development; soil erosion; riverbed scouring
Waterway re-plumbing (including reservoirs and dams, diversions, channel levees, channel deepening, and discharge focusing)	Coastline erosion
Coastal management (groynes, jetties, seawalls, breakwaters, harbors)	Coastal erosion or sedimentation; wetland, mangrove, and dune alterations
Trawling	Seafloor resuspension

Adapted from Syvitski and Kettner (2011).

It is difficult to precisely quantify planetary boundaries and thresholds (Steffen et al., 2015). The Earth's ecological thresholds depend not only on the technological capacity and humankind's ability to adapt to environmental perturbations, but also on the feedbacks between systems. As a result, scientists have produced varying estimates of harm to current and future ecological and human systems. While not all scientists agree that humankind has pushed the planet past its planetary boundaries or ecological thresholds, there is a strong consensus among the scientific community that the changes in the Earth's environment are occurring at an unprecedented scale and rate, and that these changes may be irreversible on a human timescale (Steffen et al., 2015).

[6] Ecosystem functions can be simply defined as biological or system processes (Costanza et al., 1997). However, where ecosystem functions are a natural process, services are "the benefits people obtain from ecosystems including functions and "increasingly useful ways to highlight, measure, and value the degree of interdependence between humans and the rest of nature" (Costanza et al., 2014, p. 157; Millennium Ecosystem Assessment, 2005).

STUDY SITE: LOS LAURELES CANYON, TIJUANA AND THE TIJUANA RIVER VALLEY, SAN DIEGO

This region was chosen as a focal site for this dissertation because of the challenges it faces in mobilizing a coordinated response towards adaptive management and environmental security challenges further exacerbated by the challenges presented by the Anthropocene. Environmental management in non-contested regions is difficult and sluggish, however with the layering of border politics and divided and uneven natural resources at the San Diego-Tijuana border, the ability to innovate here is greatly inhibited for those on the front lines of environmental management. There is much to be learned from regions where borders interfere and much to be understood about the psychological impacts on those who manage these threatened, and in some cases, failing ecosystems.

The Tijuana River Watershed is an approximately 1,750-square mile binational area that includes a diverse and complex drainage system ranging from 6,000-foot pine forest-covered mountains to the tidal saltwater estuary at the mouth of the Tijuana River in the United States, with the Tijuana River originating at the confluence of Arroyo del Alamar and Río de las Palmas in Mexico (Tijuana River National Estuarine Research Reserve, 2010). A wide variety of land uses are present in the watershed, from largely undeveloped open space in the upper watershed to highly urbanized, residential, commercial, military, industrial, and agricultural areas in the lower watershed. Nearly three-quarters of the watershed is located in Mexico, as the Tijuana River drains to the Pacific Ocean through an approximately 8-square mile area called the Tijuana River Valley (TRV) that is located adjacent to the border. The TRV contains the largest intact coastal wetland system in Southern California, designated a Ramsar Wetland of International Importance.

Despite the significance of the Tijuana Estuary, threats to environmental security and manifestations of the Anthropocene are observed in abundance here due to intense pressure from development associated with the area being situated on an international border between two major metropolitan areas - San Diego (California, United States) and Tijuana (Baja California, Mexico). Tijuana is a highly desirable location for migration from Latin American and Caribbean countries due to its economic opportunity related to manufacturing and close proximity to the United States. In 2010, the population of the San Diego-Tijuana border region was 4.8 million, making it the largest bi-national metropolitan area shared between the United States and Mexico (Al-Delaimy, Larsen, & Pezzoli, 2014). The resulting rapid and irregular growth is manifested in Los Laureles Canyon (Figure I.2), a 4.6 square mile watershed sub-basin adjacent to the TRV, where according to IMPLAN's 2005 census, the total population is 80,000. However, based on a preliminary on-the-ground housing count conducted in 2014 associated with the Flood Resilient Infrastructure and Sustainable Environments project household level survey, it is estimated that a larger population resides in Los Laureles Canyon (Goodrich, unpublished data, 2014).

Flooding in the City of Tijuana has become an urban dilemma, as rapid urbanization continues to drive people to live in vulnerable, erosive canyons where risks are maldistributed among those least able to mitigate the hazard. Where nuisance flooding[7] is more common in the city center, Los Laureles Canyon, a steep narrow canyon is subject to erosion and landslides during rain. The resulting proliferation of sediment can fill and overtop sedimentation retention basins, compromise flood conveyance channels and bury and choke natural systems downstream.

[7] Defined by Sweet, Park, Marra, Zervas, and Gill (2014) as flooding which causes such public inconveniences as frequent road closures.

Running rivers of mud and debris can scour unpaved roads and destabilize already tenuous slopes resulting in mudslides, destruction of homes, and human injury including loss of life (Goodrich et al., 2018).

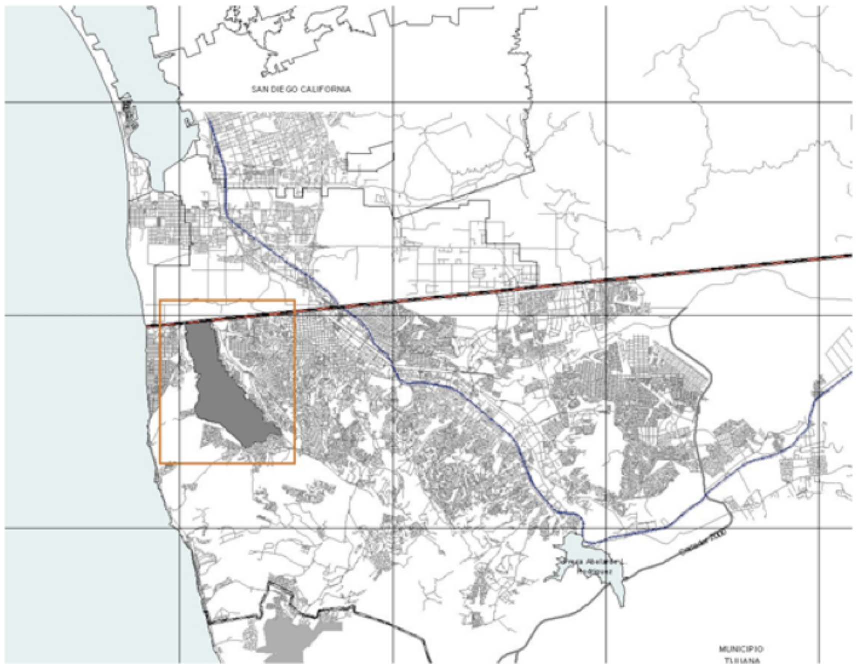

Figure I.2. Los Laureles Canyon in a regional context.

Like the TRV, the City of Tijuana has historical, as well as contemporary, examples of disasters that have been caused by climatic events and resulted in loss of life and damage to infrastructure and dwellings. A regional climate study indicated that intense precipitation events can occur in normal years and even during typically drier La Niña events, causing Tijuana to be exposed to more extreme weather events in the next decades (El Colegio de la Frontera Norte, 2015). In response to this information, a social vulnerability analysis and the development of short-, mid-, and long-term adaptation strategies were funded by the Instituto Nacional de Ecología y Cambio Climático (INECC).

Urbanization occurred before public infrastructure was planned and built, resulting in a notable absence of paved roads, sewers, storm drainage, and other services; these informal settlements do not meet official municipal standard building codes, zoning, or public infrastructure regulations (Al-Delaimy et al., 2014). Additionally, development of the built environment has stripped the natural environment (i.e., biological and geomorphological functions) of it stabilizing features, storage capacity, and surface resistance (deGroot, Wilson, & Boumans, 2002) only increasing its vulnerabilities.

The terrain of Los Laureles Canyon is generally rugged with steep hillsides descending to a relatively narrow canyon floor. Erosion is a significant problem in the area with occasional landslides as a result. Although Tijuana experiences little precipitation, rain can catalyze erosion and soak the ground resulting in slope failure. Heavy rain can cause a proliferation of sediment that can fill and overtop sedimentation retention basins, compromise flood conveyance channels, and choke natural systems downstream, across the border, in the TRV, underscoring the social-ecological dilemma this study area faces.

In contrast to the Mexican side of the border which is high in population density, the TRV has rural housing and equestrian (business) presence as well as government facilities but is primarily natural habitats or in agricultural use (TRNERR, 2010). Agriculture, however, is less prevalent than in the past due to saltwater intrusion of the freshwater table (City of San Diego, 2007; TRNERR, 2010). Multiple public landowners manage stormwater and flooding in the TRV and the few remaining private inholdings are small businesses or private residences.

This natural habitat is part of an ecosystem that supports substantial biodiversity. Although it is surrounded by urban development on three sides (the Pacific Ocean is to its west), and a highly surveilled International Border, the TRV has an isolated, rural ambience and a history of environmental advocacy and opposition. The Tijuana River flows during rain events, but is subject to flooding during major storms; typical of a Mediterranean system, it is relatively dry most of the year (Nordby & Zedler, 1991). The TRV is exposed to various contaminants conveyed by the Tijuana River in storm events from sewage runoff and spills, urban runoff, and illegal dumping. Past storms have resulted in bacteria, chemical, and heavy metal levels exceeding water quality standards (County of San Diego, 2013; Nordby & Zedler, 1991). In addition to riverine flooding, flooding is also experienced on the western (Pacific Ocean) edge of the River Valley from tidal waters being pushed inland. Here, various public agencies have jurisdictional and management authority over land and facilities: the Tijuana River National Estuarine Research Reserve, a Federal-State entity; the United States Border Patrol, Navy, Fish and Wildlife Service; San Diego County; City of San Diego; California State Parks; and the International Boundary and Water Commission.

The Tijuana River Valley is exposed to sediment, debris, and a proliferation of plastics (and increasingly mini- and micro-plastics) and various contaminants from sewage runoff and spills, urban runoff, and illegal dumping conveyed by the Tijuana River and sub-drainages of the River in storm events (Biggs et al., 2018). Past storms have resulted in bacteria, chemical, and heavy metal levels exceeding water quality standards (Nordby et al., 1992). In addition to riverine flooding, flooding is also experienced on the western (Pacific Ocean) edge of the River Valley from tidal waters being pushed inland and is expected to increase due to sea level rise from climate change.

Communities within this area were found to have a high social vulnerability to climate change: there is a high percentage of the population receiving public assistance; low per capita income; high unemployment; high percentage of the population less than high school educated; high percentage of households run by a single parent; high number of persons per occupied household; and high percentage of rental units (Robinson, Leight, Trueblood, & Wood, 2013).

Higher levels of social sensitivity were determined for the Tijuana populations when compared to San Diego, thus, different vulnerabilities emerge as a result of the dynamics of social and biophysical processes and the socioeconomic and environmental condition (Robinson et al., 2013).

Flooding is not a new phenomenon in the Tijuana River Valley, but if stronger, more frequent extreme events are anticipated due to climate change, historical record will aid in the understanding of the potential for flood hazards. Although the surface flow for the Tijuana River is limited or nonexistent for much of the year, periodic albeit powerful floods have in the past shaped and will continue to shape much of the area (Safran et al., 2017). Historical ecology studies, photographs, and records from the last 150 years show shifts in the course of the river and several major floods, inundating large sections of Tijuana, as the Tijuana River could swell up to two miles in width (Safran et al., 2017).

Extreme events and riverine flooding are of particular concern in both communities, however, impacts are felt quite differently due to the built and social landscape. In the TRV, the River converts from a man-made channel to a more natural yet highly disturbed and modified system. Multiple public landowners manage the Valley for stormwater and flood control. The few remaining private inholdings are small businesses or private residences. Flooding here is experienced as a threat to business, agriculture, facilities, and human health due to the polluted flow.

FOUNDATIONAL PROJECTS

Research approaches and data within this dissertation serve to advance understanding of challenges to adaptive management in this bioregion. I argue that transformative approaches are needed to transcend these challenges: the identification of deficits in social capital, the co-production of knowledge about hazards by those who experience it, and the characterization and acknowledgement that failures in adaptive management and related climate change impacts result in psychological impacts. Through application of findings, social capital can be built, tools to address threats can be more actionable, and interventions can be trauma-informed. The two projects discussed below, Flood Resilient Infrastructure and Sustainable Environments (FloodRISE) and the Adaptive Mind, served as foundational to this dissertation by serving as platforms for hypothesis generation, data collection, analysis, and interdisciplinary collaboration.

Flood Resilient Infrastructure and Sustainable Environments (FloodRISE)

The need for institutional, academic, and community collaboration manifest in an extreme form at borders between nations, where disconnect between institutions, academics, and national cultures produce mixed social and ecological consequences (Carruthers, 2008; Kopinak, 2003; National Environmental Justice Advisory Committee, 1999). This is especially true where, in places like Tijuana and San Diego, borders also represent a division between purported developmental stages of national societies, between the so-called developed and developing worlds.

Considering together the social and ecological consequences of global change, research is increasingly being conducted in problem-driven teams (Stokols, 2013). FloodRISE, the project from which data and findings in this dissertation are drawn, is an interdisciplinary effort I was involved in to make flood risk information more readily available to communities in this bioregion by engaging directly with end-users, including residents. Foundational to this dissertation is the notion that it is critical to narrow the gap between expert knowledge of natural hazards assessment, analysis and management on the one hand, with community knowledge and experience regarding vulnerabilities, appropriate responses, and the capacity to apply this expert knowledge on the other. The project, funded by the National Science Foundation was centered on efforts to develop more potent and accurate two-dimensional hydraulic models, developed at the University of California, Irvine that were used for flood hazard mapping in Newport Beach,[8] California; the Tijuana River Estuary straddling California and Mexico, and the Los Laureles Canyon community in Baja California. Quantitative and qualitative data from the southern sites of this project discussed in this dissertation represent social science research approaches deployed to determine how visualization tools are understood, used, and improved by end-users. To engage in a collaborative process as envisioned by the project architects, a Research Integration and Impact Team (RIIT) was assembled to ensure that the FloodRISE project informed and influenced how communities act to increase long-term resiliency to flood hazards and how students, researchers, and communities engage with each other through careful process design. This translational and interdisciplinary science involved interpreting findings in ways that resonated with the context-specific needs of users and leveraged the community capitals of residents vulnerable to flooding and other natural hazards.

Adaptive Mind

Environmental professionals and their stakeholders are increasingly asked to deal with uncertainty, surprise, and difficult transformative change as they face growing threats from climate change, including sea-level rise and extreme events. This is in addition to the baseline demands of their work, limited budgets, and capacity. As professionals seek to protect and improve ecosystems, I posit that they face three profound challenges: (1) coping with what they know (i.e., what science tells us is coming over the short- and long-term and the intimate

[8] Although a research site of the FloodRISE project, findings from Newport Beach are not covered in this dissertation.

knowledge of implications to systems in the Anthropocene); (2) coping with stresses associated with working with the communities[9] that rely on these ecosystems (and the services that they provide) and are most vulnerable to this change; and (3) coping with both acute natural disasters and chronic change.

While recent research points to the psychological impacts associated with climate change in the general public, my research focuses on the growing psychological crisis among this specific population of environmental professionals. The Adaptive Mind project was launched in 2017 to help professionals build their psychosocial coping capacities and skills in dealing with these challenges to enable ongoing (and improved) adaptive management. This project served as a platform for delivering a survey among environmental professionals within professional communities of the National Oceanic and Atmospheric Administration's (NOAA) National Estuarine Research Reserve System, NOAA Sea Grant Extension, and Urban Sustainability Directors Network on their perceptions of these realities, experiences in their work including burnout, and their needs to cope more effectively with the range of psychosocial challenges associated with the demands of their work at this time. Results to-date characterize the challenge and call for in-depth trainings, peer support, and institutional shifts in organizational culture to better support the very individuals whose job it is to support all that is involved in protecting social-ecological systems.

[9] In some cases, these communities are where the environmental professional themselves reside.

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CHAPTER 1:
EVALUATING SOCIAL CAPITAL TO REDUCE ENVIRONMENTAL HAZARDS

INTRODUCTION

Climate change has and will continue to present society with an array of environmental and social challenges. The International Panel on Climate Change (IPCC) describes the planet as having already undergone unequivocal and profound changes, unprecedented over decades to millennia (IPCC, 2014). Furthermore, flood risk is expected to be amplified due to climate change impacts due in part to sea level rise and change in rainfall patterns and storm frequency. Floods affect natural and built environments and represent one of the most hazardous environmental and health risks of our time (Miceli, Sotgiu, & Settanni, 2008).

Not only is flooding an economic peril, but a threat to social well-being and lives, particularly for the residents of the rapidly expanding towns and cities of developing countries (Jha, Block, & Lamond, 2012). Successful implementation of flood risk management and emergency preparedness measures have resulted in a decrease in immediate loss of life from flooding, however, fatalities still remain high in developing countries where flood events have a disproportionate impact on the socially disadvantaged (Jha et al., 2012).

Humans interact with the natural and built environments as part of daily life. They are inextricably linked as environments impact people and people impact their environments. The natural environment may be the source of basic needs such as water and it may provide a household's livelihood by supporting food production (de Groot, Wilson, & Boumans, 2002). It also can be associated with natural hazards such as flooding and landslides. The built environment offers shelter, vital infrastructure such as sewers and streets, businesses/employment, and community gathering centers such as churches and schools.

However, in creating the built environment, humans may disrupt the natural environment creating a complex and discordant relationship, which can amplify the negative impacts of environmental hazards and undermine the social and economic vitality of the community.

In many poor communities throughout the world, individuals live in areas that are hazardous because of the conditions of the natural environment including steep slopes and areas prone to flooding (Jha et al., 2012). Often, these areas offer land that is relatively cheap for households with limited resources. Thus, people with limited means have very constrained choices in terms of living environments and make trade-offs such as settling in vulnerable, disaster-prone conditions to create a home for their families. At the same time, houses and businesses are built by people locating to these hazardous environments and often this development exacerbates existing problems and causes new issues to emerge. Some of the negative impacts can be mitigated by planning, behavioral change, and strategic actions taken by community members. To do so requires that individuals perceive the types of hazards in the natural and built environments, including their interactions, and understand the types of changes or adaptations necessary to reduce their risk (Lindell & Perry, 2012).

The above plays out in the communities of Los Laureles Canyon in Tijuana, Mexico, a poor community built in a relatively narrow canyon with steep slopes subject to erosion and landslides. While it is known that flooding and erosion is a hazard in Los Laureles and is being quantified through engineering approaches, this research sought to deepen understanding of its social- ecological drivers. It was hypothesized that community members who were active in their community would be more likely to take actions to prevent erosion, however, it was found that this relationship is far more complex. This work builds upon an in-person sample survey of households through the University of California, Irvine Flood Resilient Infrastructure and

Sustainable Environments (FloodRISE) project and in-depth interviews residents of Los Laureles who live adjacent to erosion hot spots or areas that contribute the highest levels of sediment yield in the system (Gudino-Elizondo et al., 2019; Taniguchi et al., 2018). Results offer further clarity about drivers of erosion (and related flooding) from a social-ecological perspective and explore barriers to resilience to natural hazards due to deficits in social and other capitals, using the Sustainable Livelihoods Approach (Pons Cortes, 2008). By understanding resident perspectives and experiences, co-benefits for ecological health and human security are illuminated through a better articulation of current conditions and potential solutions.

Erosion and Other Urban Risks in Los Laureles Canyon

Flooding in the City of Tijuana has become an urban dilemma, as rapid urbanization continues to drive people to live in vulnerable, erosive canyons where risks are maldistributed among those least able to mitigate the hazard. Where nuisance flooding[10] is more common in the city center, Los Laureles Canyon, a steep narrow canyon is subject to erosion and landslides during rain. The resulting proliferation of sediment can fill and overtop sedimentation retention basins, compromise flood conveyance channels, and bury and choke natural systems downstream. Running rivers of mud and debris can scour unpaved roads and destabilize already tenuous slopes resulting in mudslides, destruction of homes and human injury including loss of life (Goodrich, Boudreau, Crooks, Eguiarte, & Lorda, 2018).

During rainy periods, erosion[11] can result in landslides in the canyon. Although Los Laureles Canyon has a low average annual rainfall, a large frontal storm with heavy rain can cause a proliferation of sediment that can fill and overtop sedimentation retention basins,

[10] Defined by Sweet, Park, Marra, Zervas, and Gill (2014) as flooding which causes such public inconveniences as frequent road closures.

[11] Erosion is a continual process fueled by wind, water, and gravity (FEMA).

compromise flood conveyance channels and exacerbate flooding, and choke natural systems downstream.

Although efforts to model for flood hazards have been undertaken for the canyon by Luke et al. (2018), there still remains much to be understood about the relationship between flooding and sediment, particularly in areas that have been identified as erosion hot spots by Taniguchi et al. (2018) and Gudinoz Elizondo et al. (2019). Various theories as to why erosion is so high in these particular areas exist, however, beg for further investigation via qualitative research with residents adjacent to these vulnerable, and dangerous, areas. Results from in-depth interviews with over 40 hot spot residents will be discussed (and considered along with data from a household-level survey) and illuminate the circumstances that have contributed to the erosiveness of areas from the perspective and lived experience of a hot spot resident and the role of community capitals on addressing erosion in hot spots.

Environmental burdens and health problems due to urbanization in the study area are well documented (Al-Delaimy, Larsen, & Pezzoli, 2014). Scientists and environmental professionals have worked in the Canyon around an array of issues including erosion. For example, installation of sensors to measure slope movement and efforts to stabilize the terrain with planting and pavers are some of the efforts to understand and control erosion, respectively, in the canyon. The community itself has taken measures to improve the erosive conditions as evidenced by waste-tire retaining walls, for example. Despite these initiatives, extreme events, riverine flooding, erosion and landslides remain major environmental hazards in the Canyon. While nuisance flooding is more common in the city center of Tijuana, pluvial flooding[12] has become an urban dilemma in Los Laureles Canyon. Running rivers of mud and debris can scour unpaved roads

[12] Pluvial flooding dicussed further in Chapter 2

and destabilize already tenuous slopes resulting in mudslides, destruction of homes, and human injury including loss of life (Goodrich et al., 2018).

In Los Laureles, ecosystem services have been disrupted or reduced due to human development in the canyons. Examples include climate regulation, disturbance moderation (of extreme events like fires, flooding, erosion), water quality, soil retention and formation, nutrient cycling, and waste treatment (deGroot et al., 2002). These are the very services that protect people from environmental health and natural hazards. Additionally, degradation of natural resources can also impact quality of life by stripping away aesthetic, recreational, cultural, spiritual, and historic resources. In general, therefore, environmental risks from the natural environment are exacerbated by human development or the built environment.

Sustainable Livelihoods Approach

This particular region offers a challenge, yet also an opportunity, to define a bioregional community. Whether defined spatially or by social structure, communities especially in this border region, are not homogeneous. The variation of interests and behaviors of individuals or households within these communities influence the state of environmental resources (Agrawal & Gibson, 1999; Kramer, Urquhart, & Schmitt, 2009). Although there are many definitions of community, Mattessich and Monsey's (2004) definition, "people who live within a geographically defined area and who have social and psychological ties with each other and the place they live" (p.56) applies well in this bioregion. Research in Los Laureles Canyon provides a unique case study of a binational community, including individuals in decision-making roles within a geography of a shared watershed that has social-ecological systems bisected by the United States-Mexico border. Arguably, a key factor in implementation and success is enhancing social capital. Social capital, the connections among people and organizations to make things happen, positive or negative, is an important indicator of community capital as it is considered to be an entry point for community change (Emery & Flora, 2006). In resilience work, this change is broadly defined as the capacity to "get on back with life quickly after a shock or some disturbance" (Walker & Salt, 2012, p. 62). Social capital is basic to enhancing adaptability and the capacity of a community to work together is critical to social-ecological systems and their resilience (Walker & Salt, 2012). Furthermore, community resilience as summarized by Singh-Peterson & Underhill (2017) is the "ability of communities to understand and address disaster risks and impacts" (p. 125).

Emery and Flora (2006) offer a Community Capitals Framework, a derivative (among many) of the livelihoods literature and Sustainable Livelihoods Approach as a tool for analyzing community development from a systems perspective by identifying: (1) assets in each capital; (2) capital invested; (3) interaction among the capitals; and (4) resulting impacts across capitals. In planning for resilience to a changing climate, these interactions are particularly important as collaborative strategies for critical investments allow for assets to build upon themselves, a mutually reinforcing process that can be visualized as an upward spiral, also known as spiraling-up (Emery & Flora, 2006; Gutierrez-Montes, 2005). Through this case study, I examine social capital and evidence of deficits in Los Laureles and social capital and its power for cumulative causation, or likelihood for other assets to be gained.

Adger (2003) described adaptation as a dynamic social process where the ability of society to adapt is determined in part by the ability to act collectively. The interaction between social and natural capital is a pertinent element to adaptive capacity and the likelihood that adaptation measures will be implemented. As a large body of social science literature illuminates that behavioral and norm change, here, as it relates to response to climate threats, is influenced by local institutions and determined, in part, by the ability to act collectively (Aldrich, Page, & Paul, 2016). This, in turn, influences a community's ability to be resilient to hazards unique to this region.

RESEARCH DESIGN AND METHODOLOGY

Two mixed method studies were conducted to better understand erosion in Los Laureles Canyon from the perspective of its residents within the context of current development trends and existing environmental hazards in the area, such as erosion and slope failure (and their attendant risks for homes and their occupants). The studies were designed as a case study of Los Laureles Canyon with residents as embedded units of analysis within community, when considered a collection of individuals with a common interest whether in close proximity or widely separated (Phillips & Pittman, 2015; Yin, 2014).

Study 1: Household-Level Surveys

Sampling

Despite significant effort during the FloodRISE household survey in LLC, the research team was unable to obtain a random sample due to the conditions of LLC and lack of formal addresses/neighborhood grid. Thus, the Los Laureles Canyon surveys were delivered to randomly selected cells within a grid that was overlayed on the Canyon (Figure 1.1).

Using the Los Laureles subwatershed map from the Los Laureles Canyon Master Plan, the study area was divided into subareas that contained a grid of 58 cells that are approximately 0.1 square miles in size (Instituto Metropolitano de Planeacion de Tijuana, 2007). This map was overlayed with a Mexican government predicted flood zone "Riesgo Por Inundation" (from Instituto Metropolitano de Planeacion de Tijuana) and the UCI Engineering FloodRISE model

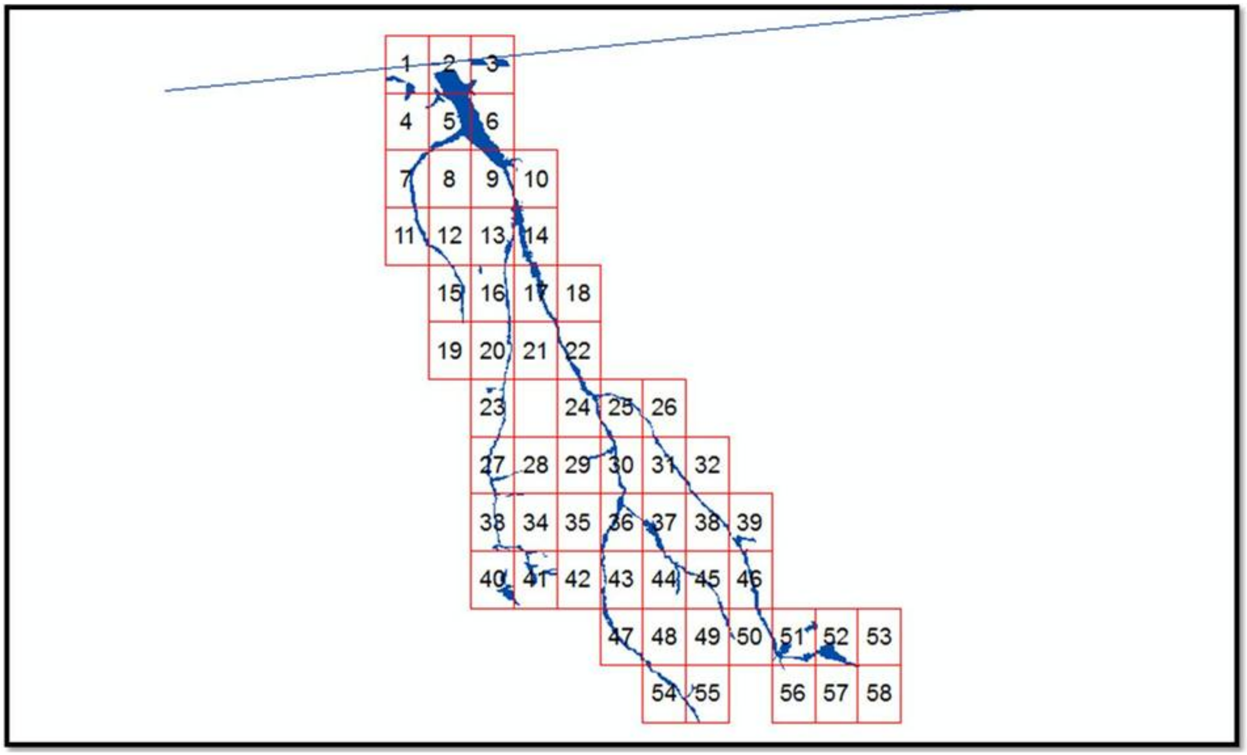

Figure 1.1. Grid overlay for survey distribution.

predicted flood area. From this effort, subareas inside (IN) or outside (OUT) of flood areas were determined. Subareas IN both the IMPLAN and UCI Engineering FloodRISE model were solely present along what was identified as the "main stem" of the flood conveyance channel (cement lining in the southern channel that transitions into unlined (dirt) channels in the northern arm).

Although there are estimates for dwellings in Los Laureles, a housing count in the field was conducted using a method similar to above to arrive at an extrapolated value to determine the number of subareas required to obtain a sufficient sample size. Five cells were randomly selected and divided into four quadrants. A quadrant was randomly selected for each subarea and was canvassed. Every dwelling was counted and noted using a Global Positioning System (GPS) unit. Based on the housing count, there was an average of 114 dwellings for quadrant, or 456 dwellings per subarea. However, we believe that this dwelling count may be conservative considering that several of the random cell quadrants fell in lesser-developed areas, unlike the densely-developed areas that characterize the subareas adjacent to the main stem. It was also taken into consideration that inaccessible dwellings (i.e., no clear path or blocked/on hillside homes) would not be visited. Based on this value, an estimated response rate, and a target survey completion number, it was calculated that six subareas would be required for survey delivery.

Six subareas with the highest percentage of flooded areas were selected and included Subarea 2 (37.39% flooded), Subarea 6 (15.78% flooded), Subarea 7 (38.69% flooded), Subarea 12 (11.55% flooded), Subarea 17 (17.34% flooded), and Subarea 27 (11.05% flooded) (listed here from south to north). These six subareas were targeted for the delivery of the door-to-door household level survey. Five survey enumerators were assigned into teams of two with one independent enumerator. Each pair focused on a subarea to ensure maximum coverage and familiarity. Surveying began in the southern subareas of the channel and moved north. The base layer map was used to identify landmarks (e.g., streets) that were used as boundaries for the subareas. Surveys were tracked using house number, street number, survey number, and GPS location.

The map exercise was embedded at approximately mid-point during the survey. Respondents in each of the selected subareas were asked by the survey enumerators to draw on a hard copy map of their subarea. Respondents were asked to draw: (1) a star to indicate their house and (2) a line around areas that they believed would be at risk in the future. The responses were subsequently digitized using a Geographic Information System (GIS) and analyzed in conjunction with other spatial data (e.g., location of channel thalweg).

The survey comprised of 85 questions was delivered in Los Laureles canyon by a team of Spanish-speaking survey enumerators who were also local residents of the area. O’Hegarty et al. (2010) documented barriers to participation in colonias during the Mexican census including irregular housing, little or no knowledge of English, limited formal education, concerns regarding confidentiality, and complex and fluid households. Some strategies for overcoming these barriers were applied including translations, enumeration strategies, advertisements, and reassurance about confidentiality, and resulting survey response rates and completed surveys reveals success in addressing the concerns. As community collaboration, an enumeration strategy, is associated with increased participation rates, local spanish-speaking residents (with experience as survey enumerators for the Mexican census) were selected and trained as survey enumerators (O'Hegarty et al., 2010). Considering the length and detail of survey questions, difficult terrain and access to properties and households, the role of the community member enumeration team may have played a role in the high level of participation in the survey (53.43%) (Table 1.1).

Table 1.1. Response Rate to Household-Level Survey

	Response	Non-response*
# of residences visited	367	421
	Total # of residences	788
	Total response rate	53.43%

*Non-responses were classified as either an inaccessible residence, residence was abandoned or uninhabited, person at property was not a resident (visitor/temporary), resident was not home (in this case the survey enumerator attempted to return twice before classifying as a non-response), resident did not want to participate in survey, or survey was terminated by resident during the course of the survey.

Question themes included: (1) perceptions of flooding; (2) attitudes about the role of government; (3) information sources (past & future); (4) experience with flooding (and erosion); (5) causes of flooding; (6) preparedness; and (7) demographics and also included a mapping exercise and flood experiment.

The Independent Variable of Interest

The independent variable of interest was a measure of community activity as there was interest in the relationship between reports of community activity and actions taken to prevent erosion in community. Respondents were asked, "how active overall would you say you are in your community?" and given response options 1 (not active at all) to 7 (highly active). To facilitate interpretation of the results, responses were dichotomized to either not active or active.

Outcomes of Interest

The two outcome variables were (1) taking actions to prevent soil erosion in the community and (2) taking actions to prevent soil erosion in the home. They were measured by the responses no (0) or yes (1).

Other Co-Variates

Variables were selected from the larger survey based on the Sustainable Livelihoods Approach which points to a relationship between social capital and shared values and behaviors (Pons Cortes, 2008). Key sociodemographic variables such as age, gender, and income were also selected. The following variables were included: age; gender; education; awareness of flooding in the community (low vs. high); most recent flood experience (within 10 years, 10-20 years, 20-30 years, 30-40 years); home in an area vulnerable to flooding (yes, no, not sure); affected by a flood in your lifetime (yes, no, not sure); affected by erosion at current residence (yes, no, not sure); years lived in current neighborhood (for each 5 years); intent to live in current neighborhood (yes, no, not sure); location in community (cell #); income (less than $1,001 (pesos), $1,001 - 3,000, $3,001-5,000, more than $5,001); active in community (1 (not at all), 2-7 (active to highly active); participation in organizations (community organization, church, no participation); and satisfaction with your neighborhood (not satisfied, very satisfied).

Statistical Analysis

Means, standard deviations, and percentages were used to describe responses to the FloodRISE household-level survey that took place in Los Laureles, Mexico in the winter of 2014-2015 (Table 1.2). Simple logistic regression was then used to assess whether being *active* *in community* and the covariates were related to the two outcomes of interest: (1) taking actions to prevent soil erosion in the community and (2) taking actions to prevent soil erosion in the home (Table A.1 in Appendix). Then a multivariable logistic regression model was fit that included being *active in the community* and all covariates to assess whether associations between being *active in community* and the outcomes were independent of the covariates (Table 1.6).

Study 2: In-Depth Interviews with Erosion Hot Spot Residents

Several hotspots of erosion, (i.e., areas within the canyon that account for significant percentages of the total sediment budget for the watershed) have been identified due to their physical properties (e.g., channel erosion) by engineering research (Taniguchi et al., 2018; Gudinoz Elizondo et al., 2019) (Figure 1.2). However, in such a highly urbanized social-ecological system, it is necessary to better characterize social drivers of sedimentation, if present. As such, interviews were conducted with residents who live adjacent to the identified erosion "hotspots" to: (1) improve understanding of context at research study site; (2) assess if social drivers are contributing to sedimentation in the canyon, and if so, how; and (3) characterize the role of community capitals in the context of an erosive, at-risk community. Additionally, the results from the household-level survey begged for additional context.

Sampling

Development of the interview instrument followed an interpretive logic of inquiry by taking the following bias-avoiding steps: (1) constitutive understandings of causality; (2) reflecting on the relevance of researcher identity; (3) the need to improvise in response to field conditions; and (4) data co-generation in field relationships (Schwartz-Shea & Yanow, 2012). The primary mode of data collection was in-person interviews. The interviews were semi-structured, following a general set of questions, but with ample flexibility to follow different themes emerging during the interview. This approach is particularly useful in this study as individuals were interviewed only once and several interviewers conducted the field work (Bernard, 2012). Interviewees were determined by physical proximity to the erosion hot spots identified by Taniguchi et al. (2018) and Gudino-Elizondo et al. (2019) (Figure 1.3). Interviewers started at the GPS coordinates of the hot spot and proceeded to visit every home that was in visual line of sight. GPS coordinates were marked at every home where an interview was conducted. If a resident was not at home at the time of the interview, a second attempt was made.

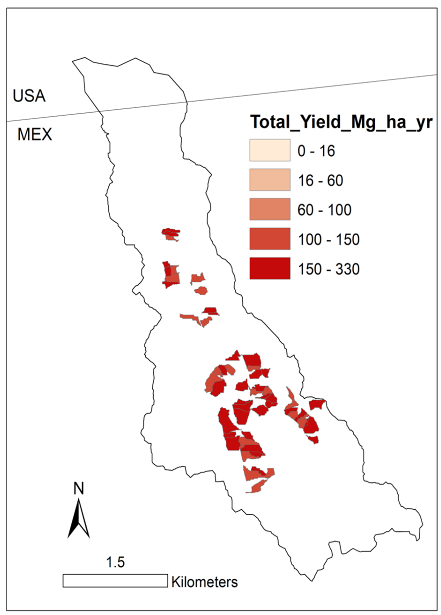

Figure 1.2. Erosion hot spots (Taniguchi et al., 2018; Gudino-Elizondo et al., 2019).

Interviewers took notes and also audio recorded the interview with permission from the interviewee. Audio files were transcribed in Spanish and transcriptions and field notes were translated to English. The resultant transcripts and interview notes were coded for analysis. The data was organized and analyzed using an iterative process, beginning with open coding to identify general themes and concepts followed by axial coding (categorization) and identification of patterns and relationships among the concepts (Feldman, 1995; Saldaña, 2013).

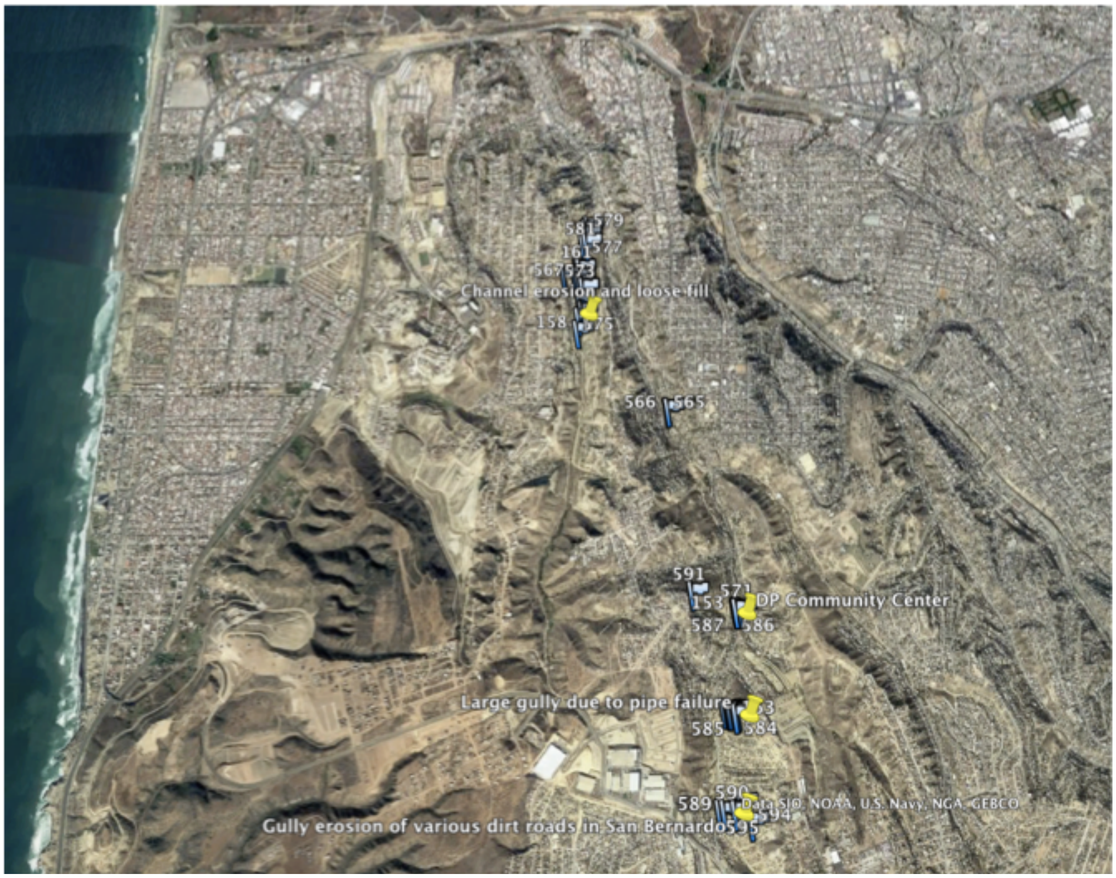

Figure 1.3. Interviews clustered around erosion hot spots.

FINDINGS

Study 1: Household-Level Surveys

The average age of respondents was 44 years. 63% of respondents were female. 59% had experienced a flood event within the last 10 years (survey was conducted in 2014). 60% reported income less than 3,000 US dollars annually. 84% reported that they intend to live in their current neighborhood "long-term," counter to the notion that many residents are temporarily living in Los Laureles Canyon or are transient due to economic drivers. Table 1.2 summarizes responses to the FloodRISE household-level survey in Los Laureles Canyon.

Table 1.2. Responses to the FloodRISE Household-level Survey, Los Laureles Canyon, n=367

Variable	*M* or *n*	*SD*
Age	43.7	16.4
Female	232.0	
Education	4.0	1.8
Awareness of where flooding could occur in community	6.2	1.4
Responded <4 out of 7	36.0	
Year of most recent flood experienced		
within 10 years	218.0	
10-20 years	30.0	
20-30 years	91.0	
30-40 years	9.0	
Home in an area that is vulnerable to flooding		
Yes	238.0	
No	96.0	
Not Sure	30.0	
Affected by a flood in lifetime	209.0	
Home in an area that is vulnerable to erosion		
Yes	225.0	
No	122.0	
Not Sure	18.0	
Affected by erosion at current residence	130.0	
Years lived in your current neighborhood	22.8	13.9
Intent to live in current neighborhood		
Temporary	10.0	
Long-term	307.0	
Not Sure	35.0	
Community (cell number)		
2	100.0	
6	42.0	
7	122.0	
17	43.0	
27	60.0	
Income		
Less than $1,001	98.0	
$1,001-3,000	122.0	
$3,001-5,000	87.0	
$5,001-7,000	27.0	
$7,001-9,000	9.0	
More than $9,000	7.0	
Active in community	2.9	2.3
Participation in		
Nonprofit/charitable org or community/public service	40.0	
Church	43.0	
Satisfaction with community	6.0	1.5
Actions to prevent soil erosion in community	72.0	
Actions to prevent soil erosion around house	163.0	

The residents of the area acknowledged erosion as an environmental hazard. 61.3% of the survey respondents identified their current home as vulnerable to erosion and over 89% said their community was vulnerable to erosion (Table 1.3).

Table 1.3. Responses to the FloodRISE Household-Level Survey: Home and Community Vulnerable to Erosion

	Yes	**No**	**Not Sure**	**Total**
	n (%)	n (%)	n (%)	n (%)
Home	222 (61.3)	122 (33.7)	18 (5.0)	362 (100.0)
Community	324 (89.3)	23 (6.3)	16 (4.4)	363 (100.0)

35% of the survey participants said that their current residence has been affected by erosion. Over twice that percentage (72.2%) reported that erosion has affected their community (Table 1.4).

Table 1.4. Responses to the FloodRISE Household-Level Survey: Home and Community Affected by Erosion

	Yes	**No**	**Not Sure**	**Total**
	n (%)	n (%)	n (%)	n (%)
Home	127 (35.0)	233 (64.2)	3 (<0.01)	363 (100.0)
Community	262 (72.2)	23 (20.9)	25 (6.9)	363 (100.0)

Such awareness of the risk may be due to personal experience with erosion and related hazards such as landslides or observations of disaster events in the community such as the 2010 flood accompanied by mudslides and loss of property in the area.

Cells with the highest % of respondents who reported "yes" to taking actions to prevent soil erosion in their community were cell 6, 17, 27, 2, then 7, respectively (Table 1.5).

Table 1.5. % of Respondents who Reported "Yes" to Taking Actions to Prevent Soil Erosion in their Community

Cell	Total sample from each cell	n responded yes (%)
2	99	40 (40.4)
6	42	25 (59.5)
7	121	47 (38.8)
17	43	23 (53.5)
27	60	28 (46.7)

Table 1.6. Results from Multivariable Logistic Regression Models Assessing Associations between Being Active in the Community and Taking Action to Prevent Erosion in the Community and in the Home Adjusted for All Other Covariates

	Outcome 1: Have you taken any actions to prevent soil erosion in your community?			Outcome 2: Have you taken any actions to prevent soil erosion around your house?		
	Coefficient	**OR**	**P**	**Coefficient**	**OR**	**P**
Active in community?	-0.060	0.87	0.88	0.702	5.04	<0.001***
Age	0.013	1.03	0.01*	0.004	1.01	0.28
Female	-0.018	0.96	0.57	0.185	1.53	0.13
Education	0.037	1.09	0.40	0.013	1.03	0.76
Awareness of where flooding could occur in community	0.079	1.20	0.56	0.167	1.47	0.62
Year of most recent flood experienced			0.53			0.76
within 10 years	Referent	1.00		Referent	1.00	
10-20 years	-0.377	0.42		-0.292	0.51	
20-30 years	-0.108	0.78		-0.155	0.70	
30-40 years	0.124	1.33		-0.444	0.36	
Home in an area that is vulnerable to flooding			0.28			0.66
Yes	Referent	1.00		Referent	1.00	
No	0.111	1.29		0.049	1.12	
Not Sure	0.407	2.55		0.076	1.19	
Affected by a flood in lifetime	0.083	1.21	0.22	0.004	1.01	0.23
Home in an area that is vulnerable to erosion						
Yes	0.299	1.99	<0.001***	0.281	1.91	<0.001***
No	Referent	1.00		Referent	1.00	
Not Sure	0.083	1.21		-0.481	0.33	
Affected by erosion at current residence	0.455	2.85	<0.001***	0.378	2.39	<0.001***
Years lived in your current neighborhood	0.037	1.09	0.19	0.057	1.14	0.59
Intent to live in current neighborhood?			0.78			0.50
Temporary	-0.161	0.69		-0.456	0.35	
Long-term	Referent	1.00		Referent	1.00	
Not Sure	-0.036	0.92		0.292	1.96	
Community (cell number)			0.10			0.01*
2.00	Referent	1.00		Referent	1.00	
6.00	0.207	1.61		-0.076	0.84	
7	-0.027	0.94		-0.284	0.52	
17.00	0.487	3.07		0.072	1.18	
27.00	0.033	1.08		0.358	2.28	
Income			0.14			0.18
Less than $1,001	Referent	1.00		Referent	1.00	
$1,001-3,000	0.281	1.91		-0.137	0.73	
$3,001-5,000	0.255	1.80		-0.041	0.91	
More than $5,001	0.332	2.15		0.248	1.77	
Participation in						
Nonprofit/charitable org or community/public service	0.430	2.69	0.02*	0.196	1.57	0.38
Church	-0.155	0.70	0.44	0.025	1.06	0.97
Satisfaction with community	0.233	1.71	0.06	0.220	1.66	0.15

* p<.05, ** p<.01, *** p<.001

Further analysis through a multivariable regression model suggests significant relationships between a number of variables assessed in the survey. Actions taken to prevent erosion in respondent's community were significantly related to: (1) age (p=.01); (2) home in an area vulnerable to erosion (p=<.001); (4) affected by erosion at current home (p =<.001); and (5) participation in a non-profit/charitable organization (p=.02). Active in community, the independent key variable of interest was not significant (p=.88).

Actions to prevent soil erosion around one's home were significantly related to: (1) home in an area that is vulnerable to erosion (p=<.001); (2) affected by erosion at current home (p=<.001); (3) where respondent lives within Los Laureles Canyon (cell #) (p=<.01); and (4) activity in community (p=<.001).

Of the 364 respondents, 200 (55%) said that they were not at all active in the community. The number of respondents that responded with 2, 3, 4, 5, 6, and 7, were 11, 21, 35, 27, 11, and 59 respectively.

Reports of being active in the community were not significantly associated with taking action to prevent soil erosion in community (p=0.88) after accounting for all the included covariates (Table 1.6). The same null association was observed in the single variable model (Appendix, Table A.1). However, it was that observed that people who participated in a nonprofit or charitable organization had 169% higher odds than people who did not participate in those organizations (OR=2.69; p=0.02). There was no significant relationship between participation in church and taking action to prevent erosions in the community (OR=0.70; p=0.44). Additionally, of interest, *residents that were affected* by erosion at their current residence had a 185% higher odds of taking action to prevent soil erosion in the community (OR=2.85; p<0.001) compared to residents who were not affected. People who reported being vulnerable to erosion (compared to those who were not vulnerable) had 1.99 times higher odds of taking action to prevent community erosion (OR=1.99; $p<0.001$).

For taking action to prevent erosion in the home, people who reported being active in the community had 5 times the odds (OR=5.04; $p<.001$) of taking action to prevent erosion in the home compared to participants who are not active in the community (Table 1.6), controlling for all other covariates.

Sensitivity Analysis

Associations between being active in community and the outcomes of interest were tested as a continuous instead of a dichotomized variable and the results were similar. For taking actions to prevent erosion in the community, there were no significant relationships in either the single variable or the multivariable models. For taking action to prevent soil erosion in the home, in the multivariable models, each 1 unit increase in active in community was associated with a 38% increase in the odds of taking action to prevent erosion (OR=1.38, 95% CI=1.22-1.58; p =<0.001).

Study 2: In-Depth Interviews with Erosion Hot Spot Residents

Building upon Goodrich et al. (2018) community capitals assessment[13] for climate change adaptation in the region, interviews were coded using the Sustainable Livelihoods Approach as a lens for analysis (Table 1.7). Table 1.7 summarizes qualitative data collected from in-depth interviews with community members co-located with erosion hot-spots and categorizes where there were limitations to/deficits in community capitals within Serrat's (2017) framework.

[13] This analysis used Emery and Flora's (2006) Community Capitals Framework.

Table 1.7. Examples of Limitations to/Deficits in Community Capitals Assets

Capital asset	Limitations to/deficits of capital (themes and selected quotes)
Social	● **Insecurity and crime** “[Crime is a] huge problem. Where [there] is the arch, to one side, if you see there, there is a cross. A man and an American woman were killed there, they were shot...Yes, the truth is that it is very dangerous. Last week, there were seven dead in one night.” ● Self-policing “...people who come from other places to throw away the trash. Sometimes my neighbor tells me that trucks come with trash. Before, I went and followed them with my phone and said, "you know, I already talked to the police and he told me to take some pictures because the patrol is there, I want you to collect all the trash."” “At night, the vans [from other communities] are throwing [trash] at the entrance….Once, [me] and my neighbor wanted to stop a truck that had thrown trash, and they tried to run over us.”
Political	● **Root causes (treating the symptom)** ○ Lack/inconsistency of services “Yes, [we want channeling] because we went and told him, what are we going to wait [for]? A misfortune just like in Rancho de las Flores[?]. You see that...a car was taken with the babies, they died, [that] was when they hurried and made the channel, they even made a very nice part there. But are we going to expect something like that to happen here? When it rains, actually, they said that it was going to rain today, and we hope it does not rain, because we know that the day it rains, nobody can leave the house. It is very very dirty. That is why we have asked all [the] time [for] channeling. ○ Ignored by government “...with these colonies, they usually do not pay much attention. [In] Playas, if something breaks down, there is a pothole, the lighting is broken, and they fix [it] fast. This community I imagine that because they are humbler [they do not pay much attention]. Because on this side I imagine that they do not pay taxes.” ○ Broken promises (particularly during election campaigns) “There is no support. That day the delegate came to the park said she was going to send [people] to collect the trash, and she sent eight black bags. There definitely is no support of any kind, security or anything.” “[Promoters] do come to take pictures when we have temporary employment. They come from the delegation...they start taking pictures there…“ahh we are working with the community.”’ ○ Short political terms “Two years ago, this administration offered the paving, but now it is over, and they left and did nothing.”
Financial	● **Fraud/corruption** “The people who move dirt want money and allow trucks to move sediment. 50 pesos.” ● **Illegal dumping and industry** “I tell you, sometimes when the trucks come, they say, "give me 20 pesos, throw the trash in there.”
Natural	● **Erosion** “...there were hills, naturally they had very large holes... every time it rains, it erodes, because it is not well compacted, because the water...makes some cracks...three to five meters, depending on the area.” “Because when it rains the stream runs a lot and the land separates.”
Cultural	● **Diminished quality of life** “...I do all this for the dignity of the person...it is not worth living as we are living. There is definitely no dignity because only animals can live like that. There is need, that is why I dedicate myself to this.”
Built	● **Relationship between flooding, erosion and trash leads to broken infrastructure, drainage issues, and blockages (in some cases of emergency exits)** “Right now, I worry a lot…all of that is going to clog.” “In the rainy season there are people with disabilities, there are elderly, we are without communication. We can not go out, cars do not enter or leave.” “Then, I told them that I explained to them that in times of rain, we have it very hard, the channel was very eroded, and we were left without access.” “We could not go down, it was very deep and very wide.” “It is a bit difficult when it rains, because you can not even walk, when it rains you bring a stick and you fall, and you get up until you get home...when it is raining you can not even go down. There are people who have fallen and have broken feet when going down, because the mud is very sticky, and because the truth is that it is not possible.”

(adapted from Pons Cortes, 2008)

Serrat (2017) describes the capital assets in this framework to include:

1. **Human capital** (e.g., health, nutrition, education, knowledge and skills, capacity to work, capacity to adapt)

2. **Social capital** (e.g., networks and connections (patronage, neighborhoods, kinship), relations of trust and mutual understanding and support, formal and informal groups, shared values and behaviors, common rules and sanctions, collective representation, mechanisms for participation in decision-making, leadership)

3. **Natural capital** (e.g., land and produce, water and aquatic resources, trees and forest products, wildlife, wild foods and fibers, biodiversity, environmental services)

4. **Physical capital** (e.g., infrastructure (transport, roads, vehicles, secure shelter and buildings, water supply and sanitation, energy, communications), tools and technology (tools and equipment for production, seed, fertilizer, pesticides, traditional technology)

5. **Financial capital** (e.g., savings, credit and debt (formal, informal), remittances, pensions, wages)

DISCUSSION

Findings from the household-level survey, particularly the lack of an association between self-reports of activity in community and action related to erosion prevention within their community, is curious based on understandings of social capital. It was hypothesized that there would be a strong relationship between reports of activity in community and actions related to erosion prevention. Instead, this relationship was not strong in this study whereas the relationship between self-reports of activity in community and action related to erosion prevention around their house (individual action) was strong. The relationship between other significant variables and activities to prevent erosion in community such as age, vulnerability to erosion, and participation in a non-profit/charitable organization warrant further investigation.

Data from in-depth interviews helps to suggest major themes such as insecurity and crime, fraud/corruption, and deficits in political capital as limiting factors of community-focused activities to address the erosion (and related flooding) issue.

Above all, residents report the most serious problem in their community as lack of pavement that leads to flooding, erosion, and blockages of flood conveyance channels:

> *"It is ok for those going to work, but imagine an emergency, the child gets sick and we need to get out. I think that is that, the pavement, right? Well, the trash and that has to be organized too, be clean, everyone in their home and their house. I think that is the main thing to be able to get pavement on the street."*

While reports from residents indicate significant limitations to social capital, there are indications of opportunities for enhancements. There is an array of adaptive activities occurring in Los Laureles Canyon, both pre- and post- rain/floods. Residents, despite lack of consistent government services or attention have demonstrated many examples of self-interventions:

> *"Nobody, just us. What you see, we have done."*

Numerous examples of gabions, tire retaining walls, temporary bridges, and pavement/channelization were described as constructed by the residents themselves:

> *"When they were put in, it was very beautiful. As I say, the channel was very narrow, everything was very nice because they fixed with machine. It looked very nice, but when the first rain came, that's when you started seeing it on the street, a very deep ditch. We have improved it."*

Community organizing, including demands to the delegation, though limited in its efficacy in achieving outcomes such as pavement to stabilize the channels in the erosion hot spots, has led to the emergence of leadership (a strong indicator of social capital):

> *"We have a group of leaders, who were on the council and we continue working, like forty leaders. Each leader manages around one hundred people, we are about four thousand people together."*

> *"We have joined several people and we have advocated for our street."*

APPLICATION AND FUTURE RESEARCH

The data from the two studies suggests several pathways forward for improving sustainable livelihoods at the community-level, particularly as related to natural hazards. Opportunity for most gain, as determined through interactions with hot spot residents are where, as Emery and Flora (2006) reflected, “success builds on success,” (p. 22). Action from government, though delayed in these communities due to numerous factors described above in Table 1.7 did occur in some cases, often reported as a result of diligence by community leaders. The Sustainable Livelihoods Approach helps to organize the factors that constrain – and enhance – livelihood opportunities and show how they relate to one another (Serrat, 2017). It also illuminates the reality that the poor must often make trade-offs that comprise livelihoods assets. Especially in Los Laureles Canyon, where government and its services cannot be relied upon, other forms of capital available to the poor must be explored, particularly human capital that elevates knowledge and ways of knowing.

Examples to follow highlight the power of knowledge as human capital: during the development of flood hazard maps, a resident recalled a mattress blocking a culvert causing head-high flooding. Models, before this account, did not reflect a scenario of a culvert blockage, and hazard representations were underwhelming and not reflective of the lived experience in the Canyon. Similarly, while studying erosion in Los Laureles, hot spots were determined using numerical modeling and derived conclusions about sediment yields from a purely physical perspective. Layering information about deficits in livelihood assets can supplement understanding about root causes of natural hazards and amplify opportunity for elevating local knowledge, a more abundant and accessible (human) capital in this community. This research also overlays important social data on top of existing scholarly understanding of the physical drivers of erosion and flooding in the vulnerable communities of Los Laureles Canyon and environmental impacts downstream in the Tijuana River Valley. Thus, it can serve as a model for interdisciplinary discovery where social science and qualitative data can enhance more physical understandings of hazards. Results from this research provide critical knowledge for future research on environmental hazards, and promote more interdisciplinary research in Los Laureles Canyons and similar environments.

Understanding these hazards, especially anthropogenic effects, from the residents' perspective offers an opportunity to design and integrate mitigation and adaptive strategies into existing contexts. It also allows for opportunities for improved co-production of science and actionable science, where the lived experience of a resident living within a site of study can provide the nuanced contextual information, beyond numerical data. With a deeper understanding of drivers of erosion, including limitations to community capitals, interventions such as providing scientific information (such as location and drivers of erosion hot spots) through training and technical assistance to decision-makers and elected officials may provide a voice that residents may not have in current political and cultural contexts. Continued gathering of scientific and interdisciplinary evidence of the need for paving and other structural considerations may lead the action needed for improved social and ecological outcomes in the region. Additionally, increased observation, measurement, evaluation and documentation of processes linked to enhancements of social capital may help us apply livelihoods frameworks to better understand how to engage community at various scales and elevate capital that is most accessible and requires and doesn't require trade-offs that compromise other forms of capital.

A great challenge ahead, however, is mobilizing capital assets in a manner that increases participation so all voices are heard and all affected parties experience reduced risk. The capacity of communities to cope, acclimate, and adapt will depend on strategies that sustain, protect, and improve the social-ecological systems that the community inhabits and defines in an increasingly complex and uncertain environmental and political climate (McGinnis, Woolley, & Gamman, 1999). Synergistic activities that promote community-scale participation and the increase in community capitals will help to overcome potential political paralysis, manage local resources to improve condition, and allow for innovation and more equitable outcomes across scales and boundaries (Goodrich et al., 2018).

Strong relationships with the local community-based organizations in place to implement and integrate this research will help to build a foundation for related training and technical assistance. Future community-based efforts could implement these strategies and correspondingly, future research could evaluate and assess their effectiveness and potential for transfer to other places. Therefore, the proposed research and framework for assessing deficits to more effectively cultivate community capitals could prove useful in other vulnerable communities, as well as other developing countries, to assist in the development and evaluation of strategies to reduce the negative impacts of urbanization and resulting erosion and other environmental hazards.

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CHAPTER 2:
COLLABORATIVE FLOOD MODELING IN TIJUANA, MEXICO: LINKING FLOOD HAZARD MODELING AND COMMUNITY-BASED RESEARCH[14]

INTRODUCTION

Flooding is emerging as a growing challenge around the world (Jongman, Ward, & Aerts, 2012). Over the last decade, flooding accounted for nearly half of all weather-related disasters and affected 2.3 billion people with Asia and Africa being impacted more than other continents (Centre for Research on the Epidemiology of Disasters, 2015). Di Baldassarre et al. (2010) note an order-of-magnitude increase in flood fatalities in Africa between 1950-2010, which points to an important difference from developed countries where trends in flooding are marked by an escalation of flood damages (Cartwright, 2005; Hinkel et al., 2014; Jongman, Ward, & Aerts, 2012; Sundermann, Schelske, & Hausmann, 2014). Beyond threats to life and property, floods pose increased risk of water-borne and vector-borne disease, mental health disorders, and exposure to toxins (Few, 2003; Rataj, Kunzweiler, & Garthus-Niegel, 2016; World Health Organization, 2002).

The impacts of flooding have been concentrated in cities (Sundermann et al., 2014). This is mainly attributed to: (a) rapid urban growth over the past two decades leading to more than 3 billion people (and roughly half of the world's population) living in cities (Cohen, 2006; Wolsko & Marino, 2016), (b) the proliferation of impervious surfaces which negatively alters hydrologic regimes (Fletcher, Andrieu, & Hamel, 2013; Sundermann et al., 2014; Walsh, Fletcher, & Ladson, 2005), and (c) heightened vulnerabilities of affected communities (Global Facility for Disaster Reduction and Recovery, 2016; White, 2011). Increasing future impacts to coastal cities

[14] Manuscript in preparation for journal submission with co-authors V. Basolo, A. Luke, J. E. Schubert, D. Feldman, R. Matthew, A. Eguiarte, D. Boudreau, K. Serrano, A. Reyes, S. Contreras, A. AghaKouchak, D. Houston, W. Cheung, & B. Sanders.

from the combined effects of urbanization and sea level rise has been well documented (Hallegatte, Green, Nichols, & Corfee-Morlot, 2013; Hanson et al., 2011; Hinkel et al., 2014). However, an emerging challenge is pluvial flash flooding (PFF) — flooding and erosion within cities caused by intense rainfall and runoff that will strengthen in a warming climate that sustains more intense precipitation (Abram et al., 2019; Falconer et al., 2009; Rosenzweig et al., 2018; Yin, Yu, Yin, Liu, & He, 2016). PFF is fast moving — developing over a matter of hours causing localized damages, disrupting transportation and business activity, and posing threats to public health and safety (Falconer et al., 2009, Yin et al., 2016). Low resource settings are particularly vulnerable to PFF because urban growth has outpaced the capacity of cities to provide adequate services for citizens including management of environmental hazards (Cohen, 2006). Another key issue is that low resource communities are often excluded from decision-making processes to prepare for and avert or mitigate flooding (Lebel, Anderies, Campbell, Folke, & Hatfield-Dodds, 2006). This is part of a larger problem: scientific knowledge about flood hazards and vulnerabilities is not being effectively translated into information that is useful for decision-making (Spiekermann, Kienberger, Norton, Briones, & Weichselgartner, 2015).

Flood simulation technology has now matured to the point where almost anyone, irrespective of educational background, can intuitively visualize flooding in relation to familiar reference points and immediately grasp important implications (Almoradie, Cortes, & Jonoski, 2015; Mackay et al., 2015; Sanders, 2017; Wilkinson et al., 2015). However, making visualizations useful for decision-making related to flooding requires an iterative process whereby modeling experts and end-users of flood visualizations interact (Campos et al., 2016; Dilling & Lemos, 2011; Evers et al., 2012; Luke et al., 2018; Meyer et al., 2012; Voinov & Bousquet, 2010). Historically, flood hazard models and maps have been developed iteratively by engineers in consultation with stakeholders, for example gathering data about the site, building preliminary models, and making improvements over time based on available data and feedback (National Research Council, 2009). However, the extent of consultation with stakeholders is highly varied, and increasingly engineers may work in isolation from the site that they model and never interact with the end-users of the model (Soden, Sprain, & Palen, 2017).

In this paper, Collaborative Flood Modeling (CFM) is presented as a participatory method to create actionable information to address PFF. CFM is iterative process whereby engineers and social scientist simultaneously advance flood hazard models and engage end-users to meet decision-making needs related to flooding. In this case, CFM is a deliberate choice – a normative view - among researchers to co-produce knowledge because the process (1) promotes inclusion of different perspectives and (2) increases knowledge use in decision-making (Lemos et al., 2018). While there are many examples of community-based research from numerous disciplines, the CFM method was designed using models primarily from the public health field, primarily due to specific principles of and rationale for public health research, including maximum adoption and impact (Israel, Schulz, Parker, & Becker, 1998). Due to a lack of examples from community-based research in the engineering field, a research aim was to examine the transferability from public health to engineering and characterize flood hazard modeling outputs as an outcome.

CFM was applied in a low resourced community in North America — Los Laureles Canyon (LLC) in Tijuana, Baja California (B.C.), Mexico — carried out by an interdisciplinary research team under the Flood Resilient Infrastructure and Sustainable Environments (FloodRISE) project funded by the National Science Foundation. LLC is an area of informal development along the United States (U.S.)-Mexico border with steep hillsides that experience significant erosion during intense rainfall, and where high concentrations of pathogenic organisms are present in runoff from sewage contamination (Gersberg, Rose, Robles-Sikisaka, & Dhar, 2006; Goodrich, Boudreau, Crooks, Eguiarte, & Lorda, 2018). Moreover, housing on unstable hillsides is particularly vulnerable to health and safety risks from intense rainfall (Global Facility for Disaster Reduction and Recovery, 2016). With the application of CFM, PFF flood hazards are communicated in tractable, user-friendly ways that catalyze efforts to reduce vulnerabilities, and in turn, risks. Indeed, CFM presents new opportunities to enhance many aspects of PFF management including planning, preparedness, mitigation, early warning, emergency response, and recovery.

METHODS

Site Description

Tijuana is the largest city in Baja California, Mexico with a reported population of 1,641,570 as of 2015 (Instituto Nacional de Estadística Geografía e Informática de Mexico, 2015). Geographically connected to the conurbation of Los Angeles and San Diego, the city serves as an important industrial and financial center of Mexico, and approximately 90,000 people cross the border northbound each day at the San Ysidro Land Port of Entry (U.S. General Services Administration, 2018). Tijuana experiences a warm dry summer and a cool wet winter. Average high/low temperatures for January and July are 23/18ºC and 18/8ºC, respectively, and average annual precipitation is 27 cm (U.S. Climate Data, 2019). The Tijuana River drains a 1,380 km^2 watershed that is approximately 75% in Mexico and discharges to the Pacific Ocean just north of the U.S. border in Imperial Beach, California. Tijuana experienced fluvial flooding on several occasions prior to the construction of an upstream reservoir and channelization of the river through the City and across the U.S. border. Within the city, communities remain vulnerable to pluvial flooding and hillslope erosion especially in canyon areas. LLC, located in the Northwestern part of the City, is one such area that is the focus of this study. LLC is a 10.5 km^2 relatively long and narrow catchment that drains north towards the U.S. border, and into the Tijuana River Valley, as shown in Figure 2.1. LLC is primarily a residential community of informal development in steep canyon terrain with inadequate drainage, sanitation infrastructure and soil conservation practices. During storms, slope instability and structural failure is common, drainage channels can be blocked by eroding sediment and debris, and sewage is mobilized and transported across the U.S. border and into the Pacific Ocean where it causes water quality and public health problems. The northern border and outlet of LLC is marked by a roadway embankment approximately 22.5 m high with a culvert consisting of five stormwater pipes which are undersized for the 100-year flood discharge, and are prone to blockage by debris. Historically, one such blockage event occurred resulting in the inundation of many homes and concern about a possible embankment failure, which would have sent a dam-break flood of contaminated water into the Tijuana River Valley; however, the risk of failure passed after the flood peak subsided.

Collaborative Flood Modeling Process

Previous research has clearly demonstrated that end-users need to be involved in the development of flood risk management tools (Dawson et al., 2011; Evers et al., 2012; Pasche et al., 2009; Steinführer et al., 2009). Here, end-users refers to community members and authorities in a flood zone with governance, management, planning, design and/or operations responsibilities. End-users may include residents, businesses, developers, planners, regulators, resource managers, emergency management and public works personnel, and non-governmental organizations. It is important to not only include constituents whose behavior and actions will

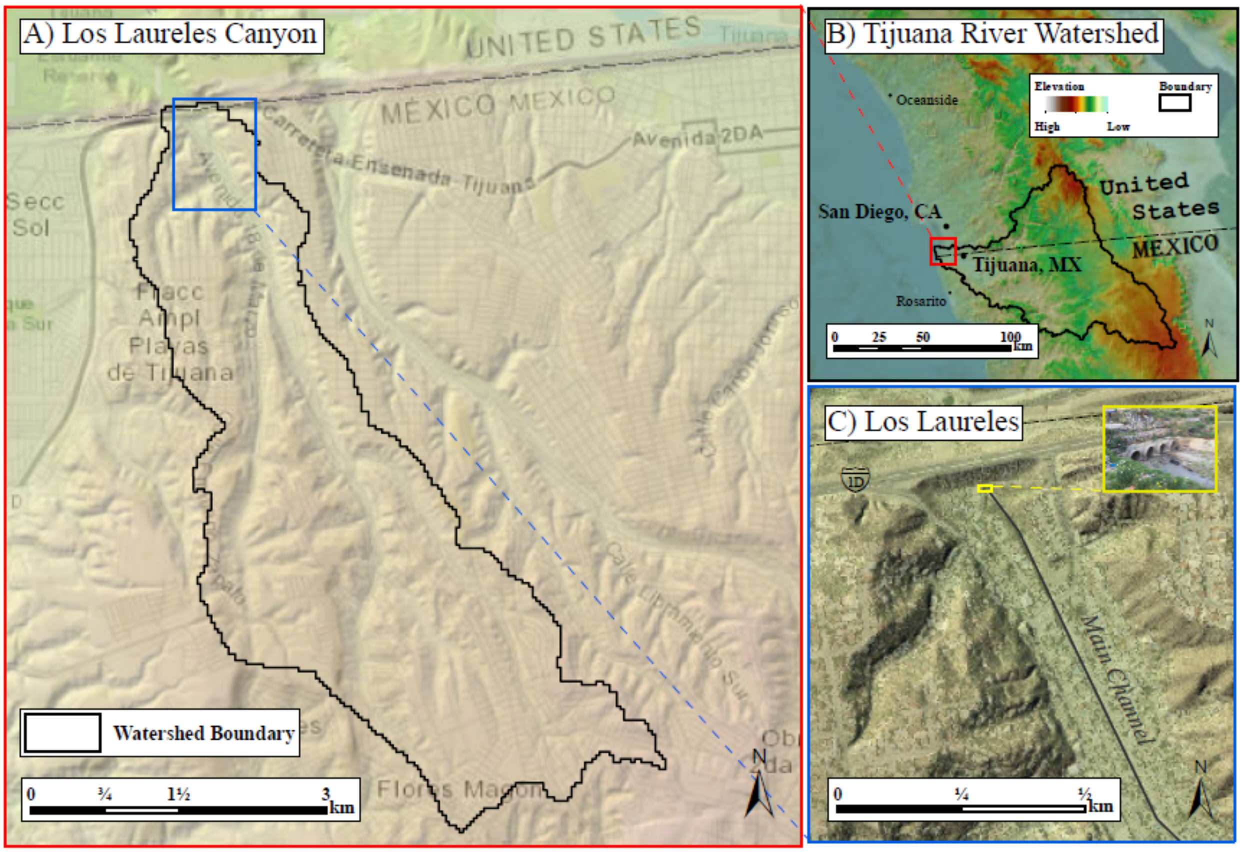

Figure 2.1. LLC in Tijuana, Mexico drains north across the U.S. border into the Tijuana River Valley (A), which terminates at the Pacific Ocean. The broader geographic context and the Tijuana River Watershed is shown in (B). A roadway embankment marks the northern border of LLC and an undersized culvert leads to deep ponding of flood water during extreme events (C). The Los Laureles community is the neighborhood near the northernmost point of Los Laureles Canyon at the U.S./Mexico border.

influence the outcome of flood events (which we define as decision-makers), for example through preparedness and emergency response related decisions and through the establishment and enforcement of policies that guide planning and mitigation, but also those with local knowledge and experience about flooding in the community (which we define as authorities) who are aware of site specific hazards and vulnerabilities.

The FloodRISE collaborative flood modeling process was designed using principles of and rationale for community-based and participatory research outlined by Israel et al. (1998) and Meyer et al. (2012). Israel et al. (1998) in their assessment of improving partnership approaches discuss key principles: (1) recognize the community as a unit of identity; (2) build on strengths and resources in community; (3) facilitate collaborative partnerships; (4) integrate knowledge and action for mutual benefit of all parties; (5) promote a co-learning and empowering process that attends to social inequalities; (6) involve a cyclical and iterative process; and (7) disseminate knowledge gained to all partners.

Meyer et al. (2012) describe the development of flood maps in Europe through participatory processes, and distinguish between substantive and instrumental rationales when designing participatory processes. The substantive rationale aims to increase the depth and breadth of knowledge that contributes to decisions, while the instrumental rationale emphasizes building trust among end-users and raising awareness and motivation to take action. The FloodRISE approach was developed using both rationales due to their corresponding importance for successful engagement, implementation and longevity and was furthered by principles of community-based research discussed above. Thus, four stages of end-user interaction emerged, coupled with model development and iteration (based on end-user interaction), listed below and depicted in Figure 2.2 were planned and completed by an interdisciplinary research team comprised of engineers and social scientists:

1. Expert consultation
2. Household-level surveys
3. Focus group meetings with end-users
4. Training sessions and outreach with end-users

There were two main goals of expert consultation, the first phase of end-user engagement: (1) to understand what had been done in the past, what the important issues are from the locals' perspective and how modeling tools and academic domain knowledge can contribute to the on-going work; and (2) build interest in the project among end-users and a spirit

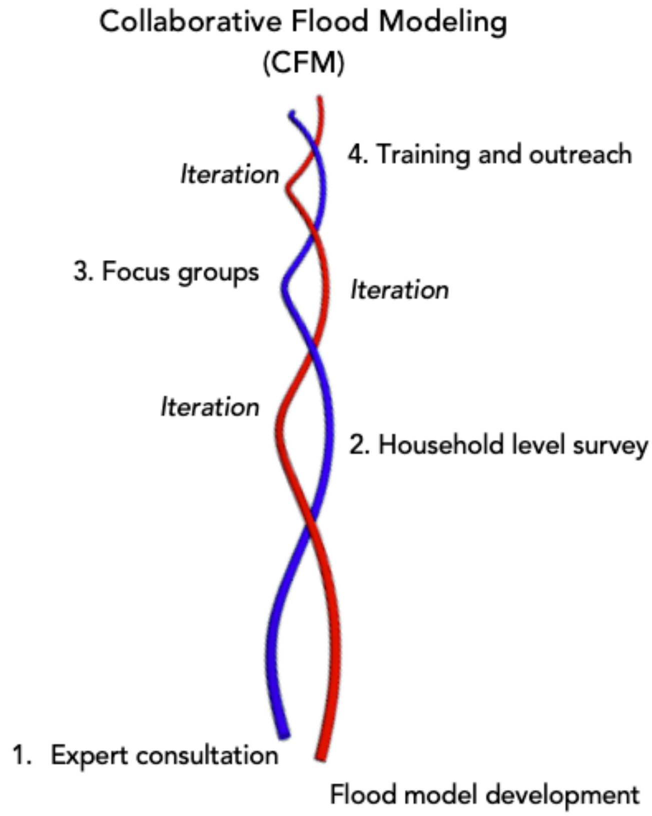

Figure 2.2. Collaborative Flood Modeling was developed as a four-stage process of coordinated end-user interaction and flood model development and iteration. This figure depicts a cyclical and iterative process, a principle of community-based research as identified in Israel et al. (1998).

of cooperation that is needed for successful outcomes. To pursue these goals, partners at the Tijuana River National Estuarine Research Reserve were engaged as members of the research team and acted as liaisons by establishing opportunities for engagement with key contacts in government agencies including the International Boundary and Water Commission, Protección Civil (safety and weather agency in Tijuana, Mexico), and IMPLAN (planning authority in Tijuana, Mexico) as well as researchers from San Diego State University (SDSU) and El Colegio de la Frontera Norte (COLEF). TRNERR personnel provided a tour of the sites to engineering researchers and shared available data including recent aerial lidar data and orthoimagery which extended over both sides of the U.S./Mexico border. Also, SDSU personnel shared valuable data characterizing the geometry of drainage channels.

Household-level surveys were conducted to measure household perception of flood risks (including spatial risk perception), the alignment between perceived risks and actual risks, and the potential usefulness of mapped flood risk information for the community. Understanding spatial risk perception is important not only because of the potential for highly localized flood hazards in the LLC, but because most previous studies generally ask participants to rate the flood risk of their home or community without much spatial specificity (Kellens, Zaalberg, Neutens, Vanneuville, & De Maeyer, 2011). An in-person survey approach was conducted with a sample of households in the LLC. The survey was designed using methods described in Dillman, Smyth, and Christian (2009) and conducted by field interviewers recruited and trained specifically for this research. The questionnaire used in the survey was first developed at a companion site in the U.S., Newport Beach, California and reported by Feldman et al. (2016) and Houston et al. (2017), and for this study the survey was translated into Spanish by a native speaker and pre-tested (Basolo et al., 2016).

Focus group meetings with end-users were completed to understand more specifically the decision-making needs of several groups of end-users within the community: city planners and public works personnel, emergency responders, and community members/NGOs. Luke et al. (2018) provide a detailed description of methods and results, and thus only a synopsis is presented here. The LLC focus groups included 24 participants with 6 representing government (planning and public works), 11 representing emergency managers, and 7 representing non-governmental organizations or other community members. Participants were recruited through personal communication and referral sampling. The focus group lasted 2.5 hrs, during which a facilitator elicited information regarding the focus group's perception of the flood hazard maps. A large-format hardcopy of each map was distributed to all participants along with a glossary that described terminology. After individually examining the map, the facilitator would ask the modeler who produced the map to explain the hazard map and establish a common understanding. Participants were able to ask the engineer questions, while the facilitator would ask questions to test understanding. Data were generated from focus groups by the facilitator adhering to a script with questions specific to each baseline hazard map. Data were collected from the focus groups by recording conversations and reinforced by note-taking. Furthermore, transcripts were prepared of all conversations based on audio recordings. After presentation of all maps, survey data were collected with questionnaires. The surveys were designed to elicit information that would be useful for improving flood visualizations including alternative cartographic preferences and model scenarios. Additionally, preferences for different maps based across groups of end-users were also measured.

With the four rounds of end-user interactions described above, flood models and visualizations were iteratively developed before being uploaded into an online, interactive system for public access. This system was subsequently used in training sessions and outreach with end-users, which corresponds to the final stage of end-user engagement as described above. In the training sessions, held in a computer laboratory, government officials with wide ranging flood management responsibilities and academics were present and were guided through a tutorial on use of the online viewer. Participants learned to access different maps corresponding to different scenarios, to pan and zoom to different areas, and also to identify conditions on site specific basis (such as a street address). Participants also expressed the desire to learn specific ways to operationalize use of the system and develop strategies to expand the system to other parts of the city.

Flood Model Description

Flooding was simulated in LLC using BreZo (Kim, Sanders, Schubert, & Famiglietti, 2014; Sanders, Schubert, & Detwiler, 2010), which solves the 2D shallow water equations using a finite-volume scheme. A mixed mesh of quadrilateral and triangular computational cells was created using Gmsh (Geuzaine & Remacle, 2009) to cover the watershed (Figure 2.1) with an average cell area of 13.4 m^2 and areas of localized refinement for important flow paths. Ground elevation was specified at vertices of the computational mesh based on: (a) spot GPS measurements of channel bank and bottom elevations with 3 cm vertical root mean squared error and (b) aerial lidar survey data of ground elevation with a 0.76 m horizontal resolution and a 7.6 cm vertical root mean square error (Luke et al., 2018). Resistance was characterized using spatially varying Manning's n values, where a value of 0.015 $m^{-1/3}s$ was used for concrete surfaces, and 0.035 $m^{-1/3}s$ was used for natural areas of the floodplain.

The BreZo model was configured to simulate three meteorological forcing scenarios corresponding to 24 hour rainfall amounts of 50, 80 and 100 mm representative of an annual exceedance probability of 0.01, 0.05, and 0.2, respectively (Luke et al., 2018). Initially, a coupled modeling approach was used whereby a hydrologic model was applied to transform rainfall into streamflow from one over of a dozen sub-basins, and then BreZo routed streamflow through the valleys of the LLC. Hydrologic modeling adopted a 24 hour nested storm hyetograph for each rainfall scenario based on the method of Sholders (2003), the Soil Conservation Service (SCS) curve number method was applied to compute losses from interception and infiltration (Ponce & Hawkins, 1996), and overland flow and channel flow were routed within each sub-basin using kinematic wave model described by the United States Army Corps of Engineers (2000). Curve number values were defined based on land use data from the University of Arizona Remote Sensing Center and values from the United States Army Corps of Engineers (2000). In response to end-user feedback, BreZo was also configured for “rain-on-grid” modeling of flooding whereby the hydrodynamic model was relied upon for routing within each sub-basin. In this case, the SCS curve number method was again applied to compute losses and the effective rainfall was added as a spatially distributed source to BreZo. Hence, two different flood inundation modeling approaches were used: a coupled model approach (hereafter, FloodRISE-C), and a rain-on-grid approach (hereafter, FloodRISE-G). End-user feedback also prompted the introduction of channel blockage scenarios since this is a common occurrence during flood events. For these scenarios, the cross-sectional area of channel culverts were fractionally reduced (50% and 100%) and paired with the meteorological scenario corresponding to 100 mm of rainfall.

Each BreZo simulation was run with a variable time step that maintained a Courant number less than unity, and required several hours to complete using 16 cores of the High Performance Computing system at UC Irvine. Several attributes of each simulation were mapped spatially including the maximum flood depth, the maximum flood force represented by the product of flood depth and velocity (a proxy), the maximum shear stress, and the duration of flooding. Each flood attribute was loaded into ArcGIS (ESRI, Redlands, California) for visualization purposes and preparation of printed maps that were used in household surveys and focus group consultations.

RESULTS

The final flood visualizations were organized into an interactive, online, and publicly accessible flood hazard viewer using ArcGIS Online (ESRI, Redlands CA). Figure 2.3 shows visualizations of flood force (Figure 2.3A), flood depth (Figure 2.3B), and flood shear stress (Figure 2.3C) taken from the online flood hazard viewer available here: http://bit.ly/floodrisell. Next, ways in which each iteration of end-user consultation shaped these visualizations and contributed to decision-making needs within the community are described.

Influence of Expert Consultation

Expert consultation was essential for the research team to understand the on-going and previous work at the site. In the LLC, it was found that there was already broad understanding that flooding and erosion is a problem, and that local authorities were investing significant effort and resources into flood hazard mitigation (e.g., catch basins in LLC, city planning outreach). Had a flood model and visualization tool been developed without input from the local experts, there would have been significant potential to be duplicative, irrelevant, or perpetuate a model described by Cash et al. (2006) as a loading dock, where research is produced that has been conceived, designed, conducted and interpreted without collaboration (Cash et al., 2006). However, the prospect for local efforts to be supported by advanced modeling techniques and better data and access to state-of-the-art computational resources was well received by end-users. Without interaction with end-users, it is very unlikely modeling tools and visualizations will be relevant to them. Connections with researchers from SDSU were especially important based on several years of experience investigating the causes and dynamics of sediment transport in the LLC and other parts of the watershed.

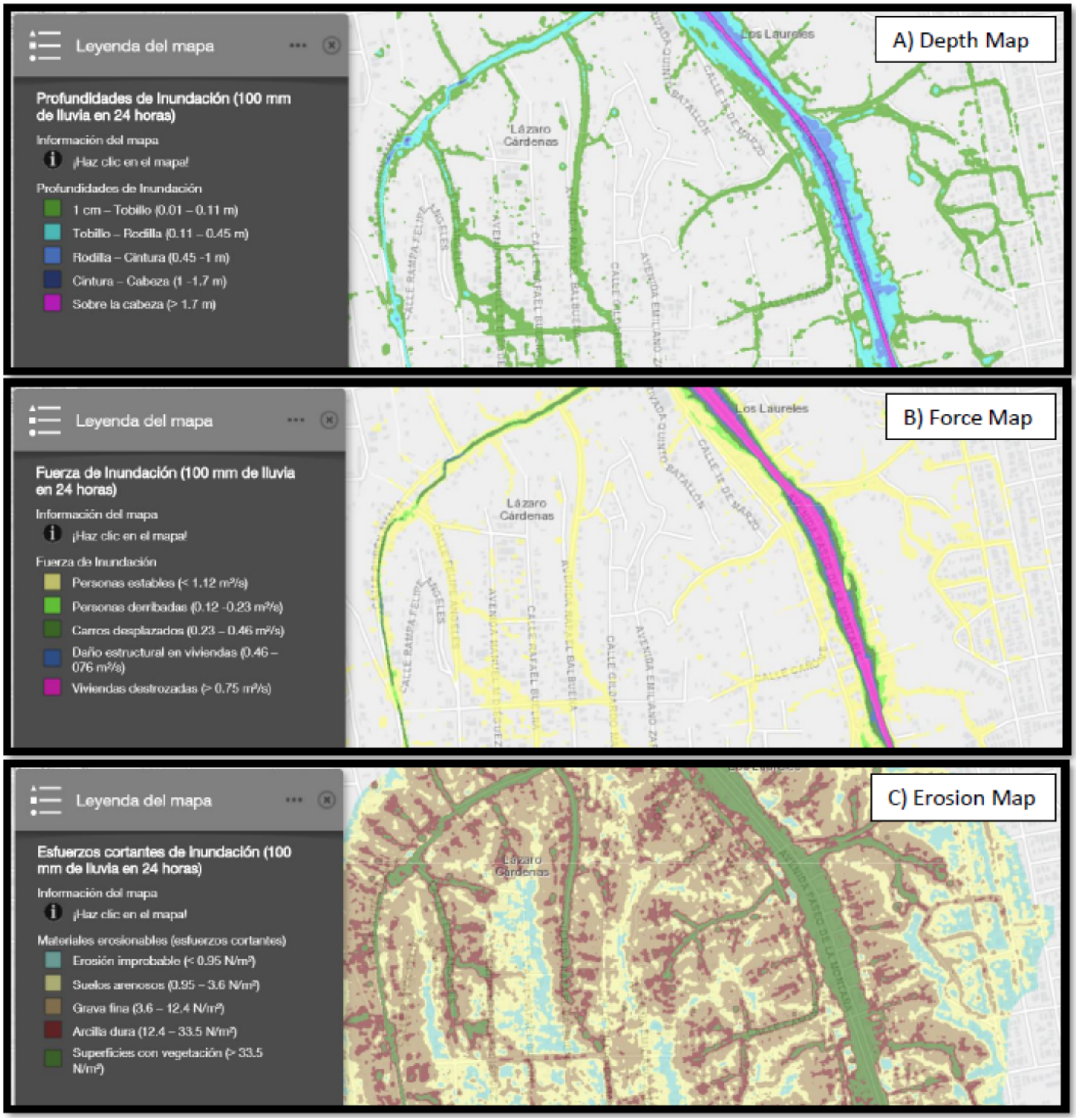

Figure 2.3. Visualization of three aspects of PFF from 100 mm of rainfall over 24 hours: (A) maximum flood force, (B) maximum flood depth, and (C) maximum shear stress visualizations accessed from the LLC online flood hazard viewer, which also includes similar maps for cases involving 50 and 80 mm of rainfall representative of more frequent events. These visualizations are accessible through an online GIS so browsers can pan, zoom, change basemap, and switch between maps: adapted from http://bit.ly/floodrisell.

Influence of Household-level Surveys

A number of topics were addressed in the household level survey (n=367) including: (1) perceptions of flooding; (2) attitudes about the role of government; (3) information sources; (4) flood experience; and (5) hazard preparedness. A mapping exercise and experiment were embedded in the questionnaire. Notably, the self-reported level of awareness of flooding among respondents was very strong (mean=6.22) using a numerical measurement scale (1=not aware, 7=strongly aware). Survey respondents were also asked how prepared their household is to deal with a flood. Unlike self-reports of flood awareness, self-reports of levels of preparedness were low (mean=3.56) (1=not prepared, 7=completely prepared). Additional analysis of preparedness is reported by Basolo et al. (2016). Although respondents were very aware of flood risk, the data suggest that they are not adequately prepared for a flood event. This points to an opportunity for increasing levels of flood preparedness within households poised to act on more specific information about flood hazards through increased engagement, especially through visualization of household level risk.

Survey results provided early evidence that the FloodRISE-C hazard map did not align well with spatial awareness of flood hazards within the community. Respondents were asked whether their home was located in an area vulnerable to flooding, and based on household geographical coordinates, it was also determined whether the household was inside or outside the IMPLAN, FloodRISE-C and FloodRISE-G flood hazard zones. The spatial alignment between respondent awareness of a flooding vulnerability and the three flood hazard models was measured using the critical success index (CSI), a parameter developed to measure warning skill in a spatial map (Schaefer, 1990) where a CSI of 100% corresponds to perfect skill and 0% represents no skill. This calculation showed a relatively low agreement between the FloodRISE-

C map and resident hazard awareness (CSI=16%), whereas the IMPLAN map (CSI=59%) and FloodRISE-G map (CSI=46%) demonstrated better agreement. The FloodRISE-C flood hazard map underpredicted the spatial extent of hazardous areas because areas predicted to flood were only those where flood flows exceed the capacity of formal drainage channels. Indications that the FloodRISE-C map was deficient would also arise during focus group discussions, as described next, and understanding why it was deficient (failure to capture sheet flows at the sub-basin scale) enabled the FloodRISE team to significantly improve the flood hazard maps through the development of the FloodRISE-G approach. This exemplifies how collaboration between experts in flood hazard modeling and end-users of flood hazard information works to improve model quality.

Additionally, and perhaps most significantly, open-ended questions embedded within the survey allowed for residents to describe their experience with flooding. Residents who live within proximity of a set of five culverts beneath an earthen berm under the U.S.-Mexico border, and at the confluence of the sub-drainage of Los Laureles canyon, recalled a particularly PFF event of head-high flooding due to the blockage of one of the culverts by large debris (a mattress). In early iterations of the flood modeling, model outputs depicted minimal flood risk in this area. Based on resident experience gathered from the survey, modelers developed entirely new flood scenarios — later termed the “blockage scenarios” (Figure 2.4) — based on varying percentage blockages of these culverts, an effort that would otherwise not been pursued. Results were drastically different than pre-resident consultation yet reflective of what the researchers were told by residents.

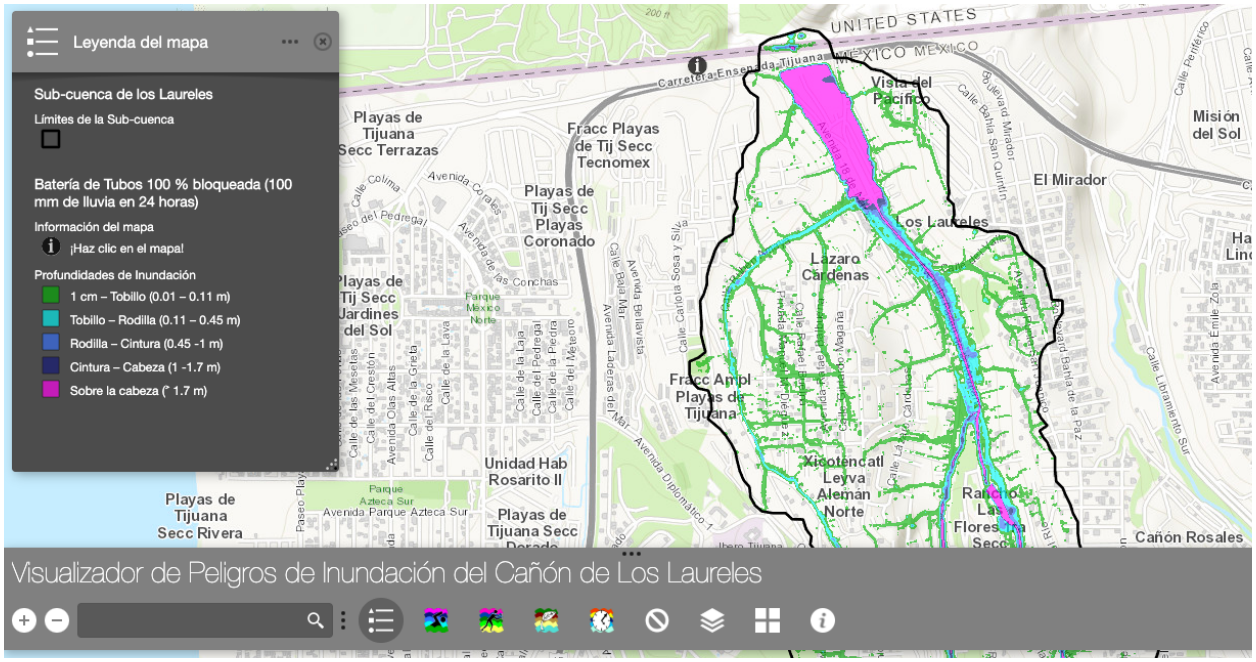

Figure 2.4. Map of maximum flood depth from 100 mm rainfall scenario under a culvert blockage scenario, resulting in extensive ponding near the outlet (northern boundary) of the catchment. Resident interviews generated a report that a mattress previously clogged the main culvert leading to deep flooding.

Influence of Focus Group Meetings with End-Users

Focus groups in LLC included city planners/public works personnel, academia, emergency responders, and community/NGO groups. Their feedback pointed to a number of ways to improve flood visualizations through changes in cartographic elements (e.g., map titles, legends, contextual information) and model scenarios, essentially ways to make the maps more useable, as described by Luke et al. (2018). For example, end-users preferred that the meteorological scenarios be titled based on rainfall depth, not annual exceedance probability, and expressed interest in non-technical language. Contextual information of interest included access roads, flood channels, sediment basins, and locations of dwellings and shelters. Beyond relatively simple cartographic changes, end-users expressed interest in a map that relates flood conditions to erosion and pluvial hazards, which were absent from the first set of maps. End-users also requested visualization of different scenarios beyond the three meteorological conditions including maps depicting channel blockages/obstructions, future channelization, and future land use. For a complete description of end-user preferences, see Luke et al. (2018).

Focus group feedback (as well as data from the household-level survey) helped the research team to recognize the deficiency of the FloodRISE-C approach and the need for the FloodRISE-G approach. When focus group participants were asked to report which (among several maps) would be most useful in their everyday work, a majority selected the government issued and relatively coarse-resolution IMPLAN map over the finer resolution and more detailed FloodRISE maps similar to those shown in Figures 2.3A and 2.3B. This preference, when combined with alignment of perceptions and mapping of risk extracted from household survey data lead the research team to recognize the need to adopt a pluvial flood modeling approach which lead to the FloodRISE-G maps shown in Figures 2.3A and 2.3B.

The focus groups underscored the importance of tailoring map products to the audience and need. For example, when presented with a menu of maps, community members selected flood visualizations in greater numbers than any other groups, specifically, those that depicted duration of inundation greater than ankle depth, with reports of the need to know how long transportation routes would be impacted. Emergency responders chose government products over FloodRISE products, suggesting the role of established organizations and their products in guiding decision-making.

Finally, another important lesson from the focus groups was the extensive interest in learning how to use the modeling tools (i.e., the flood simulation technology). Technically oriented focus group members such as engineers and academics were more interested in generating the visualizations than using the information content of the static maps. For technical projects, such as flood control infrastructure design or watershed studies, the flood model will need to be updated to incorporate the geometry and anticipated impact of proposed project conditions. Thus, static visualizations from past studies have limited practical use for engineering. The focus groups identified the importance of teaching the modeling software to technical professionals in addition to aligning the modeling output to end-user requests.

Adoption for Practice: Training Sessions and Outreach with End-Users

The last phase of end-user engagement involved training sessions with a presentation, practice, and open dialogue format. End-users were asked to report opportunities for the tool to directly inform and impact individual, organization, and/or community decisions regarding flood risk. Four types of uses of the tool were reported by personnel in the following areas: planning (P), water supply and wastewater (W), weather safety (S), military (M), transboundary organizations (T), and academia (A):

1. Policy and Planning Applications
    - Define high risk flood areas. (S, W, M)
    - Inform risk mitigation or public safety policies to protect residents (P)
    - Incorporate into the Minute 320 of the International Boundary and Water Commission of the United States and Mexico, the general framework for binational cooperation on transboundary issues in the Tijuana river basin. (T, T)
    - Incorporate into the urban development program of the City of Tijuana (P)
    - Plan evacuation routes (S, M)
2. Infrastructure Management
    - Improve design of storm drain system for new development projects (A)
    - Inform design of flood resilient infrastructure (W)
3. Support Research
    - Inform ongoing research into geological and hydrometeorological risks (A, A)
4. Community Awareness and Outreach
    - Increase understanding of flood risk among residents (W)

- Discourage development in high risk areas (S, P)

These results indicate that the tool is viewed by end-users as having potential for a wide range of uses, and this points to considerable value for informing the complex web of decision-making that determines flood risk (Morss, Wilhelmi, Downton, & Gruntfest, 2005). These results also indicate that the tool is especially valued for planning, based on the number of personnel citing planning-oriented uses and the total number of cited uses. Broadly, the reported uses and the overall positive reception of the tool by end-users reinforce previous findings by Wilkinson et al. (2015) that flood information tools co-developed with end-users achieve several important outcomes such as: (a) builds greater shared understanding about flood risks; (b) facilitates the exchange of ideas; (c) provides a framework for how to approach development; (d) encourages interaction among scientists and end users; and (e) provides a wealth of information that is accessible and understandable to end-users.

Influence of Process Design Using Principles of and Rationale for Community-Based and Participatory Research

Successful integration of community needs, research, and education through co-production is no small endeavor despite the evidence that it increases the likelihood that knowledge will be used in decision-making (Lemos et al., 2018). Costs are high, time investment is great, constant requests from participation among end-users can lead to fatigue, and “close interaction may be taxing or intimidating for both scientists and stakeholders, who may feel they do not have the training, personal inclination, understanding of each other’s contexts, or organizational support to participate in co-production” (Lemos et al., 2018, p. 722).

Despite the obstacles, to engage in a collaborative process as envisioned by the project, a Research Integration and Impact Team (RIIT) was assembled to ensure that the FloodRISE project informed and influenced how communities act to increase long-term resiliency to flood hazards and how students, researchers, and communities engage with each other through careful process design. However, three Israel et al. (1998) principles were most instrumental in guiding the development of the FloodRISE CFM approach, focus on four stages of end-user interaction, and implementation by the RIIT team:

1. **Recognize community as a unit of identity**: FloodRISE focused its research in communities vulnerable to flooding, however, included individuals in decision-making roles within Los Laureles Canyon, a unit of identity.
2. **Builds on strengths and resources within the community**: Communities of identity contain many individual and organizational resources, but may also benefit from skills and resources available from outside of the immediate community of identity (Israel et al., 1998). The FloodRISE project team included practitioners at TRNERR, individuals who were not necessarily members of the community of identity (Los Laureles Canyon). These practitioners provided the partnership structure through their organization to help convene, and in some cases, span boundaries (i.e., a boundary spanning organization) by operating at the "skin" of their organization interpreting research goals to the community and vice versa, focusing on creating a process that increased participation among and influence of community in the research (Israel et al., 1998; Leifer & Huber, 1977, p. 235).
3. **Integrated knowledge and action for mutual benefit of all partners**: information was gathered by FloodRISE researchers to inform the development of flood models to ultimately improve flood resilience and benefit community members of Los Laureles Canyon. However, researchers can also gain from community-based projects including publications, promotions, prestige, and grant funding (Eissenberg, 2014). While researchers may encounter unique challenges to engaging in community-based research, it is important to note that communities engaged in the research shoulder many burdens such as (often unpaid) time investment and knowledge sharing. This must be weighed against the benefits the research may bring.

DISCUSSION

While the scholarship of community-based research is much deeper and nuanced than this paper can address, it is important to reflect on the challenges associated with its implementation. First, acknowledgement that the FloodRISE project did not fully actualize all principles of community-based research in its process, rather, fell within a spectrum of community-engaged research, arguably a novel endeavor in the engineering field. One principle - promote a co-learning and empowering process that attends to social inequalities - was particularly challenging to implement. Increasing power and control over the research process, for example, might look like community members participating as equal members across all phases of the research process (e.g., problem definition, data collection, interpretation of results, and application of the results to address community concerns). The FloodRISE process would need to be adapted, enhanced and certainly extended in order to fully actualize this in practice.

In addition to principles, Israel et al. (1998) also discuss a number of key rationales in the literature for pursuing community-based research, amplifying why researchers might engage in such a challenging, yet rewarding, endeavor. In many cases, these rationale underscored Meyer et al. (2012) substantive and/or instrumental rationale as discussed earlier. While the FloodRISE project neither claims to have had the capacity or role to pursue each of these rationale, nor reports them all as evidenced in the process, several rationale discussed below in relationship to FloodRISE were reinforced by project outcomes. Arguably, increasing and diversifying commitment to rationale could further enhance project outcomes.

Like examples from the public health field, community-based research in the engineering-driven FloodRISE project resulted in:

1. **Joining together of partners with diverse skills, knowledge, expertise and sensitivities to address complex problems** as evidenced by the interdisciplinary nature of the FloodRISE team engaging engineers, social scientists, and practitioners based at the boundary organization (TRNERR).

2. **Strengthening the research and program development capacity of the partners** as evidenced by new skills gained by boundary organization due to involvement on the RIIT in each of the four stages.

3. **Providing additional funds and possible employment opportunities for community partners** as evidenced by the community survey enumerators that were employed and trained by the project. The high survey response rate (n=367) is attributed to their experience, skill, and ability to overcome issues of access in the community.

4. **Improving the quality and validity of research by engaging local knowledge and local theory based on the lived experience of the people involved** as evidenced by

flood model scenarios directly informed by information gained through surveys and focus groups. Specific information related to conditions and externalities (e.g., pluvial flooding, blockages) would have otherwise not been included in model outputs.

5. **Enhancing the relevance, usefulness, and use of the research data by all partners involved as evidenced** through training and outreach, where model outputs and technology was shared with end-users and was made publicly accessible via an online viewer. Interest at this training by end-users to carry forth the FloodRISE products in their work indicates relevance and usefulness.

CONCLUSIONS

The fusion of community-based, participatory research and flood hazard modeling, or CFM, was presented here as a new paradigm to address PFF in a low resource setting. End-users including residents, academia, government authorities, and non-governmental organizations expressed interest in and a commitment to co-developing flood hazard visualizations with flood modeling experts. And through a four-step process of coordinated end-user interaction and flood model development and iteration, a set of flood hazard visualizations were co-produced and found useful for meeting a variety of end-user decision-making needs, especially with respect to planning. CFM did not lead to a single flood map for flood risk communication, but rather a menu of maps including maps of flood depth, flood force, erosion potential and flood duration as well as high levels of interest in the information. CFM also adapted to community-driven interest in different flooding scenarios, such as the possibility of blockages of drainage infrastructure. Furthermore, CFM demonstrated the potential for local knowledge to reveal limitations in hydrologic modeling approaches (FloodRISE-C) that could then be corrected (FloodRISE-G). In short, this application shows that CFM: (1) puts powerful hydrologic modeling systems at the disposal of non-experts to contemplate flooding and strategies to manage risks and (2) allows modeling experts to benefit from local knowledge of hydrologic processes that affect flooding which, in turn, leads to better quality models.

These results build on only a limited number of previous studies that successfully combine community-based research with flood hazard/risk modeling (e.g., Evers et al., 2014; Luke et al., 2018; Wilkinson et al., 2015) and expands upon examples from the public health field into engineering research and practice. These results are also in general alignment with reported need to address flood risk by informing a complex web of decision-making (e.g., Morss et al., 2005) with actionable information (e.g., Spiekermann et al., 2011).

Several forms of end-user engagement were utilized to engage potential end-users of flood visualizations, including meetings, household surveys, focus groups, and training sessions; and each form made distinct contributions towards the production of actionable knowledge. For example, early engagement of authorities created access to useful information, built an atmosphere of cooperation, and resulted in a high level of participation in focus group meetings and training sessions. Surveys provided critical context for the level of knowledge community could bring to bear on the project and ensured early in the process that the line of research was not misguided (i.e., getting the question right). Focus group meetings contributed to improving model scenarios and formatting visualizations to meet mapping preferences as described in more detail by Luke et al. (2018). Training sessions were important not only for increasing end-user awareness of and familiarity with an online decision-support tool, but for measuring the level of end-user interest in carrying forth the work in their own applied realms and specific opportunities for its use within the complex web of decision-making that affects flood risk.

Through each stage of engagement, and corresponding model iteration, improvements and changes to the hydrologic modeling approach became possible, which in turn benefitted the next stage of engagement. While the four-stage CFM process presented herein and shown in Figure 2.2 generated project outputs of use to its end-users, is the not the only process available to yield such results. In fact, there are surely many different pathways that respect and apply principles and rationale of both community-based and participatory research and flood hazard modeling/mapping for a robust, iterative approach. Nevertheless, this approach is a benchmark for consideration by others interested in producing flood hazard information that is responsive to end-user needs in flood affected communities.

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CHAPTER 3:
SUPPORTING ENVIRONMENTAL PROFESSIONALS

INTRODUCTION

The connection between mental health and environmental health has been long characterized and the field of environmental psychology well established. More recently, documentation of climate change's effects on human psychology has been expanded as climate change and its effects have become better understood. There is now a burgeoning recognition of mental health impacts of climate change on individuals and communities (i.e., on the general public) including by the American Psychological Association (APA) (Clayton, Manning, & Hodge, 2014; Clayton, Manning, Krygsman, & Speiser, 2017; Coyle & Van Susteren, 2011; Swim et al., 2009). Clayton, Manning, Krygsman, and Speiser (2017) put forth a call in its recommendations to expand mental health services and the profession itself to address and build support for individuals in the face of a changing climate, in order to "alleviate adverse mental health outcomes" (Clayton et al., 2017, p. 10).

Among a number of contributions in Clayton et al.'s (2017) report, it characterizes the direct and indirect impacts of climate change that result in acute and chronic mental health impacts (Table 3.1). For example, human health effects can stem from disasters exacerbated by climate change while other more gradual changes may generate different psychological responses (Table 3.2). Increased stress can put strains on social relationships and impact physical health as well as community mental well-being such as loss of social identity and cohesion and increased violence.

Table 3.1. Climate Change Impacts

	Acute	Chronic
Climate change impacts	• Floods • More severe storms (e.g. hurricanes) • Wildfires • Heat waves	• Sea level rise • Weakened infrastructure • Less secure food systems • Climate migration • Biodiversity loss

Table 3.2. Mental Health Impacts

	Acute	Chronic
Mental health impacts	• Trauma and shock • Post-traumatic stress disorder (PTSD) • Compound stress • Anxiety • Substance abuse • Depression	• Higher rates of aggression and violence • More mental health emergencies • An increased sense of helplessness (i.e. fatalism) • Intense feelings of loss

Some communities and populations are more vulnerable to the impacts of climate change including those with pre-existing disabilities or chronic illness, socioeconomic and demographic inequalities, and children (Clayton et al., 2017). Professionals who engage with climate change as part of their work may also be a sensitive community, especially those working in impacted communities and sectors and particularly among those who are directly and vicariously exposed to the impacts of climate change while being asked to enact adaptive solutions to climate change. Professionals is a broad category; it can include urban planners, scientists, engineers, psychologists, emergency first responders, public health service providers, community activists, adaptation professionals, and decision-makers. Clayton (2018) describes that climate scientists and conservation practitioners are likely to respond differently from the general public as they are typically more knowledgeable about, and attentive to, evidence for a changing environment, and are confronted with it through research and personal experiences on an almost daily basis.

Slowly but increasingly, it is recognized that climate change, and life in the Anthropocene brings with it and requires transformative change (Goodrich & Nizkorodov, 2016). Given its profound, permanent and pervasive effects emerging at different rates in different regions and for different communities, capacities are needed to face, accept, and live with these unprecedented changes (at least in modern human experience). In a nationally representative survey of American adults (n=1,114), 29% reported being alarmed about climate change and 30% reported concern (Leiserowitz et al., 2018). Bendell (2018), among other scholars and philosophers such as Slajov Žižek (2011), writes about near-term collapse in society with serious ramifications for the lives of readers, and describes impending climate tragedy. No one in public office, academia or most other institutions has been formally trained in how to deal with these new challenges yet unprecedented levels of uncertainty, constant change, trauma and transformation describe the outlook.

A letter by Gordon, Radford, and Simpson (2019) to *Science* stated "grieving environmental scientists need support" and appeals to the scientific community to establish "improved psychological working environments for scientists" (p. 193). Despite observations and anecdotal evidence from Fritze, Blashki, Burke, and Wiseman (2008) that those working in the field of climate change are anecdotally more at risk for intense worry, there is little empirical evidence beyond statistics from an online survey of conservationists expressing constant worry (Fraser, Pantesco, Plemons, Gupta, & Rank, 2013) Lesser is known (and are of focus of this chapter) about communities that serve in a professional role that addresses climate change impacts, hereafter environmental professionals, and their unique experiences.

Clayton (2018) urgently calls for research "to examine not only the degree of anxiety felt by climate scientists, but also ways in which their mental health might be affected by the combination of uncertainty, frustration and worry, along with professional interest, involvement, and social support that they encounter" (Clayton, 2018, p. 261). Climate change can be characterized in a number of ways. Most pertinent here, however, is by the demands – particularly psychological – that it places on those who are directly and vicariously exposed to the impacts of climate change *while* being asked to devise and enact adaptive solutions to climate (Andrews, 2017; Bruce, David, & Michael, 2018; Head & Harada, 2017).

Burn-Out and Emotional Labor

As has been documented for professionals in human services,[15] strong emotional feelings are likely to be present in the work setting and chronic emotional stress induces burnout (Maslach & Jackson, 1981). There appears to be a general burn-out crisis in the US already; Wigert and Agrawal's (2018) study of 7,500 Americans found that 23% of employees feel burned out very often or always and 44% feel burned out sometimes. They offer five factors that were most highly correlated: (1) unfair treatment at work; (2) unmanageable workload; (3) lack of role clarity; (4) lack of communication and support from manager; and (5) unreasonable time pressure. Effects of employee burnout include sick days, less likelihood to discuss performance goals with their manager, increased likelihood to visit the emergency room, increased likelihood to leave their current employer, and less confidence in performance (Wigert & Agrawal, 2018).

[15] e.g., police, counselors, teachers, nurses, social workers, psychiatrists, psychologists, attorneys, physicians, and agency administrators

Recent literature on emotional labor,[16] a well-studied topic in the field of organizational behavior, has made links to the climate scientist profession while examining contextual drivers that include the social norms of science and the range of behaviors and strategies employed to manage their emotions about climate change and the future (Head & Herada, 2017). It was observed that scientists embody dispassion, suppression (of painful emotions), humor, and disconnecting from work. The study also emphasized that while emotional denial and suppression of the knowledge of climate change impacts allowed for scientists to persevere in their work, painful emotions (e.g., anxiety, fear, loss) need to be acknowledged and addressed (Head & Harada, 2017). Those who hold great knowledge about climate change, for example esteemed climate scientists, write letters that express how they feel about the science that they know.[17] Frequency counts for emotion terms were counted in a study by Clayton (2018) included frustrated, concerned, sad, angry, afraid, perplexed/bewildered, powerless/vulnerable, and despairing.

While documentation of the impacts of climate change on the mental health of climate change scientists have been addressed now in some literature, the scope of the problem among practitioners — those who apply the science produced in research in various domains including that of climate change adaptation — has not yet been conclusively established. In the climate adaptation field, anecdotal reports and grey literature point to burn-out, emotional distress, and in some cases, the impulse to leave these difficult jobs, particularly in sectors and regions where there are increasingly evident pressures from climate change (Steffen et al., 2015).

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[16] e.g., Employees required as part of their terms of employment are required to display appropriate emotions to customers or clients (Hochschild, 1983).

[17] Is this how you feel? is an online platform for letters written by climate scientists (isthishowyoufeel.com).

This study described within was designed to better understand the psychological experiences among the professional community that engages with the application of climate change science in their work and characterize the support services that they may need. This paper presents the findings of a survey embedded in a larger project – The Adaptive Mind[18] – that characterizes the experiences of professionals to better understand needs and ways in which those needs may be better met. It concludes with recommendations for continued study and next steps for the project.

ADAPTIVE MIND SURVEY

For the purposes of this study, participants were eligible if they broadly identified as an environmental or climate change professional.

Sample

Participants for the study were identified by their professional roles and recruited by email. Three professional groups were subject of this study: the National Oceanic and Atmospheric Administration's (NOAA) National Estuarine Research Reserve System (NERRS), the Urban Sustainability Directors Network, and NOAA's Sea Grant Extension Program. Each professional group (and subgroups) play a unique role in their professional landscape of environmental, including training and technical assistance, boundary spanning,[19] education, research, land management, city planning and extension (Table 3.3). The NERRS was specifically chosen due to its unique national coastal representation (29 Reserves around the United States) and the programs in place at each of the 29 Reserves that embody a variety of

[18] The Adaptive Mind project was launched in 2017 to help coastal professionals build their psychosocial coping capacities and skills in dealing with these challenges to enable ongoing (and improved) adaptive management.

[19] Manuscript in review for Current Opinion in Sustainability, *Who are boundary spanners and how can we support them* (Goodrich et al., in review) discusses the role and attributes of boundary spanners further.

roles that engage with climate change: research, education, stewardship (i.e., land management), program management, and training/technical assistance. Those engaged with training and technical assistance had similar professional demands to NOAA's Sea Grant Extension Program including boundary spanning, or linking of science to decision-making (Bednarek, 2018). Individuals engaged in the Urban Sustainability Directors Network hold sustainability director positions within U.S. cities, often jobs with significant responsibilities to protect coastal cities and their infrastructure from impacts of rising sea levels.

Table 3.3. Survey Respondents and their Professional Role

Professional Group		Population size	Professional role
National Estuarine Research Reserve System (NERRS)		n = 145 (total NERRS)	
	Coastal Training Program	n = 29	Training and technical assistance; boundary spanning
	Education Program	n = 29	Education
	Research Program	n = 29	Research
	Stewardship Program	n = 29	Land management; restoration
	NERRS Managers	n = 29	Land management; staff supervision
Urban Sustainability Directors Network		n = 63	City planning
SeaGrant Extension		n = 384	Extension; boundary spanning

The survey was administered through an online platform and included 37 questions that addressed themes including work, experiences, needs, and support. These questions explored professional role and responsibilities, climate change, disaster preparedness and response, stress and burnout, scaled related to feelings statements (in both frequency and strength), support services and training, and demographics. The survey also asked participants to reflect on their work and describe it using a metaphor. Feelings scales were adapted from Maslach and Jackson's (1981) Measurement of Experiences Burnout study and reflected feelings statements and both strength and frequency of feelings commonly used in psychological assessments (e.g., worry, hopelessness, sadness, anger) and in the Beck Depression Inventory-II (BDI-II) (Beck, Steer, & Brown, 1996). Frequency questions were asked using the scale 1- 7 (1= A few times a year, 2= Monthly, 3= A few times a month, 4= Every week, 5= A few times a week, 6= Every day, 7= Never).

RESULTS

Of the respondents, 37.3% have been in their jobs 0-5 years, 28.8% > 5-10 years, 14.4% >10-15 years, 14.4% >15-20 years, .84% >20-25 years and 4.2% >25+years. Highest level of education completed: 8.5% college degree (e.g., B.A., B.S.), 58.5% graduate degree (e.g., M.A., M.S.), and 31.4% post-graduate degree (e.g., Ph.D., J.D.), and 1.7% other. 67% are female, 32.2% male and .85% preferred not to answer. 7.6% are 21-29 years of age, 28% are 30-29, 32.2% are 40-49, 22.9 are 50-59, and 9.3% are 60 or older. 89.7% are white/Caucasian. Representation was highest among the pacific region (Washington, Oregon, California, Alaska, Hawai'i) (28.2%) followed by the south atlantic region (Delaware, Maryland, District of Columbia, Virginia, West Virginia, North Carolina, Georgia, Florida) (21.7%).

The survey yielded a 23.81% response rate. Across professional groups, 80% of respondents (n=122) reported that they have experienced burnout[20] (Figure 3.1).

[20] Definition of burnout was provided as prompt before burnout assessment to ensure a common understanding: Chronic stress at work can be emotionally draining and poses the risk of burnout. "It can lead to physical and emotional exhaustion, cynicism and detachment, and feelings of ineffectiveness and lack of accomplishment." (From Maslach & Leiter, 2016, p.103).

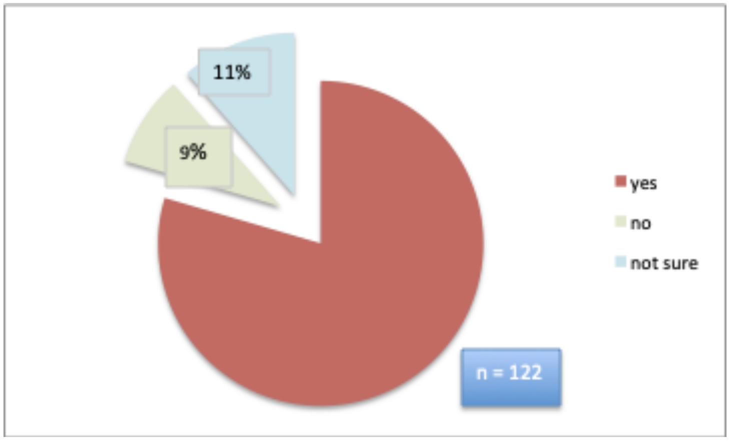

Figure 3.1. Burnout.

Respondents reported various activities that make up their work including communications and outreach and planning and plan development in highest numbers (Figure 3.2).

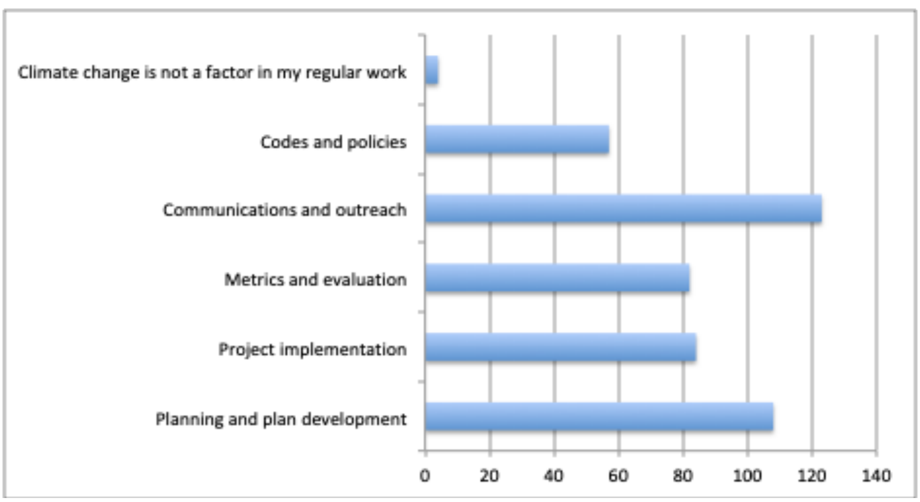

Figure 3.2. Reports of typical activities conducted as part of respondents' work.

Respondents were prompted to respond to a scale 1-7 (1= A few times a year, 2= Monthly, 3= A few times a month, 4= Every week, 5= A few times a week, 6= Every day, 7= Never) about the frequency of feelings related to statements including "I am emotionally exhausted from the topics I address through my work," "The work I do is not enough to address climate change," and "I am determined to succeed in my work because of what I know about climate change and potential impacts." In each category, respondents in high percentages report monthly to daily agreement.

A t-test and ANOVA analysis were run to compare all feelings statements among all professional sub-groups within the NERRS, Sea Grant Extension Program, and the Urban Sustainability Directors Network. Results from these tests enabled an analysis that would allow for comparisons of feelings across professional roles suggesting that certain professional roles (e.g., communication, research) may elicit more frequent or stronger feelings and allow for targeted interventions (Table 3.4).

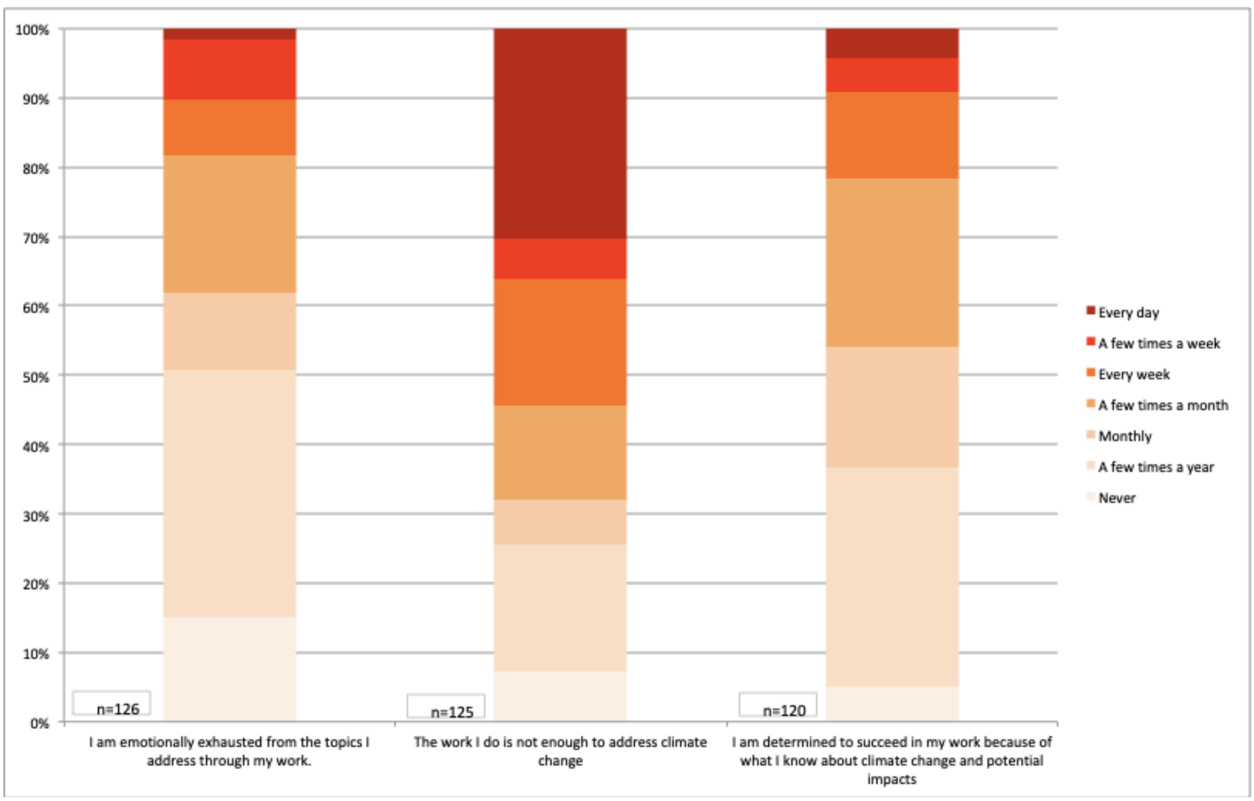

Figure 3.3. Frequency of feelings among respondents.

Through the t-test, frequency of feelings were compared across professional groups (Table 3.5). P-values are from t-tests of mean differences between each profession and all other professions combined.

Through the ANOVA analysis, frequency of feelings were compared across professional groups (Table 3.5). P-values are from ANOVA of mean differences between profession of interest and each other profession. Though not across all feelings, there were significant differences among professional roles in their feelings of hopelessness and anger, though within group, reports of each feeling.

The qualitative metaphor data also provided data to characterize the experience of professionals in the field. The question asked was "People sometimes attempt to explain their work by using a metaphor. What is your metaphor?" Selected responses include:

> *"My work is like a hurricane. I am surrounded by the wall (chaos) and I try to operate from the eye (calm)."*
>
> *"Running on a gerbil wheel"*
>
> *"I am glue. holding feet to the ground, keeping people working together and making sure that we stick to the desired outcomes."*
>
> *"It sounds funny but I often describe myself as a bureaucratic ninja. Or my role is to "constructively disrupt the system."*
>
> *"My work is like rolling a large rock up a hill (check out the music video for Away from the Sun by 3 Doors Down). It is most difficult on Monday morning and with any luck, I gain momentum during the week. Sometimes it gets a little easier to roll the rock (sometimes). Other times it is a constant hard struggle, like dragging a large wet blanket through the sand.*
>
> *"Hospice/midwife"*
>
> *"I don't think I use metaphors when explaining my work, but in my own head it's sort of like a dark tunnel with no light at the end."*
>
> *"I am a climate death doula. That sounds really morbid, but I hold people's hands through the really painful conversations and decisions, while maintaining a professional boundary. My bosses really think I'm just talking about science."*
>
> *"Climate change is a black hole."*

Table 3.4. t-Test and ANOVA Analysis for Frequency of Feelings among All Professional Roles

Feelings Statement	**NERRS Coastal Training Program**	**NERRS Manager**	**NERRS Research**	**NERRS Stewardship**	**Sea Grant Extension**	**Urban Sustainability Directors Network**
I am emotionally drained by my work.						
mean (SD)	2.85 (1.52)	1.90 (1.52)	2.43 (1.50)	2.30 (1.34)	2.09 (1.40)	3.00 (1.64)
p-value$_{t\text{-test}}$	0.380	0.230	0.880	0.660	0.070	0.030*
p-value$_{ANOVA}$	referent	0.138	0.473	0.391	0.129	0.756
p-value$_{ANOVA}$	0.138	referent	0.399	0.554	0.726	0.046*
p-value$_{ANOVA}$	0.473	0.399	referent	0.837	0.484	0.237
p-value$_{ANOVA}$	0.391	0.554	0.837	referent	0.701	0.201
p-value$_{ANOVA}$	0.129	0.726	0.484	0.701	referent	0.016*
p-value$_{ANOVA}$	0.756	0.046*	0.237	0.201	0.016*	referent
The work I do inspires me to do more of it.						
mean (SD)	4.71 (1.33)	4.70 (1.49)	4.08 (1.49)	4.10(1.66)	3.61 (1.82)	4.64 (1.25)
p-value	0.180	0.330	0.680	0.790	0.010*	0.050
p-value$_{ANOVA}$	referent	0.982	0.280	0.332	0.025*	0.873
p-value$_{ANOVA}$	0.982	referent	0.333	0.380	0.049*	0.908
p-value$_{ANOVA}$	0.280	0.333	referent	0.971	0.347	0.265
p-value$_{ANOVA}$	0.332	0.380	0.971	referent	0.371	0.332
p-value$_{ANOVA}$	0.025*	0.049*	0.347	0.371	referent	0.007**
p-value$_{ANOVA}$	0.873	0.908	0.265	0.332	0.007**	referent
I am emotionally exhausted from the topics I address through my work.						
mean (SD)	2.31 (1.70)	2.00 (1.70)	1.64 (1.50)	1.50 (0.85)	1.67 (1.59)	2.82 (1.69)
p-value	0.630	0.870	0.260	0.060	0.080	<0.001***
p-value$_{ANOVA}$	referent	0.645	0.279	0.228	0.219	0.327
p-value$_{ANOVA}$	0.645	referent	0.587	0.482	0.561	0.156
p-value$_{ANOVA}$	0.279	0.587	referent	0.828	0.963	0.022*
p-value$_{ANOVA}$	0.228	0.482	0.828	referent	0.771	0.023*
p-value$_{ANOVA}$	0.219	0.561	0.963	0.771	referent	0.004**
p-value$_{ANOVA}$	0.327	0.156	0.022*	0.023*	0.004**	referent

* p<.05, ** p<.01, *** p<.001

I am hopeful about environmental futures.						
mean (SD)	3.14 (1.83)	3.10 (1.66)	2.14 (1.79)	2.60 (1.78)	2.38 (1.54)	2.91 (1.61)
p-value	0.320	0.420	0.240	0.880	0.200	0.340
p-value$_{ANOVA}$	referent	0.950	0.114	0.431	0.152	0.660
p-value$_{ANOVA}$	0.950	referent	0.167	0.502	0.231	0.751
p-value$_{ANOVA}$	0.114	0.167	referent	0.507	0.663	0.151
p-value$_{ANOVA}$	0.431	0.502	0.507	referent	0.709	0.607
p-value$_{ANOVA}$	0.152	0.231	0.663	0.709	referent	0.198
p-value$_{ANOVA}$	0.660	0.751	0.151	0.607	0.198	referent
I am hopeful about social futures.						
mean (SD)	3.08 (1.85)	2.33 (1.32)	2.38 (1.61)	2.40 (1.65)	2.28 (1.44)	2.27 (1.48)
p-value	0.170	0.880	0.970	1.000	0.590	0.560
p-value$_{ANOVA}$	referent	0.267	0.253	0.297	0.118	0.113
p-value$_{ANOVA}$	0.267	referent	0.939	0.925	0.929	0.917
p-value$_{ANOVA}$	0.253	0.939	referent	0.981	0.838	0.824
p-value$_{ANOVA}$	0.297	0.925	0.981	referent	0.831	0.819
p-value$_{ANOVA}$	0.118	0.929	0.838	0.831	referent	0.982
p-value$_{ANOVA}$	0.113	0.917	0.824	0.819	0.982	referent
I am determined to succeed in my work because of what I know about climate change and potential impacts						
mean (SD)	5.00 (1.22)	3.20 (2.20)	2.62 (1.71)	3.80 (1.75)	3.70 (2.10)	4.79 (1.39)
p-value	0.010*	0.240	0.010*	0.70	0.290	<0.001***
p-value$_{ANOVA}$	referent	0.016*	0.001**	0.107	0.025*	0.713
p-value$_{ANOVA}$	0.016*	referent	0.430	0.446	0.435	0.014*
p-value$_{ANOVA}$	0.001**	0.430	referent	0.112	0.063	<0.001***
p-value$_{ANOVA}$	0.107	0.446	0.112	referent	0.871	0.122
p-value$_{ANOVA}$	0.025*	0.435	0.063	0.871	referent	0.013*
p-value$_{ANOVA}$	0.713	0.014*	<0.001***	0.122	0.013*	referent
The ability to do my job is diminished by persistent worry about the environment and the communities I work with						
mean (SD)	1.23 (1.17)	.40 (.52)	.57 (.85)	.70 (.82)	.81 (1.15)	1.06 (1.25)
p-value	0.230	0.020*	0.210	0.550	0.790	0.250
p-value$_{ANOVA}$	referent	0.072	0.118	0.248	0.244	0.633
p-value$_{ANOVA}$	0.072	referent	0.704	0.538	0.297	0.095
p-value$_{ANOVA}$	0.118	0.704	referent	0.775	0.490	0.161
p-value$_{ANOVA}$	0.248	0.538	0.775	referent	0.775	0.360
p-value$_{ANOVA}$	0.244	0.297	0.490	0.775	referent	0.359
p-value$_{ANOVA}$	0.633	0.095	0.161	0.360	0.359	referent

* p<.05, ** p<.01, *** p<.001

What I know about the topics I work on discourages me to pursue my work any further						
mean (SD)	0.92 (1.12)	0.1 (.32)	0.29 (.47)	0.6 (.84)	0.67 (.92)	0.48 (.76)
p-value	0.200	<0.001***	0.070	0.820	0.330	0.630
p-value$_{ANOVA}$	referent	0.018*	0.044*	0.347	0.337	0.103
p-value$_{ANOVA}$	0.018*	referent	0.582	0.172	0.056	0.192
p-value$_{ANOVA}$	0.044*	0.582	referent	0.352	0.145	0.444
p-value$_{ANOVA}$	0.347	0.172	0.352	referent	0.821	0.695
p-value$_{ANOVA}$	0.337	0.056	0.145	0.821	referent	0.365
p-value$_{ANOVA}$	0.103	0.192	0.444	0.695	0.365	referent
The work I do is not enough to address climate change						
mean (SD)	4.07 (2.23)	3.33 (2.12)	2.57 (2.06)	3.6 (2.17)	3.76 (2.19)	3.88 (1.95)
p-value	0.440	0.660	0.050	0.960	0.710	0.420
p-value$_{ANOVA}$	referent	0.414	0.062	0.590	0.641	0.775
p-value$_{ANOVA}$	0.414	referent	0.399	0.783	0.593	0.492
p-value$_{ANOVA}$	0.062	0.399	referent	0.241	0.080	0.054
p-value$_{ANOVA}$	0.590	0.783	0.241	referent	0.836	0.714
p-value$_{ANOVA}$	0.641	0.593	0.080	0.836	referent	0.816
p-value$_{ANOVA}$	0.775	0.492	0.054	0.714	0.816	referent
I think about changing my career to something that doesn't deal with climate change						
mean (SD)	1.38 (1.66)	0.11 (.33)	0.43 (1.09)	1.1 (1.66)	0.45 (.71)	.70 (.73)
p-value	0.100	<0.001***	0.400	0.390	0.110	0.780
p-value$_{ANOVA}$	referent	0.004**	0.015*	0.503	0.006**	0.039*
p-value$_{ANOVA}$	0.004**	referent	0.462	0.035*	0.366	0.125
p-value$_{ANOVA}$	0.015*	0.462	referent	0.110	0.936	0.405
p-value$_{ANOVA}$	0.503	0.035*	0.110	referent	0.079	0.270
p-value$_{ANOVA}$	0.006**	0.366	0.936	0.079	referent	0.330
p-value$_{ANOVA}$	0.039*	0.125	0.405	0.270	0.330	referent
Worry						
mean (SD)	3.29 (1.64)	2 (1.49)	2.43 (2.17)	2 (1.05)	2.61 (1.78)	2.76 (1.79)
p-value	0.120	0.210	0.740	0.100	1.000	0.560
p-value$_{ANOVA}$	referent	0.079	0.197	0.079	0.226	0.346
p-value$_{ANOVA}$	0.079	referent	0.555	1.000	0.339	0.233
p-value$_{ANOVA}$	0.197	0.555	referent	0.555	0.751	0.556
p-value$_{ANOVA}$	0.079	1.000	0.555	referent	0.339	0.233
p-value$_{ANOVA}$	0.226	0.339	0.751	0.339	referent	0.726
p-value$_{ANOVA}$	0.346	0.233	0.556	0.233	0.726	referent

* p<.05, ** p<.01, *** p<.001

Hopelessness						
mean (SD)	2.07 (1.54)	0.7 (.82)	1.43 (1.65)	0.8 (.42)	1.27 (1.26)	1.39 (1.20)
p-value	0.070	0.030*	0.820	<0.001***	0.750	0.740
p-value$_{ANOVA}$	referent	0.010*	0.179	0.016*	0.049*	0.094
p-value$_{ANOVA}$	0.010*	referent	0.164	0.859	0.209	0.129
p-value$_{ANOVA}$	0.179	0.164	referent	0.230	0.698	0.931
p-value$_{ANOVA}$	0.016*	0.859	0.230	referent	0.300	0.193
p-value$_{ANOVA}$	0.049*	0.209	0.698	0.300	referent	0.696
p-value$_{ANOVA}$	0.094	0.129	0.931	0.193	0.696	referent
Sadness						
mean (SD)	2.64 (1.60)	1.6 (1.58)	1.71 (1.54)	1.40 (1.43)	2.33 (1.85)	1.88 (1.39)
p-value	0.110	0.400	0.440	0.180	0.220	0.520
p-value$_{ANOVA}$	referent	0.114	0.123	0.060	0.540	0.132
p-value$_{ANOVA}$	0.114	referent	0.862	0.778	0.201	0.626
p-value$_{ANOVA}$	0.123	0.862	referent	0.632	0.222	0.745
p-value$_{ANOVA}$	0.060	0.778	0.632	referent	0.105	0.403
p-value$_{ANOVA}$	0.540	0.201	0.222	0.105	referent	0.245
p-value$_{ANOVA}$	0.132	0.626	0.745	0.403	0.245	referent
Anger						
mean (SD)	2.36 (1.28)	0.9 (1.10)	1.64 (1.55)	1.5 (.97)	1.76 (1.60)	1.88 (1.73)
p-value	0.080	0.030*	0.780	0.430	0.990	0.610
p-value$_{ANOVA}$	referent	0.022*	0.216	0.176	0.219	0.326
p-value$_{ANOVA}$	0.022*	referent	0.240	0.379	0.121	0.077
p-value$_{ANOVA}$	0.216	0.240	referent	0.821	0.813	0.627
p-value$_{ANOVA}$	0.176	0.379	0.821	referent	0.640	0.491
p-value$_{ANOVA}$	0.219	0.121	0.813	0.640	referent	0.747
p-value$_{ANOVA}$	0.326	0.077	0.627	0.491	0.747	referent

* p<.05, ** p<.01, *** p<.001

Table 3.5. Frequency of Feelings Compared across Professional Groups (t-Test)

Feelings Statement	Professional group
I am emotionally drained by my work.	*Urban Sustainability Directors Network* Significantly more often than the rest of their environmental professional (peers) combined (p=0.03)
The work I do inspires me to do more of it.	*Sea Grant Extension* Significantly less often than the rest combined (p=0.01)
I am emotionally exhausted from the topics I address through my work.	*Urban Sustainability Directors Network* Significantly more often than the rest combined (p=<.001)
I am hopeful about environmental futures.	No significant differences between groups
I am hopeful about social futures.	No significant differences between groups
I am determined to succeed in my work because of what I know about climate change and potential impacts.	*NERRS Coastal Training Program* Significantly more often than the rest combined (p=<.01) *NERRS Research* Significantly less often than the rest combined (p=<.01) *Urban Sustainability Directors Network* Significantly more often than the rest combined (p=<.001)
The ability to do my job is diminished by persistent worry about the environment and the communities I work with.	*NERRS Managers* Significantly less often than the rest combined (p=.02)
What I know about the topics I work on discourages me to pursue my work any further.	*NERRS Managers* Significantly less often than the rest combined (p=<.001)
The work I do is not enough to address climate change.	No significant differences between groups
I think about changing my career to something that doesn't deal with climate change.	*NERRS Managers* Significantly less often than the rest combined (p=<.001)
Worry	No significant differences between groups
Hopelessness	*NERRS Managers* Significantly less often than the rest combined (p=<.03) *NERRS Stewardship* Significantly less often than the rest combined (p=<.001)
Sadness	No significant differences between groups
Anger	*NERRS Managers* Significantly less often than the rest combined (p=<.03)

IMPLICATIONS AND FUTURE RESEARCH

In the biophilia hypothesis, Kellert and Wilson (1993) claim that "we, as human beings, have an innate love for the natural world, universally felt by all, and resulting at least in part from our genetic make-up and evolutionary history" (Bratman, Hamilton, & Daily, 2012, p. 119). This may be particularly the case among individuals who chose to dedicate their careers to a profession that exposes them in disproportionate ways to loss of places and species that they work to protect.[21] Words expressed in the qualitative data are particularly telling of the experiences of those surveyed and underscore the outlook for some including, "black hole," "dark tunnel with no light," and "climate death doula." These metaphors suggest grim outlooks for their careers and futures, emphasizing the need to address this challenge with additional research that supports interventions, before environmental professionals suffer from burnout that won't allow for the ability to continue in their line of work. Likewise, understanding experiences of environmental professional groups experiencing lesser degrees of stress may offer examples of how to transfer strategies for coping and resilience.

Unprecedented levels of uncertainty and transformation related to climate change is the outlook for communities and ecosystems. Environmental professionals are likely to differ in the way they respond to climate change when compared to the general public because: (1) they are typically more knowledgeable and (2) they are confronted with it almost on a daily basis which can serve as a prerequisite for emotional stress (Clayton, 2018; Fraser et al., 2013). This is especially true for environmental professionals for whom climate change threatens something

[21] 72% of respondents reported that a trait that makes them successful in their work is caring about the environment "to a great extent" (in a scale of 0=not at all to 5=to a great extent).

that is valued (Clayton, 2018). As seen in the metaphors provided by respondents, there are clear examples of overwhelm, despair and grief, and even direct references to death.

Those who will be called on to lead and support communities in this future need insights, practices, training, and support to do so well, for both their personal wellness and to ably serve their respective communities. This need is especially great where these professionals themselves are experiencing the impacts of climate change firsthand. More research is needed to better characterize the unique experiences of environmental professionals to inform development of training and support for continued motivation. Currently, another professional group, the American Society for Adaptation Professionals, is being recruited to participate in the study, which will further knowledge by including more professional groups. Among many sectors of interest, educators in higher education may be a potential additional sample population as they have the unique role of teaching sustainability and climate science to young adults and the burden of having to convey difficult information (perhaps, a different variation of a boundary spanner) to students can carry emotional weight. Further studies to compare across groups and that increase non-coastal regions of the United States would enhance also the research.

While there are many prospects for future research, using this data to characterize the experience of environmental professionals has immediate application for these particular respondents and their organizations. A goal of the Adaptive Mind project, of which this survey is embedded, is to provide an opportunity to both learn from and meet the needs of various workforces (through survey assessment) and deliver resulting products to its audiences (ultimately through data-informed program development). There is a unique opportunity, particularly among the NERRS, as place-based research platforms with diverse sectors that embody the unique roles of environmental professionals (e.g., managers, scientists, boundary spanners, educators, stewards) to experiment with application of this data. Prospects include training/adult learning, direct engagement with communities and decision-makers/environmental professionals, peer-to-peer networks, and science transfer. Ultimately through communication of the results, staff/professional/workplace development opportunities may allow for a change in organizational culture around the delivery of psychosocial support needs of staff due to climate change and related impacts.

By comparing experiences across professional groups, specific interventions can be tailored and prioritized by better understanding the demands of their particular roles and where strengths and vulnerabilities lie. For example, NERRS Managers report feelings related to changing careers to something that doesn't deal with climate change, hopelessness, and anger significantly less frequently than other professional groups. This suggests areas where this professional group may build upon their strengths and points to additional research opportunities to more qualitatively understand drivers behind less negative feelings. On the other hand, professionals within the Urban Sustainability Directors Network reported more frequent emotional drain and exhaustion from the topics addressed in their work. This points to an opportunity to better understand how to better support them in these specific areas.

Despite high levels of burnout, open-ended responses indicated that respondents were taking action to prevent it. These included: exercise, prayer, spending time in nature, meditation and mindfulness practice, and other self-described self-care. Respondents also expressed interest in fitness activities, wellness activities, arrangements/flexibility for work schedule (e.g., check-ins, release time, telework), restorative physical environments (e.g., game rooms, green spaces in/outside work and psychological/support services to be provided through their workplace. Additionally, training opportunities of interest (i.e., skill building) included a variety of topics including: dealing with emotionally distraught/upset people; dealing with conflict/contentious conversations; dealing with social/environmental injustice and discrimination; dealing with emotions in light of environmental/climate changes; dealing with emotions related to social transformation; gaining additional technical skills; communicating with climate contrarians/people who don't believe in climate change; conveying the urgency of action without creating fear, overwhelm, and paralysis; and navigating historical legacies of distrust and division.

Although the results from the survey that point to troubling levels (monthly to daily) among professionals of emotional exhaustion and feelings that their work is not enough to address climate change, there is also a strong indication that there is a determination to succeed because of what is known about the impacts of climate change. Clayton's (2018) study that counts frequency of words in letters written by climate scientists also reveal positive frequency counts as well including hopeful, optimistic, excited, grateful/privileged, determined/resolved, interested/curious, and fascinated. While professionals report that they are emotionally exhausted from the topics they address through their work and feel that the work they do is not enough to address climate change, they also report that they are determined to succeed in their work because of what they know about climate change and potential impacts. Critical to supporting these professionals is the acknowledgement of the collective experience and the ability to support this community before high levels of burn-out leads to deeply value-driven individuals abandoning their work. In such environmentally troubled, uncertain and politically divided times, these are the very individuals most needed to advance innovations and transformation and enhance our social and ecological outcomes in the face of a changing climate.

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CONCLUSION

The three chapters in this dissertation focused on barriers to successful adaptive management to inform strategies to advance it. Feldman (2008) and Allen and Gunderson (2011) outline a number of common barriers to adaptive management including lack of stakeholder engagement. Chapters one and two focused on this particular barrier of stakeholder engagement and experimented with designing community-based research to overcome it, particularly in developing flood hazard models. It also explored the more systemic and root causes of the ability of communities to engage due to lack of community capitals, and offered suggestions for elevating knowledge as capital. More accurate and usable flood hazard models, for example, resulted from consulting local knowledge. This dissertation also contributed to the characterization of new barriers to adaptive management, namely borders, both physical and psychological. It discusses the unique setting of the San-Diego binational bioregion and the geopolitics and maladaptive institutions that create conditions for a failed unified vision and approach to social and ecological dilemmas. Finally, it adds to the list of barriers by characterizing a growing problem for environmental professionals in the Anthropocene – their ability to adaptively manage (e.g., learn from failures) is lessened due to psychological impacts of their work including stress, grief, and burnout. While contributing to the literature of failures may seem like an effort to explain away why more progress isn't being made in environmental management, on the contrary, only by illuminating barriers can ways to overcome them be informed.

Through the three studies presented in this dissertation, I oriented my research to examine two questions: (1) What are strategies for improving adaptive management in the San Diego-Tijuana bioregion and what role does a binational community have to play in this? And (2)

What are the consequences of failed adaptive management and corresponding environmental outcomes) on those that engage with it and what are the data needs to address the gaps? It became apparent through this research process that the contextualization of the system in a social-ecological frame was critical to coming to a more informed answer.

A SOCIAL-ECOLOGICAL SYSTEM IN A BINATIONAL BIOREGION

Where an artificial boundary fragments the natural and social environment as seen in the U.S. – Mexico border region, places become described by what they are and are not part of (Kemmis, 1999 as cited in McGinnis, Woolley, & Gamman, 1999). Bioregionalism is a framework that transcends these limiting characterizations by allowing for the examination of the complex relationships between human communities, government institutions, and the natural world, and provides a lens through which to implement environmental policy (McGinnis et al., 1999). In many disciplines, epistemologies and orientations, a bioregional framework has helped to examine local knowledge, globalization, global environmental issues, and conservation and restoration; its emphasis on place and community allows for an alternate approach to confronting human and ecological issues (McGinnis et al., 1999). This framework, for example, has helped to interpret characterizing watershed-based organizations and contextualizing narratives about how a degraded binational watershed impacts the sense of place of border dwellers (Dicochea, 2010). It is also used here in this dissertation as a concept to understand the context of the border region and apply it to designing the research within. This area cannot be studied and better understood without the context that reflects its unique binational character and the challenges that arise within its circumstances.

Bioregional theory and practice, like collecting place-based knowledge and uniting with scientific understanding of ecosystems, can be useful in studying communities and their connection to place. In addressing climate change, for example, Feldman and Wilt (as cited in McGinnis et al., 1999) offer environmental problems as perfectly suited to be addressed on a bioregional scale. Bioregionally-oriented approaches recognize that no region or set of regions can address problems, however, management approaches that are regionally-based, integrated, and that involve affected stakeholders directly in design of programs are most promising for improved environmental outcomes (Feldman & Wilt, 1999 as cited in McGinnis et al., 1999).

The San Diego-Tijuana region illustrates the challenges of binational environmental management in the context of a harsh physical environment, rapid growth, and economic integration that manifest in depletion of surface and groundwater, air and water pollution, hazardous waste, and limited conservation opportunities left to support remaining biodiversity (Liverman, Varady, Chavez, & Roberto, 1999). Straddling the busiest land port of entry in the world, Tijuana, Mexico and the cities of southern San Diego County in the United States are, ecologically-speaking, one bioregion, with shared watersheds, airsheds, ocean currents, native vegetation and, increasingly, vulnerabilities to global-scale change. They do not, however, face this change with equal vulnerability. Attributes of well-being are deeply interconnected: security, basic material for decent chances for life, health, social relations, and freedom of choice. Nowhere is the unequal nature of the security problem posed by degradation of ecological services more visible than at the borders between developed and developing countries. In some cases, distant from the national centers of decision-making, national borders interrupt and dissect ecosystem boundaries across scales (e.g., watersheds, airsheds, floristic regions, wildlife habitat). Pollution of water and air cross even the most fortified national borders.

Given continuing degradation of global ecological systems and the catastrophic imagery undergirding mounting calls for securitization of environmental debates, resilience theory's political applications and focus on state shift and transformation provide a vocabulary and institutional proposals for understanding the goals of environmental security in the shared ecosystems of the Tijuana-San Diego region (Armitage, 2008; Carpenter et al., 2011; Folke et al., 2004; Peterson, 2000; Scheffer et al., 2012). Resilience, as a cross-disciplinary approach to examining social and ecological systems, is focused on the stability and flexibility of these systems in close interaction. Based on the work of ecologists, resilience theory has expanded to include a dedicated focus on social systems, and in particular emphasizes adaptive governance, a kind of multi-scale experimental policy program with built in social-learning (Folke, Hahn, Olsson, & Norberg, 2005; Holling, 1996). Expanding on the original models of resilience based on observations of natural systems to include knowledge and community capacity can be considered forms of social resilience.

At the edges of national sovereignty between the U.S. and Mexico, San Diego and Tijuana present a unique and extreme version of the common issues that plague the adoption of the progressive edge of ideas like adaptive governance and adaptive co-management. Contemporary resilience-based adaptive governance and co-management schemes look for flexible institutions capable of adapting both to specific local stressors and broader global change (Armitage, 2005; Berkes, 2007; Berkes, Folke, & Gadgil, 1994; Berkes & Ross, 2012; Duit & Galaz, 2008). Ideal institutions provide an alternative to the state-centered programs currently failing the border environment, emphasizing reflexivity and flexibility (Allen & Gunderson, 2011; Allison & Hobbes, 2004; Walker, Holling, Carpenter, & Kinzig, 2004). Yet, they have some requirements that will be especially hard to achieve in the border context, including the need for long-term policy experimentation, political continuity, and robust public engagement.

Holling (2001) claims that if resilience is the key strategy for understanding and responding to ecological crisis, then useful and usable knowledge and the social trust to apply that knowledge represent the sustaining foundations for social development. He claims that humans can influence the progression through adaptive cycles of collapse and reorganization through social learning. Furthermore, that ecosystem management must build and maintain ecological resilience as well as social flexibility to cope, innovate, and adapt.

This concept is already in practice in applied conservation and resource agencies, often through the concept of adaptive management (Allen & Gunderson, 2011; Lee, 1999). Such concepts propose an adaptive cycle for research and management interventions, with the idea of learning over time. Adaptive governance creates a model political and institutional form to this idea. Many of the central features of adaptive governance regimes, however, assume that communities and ecosystems are within their nation's boundaries (i.e., can be governed by a set of common institutions) and, even more fundamentally, where communities can engage in co-management, co-development, and deliberation.

In the context of the border, which includes a lack of shared language to conduct such community-integrating exercises and governance gaps produced by shared ecosystems crossing national jurisdictions, the stressors of the Anthropocene beg for critical analysis of how to build, or raise up, existing communities to hold those institutions responsible. This is an obvious and serious problem for any local governance theory attempting to operate at the Tijuana-San Diego border. Adaptive governance recommends collaborative local governance of joint social-ecological systems and also predicts the necessity of such institutions in a future characterized by global earth system change (Armitage, Berkes, & Doubleday, 2010; Folke et al., 2005).

ENVIRONMENTAL SECURITY ACROSS BORDERS

Although not characterized by overt warfare, the border between Tijuana and San Diego is both a symbolic and physical site of conflict. Environmental peacebuilding between local communities sharing ecosystems and between national communities may be as necessary as in post-war security building, and may provide hints for larger-scale conflicts over development and historical responsibility taking place at the global level. The spatial mismatches between ecosystem boundaries and political borders are mirrored by 'temporal mismatches' in the time horizons of politicians and the long term needs of resilient and flourishing social-ecological systems. Folke, Pritchard, Berkes, Colding, and Svedin (2007) see the possibility of mental displacement that this produces:

> The modern world creates and tightens intersystem linkages, hierarchies, and interdependencies between local resource users and the wider society through the market, political control, and social networks. Interestingly, the result of the tightening is to distance resource users from the resource base, to disconnect production from consumption and to disconnect the production of knowledge from its application (p. 12).

Mexico's short local election terms and stark division of ecosystems by the United States' building of the physical wall produce, arguably, a kind of perfect form of these mismatches. Thus, there are many challenges to applying such an institutional framework in a pragmatic and politically-relevant way, including more pragmatic political and social questions related to lack of trust, physical boundaries, the time horizons of politicians and weaknesses of bureaucracies tasked with regulating transboundary environmental impacts.

The play between productive and destructive forces, in the context of divided political systems and natural resource regimes, can greatly reinforce gross social inequalities and create enormous disparities in wealth, comfort, and consumption of resources that may lead to conflict. Such challenges form the essential core around which the interdisciplinary environmental sciences, social sciences, and humanities organize themselves and recognize each other.

Security implications of environmental crises have gained strength (Dalby, 1998; Floyd, 2008). By framing environmental crises as urgent threats to national survival, those adopting traditional security approaches seek to engage national bureaucracies and increase attention from officials who have long prioritized environmental threats below military, economic, and social issues (Homer-Dixon, 1991). Seeing the linkages between ecological change and politics, environmental security considers the planetary biosphere as an essential support system upon which humanity depends. Scholars have welcomed the concept of environmental security which has emerged from this debate as a meaningful and welcome way of packaging environmental human protection in a way which does not focus on simplified population or resource projections. They argue, despite concerns that the linking of securitization to the environmental debate, environmental security analytically allows for an accounting of vulnerabilities and their typologies and the potential associated conflict and violence with environmental degradation or loss (Trombetta, 2009). At the same time, a more contemporary and less dire version of this argument "plays down the values traditionally associated with the nation-state - identity, territoriality, sovereignty — and implies a different set of values associated with environmental change — ecology, globality, and governance" (Dyer, 2001, p. 68).

That these worlds exist for San Diego and Tijuana within few miles only accentuates the threat of increasing separation of communities along the border in times of shared ecological change and uneven vulnerability. This is an important challenge for constructing a more inclusive and regionally-meaningful form of environmental security discourse that does not automatically reserve them to national resource bureaucracies. While border regions present extreme versions of some of the chief challenges of adaptive governance by its scholars, (e.g., lack of leadership for implementation of the complex problem of adaptive management, translating learning into practice, cost and delays associated with gathering information) they also represent a fruitful point of critical departure by invalidating by geographic context any purely-state-centric idea of environmental security (Allen & Gunderson, 2011; Armitage et al., 2010).

At the border between the U.S. and Mexico, deploying a broader idea of environmental security will also have to confront, in microcosm, many of the most persistent and thorny global debates over development and responsibility for global change, especially where wealth and poverty are at extremes. This may disorient and even disqualify some political responses to uneven consequences produced by global change and social-economic inequality that preexists environmental crisis. At the same time, it presents opportunity because it, by contextual necessity, must engage harder debates over development and responsibility in global environmental politics. That such kinds of research centered on real places and different kinds of social and ecological conflict take place of necessity here at the edges of national sovereignty highlight key governance gaps in binational adaptations of both older ideas like bioregionalism and new, promising theories of adaptive governance, co-management and common pool resource institutions. At a broader level, it also may serve as an example of how human and environmental security are always intertwined, even in places which do not have the shared political institutions, languages, or sense of future to which more narrow, state-centered versions of security discourse appeal.

Despite intense pressure from urban development at the highly surveilled international border between two major metropolitan areas - San Diego (California, United States) and Tijuana (Baja California, Mexico) — the Tijuana River Valley in the U.S. contains one of the largest remaining wetland habitats in southern California — the Tijuana River Estuary

(Goodrich, Boudreau, Crooks, Eguiarte, & Lorda, 2018; Zedler & West, 2008). Significant investments have been made by federal, state, and local governments in the U.S. to protect the Tijuana Estuary. Environmental security, which includes both human health and conservation is of paramount priority for those who manage the public and federally protected land, as it is threatened by choking sediment, debris, and sewage passing from the heavily urbanized Mexican-side of the border through the Tijuana River Valley to the Pacific Ocean.

Across the border, Tijuana is a highly desirable location for migration due to economic opportunity related to industry and close proximity to the United States. In Tijuana, the discrepancy in income ratios relative to nearby markets that attracts companies to invest in assembly plants, or maquiladoras, is a primary cause of the rapid economic and population growth of the region, especially since the signing of the North American Free Trade Agreement (NAFTA) in 1994 (Kopinak & Soriano Miras, 2013).

There are good reasons to look at Tijuana and San Diego as an example of the effect of division. Its residents vary in their exposure to institutional, linguistic, and physical barriers, but the lack of effective planning for urban development has resulted in a set of shared social and ecological risks, both for the residents of vulnerable canyon communities in Tijuana and for protected areas and local cities on the U.S.-side of the border. As planners, security experts, and economic interests focused on the border region begin to interpret and assess the regional effects of global climate change, sea-level rise, and projections of future availability of water and food, there is also a renewed need to focus on the unequal vulnerability between the communities in San Diego and Tijuana and the interacting social and ecological changes ahead. I do so here in this dissertation by characterizing the communities immediately around the border and the special place that the Tijuana River Estuary has in linking together binational consciousness.

Here, human and environmental protection are both under threat, although it is often perceived as simply an environmental problem on the U.S.-side and a social problem on the Mexican-side. This gap in reasoning is problematic, making shared deliberation and decision-making between two countries idealistic at best. Threats to the human and environmental security of the system are broadly in line with many of those considered in the scarcity-conflict literature, but lack a single central state as an audience.

Floyd and Matthew (2013) discuss changing ecological matters and their social consequences, including new causes of warfare. It is well documented that in border regions in Eastern Africa, for example, there is tension and increasing potential for inter-state conflicts related to natural resources (Okumu, 2010). Environmental scarcity played an aggravating role in the genocide of Rwanda, where a declining agricultural resource base led to decreased agricultural productivity, migration from areas of intense ecological stress and ethnic inequalities in resource distribution (Percival & Homer-Dixon, 1995). In the case of the Tijuana- San Diego border, although not engaged in war, everyday life (especially for those on one side of the border) presents a perpetual state of conflict. It is not apocalyptic to imagine a scenario of scarcity-driven conflict in this region in the not-so-distant future as it suffers from deforestation (i.e., scarcity of forest resources), water pollution (i.e., scarcity of clean water), and climate change (i.e., scarcity of regular patterns). Although these issues may seem isolated to national governments and residents of cities on each side of the border, a problem-driven interdisciplinary focus reveals detailed connections between the drivers of social precarity and ecological outcomes.

There has not been an absence of policy response to the environmental problems that have plagued this border region, in response to NAFTA, for example including the creation of binational entities, the Border Environmental Cooperation Commission (BECC) and the Commission for Environmental Protection (CEC). The attempt to incorporate diverse institutional and civil society players into bioregional conversation is happening in the Tijuana-San Diego border region as well. Ongoing bi-national coordination through BECC, CEC, the Good Neighbor Environmental Board (GNEB), North American Development Bank (NADB), ongoing revisions to the 1944 Colorado Water Compact, and the Border 2020 initiatives tie institutions from the U.S. and Mexico to each other and, in a limited but important sense, to local organizations and community.

That these initiatives remain underfunded and without mandates to build local institutions is obvious to those who work, and live, at the border. Although there are many agencies involved in discussions through different treaties and agreements, their practical efficacy to adaptively manage and affect ecological outcomes on both sides of the border has been severely limited, evidenced by the many persistent cross-border environmental problems and the radical inequality which exists between relatively affluent and healthy communities in the U.S. and physically proximate communities in Mexico. Disconnected at institutional, societal, and even linguistic levels, communities cohabitating shared ecosystems along the border do not have clear and responsive political representation to address their problems *together.*

This governance gap is key to understanding shared issues and potential solutions. As outlined in California's Fourth Climate Assessment Report (2018), threatened by drought, fires, pollution, and intensifying rainfall, Tijuana and San Diego largely approach their particular risks in isolation despite their shared context. Few if any resources for collective decision-making, reciprocal trust-building, and policy experimentation (prerequisites of adaptive governance and co-management schemes) exist here. To treat threats in isolation, though, intensifies the risk faced by communities on both sides of the border wall.

While the human and natural systems of the Tijuana River Watershed are wholly interdependent on each other, a one-size-*does-not*-fit all approach may lead to in-roads for measurable and securitized outcomes. Following more bureaucratic reorganizations of natural resource agencies around watersheds many regions in the U.S. have begun taking on more decentralized and local responsibility for protecting ecosystems and the vital services they provide (Millennium Ecosystem Assessment, 2005).

Confronting widespread disconnection from environmental issues in the 1960s and 1970s, radical bioregionalists believed that modern societies needed reconnection with the land and within the people living there (Berg & Dasmann, 1978; Snyder, 1974). For them, this meant creating local-scale political institutions with meaningful decision-making processes where the political limits matched ecosystem boundaries. They believed this would create a sense of collectivism in community, and through deliberation, reconstitute the community itself around the shared responsibility for stewarding and restoring natural systems, especially in areas already degraded by human influence.

The border presents a conundrum for these theories, many of which assumed away national politics in their embrace of the local, often assuming that a revolution in culture and worldview would re-center politics around the local community in a way that would encourage taking responsibility for the environment. These kinds of romantic assumptions would confront major problems where ecosystems are shared between nations, making the kinds of community-constituting debate, exchange of ideas and shared decision-making underlying bioregional politics even harder due to differences in culture, history, and language (Haines, 2015; McGinnis, 1999).

An interesting point of entry into this binational ecosystem could be through the many efforts have been targeted towards communities in Tijuana to protect the Tijuana Estuary. For various reasons (e.g., inability to interface with the resource in the U.S., limited benefits from its ecosystem services, competing and more direct interests in Tijuana) this approach may not be the most fruitful in inspiring interventions much needed such as soil stabilization techniques, habitat restoration, and waste management. However, when pointed to more immediate needs related to well-being and quality of life (a human security and ecosystem services frame) undertaking interventions that may have a more direct impact may be more palatable and relatable, especially related social precarity and informal development in Mexico. For instance, while removing trash from culverts ultimately reduces marine debris when floodwaters reach the Pacific Ocean in the U.S., it may be far more compelling to residents to remove debris to mitigate flood risk to households and roadways in rain events.

As three-quarters of the Tijuana River Watershed lies in Mexico, addressing concerns in the estuary without a cross-border vision is confusing and ultimately unproductive. The risk of extreme sewage or sedimentation events to the estuary is intensified in the canyons, where in even moderate rain events wash out roads, flood conveyance channels full of debris and sewage overflow, and large sections of canyon hillsides denuded of native vegetation by ranching and development collapse and threaten housing and life. The vulnerability to an extreme event in the canyons is accentuated by the lack of police, medical, and fire services in the area to respond in case of a flooding situation, as exemplified especially in wet years common in El Niño years of

Pacific Oscillation (Luke et al., 2018). The 2015–2016 El Niño, for instance, was one of the strongest of the last 145 years (Bernard, 2012).

Binational entanglement requires working versions of theoretical models of connections between science and policy, themselves oriented around the particular social and ecological priorities of the San Diego-Tijuana region. To intervene in highly unequal settings requires collaboration, sensitivity to economic factors, and understanding the patterns of regional development and the challenges that result. That these conflicts are currently highly militarized and nationally contentious only makes local and regional collaboration more essential to improved outcomes, even if treated as "non-defense-related security issues" (Ganster & Lorey, 2004, p. 220).

A fundamental challenge in considering adaptation in the Anthropocene is how to ensure human security — such as in the form of food supply and clean water — while maintaining the Earth's life-support systems and the services they provide. Meeting both may be the "greatest research challenge to ever confront humanity" (Wilcox, Sorice, & Young, 2011, p. 112). Arguably, this will also present a significant, and unprecedented, political challenge (Matthew, 2014). Natural scientists can benefit from scientific endeavors with social scientists, and vice versa, as policy development and implementation must be informed by the most recent and overwhelming science, despite lack of consensus on stratigraphy or how we relate, by epoch, to our current and future state.

Equally, if not more critically, becoming more resilient to the hazards a changing climate will bring will require the engagement of those who will experience it. There are many meanings and interpretations of resilience in the literature and in practice, and especially when considering modified (i.e., engineered) systems, but Walker & Salt (2011) define it simply as the capacity of a system to absorb disturbance and still retain its basic function and structure. They encourage resilience thinking. which in the Anthropocene, begs for identification of feedbacks that have already been disrupted or destabilized and thresholds that have been crossed, resulting in a tipping point or worse, a regime shift or hostile state that is difficult to return from or reverse (Biggs, Carpenter, & Brock, 2009; Walker & Salt, 2011). Steffen et al. (2015) indicate that based on current patterns of human behavior, the few ecological thresholds that haven't been crossed will be exceeded by the end of the century. Walker and Salt (2011) argue that at least two resources (capture fisheries and freshwater) are beyond current levels of demand, much less future demand, and can only be met by engineered solutions. This is particularly troubling for those in developing nations where capacity for adaptation to a state of diminished resources - engineered or otherwise - is economically limited (Steffen et al., 2015).

Prospects for resilience in the Anthropocene are deeply disconcerting, however, this is a critical moment for resilience thinking that must be applied as climate change and human activities become ever stronger drivers of change coupled with the dynamism of Earth's systems (Walker & Salt, 2011). The complexity of the interaction among multiple agents of global change will not yield to simple causal relationships and will present unpredictable outcomes (Wilcox et al., 2011). For example, human activity can impact ecosystems in a way that detracts from their function, thus their ability to deliver an ecosystem service, therefore diminishing the capacity to satisfy human needs and security, an ecosystem *dis*service. The human population's vulnerability and exposure to flooding, among other grave natural hazards facing society will only increase due to trends in rising sea levels, urbanization, and deforestation as populations increasingly shift from rural-to-urban (Hallegatte, Green, Nicholls, & Corfee-Morlot, 2013; Jongman et al., 2012). As we reach the limits of our current approaches we must reframe the relationship between people, their powerful geological force, and nature to work towards a sustainable future in the Anthropocene narrative and human condition before the debate begins over when the Anthropocene might end (Berkhout, 2014; Palsson et al., 2013). This era of "transformation" will present an unprecedented psychological challenge for the communities exposed to such change and to the professionals who work to slow its advances (Holling, 2001, p. 403).

As more is understood about ecological and human systems and novel stratigraphic signals cement the Anthropocene as a formally defined geological epoch, assumptions about the challenge of environmental management and the basic framework by which an adaptive management approach has been based have been shattered (Walker & Salt, 2011). Because of the dynamism that these systems share - the continued yet rapidly changing of structure and function as human activities and climate change become ever stronger drivers of change - resilience thinking, not a new, but in some cases absent-in-practice concept, must be applied in the Anthropocene (Walker & Salt, 2011). Uncritical forms of resilience are brittle, unprepared to take on difficult cultural and political changes to authentically respond to linked social and ecological crises. Resilience thinking begs our acknowledgement of where in the Anthropocene feedbacks have already been disrupted or destabilized and thresholds that have been crossed, resulting in a tipping point or regime shift that are difficult to reverse (Biggs et al., 2009).

The research presented in this dissertation begs for re-thinking of how we operate, adaptively manage, and thrive in an unstable, uncertain, and unequal future in a binational border region, but also in other stressed social-ecological systems. Secondly, it offers that data collection, access, and distribution must be increased defragmented and equalized, and a new research agenda generated, if we are to continue to study planetary changes, their linked biogeochemical and socioeconomic impacts, and how society survives, perhaps even thrives, within it. Integrative innovations must address threats at the source, seek co-benefits, and address multiple scales. Finally, like the inextricable connectivity between the forces of biotic and abiotic processes in the natural sciences, a masterful weaving between the human and ecological dimensions in scholarship and practice will be necessary. Collaboration between the natural and social sciences, while linking knowledge to social action, is our imperative.

Border regions are a microcosm of many of the most problematic issues in global ecological and development debates. At the San Diego-Tijuana border, the developed side continues to call for environmental preservation, often not seeing livelihood or social issues as linked to ecological ones. There are, however, also stories of success, in peace parks, for example, and perhaps untapped resources that are important to reflect upon if we are to enhance a model of adaptive governance and achieve a just, equal, and ecologically-resilience binational region. If, as Barquet (2015) posits, "environmental cooperation can be an efficient instrument for improving relations between states" (p. 14) and "biodiversity is a "low politics" issue that can serve as a starting point for negotiations and peace within regional cooperation" (p.14) perhaps the San Diego-Tijuana case has the resource (its estuary) at hand to improve collaboration and trust building that underlies an adaptive governance regime that addresses inequality across the region.

Thinking in terms of environmental security in this context of widespread social and institutional disconnection may also hold insights for other global-level debates regarding the historical and current responsibilities of the so-called developed and developing nations. These perspectives are often conceived as attempting to bridge a kind of abstract gap. In Tijuana and San Diego, however, these perspectives are concrete and take place between communities which coexist, even as domestic narratives may further harden both physical and cultural barriers between the U.S. and Mexico. The promise of raising environmental issues (rather than immigration or trade) to the level of national security, would be a profound shift in San Diego-Tijuana, especially considering its (non) conflict status and legacy of the suspension of environmental laws to build the existing and planned border barrier (Sancho, 2007; Sundburg, 2015). An environmental security rhetoric in this region could broaden definitions of security and explicitly engage the political empowerment of local communities.

Social-ecological flexibility can be hastened in places like Tijuana and San Diego by renewed focus on shared ecological systems and their interrelationship with social and economic factors. Adopting a bioregional perspective demands that this be done with the express intent of creating stewardship and a sense of shared community, beginning at local levels and ascending to higher scales when necessary to meet the scale of the challenges represented. This is not a simple diagnosis. San Diego and Tijuana, however, share a deep history of human residence preceding recent migration, despite being arbitrarily separated by human barriers. This particularity is both a cause of many problems and also an opportunity to profit from cross-border visions which see ecological commonalities as central binding forces rather than focusing on cultural, linguistic, and economic disparities. It is only from the base of a regional community with an understanding of their shared context, awareness of the multiple-scales of ecological and economic flows involved, and focus on building local capacity that pleas for environmental security or binational adaptive governance will be more than simply an aspiration.

OPPORTUNITIES FOR IMPROVING ADAPTIVE MANAGEMENT IN THE BIOREGION AND BEYOND

Abundant examples teach us that if linking ecological governance to developing contexts is to be done well, it must be done in a reflexive and hybrid way, at the risk of continued irrelevance or profound gaps in credibility. Yet, transformative change is typically not embraced, rather resisted and comes with considerable amount of inter-personal, inter-group and political conflict. Simultaneously, a growing literature is recognizing how profound – technologically, economically, socially, politically, and ultimately culturally – the human response must be to minimize climate change to a level where human safety, survival, and dignified lives (not to speak of flourishing) are still possible. Only little is known to date about the professional and psychological capacities needed to face such profound change (Berzonsky, 2016; see also review and compilation in Moser, Coffee, & Seville, 2017), despite mounting evidence presented in this dissertation that the stresses connected to the current state and future of our planet are overwhelming.

This dissertation points to a critical consideration for a pathway forward in paradigms where adaptive management is failing due to the pressures of the Anthropocene: producing more (and authentic) science informed by those with lived experiences and leveraging social capital can lead to more accurate and relevant information. Additionally, natural and physical scientists can benefit from scientific endeavors with social scientists, and vice versa, as policy development and implementation must be informed by the most recent and overwhelming science generated by multiple modes of inquiry. Embedding this interdisciplinary knowledge generation in a social-ecological (and policy relevant) framework will support more meaningful thought towards objective decision-making.

While environmental degradation, scarcity, and stripping of ecosystem services can lead to conflict it also can provide an opportunity for cooperation and allows for a hopefulness for shared success in places like the border region of San Diego-Tijuana and beyond. As environmental challenges grow and prospects for binational collaboration seem more and more discouraging in current domestic political climates, human capacity to resolve problems may actually be growing at local and regional levels. We are living in a new set of conditions, yet Laird-Benner and Ingram (2011) found tremendous staying power of human relationships and commitment to place, most powerful to its actors in its context. They also found that face-to-face encounters and positive narratives, albeit increasing difficult in the growing infrastructure of borders, have favorable effects, propelling action that results in improved security.

It is not possible to achieve a binational/bioregional vision using a singular approach within maladaptive institutions that engage individuals unable themselves to adapt due to their vulnerability or enormous weight of the work. These findings are promising, perhaps more than ever, as such efforts to create a binational political community will necessitate new forms of environmental scarcity-conflict avoidance, peacemaking, and creation of robust forms of institutional collaboration towards sustained adaptation and resilience. Stakeholder engaged processes, leveraging knowledge as social capital, and acknowledging the psycho-social realm feels particularly urgent in this moment, not only at the border between the U.S. and Mexico but globally, as we acknowledge and seek a vital shared social and ecological destiny, resilience, and transformation in the Anthropocene.

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APPENDIX

Supplemental Table

Table A.1. Results from Single Variable Logistic Regression Models Run for Each Covariate and Taking Action to Prevent Erosion in the Community and in the Home

	Outcome 1: Have you taken any actions to prevent soil erosion in your **community**?			Outcome 2: Have you taken any actions to prevent soil erosion around your **house**?		
	Coefficient	**OR**	**P**	**Coefficient**	**OR**	**P**
Active in community?	0.079	1.200	0.400	0.799	6.290	<0.001***
Age (year)	0.004	1.010	0.010*	0.004	1.010	0.200
Female	-0.018	0.960	0.840	0.204	1.600	0.080
Education	0.013	1.030	0.550	-0.018	0.960	0.570
Awareness of where flooding could occur in community	-0.208	0.620	0.200	-0.201	0.630	0.360
Year of most recent flood experienced			0.290			0.680
within 10 years	Referent	1.000		Referent	1.000	
10-20 years	-0.131	0.740		-0.119	0.760	
20-30 years	0.117	1.310		0.086	1.220	
30-40 years	0.410	2.570		-0.319	0.480	
Home in an area that is vulnerable to flooding			0.180			0.790
Yes	Referent	1.000		Referent	1.000	
No	0.064	1.160		0.064	1.160	
Not Sure	0.312	2.050		-0.081	0.830	
Affected by a flood in lifetime	0.086	1.220	0.360	0.161	1.450	0.180
Home in an area that is vulnerable to erosion			0.01*			0.040*
Yes	0.310	2.040		0.217	1.650	
No	Referent	1.000		Referent	1.000	
Not Sure	-0.009	0.980		-0.495	0.320	
Affected by erosion at current residence	0.467	2.930	<0.001***	0.420	2.630	<0.001***
Years lived in your current neighborhood	0.061	1.150	<0.001***	0.037	1.090	0.050
Intent to live in current neighborhood?			0.110			
Temporary	-0.409	0.390		-0.699	0.200	0.130
Long-term	Referent	1.000		Referent	1.000	
Not Sure	-0.167	0.680		0.041	1.100	
Community (cell number)			0.110			0.010
2.00	Referent	1.000		Referent	1.000	
6.00	0.336	2.170		0.121	1.320	
7	-0.027	0.940		-0.260	0.550	
17.00	0.230	1.700		0.107	1.280	
27.00	0.143	1.390		0.356	2.270	
Income			0.470			0.560
Less than $1,001	Referent	1.000		Referent	1.000	
$1,001-3,000	0.064	1.160		-0.119	0.760	
$3,001-5,000	0.170	1.480		-0.076	0.840	
More than $5,001	0.199	1.580		0.127	1.340	
Participation in						
Nonprofit/charitable org or community/public service	0.420	2.630	0.010*	0.490	3.090	<0.001**
Church	-0.137	0.730	0.330	0.090	1.230	0.600
Satisfaction with community	0.079	1.200	0.400	-0.041	0.910	0.730

* p<.05, ** p<.01, *** p<.001