“WHEN THE RAIN FALLS”: ADAPTATION TO COMPOUND DISASTERS AND CLIMATE UNPREDICTABILITY IN NATURAL RESOURCE DEPENDENT COMMUNITIES OF RURAL HAITI

by

JOHN RYAN MCGREEVY

(Under the Direction of Donald Nelson)

ABSTRACT

This dissertation examines the connection between natural resource use and disaster vulnerability in the face of increasingly unpredictable rainfall. I use research findings to break down false narratives about small-scale natural resource users and the disasters they often face. As disasters increase in frequency, the time between them reduces, and compound disasters form. Little is known about how climate-related compound disasters impact livelihoods in those communities most directly reliant on the natural world. From a month of preliminary research in 2016 and a year of fieldwork in 2018-2019, I trace changes from the compound disaster (Hurricane Matthew followed by a months-long drought) that occurred between periods of research. I studied in the town of Camp Perrin, Haiti, once considered a place apart from the rest for Haiti, having an abundance of natural resources and remaining self-sufficient without the need of foreign or state intervention. I worked with local people to identify factors that make households more vulnerable to the disasters. I likewise identify the various adaptive strategies used in 2016 and 2017 and how they influence future household well-being and vulnerability. I combine theory from disaster studies, medical sciences, ecosystem services, livelihoods, adaptive capacity and vulnerability, and social-ecological system feedback to form new pathways of understanding of how rural Haitians and similar communities experience disaster. My findings discredit two false narratives about small island developing states and the small-scale natural resource dependent communities living in them. First, I reveal climate change induced reduction of choice portfolios for how households engage in natural resource-based livelihoods, leaving options known to be less desirable but necessary for survival. This and similar findings discredit the false narrative that local people use natural resources out of ignorance and apathy. Second, I explore systemic interactions that produce vulnerability and reduce adaptive capacity over long periods of time. This discredits the false narrative that disasters are random and temporarily isolated "natural" events. This integrative approach and these findings are essential to reframe narratives of Haiti and similar nations and to better prepare for continued change and climate unpredictability.

INDEX WORDS: Disaster vulnerability, compound disasters, extreme weather events, climate change, Haiti, Caribbean, natural resources, ecosystem services, livelihood strategies, adaptive capacity, second impact syndrome, agent-based models, social-ecological systems

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by

JOHN RYAN MCGREEVY

BA, Elon University, 2010

BS, Elon University, 2010

MA, Colorado State University, 2013

A Dissertation Submitted to the Graduate Faculty of The University of Georgia in Partial Fulfillment of the Requirements for the Degree

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JOHN RYAN MCGREEVY

Major Professor:	Donald Nelson
Committee:	Puneet Dwivedi
	Nathan Nibbelink
	Mark Schuller
	Bram Tucker

Electronic Version Approved:

Ron Walcott
Vice Provost for Graduate Education and Dean of the Graduate School
The University of Georgia
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DEDICATION

I dedicate this dissertation to my family, both Haitian and American. To my *konpè,* Elisson, you made my time in Haiti possible, got me out of many interesting situations, made sure I did not make too many cultural mistakes, and showed me unwavering kindness. To my parents, you kindled the fire of my passion that brought me here, to the end of my academic journey and the beginning of a new chapter. You shared love and encouragement through nearly 30 years of education, helping to make me the person I am today. And, most importantly, to my wife, Roxana. I left one month after the birth of our first child, and you stood strong for a full year. You were patient and kind. You cared for me when I returned, broken down by dengue fever and the stress that surrounded me. You were not always near, but you never left my side. You deserve this degree more than I do.

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INTRODUCTION AND LITERATURE REVIEW

1.1 Prologue: getting it all wrong

The first time I stepped foot in rural Haiti, I got it all wrong. It was 2006, and my untraveled self knew only of Haiti as "the poorest country in the Western Hemisphere." Popular culture gave Haiti this subtitle, and it stuck with me. The trip changed the trajectory of my life. I left the countryside feeling many of the things that echo from groups of foreigners reminiscing in the Port-au-Prince airport: sadness, longing to help, and unexpected amazement in the *jwa de viv*, the joy of life, that often exudes from poor Haitian people. I held narratives in my mind, too, false narratives planted from news broadcasts and a Western view of my role in the world. To me, Haiti was a place to save. More specifically, it was a country needing outside instruction about their natural resources and their destruction of the environment before it was too late.

In 2010, I returned to Haiti, and by chance, I experienced the worst disaster in modern history. I saw buildings turn from homes to forces of destruction as an earthquake shook the Haitian world. I did somehow still see the *jwa de viv*. The trip narrowed my trajectory toward disaster and environmental studies. In the week that followed, false narratives again clouded my view of what caused the devastation around me and how to respond. I joined the masses of outsiders seeing this as an unfortunate and isolated event. Haiti could not catch a break. They needed help from the aftermath of this "unavoidable tragedy."

Over a decade of graduate studies and working with Haitian research partners across nearly every province of Haiti has transformed my perception. The writings of the prolific and recently passed Paul Farmer, the insight of scholar-activist Mark Schuller, the mentorship of Don Nelson on adaptive capacity and international development, the teachings of professors in anthropology and integrative conservation, and the daily discussions while living with Haitian colleagues, they brought me here. I hope now to contribute to the breakdown of these false narratives that mischaracterize Haiti (and many nations like it) to the rest of the world.

1.2 Introduction: rethinking dual false narratives

Many outsiders view Haiti and similar nations through a fictive lens propagated by media, Western culture, and political leaders. With respect to natural resource use and disaster vulnerability, a set of dual false narratives emerge. The first false narrative I call "The Naïve Local," where people view small-scale natural resource users (subsistence farmers, livestock owners, forest product users, etc.) as ignorant or apathetic to the importance of their natural resources, resulting in short-sighted resource use and widespread environmental destruction. The second false narrative I call the "The Unfortunate Poor," where people view disasters in small island nations as isolated and inevitable natural events happening to unlucky poor people in an inherently risky area. These dual false narratives misrepresent natural resource users, mask causation of disaster vulnerability, and justify mistargeted intervention.

The Naïve Local narrative overlooks important components of human-environmental interaction. Small-scale natural resource users harness a wealth of knowledge of the natural world. They test this knowledge by predicting and responding to annual patterns in nature and passing it down through generations. They likewise have a higher sensitivity to environmental change and its impacts on livelihoods systems than outsiders (Berkes and Folke 2002). Local knowledge may differ from popular Western ideas of how to "properly" use natural resources, but the former often usurps common Western knowledge over the test of time (Fairhead and

Leach 1995, Fairhead and Leach 1996, Nadasdy 2005). For example, when working in Haiti's Northwest, I witnessed the aftermath of foreign entities teaching Haitian farmers to abandon mixed crop agroforestry for Western farming techniques like intensive monoculture for export. The change required expensive inputs of fertilizer, pesticide, and irrigation that tied households to cash-based economies and left them without food when anything disrupted their ability to buy these inputs.

This narrative also overlooks the history of slavery, colonialism, and neocolonialism that denuded the island of its trees, leaving the current population to bear the blame for destruction long passed. Forced labor on sugar plantations and foreign companies harvesting mahogany produced massive tree loss for outsider gain (Mintz 1986, McGreevy 2013). Making matters worse, a swine flu outbreak in nearby countries led to the preemptive mass slaughter of the locally important Creole pig as ordered by foreign governmental organizations. The American pigs sent to replace their Creole cousins quickly died in the island conditions. Since rural households used pigs as a form of stored capital to breed and use in times of need, this event became known as the "Haitian stock market crash." With this reduction in available resources in which to store and retrieve capital, rural livelihoods decreased in viability and households were left with little option other than to cut trees in times of need and/or move to the capital city in pursuit of wage labor (Diederich 1985, Murray 1987, Oliver-Smith 2012).

Instead of new narratives learned, The Naïve Local misconception continues to form false histories of blame and influences policy and outsider intervention in problematic ways (Fairhead and Leach 1996, Goldman et al. 2011). In Haiti, this takes the form of education of local people about the importance of their natural resources and false justification for measures that disconnect people from the land. The misconception prompts an ongoing flurry of outside-led projects aimed at increasing tree cover and decreasing soil erosion, with varying results. Oftentimes, the benefits dissipate quickly, and vulnerability to landslides and flooding continues to grow (Felima 2009, Freeman 2014).

The most troubling of examples from my time in Haiti surprisingly occurred at an academic conference and involved a scholar also studying in Camp Perrin, Haiti. The town has a large lake that provides an important service to the region's most impoverished households living around its rim. When the lake recedes, those without access to other farmland can plant subsistence crops on the rich soil. The ecologist at this conference had worked ten days at the lake and presented on the numerous and meticulous natural science methods he used to measure pollution levels. With my background in biology and environmental studies, I was impressed by his thoroughness. Yet, his conclusion did not impress. Without conducting social science, he argued that the best course of action would be to remove the "illegal" inhabitants from the land surrounding the lake. The justification included The Naïve Local narrative and digging up obscure laws written during the ruthless Duvalier dictatorship. More concerning still, this person discussed his plans to share his conclusions with the Haitian government. Here and elsewhere, The Naïve Local narrative wrongfully "justifies" removing the "naïve" from the land to save them from destroying the environment upon which they rely.

The Unfortunate Poor narrative misinterprets social-ecological disasters as "natural" disasters. Policy and media perpetuate a popular but unfounded view of disasters as isolated and unavoidable events occurring naturally in a set of unfortunate, poor countries (Bankoff et al. 2013, Zhang 2016). Media also blames disasters on people existing in regions seen as inherently dangerous (Adams 2003). This logic falls short on the island of Hispaniola. In 2004, Hurricane Jeanne passed over the Dominican Republic and a small portion of Haiti, taking 18 lives in the

Dominican Republic and more than 3000 in Haiti (Felima 2009). Twelve years later, Hurricane Matthew took 1600 lives in Haiti but only 4 in the Dominican Republic (Pichler 2013, Benfield 2016). Nearby Cuba lost 0 lives and 4 lives, respectfully (Pichler 2013).

Research has long discredited the merit of both of these false narratives in their various renditions around the world (Fairhead and Leach 1996, Kull 2000, Bankoff et al. 2013, Button and Schuller 2016, among others), but little is known about their combined effects. When a disaster or a series of disasters disrupt livelihoods in a natural resource dependent community, the two false narratives combine to form an incorrect popular understanding of the event. Moreover, the increasing frequency and intensity of climate change related disasters occurring in the Caribbean likewise increase the need for further analysis. Since climate-induced extreme weather events attack rural livelihoods more than other forms of disasters (Meheaux et al. 2007, Kijewski-Correa et al. 2018), their increase will produce and reproduce dual false narratives about disasters and natural resource use.

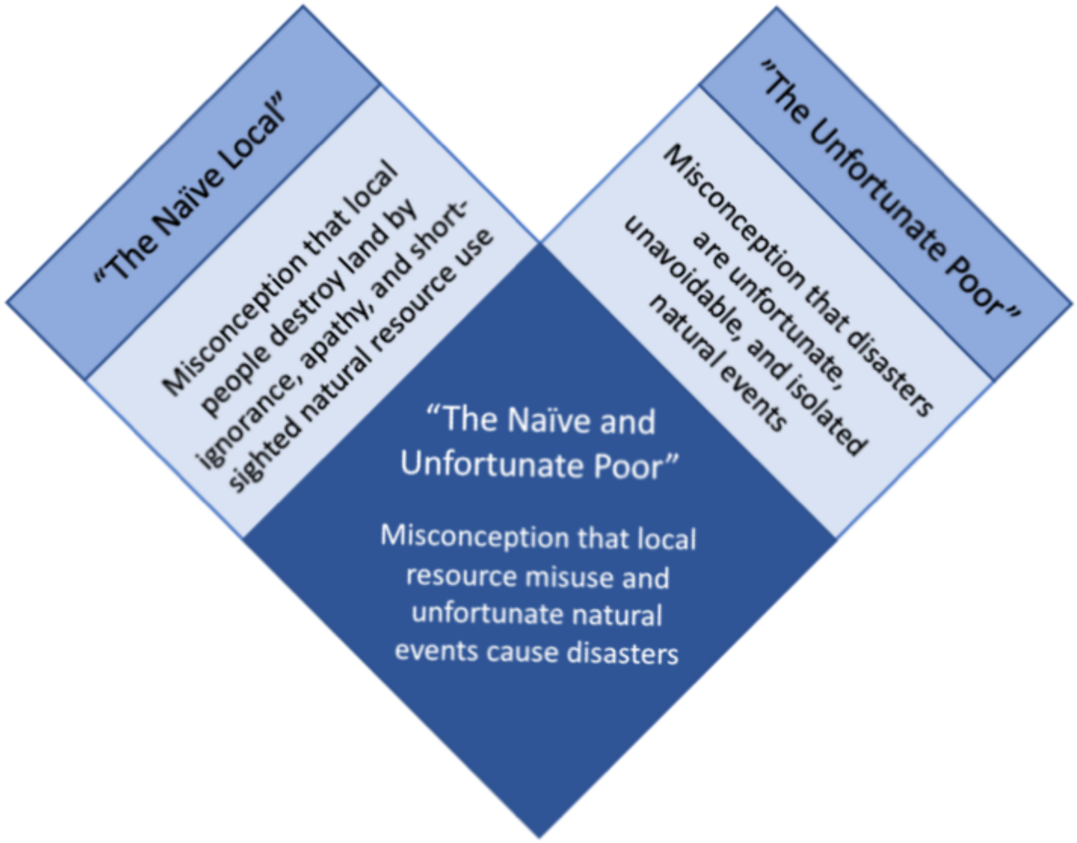

Figure 1.1 Dual false narratives and their combination in the face of increasing climate-related disasters.

Increasing disaster frequency and intensity lead to the combining of narratives in ways that reproduce and magnify false reasoning and problematic outcomes. When discussing Hurricane Matthew and the reason for its severe damage in Haiti, a news report declared that Haiti became deforested because "They take all the trees down, they burn the trees. Even the kids there, they're so hungry they actually eat the trees" (Ho 2016). The absurdity of this publicly aired claim highlights the potential for growing misunderstanding of Haiti and similar nations with increasing extreme weather events. Combining the two false narratives, as seen in Figure 1.1, places blame on a combination of unfortunate natural events and supposed local ignorance.

The new dual narrative asserts that local naivety helped produce the unfortunate event and also produced the environmental destruction that followed.

I seek to break down these dual false narratives through integrative, mixed methods research in Camp Perrin, Haiti. In this dissertation, I help reveal the human-environment system dynamics that explain strategic natural resource use and complex social-ecological disaster formation. To do so, I present guiding research questions and apply them to the recent compound disaster of a hurricane followed by a drought in Camp Perrin:

(Q1) What factors and processes explain the impact of climate-related disasters in the small-scale natural resource-dependent community of Camp Perrin?

(Q2) How do the outcomes of adaptive strategies used by households in this community and the constraints on these strategies influence the future of rural livelihoods in the face of climate change?

My findings reach past Camp Perrin to help understand similar interactions in other small island developing states and their small-scale natural resource dependent communities.

1.3 Study area: Camp Perrin

The town of Camp Perrin sits on the southwestern portion of Haiti's Southern Peninsula, with its town center just 15 miles north of Les Cayes, the regional capital. The ends of the town stretch from flat, irrigated farmland nearly touching the coastal capital to some of Haiti's highest and most forested mountain peaks. The Rivye Sud river runs through the west-central portion of Camp Perrin. Its flow varies from a wide channel of raging torrents to a narrow path of water well within the banks, depending on rainfall at its mountain source. The other major water feature is the Etang Lachaux lake sitting centrally at the transition between plains and mountains.

Camp Perrin covers nearly 83 square miles with a population of around 41,000 (Pèrez-Escamalia et al. 2009), though accurate numbers are difficult to find. This population is spread unevenly across three districts: Champlois, Lèvy, and Tibi, as seen in Figure 1.2. Lèvy is the most densely populated, has the most access to irrigation, and lies in the southern valley of the Rivye Sud on generally flat and productive soil. Tibi lies on the west bank of the Rivye Sud, with a walking/motorcycle bridge serving as the primary connection. Tibi and Champlois to the north consist of less densely populated mountainous regions, where sloping land is less desirable for agriculture and animal husbandry. The town center cuts across the border between Champlois to the north and Lèvy to the south, producing a corridor where most non-agricultural economic activity occurs, along with schools, churches, restaurants, and clinics. Those few families less reliant on agriculture typically live near the town center and commute to the regional capital to work as lawyers, teachers, professors, electricians, builders, etc.

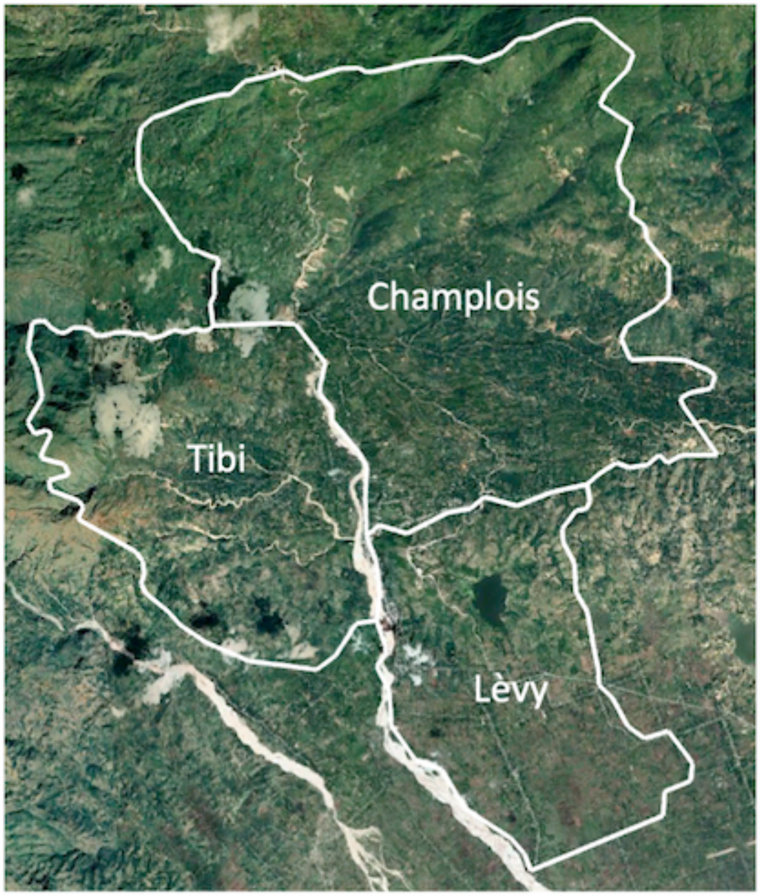

Figure 1.2 Study site with three districts outlined in white, modified from Google Earth.

Through aerial image analysis, I counted and identified the position of the more than 10,000 traditional housing units in Camp Perrin, called "lakou," intermixed with farmland and small forest patches. *Lakou* consist of one or more houses within the same fence or land boundary. They share a house garden (*jaden lakou*), space for low value livestock like chickens, rabbits, and doves, and smaller structures such as outdoor kitchens, outhouses, and grain storage units. House gardens produce herbs and smaller crops used supplementary to main courses, like tomatoes, eggplants, and leafy greens. In the farmland (*jaden)*, farmers plant either a monocrop of corn or beans, or a mixed array of crops, including yams, plantains, millet, cassava, and sweet potatoes, with lesser amounts of corn and beans. The distance between a *lakou* and a *jaden* varies greatly, either sitting adjacent to the property or (primarily for the poorest of families) up to a two-hour walk away into the high sloped mountains. In the case of far-off gardens, farmers may spend nights in small bungalows that provide convenient rest areas but become dangerous locations to sleep during major storms.

Of note for Camp Perrin when compared to other Haitian towns is that their population sees and presents their town as *yon ti kote apa* or "a little place apart." The phrase arches across restaurants, hotels, and concrete walls in hand-painted lettering. When conducting preliminary fieldwork in early 2016, common explanations for this self-separation included Camp Perrin's relative independence from other towns and other countries, its lack of need for aid from non-governmental organizations (NGOs) and the Haitian government, community-based environmental protection programs, a higher standard of living, less crime, fewer protests, and less vulnerability to disasters. After more than a decade of working across Haiti, I agree with Camp Perrin's designation as *yon ti kote apa*.

NGO presence in Camp Perrin is complex and changing. Before 2016, grassroots community groups cared for their town through fundraising, occasional investment from the diaspora, and collective action. Active farming and lending groups helped households temporarily bridge income and subsistence gaps and promoted collective investment in needed resources. NGOs largely overlooked Camp Perrin, seeing it as a place with less need for assistance. This is rare and noteworthy in a country often referred to as the Republic of NGOs, where outsiders attempt to fill the gap left by a turbulent government (Schuller 2007, Schuller 2016, Voltaire 2019). From fieldwork conducted with a Haitian colleague in 2016, local sentiment showed distrust of both the state and NGOs, questioning their effectiveness and their ability to fill their stated roles, which often do not align with local needs (McGreevy and Voltaire

2019). Yet, the disasters occurring in 2016 elevated NGO presence in Camp Perrin. Outsiders began to see Camp Perrin as a place of urgent need. Still, Haitian scholars have criticized the roles, relationships, and effectiveness of an influx of NGOs in Camp Perrin and the Southern Peninsula at large (Lamartinière 2019; Voltaire 2019).

Climate change and its symptoms (namely extreme weather events and climate unpredictability) complicate the future of Camp Perrin as *yon ti kote apa,* independent and lacking need for outside intervention. Historically, Camp Perrin has seen a much higher annual rainfall than other areas of the country (Rinaldo et al. 2012). Local peoples adapted to this relative abundance without much reliance on irrigation, except for those wealthier households that produced monocrops with more water-intensive crops. Families without access to irrigation spread their portfolio of options to include various crops and different livestock, so that if a crop-specific pest or brief drought were to disrupt one form of subsistence, other options remained. Climate change and the associated extreme weather events have changed strategies for both those with irrigation access and those dependent on rain alone.

The events of 2016 produced a year of destruction, livelihood upheaval, and unparalleled natural resource loss in Camp Perrin. Just one month after completing my preliminary research in the town, a compound disaster formed with a hurricane followed by a drought. Here, I refer to compound disasters as two or more disaster events occurring in quick succession in a way that causes more damage than the sum of damage of both disasters occurring at different points in time. The Category 4 Hurricane Matthew passed just west of Camp Perrin, with the hurricane's most dangerous "right hook" striking the town. A similar "right hook" struck near New Orleans with Hurricane Katrina (Freudenburg et al. 2009). With little barrier from the hurricane as it passed from the coast up the flat Rivye Sud valley and into the precariously steep land in northern Camp Perrin, Hurricane Matthew produced an unprecedented loss of life, livelihood, and natural resources in the town. Destroyed infrastructure that once connected the western portion of the Southern Peninsula with the core of Haiti inhibited the arrival of aid. Camp Perrin was isolated.

Before aid arrived, rains dried up, and a months-long drought immediately commenced. Crops planted after Hurricane Matthew died from lack of water, and most households remained without roofs. Those with livestock still alive sold some or all to fund funerals, medical bills, house repairs, and to buy food. Notably, people used the last of their seeds and other resources to replant a second round of crops once Hurricane Matthew passed. The drought killed most of the town's crops, even for households with irrigation access. Two rounds of crop loss in quick succession left households with no food, no crops to sell, and limited resources to plant again.

The destruction from this compound disaster takes center stage in my inquiry of how extreme weather events influence livelihoods and adaptive strategies. My research before and after a disaster provides an opportunity rare in disaster studies for a first-hand assessment of changes in pre-disaster and post-disaster variables and processes.

1.4 Literature review

I pull from theory in the fields of disaster studies, vulnerability and adaptive capacity, natural resources, Haitian and Caribbean studies, and even medical sciences. This section continues the discussion from theory on false narratives and their implications for human-environmental interaction in Section 1.2. The chapters to follow dive more deeply into the theories that apply more directly to each chapter's area of inquiry. Here, I provide an overview of those theoretical realms that connect across the entirety of the dissertation. Without the space or need to exhaust each area of theory, I focus on the how these areas apply to small island developing states and their small-scale natural resource-dependent communities, like Camp Perrin, Haiti.

Disaster studies and extreme weather events

Popular simplistic views of disasters present them as inevitable events isolated from the system dynamics in which they develop. Continued use of problematic terms like "natural disaster" in media or "act of God" in the insurance realm demonstrate the presence of these views and perpetuate them in perpetuity (Smith 2006). If someone or something were to blame, the next step in this logical fallacy is that general poverty and improper natural resource use by local people produce disaster vulnerability. This mindset forms a dichotomy between the vulnerable Global South and the non-vulnerable Global North, making disasters in the South more palatable and their underlying causes ignored (Bankoff et al. 2013). Beyond stifling responses that may otherwise work to heal the roots of disaster formation, public sentiment and the portrayal of events by media and politicians influences the amount of assistance allocated to various disasters (Olsen 2003).

Expanding analysis to the interplay between daily life and disaster events and the formation of different disaster types reveals complexities beyond this simplistic view. Disasters are not normal, natural, or isolated in time. They instead arise from long-forming processes and historical actions that continually influence daily life (Oliver-Smith 1999). Natural hazards do indeed trigger disaster events, but they do so by following pathways of existing relationships, historical actions, and landscape changes (Wisner et al. 2004). For example, the natural hazard of Hurricane Katrina became a disaster through a) the formation of low-income neighborhoods areas more prone to flooding, b) the decimation of mangroves and marshland over decades, and

c) the formation of direct water channels from the ocean to the city of New Orleans without barriers, among other natural and social factors (Freudenburg et al. 2009).

Disaster events expose inequalities already existent in the system and the breakdown of previously sustainable and less vulnerable human-environmental interactions (Wisner et al. 2004, Button and Schuller 2016). For example, prior to the earthquake of 2010, Haiti's population was spread more evenly across the provinces and the capital city of Port-au-Prince. Dictator decision-making to isolate business activities, governance, and education to only the capital city led to the population of Port-au-Prince quadrupling in the 30 years before the disaster (Dupuy 2012). Reduction in the viability of rural livelihood through centuries of outsider-induced environmental degradation likewise contributed to the urbanization. Among other factors, these processes led to hastily built structures that transformed homes, restaurants, and factories into concrete forces of destruction when exposed to the natural hazard (Dupuy 2012, Etienne 2012, Schuller and Morales 2012). It may be difficult to consider a magnitude 7 earthquake a "natural hazard" instead of a "disaster," but during that same year, 21 other earthquakes occurred with an equal or higher magnitude (USGS 2010). An 8.8 level earthquake, 500 times as powerful than Haiti's 2010 earthquake occurred just one month later in Chile (Oliver-Smith 2012). Yet, Chile lost 521 lives, and Haiti lost 316,000 lives (excluding deaths from the corresponding cholera outbreak), making it the deadliest social-ecological disaster in modern human history (Elnashai et al. 2010, Schuller and Morales 2012). Understanding the formation of disasters and their varied outcomes requires contextualization of the political, social, economic, and spatial factors combining to produce differential vulnerability that turns hazards into disasters (Button and Schuller 2016).

Disasters separate logically into pulse disasters (those occurring in dramatic and temporally short periods, such as earthquakes, hurricanes, and tornadoes) and press disasters (those forming more slowly and in a less noticeable manner, such as drought, disease, and famine) (Collins et al. 2011). Unlike the more iconic pulse disasters, press disasters inflict damage on livelihoods on a daily basis and over a long period of time (Collins et al. 2011, Button and Schuller 2016). This significance of this differentiation comes partly from the comparative impact and media coverage/aid allocated to each disaster type. Pulse disasters receive most of the media and aid attention, but press disasters cause far more deaths with far fewer intervention attempts (Wisner et al. 2004).

Disaster vulnerability is not spread equally, and those most vulnerable are often those states and communities most closely tied to the natural world that both sustains livelihoods and produces natural hazards. Climate change increases the frequency and intensity of extreme weather events and disrupts system connections between humans and the environment, which leads to disaster formation (Hilhorst and Bankoff 2013). Climate-related disasters most readily impact rural livelihoods, destroying natural resources and damaging small-scale natural resource dependent communities (SSNRD) more than urban structures (Flint and Luloff 2005). Small island developing states (SIDS) stand out with their small size, a large coastline with a small interior, histories of geopolitical subjugation, and heavy reliance on spatially limited natural resources (Pelling and Uitto 2001). With little economic diversification and the aforementioned attributes, SIDS frequently experience climate-related hazards as full-fledged disasters (Pelling and Uitto 2001, Julca and Paddison 2010). Furthering concern for disaster disparity in rural Haiti and similar combinations of SIDS/SSNRD, extreme weather events have increased in frequency and intensity steadily since the 1970s, further accelerating since 2000 (Julca and Paddison 2010).

With this increasing frequency of extreme weather event climatic disasters comes the rising probability of compound disasters. In compound disasters, two or more disasters occur in quick succession, causing more damage than the summation of both disasters occurring in isolation (Eisner 2014, Cutter 2018). Along with multiplying the damage, compound disasters do not allow adequate time for communities to respond and recover from one event before the second event occurs (Eisner 2014). For example, the rural town of Camp Perrin experienced a direct strike from Hurricane Matthew in 2016, resulting in massive tree loss, home destruction, crop loss, and deceased livestock (Delva 2016, Kijewski-Correa et al. 2018). Before households could recover to a point where they could adapt, a months-long drought commenced, leaving households with limited opportunities to recover. Compound disasters increase disaster vulnerability by reducing the time between events, prohibiting the needed replenishment of natural resources for SSNRD to respond in an adaptive manner.

Vulnerability and adaptive capacity

The concepts of vulnerability and adaptive capacity work in conjunction to explain varied experience of disaster events and the production of different abilities to respond to disasters in a manner desirable to the exposed household. Vulnerability depends on exposure, or the likelihood to experience a natural hazard, and sensitivity to the influence of said hazard (Smit and Wandel 2006). Going back to the example of earthquakes in Chile and Haiti in 2010, both states exist on fault lines and have high exposure to earthquakes. Yet, differences in population density and applied building codes led to different levels of sensitivity and vastly different outcomes in terms of property damage and loss of life (Oliver-Smith 2012).

Adaptive capacity refers more to post-disaster response, mitigating the impact of exposure and sensitivity by producing a suite of available options through which a household can adapt to the changes incurred by the disaster (Engle 2011). From this suite of available options, also called a "choice portfolio," households perceive the available connections between nature-provided ecosystems services and socially determined livelihood options and enact this connection to produce a strategy that adapts to the change (King et al. 2019). Disasters destroy natural resources and social capital, constraining the choice portfolio and reducing adaptive capacity. To understand the interaction of adaptive capacity and disasters, it is important to break down adaptive capacity into its generic and specific forms. Generic adaptive capacity increases the ability to respond to all forms of disturbance. Examples include general health and stored capital. Specific adaptive capacity increases the ability of a household to respond to a specific type of disturbance, and it may simultaneously reduce adaptive capacity to another type of disturbance (Eakin et al. 2014). An example is roof cover in Haiti. Those with concrete roofs have a high specific adaptive capacity to hurricanes, rarely losing their roof to the strongest storms. Yet, tin roofs provide a much higher specific adaptive capacity to earthquakes, since they are less likely to cause damage to life and livelihood and they are more easily repaired. This example shows the complexity of adaptive capacity and how finding the appropriate strategy for building becomes more complex for households with more exposure to different disasters and disaster types.

Feedbacks in social-ecological systems

Exploring feedbacks in social-ecological systems provides an avenue for increased understanding of processes that impact disaster vulnerability and household adaptive strategies. Social-ecological systems are complex adaptive systems with connections and processes occurring between humans and the environment, breaking down the nonexistent barrier between them (Berkes et al. 2008). In this systems view, feedback loops form as people and nature respond to the actions of one another (Liu et al. 2007). Natural resource use and other human action produce feedback loops that either work to stabilize or change a system (Chapin et al. 2009). Through analysis of feedback, the underlying causes of a disturbance and the effectiveness of adaptation to a disturbance become more apparent (Suding and Hobbs 2009). Actors can respond through adaptive strategies (actions that increase or maintain long-term well-being) or coping strategies (actions that provide short-term survival but decrease long-term well-being) (Lemos et al. 2013).

Depending on the degree of connection with the environment, different cultures and communities have different levels of sensitivity to feedback between humans and the environment. Changes to natural resources and ecosystem services, as occurs in climate-related disasters, influence the ability to respond effectively in natural resource-dependent communities (Brondizio and Moran 2008). For small-scale natural resource-dependent communities, households depend directly on the environment. In these communities, climate change and an increased frequency of related disasters alters the connections between humans and the environment through lost natural resources, increasing uncertainty, and reduction in available livelihood strategies (Pelling Uitto 2001, Thomas and Twyman 2005).

Similarly, small island developing states often rely heavily on the environment. They have limited economic diversity and limited space to flee environmental change and disturbance, making them both more aware and more vulnerable to climate-related disasters (Julca and Paddison 2010). Studying in Camp Perrin, Haiti, a small-scale natural resource-dependent community in a small island developing state, provides an ideal setting to examine how climate-related disasters impact natural resource dependence and influence the future of rural livelihoods in the face of climate change.

1.5 Mixed methods approach

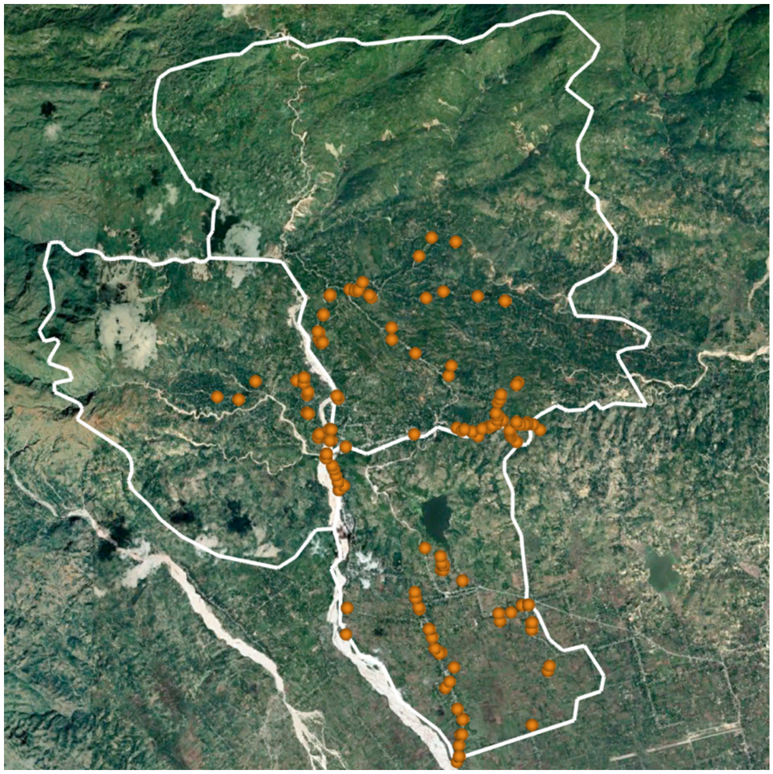

Figure 1.3 Study site with strategically random sampled *lakou* for survey implementation. Derived from Google Earth with points added from aerial image analysis.

My research combines preliminary research in 2016 and a year of fieldwork in 2018-2019, both of which I conducted in Camp Perrin, Haiti. In between the two research periods, a compound disaster struck the town. Hurricane Matthew brought devastation to Camp Perrin, and as its rains ceased, a months-long drought commenced. From this timing, my research permits a rare before and after analysis of disaster impact on households. A mixed method approach to studying vulnerability and adaptation is effective when qualitative research is first conducted to determine variables/indicators and potential relationships between them and adaptation before measuring quantitatively (Cabell and Oelofse 2012, Barret and Constas 2014). This is best accomplished through looking at different time periods, before, during, and after a disturbance, and analyzing responses of different subgroups within the same population (Engle 2011). To understand the factors and processes that influence disaster experience and associated natural resource use, I conducted focus groups, surveys, interviews, and participant observation. To complement and contextualize this data, I conducted aerial image analysis and geospatial analysis. Lastly, I integrated elements learned from all these methods to produce a spatially explicit agent-based model that uses empirical data to test changing resource use and the influence of different adaptive strategies in various disaster scenarios.

I used aerial imagery to identify all *lakou* household units visible in Camp Perrin, shown in Figure 1.3. The outcome produced GIS points for the more than 10,000 *lakou* across Camp Perrin. From this, I generated a stratified random sample, randomly selecting 50 *lakou* household units from households in the mountains and 50 *lakou* household units from households in the plains, predicting from 2016 research and preliminary analysis that these subpopulations experience disasters differently and adapt to disasters in distinctly different ways. From 2018-2019 survey analysis, the variable correlating to more statistically different disaster experiences and adaptive strategies was whether or not households have access to irrigation. Fortunately, this delineation aligns closely with the hypothesized sampling subpopulations. The complicating difference comes from those households on the cusp of "mountain" and "plains."

My final data analysis looked more closely at the influence of whether the household has access to irrigation (IRG) or does the household rely solely on rainfall (RAIN). IRG households have more desirable land (less slope, better soil, closer to the *lakou*), and RAIN households have less desirable land (more severe slope, less productive soil, farmland far from the *lakou*). These differences correspond with different disaster experiences and different adaptive strategies following disasters. RAIN households were much more likely to engage in high-intensity resource pooling for long periods of time and less reliance on remittances from abroad. IRG households were much more likely to resort to cash economy-based solutions to disaster livelihood disturbances, such as reliance on bank loans and foreign-based remittances. IRG households pooled fewer resources following the compound disaster of 2016 and more quickly returned to strategies of independent capital production and capital accumulation to defend against future disturbances. RAIN households instead invested in higher connection with similar households and sharing of resources and strategies, with a longer period before performing livelihood operations independently. The difference between the two subpopulations separates different disaster experiences and disaster responses. This provides an ideal means to analyze various strategies and initial variables that may produce alternative outcomes and explain what otherwise may be attributed to simplifications of "The Naïve Local" and the "The Unfortunate Poor."

Before conducting surveys with the 100 strategic randomly sampled households, I conducted four focus groups in the mountains and four focus groups in the plains. These focus groups served to better understand the lived experience of the compound disaster, identify locally selected variables that produce different levels of vulnerability to hurricanes and drought, and identify adaptive strategies used in the community that produced lasting well-being or produced long-term damage at the expense of short-term survival.

The findings of focus groups led directly to the development of an initial survey instrument. I tested this survey with 20 volunteers to improve the clarity of questions, reduce redundancy, and improve the flow of the survey conversation. After making adjustments, a research assistant and I conducted 100 survey sessions designed to include a more formal survey and a less formal interview, should the participants agree to share more about their experience with the disaster. In doing so, we built trust and followed local customs that encourage more extended discussion of hardships instead of quick and impersonal data mining. When connections between the variables did not become apparent through the surveys, we conducted semi-structured interviews with local experts on various subjects (forestry, agriculture, etc.) and those with specific experiences during the disasters, such as those that ran emergency shelters from their homes.

After qualitative and quantitative analysis, I produced a spatially explicit agent-based model from the findings. I selected from those variables with significant correlation to self-reported disaster experience and observable destructions measures, such as partially absent roofs, to integrate into the model formation. To better understand the effect of natural resource use and different adaptive strategies on vulnerability and speed of recovery, I ran five scenarios (baseline, hurricane, mild drought, severe drought, and compound disaster (hurricane followed by drought)). The design of this mixed methods approach allows each method to feed off the previous and inform the next portion, working together to explain the lived experience, disaster vulnerability, adaptive strategies, and thoughts for the future of each household and their wider subpopulations.

1.6 Dissertation structure

Three chapters form the body of this dissertation. Along with addressing the problems and answering the questions posed in this introduction, each of these chapters likewise stands alone as a complete manuscript. In the first body chapter, Chapter 2, I use an integrative approach to explore the connection between theory from medical science on repeat brain trauma and disasters studies theory on complex and compound disasters. Applying qualitative research and descriptive survey statistics to the above theoretical realms produces a framework for the social-ecological systems disease of Second Impact Syndrome. This framework problematizes "The Naïve Local" false narrative by demonstrating the effect of repeat hazards on natural resource use. It likewise challenges "The Unfortunate Poor" narrative in showing long-term system breakdown from repeat disasters that does not match the temporal isolation of disasters in this false narrative.

In Chapter 3, I focus on quantitative analysis of what variables correspond with the lived experience of the disasters. To do so, I compare survey responses and geospatial data with self-identified comparisons of how a respondent's household fared compared to other households during a) the hurricane and b) the drought as well as how prepared they feel for future hurricanes and droughts. The unexpected result that those with access to irrigation self-reported that they fared significantly worse than other households leads to insight into how tested adaptive strategies fail in specific conditions. Households experience constrained adaptation options through reduced natural and social capital. This challenges the dual false narratives by demonstrating unequal disaster influence across the same community and revealing how hazards can become disasters not through change but through the constraint of natural resources.

In Chapter 4, I build from the findings of Chapter 2 and Chapter 3 to produce a spatially explicit agent-based model on household disaster experience and livelihood adaptations. I input empirical data and run different disaster scenarios to see how different households and subpopulations fare under different disaster types and frequencies. The model complicates the dual false narratives by revealing how internal processes (resource pooling, investment in the cash economy, etc.) and external process like climatic disasters and their increasing frequency impact the ability of households to use natural resources to respond to disturbances.

In Chapter 5, I conclude the dissertation with the application of lessons from previous chapters to break down the problem of dual false narratives. I do so by answering the guiding research questions on 1) processes producing disasters in small island developing states and small-scale natural resource dependent communities and 2) the constraints and outcomes of adaptation to climate-related disasters with respect to rural livelihood. Intermixed in these conclusions, I provide recommendations for scholars and outsiders working in Haiti and similar nations to break down problematic narratives and revisualize the lives of small-scale resource users.

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CHAPTER 2

SECOND IMPACT SYNDROME: THE INFLUENCE OF CLIMATE CHANGE AND INCREASED DISASTER FREQUENCY ON LIVELIHOODS AND ADAPTIVE CAPACITY IN RURAL HAITI[1]

[1] McGreevy J and Adrien E. Submitted to *International Journal of Disaster Risk Reduction.*

Abstract

The frequency of compound disasters increases each decade, inflicting devastating and sometimes permanent damage on communities. Compound disaster research has traditionally focused on industrialized nations, where a response-induced disturbance or failure of critical infrastructure follows a natural hazard. Such research often promotes technocratic solutions pertinent to industrialized nations but less relevant in other systems. Compound climate-related events receive less scholarly attention. We know little about their influence on resource use and adaptive strategies, especially in communities that rely more on natural resources than critical infrastructure. We address this problem with a framework founded on a decade of collaboration with rural Haitian communities and a year of fieldwork after Hurricane Matthew. Our Second Impact Syndrome (SIS) framework traces the impacts of compound climate-related disasters on adaptive capacity and livelihoods. We present symptoms and processes that parallel current understanding of repeat brain trauma from literature on SIS in neurological systems. In disasters, SIS ultimately alters human relationships with the landscape, produces uncertainty of what constitutes an adaptive strategy, and increases dependence on outside intervention. This framework fills scholarly needs surrounding disasters, adaptive capacity, livelihoods, and community transformation at the hands of climate change. Likewise, SIS is readily applicable for disaster risk reduction through the identification of symptoms to address and potential solutions at the human-environmental interface. Other practical applications include forming a common platform upon which local communities and outside entities can better understand and discuss compound disasters.

Keywords: compound disasters; cascading risk; climate change; Second Impact Syndrome; natural resources; adaptive capacity

2.1 Introduction

Climate change has increased the frequency and intensity of extreme weather events in recent decades, and this trend will continue (Field et al. 2012, IPCC 2015, Nam et al. 2015). Multiple extreme weather events now occur in quick succession in one location, forming compound disasters that make disaster risk reduction problematic. Reducing this risk in the future requires a better understanding of the mechanisms that alter the ability of households to respond to disaster-induced changes. Increasing prevalence of compound disasters over the past twenty years has prompted new research on complexity and system interaction in the disaster lifecycle and beyond. Much of this work focuses on a social-ecological disaster followed by a technological or infrastructural disaster (such as an earthquake followed by soil liquidation and levee failure) (Yasuhara et al. 2012, Liu and Huang 2014). Compound climate-related disasters receive less attention, and recent works call for expanding our scope of compound disaster inquiry (Felsenstein et al. 2020).

Disasters are complex, promoting a systems approach. Studying them as systems embraces this complexity to answer questions about the mechanisms increasing risk (Simonovic 2010). A systems approach focuses on the interconnections between components that influence one another. Actions done by or done to one component produce feedback loops that either reinforce the system or alter it (Liu et al. 2007, Suding and Hobbs 2009). For example, the loss of a resource during a disaster (e.g., trees, livestock, crops, and soil) increases future resource loss when households sell remaining resources to rebuild and sustain themselves. Disasters also produce uncertainty and cascading risk that radiates out through the built environment and social connections of a system to reaches not immediately noticeable as connected to the disaster (Alexander 2018). Recurring droughts, for example, can alter family ties in small-scale farming communities as individuals increasingly perceive the diminishing viability of rural livelihoods, leading to urban migration or exodus to other countries.

Still, the mechanisms by which compound disasters influence the relationship between agrarian households and the natural resources they depend on is not well understood. Understanding this connection is critical for reducing disaster risk in lesser studied natural resource-dependent communities, where an absence of much built environment results in little separation between the human and natural world (Flint and Luloff 2005). Apart from outside disturbances like disasters, the health of human-environment connections in these systems depends on livelihood strategies (the approaches through which households obtain income and/or subsidence) and adaptive capacity (the ability of households to adapt in the face of disturbance) (King et al. 2019). Situated at the front lines where Haiti is battling climate change and its symptoms, we ask: "How do compound disasters influence adaptive capacity, livelihood strategies, and wider system change in natural resource-dependent communities?"

To answer this question, we join other scholars studying human-environmental interaction by building off of approaches to systems in psychology and medical literature (Norris et al. 2008, Kirmayer et al. 2009, Brown and Westaway 2011). We apply the concept of Second Impact Syndrome (SIS) to compound disaster studies to better understand system transformation and the lived experience of people at risk in Camp Perrin, Haiti. In the neurological version of this syndrome, individuals exposed to a catastrophic first impact (concussion) rapidly deteriorate following a smaller collision event that generally would not have produced such severe damage. Viewing compound disaster through the SIS lens increases understanding of change in novel ways not possible with other approaches. Our data reveals patterns in which recurrent blows to a social-ecological system produce uncertainty, system change, and reduced ability to adapt. The key advantage of the SIS systems approach in studying disaster risk reduction is that it can explain system change in natural resource-dependent communities in a non-random way. Instead, it reveals an observable and explainable system of feedback between households and natural resources.

We analyze adaptation and system change in an agrarian community in southern Haiti following a compound disaster (Hurricane Matthew and the months-long drought that immediately followed). Our paper reveals a fundamental breakdown in the connection between humans and the environment caused by the compound disaster. Households lost the natural resources they relied on for their livelihoods, reducing adaptive capacity and prompting uncertainty, disconnect with the environment, and heightened risk of future disasters.

In a compound disaster, the sum total of damage is higher than if either disaster were to occur in a one-off, singular disaster event (Kawata 2011, Eisner 2014), but the causation of this phenomenon remains complex and difficult to visualize. Application of SIS to compound disasters provides a traceable framework through which to better understand what produces this disproportionate level of damage. This framework is particularly useful when looking at a population that has experienced and responded adaptively to previous disasters of the same type as those that make up the compound disaster. For example, in Camp Perrin, Haiti, people encounter hurricanes and droughts on a semi-frequent basis. Yet, they long remained an atypical town in Haiti's Southern Peninsula by maintaining a viable rural livelihood with limited outside support. It was not until these disaster types (hurricane followed by drought) occurred in quick succession that this level of damage and this duration of livelihood disruption permeated the community. Through comparison to multiple concussions occurring in quick succession, the SIS framework provides processes and symptoms of this social-ecological disease inflicted on small-scale natural resource-dependent populations.

The study site in rural Haiti provides an urgent example of compound disasters producing uncertainty and system change. Outside observers often set Haiti aside as an enigma, as “the poorest country in the Western Hemisphere” (Sepinwall 2012). This limits the perceived applicability of Haiti’s reoccurring problems to problems faced in other countries. Our decade of collaboration with these rural communities reiterates what other scholars are beginning to collectively understand: understanding Haiti is not exceptional (Benedicty-Kokken et al. 2016, Schuller 2016). Instead, Haiti is best suited to answer our research question for two reasons: First, Haiti’s natural resource-dependent communities have a sensitivity to climate-related disturbances. Little infrastructure exists to mask the underlying connections between humans and the environment and the feedback between them. Second, Haiti reveals the changes of the Anthropocene before wealthier nations perceive them (Villanueva 2021). Haiti, the world’s unwitting canary in the coal mine, has something to teach us about system change in disasters. If the wider world is to adapt to this mounting change, it must listen.

2.2 Background

2.2.1 Compound disasters, livelihood strategies, and adaptive capacity

Increasing frequency of extreme weather events reduces the period of time in which communities and households can respond, adapt, and rebuild, as seen in Figure 2.1. The compound disaster that forms simultaneously reduces the opportunity for ecological portions of the system to replenish, regrow, and reproduce ecosystem services. Understanding the impact of compound disasters on a system requires understanding how households adapt and pursue livelihood strategies.

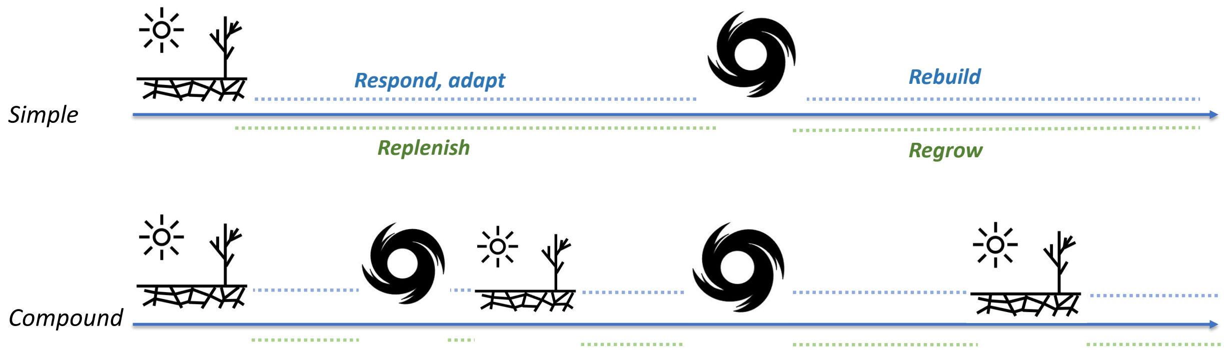

Figure 2.1 Simple vs. compound disaster timeline. Frequent extreme weather events give less time for humans to respond, adapt, and rebuild and for ecosystem services to recover (replenish, regrowth, etc.)

Traditionally, research on this subject focuses on disasters involving the built environment (Alexander 2018, Pescaroli and Alexander 2018). Complex events like the COVID pandemic question this narrow focus (Felsenstein et al. 2020). Still, compound social-ecological and climate-related disasters remain overlooked for a few reasons:

1) They appear "natural," and people label them "natural disasters" (Benjamin Wisner et al. 2004).

2) One or more of the disaster events may not receive recognition as a "disaster." The timescale for slow-forming disasters contradicts popular notions of what constitutes a disaster (Oliver-Smith 1999, Collins et al. 2011, Hilhorst and Bankoff 2013).

3) They disproportionately harm natural resource-dependent communities, an often overlooked and misrepresented population (Flint and Luloff 2005).

Separate climate events may appear unrelated, but they link at the intersection of hazard, exposure, and vulnerability (Liu and Huang 2014). We advance this understanding through analysis of adaptive capacity and livelihood strategies, which influence how compound disasters cause system change.

2.2.2 Vulnerability and feedbacks in disasters and human-environmental relations

System feedbacks dispel overly simplistic disaster models and help explain vulnerability formation. A common and dangerous mental model for aid groups to work under is that places like Haiti are unfortunate to have "natural" disasters repeatedly hit their country. This mindset does not promote inspection of social factors that transform these hazards into disasters. Instead, social-ecological systems (SES) are complex, adaptive systems with interconnected processes that break through the artificial barrier between human and non-human (Berkes 2006, Berkes et al. 2006). In SES, "people and nature interact reciprocally and form complex feedback loops" (Liu et al. 2007). Human action (notably natural resource use) produces either amplifying or stabilizing feedback loops that destabilize or stabilize system processes (Chapin et al. 2009). For example, hurricanes destroy homes, increasing the need for people to cut down trees to rebuild. With fewer trees as wind barriers and landslide protection, households and communities experience increased vulnerability to hurricanes in the future. Analysis of these feedback loops helps to inform underlying causes of system instability and recovery of a system after disturbances like disasters (Suding and Hobbs 2009).

The timing and strength of feedbacks between people and nature influences vulnerability and adaptive capacity (Oliver-Smith 2013, Suding and Hobbs 2009). Sensitivity to feedbacks increases ability of an actor to sense and respond to changes. Actors then choose from the resulting ecosystem services and livelihood strategies available to them (King et al. 2019). Livelihood strategies are either adaptive (increasing or maintaining long-term well-being) or coping (short-term recovery at the expense of long-term well-being) (Lemos et al. 2013). In natural resource-dependent communities, adaptive and coping strategies often involve natural resource use. Compound disasters modify the ability to select adaptive strategies for natural resource use with repeated blows to the system.

2.2.3 Second Impact Syndrome and its application to social-ecological disasters

Theories on repetitive impacts on the human central nervous system provide frameworks to view the increase in repetitive disturbances on social-ecological systems. Medical literature shows a rise in research on Chronic Traumatic Encephalopathy (CTE), a brain disease linked to multiple concussions. High profile research on professional football players has helped explain neurological system change. Long forming physical processes produce reduced cognitive function, increased confusion, and self-destructive behaviors like substance abuse and self-harm (Omalu et al. 2010, Gavett et al. 2011).

However, CTE alone cannot explain sudden deaths from small concussions or how exposed individuals vary widely in their ability to maintain normalcy in their lives. With Second Impact Syndrome (SIS), a violent impact produces moderate effects and a second, smaller impact produces catastrophic results (Wetjen et al. 2010). Debate continues about the mechanisms, but a second blow to any part of the system, even a limb, can induce brain swelling, permanent damage to mental function, and death (Engelhardt et al. 2020). Three mechanism prompt brain mortality in repeat trauma (Engelhardt et al. 2020), and they hold parallels in disaster studies [shown in brackets]:

1) An impact exacerbates preexisting conditions [disasters expose underlying issues already present in the system (Oliver-Smith 1999)]

2) An extreme impact produces irreparable fractures and hemorrhaging [catastrophic disasters push systems past a threshold into compound disasters and catastrophe that is difficult to adapt to (Engle 2011, Field et al. 2012, Eisner 2014); high magnitude

cascading disasters reach an escalation point with longer lasting and more devastating system damage than anticipated (Alexander 2018)]

3) A second impact aggravates the already damaged nervous system [compound disasters produce more damage than the sum of effects if the disasters occurred separately (Eisner 2014)]

The concept of reserve explains why similar patients experience different symptoms or no symptoms after the same amount of physical damage to the brain (Stern 2002, Alosco et al. 2017). Its two forms are cognitive reserve, the brain's active efforts to cope or adapt, and brain reserve, the more passive general well-being (Stern 2002). Reserve reduces the impact of traumatic brain injury on the nervous system by providing a buffer against damage. It also facilitates adaptation by rerouting information through new channels (Stern 2002, Alosco et al. 2017).

Similarly, households exposed to disasters face different forms of adaptive capacity and different routes of risk reduction and recovery. Specific adaptive capacity (like cognitive reserve) increases the ability to adapt to a specific type of impact. Generic adaptive capacity (like brain reserve) increases the general ability to respond favorably to all types of disturbance (Eakin et al. 2014). Households use buffers like excess natural resources to cope with loss and to adapt their livelihood strategies (Wisner et al. 2003, Lambin and Meyfroidt 2010). Different levels of adaptive capacity and different responses to disturbance ultimately produce different outcomes.

Phenomena of Chronic Traumatic Encephalopathy, Second Impact Syndrome, and reserve demonstrate similarities between the fields of neuroscience and disaster risk science that require testing for usefulness. Our study presents a framework of analogous overlap between the two realms of research. It tests the usefulness of this framework in understanding climate change's growing risk of multiple disasters occurring in quick succession.

The double impact of Hurricane Matthew immediately followed by a drought provides a case study through which to examine these phenomena. Hurricane Matthew crossed directly over the study site of Camp Perrin as a Category 4 storm in October 2016. The resulting damage destroyed roads and prevented the arrival of outsider assistance. Unlike most media outlets and aid groups, Camp Perrin residents discuss an often overlooked second disaster: once the hurricane rains ceased, a months-long drought followed. The compound disaster left little time for typical response, adaptation, rebuilding, and replenishment of ecosystem services. Instead, the second impact after an initially devastating disaster destroyed livelihoods, decreased adaptive capacity, and led to wider system change that points to a Second Impact Syndrome phenomenon occurring on a social-ecological system scale.

2.3 Methods

This study provides a rare glimpse of life before and after a compound disaster, combining data from preliminary fieldwork in early 2016 and year-long fieldwork from 2018 to 2019. In October 2016, Hurricane Matthew devastated the study site of Camp Perrin, Haiti. A months-long drought immediately followed. We used focus groups, surveys, interviews, and participant observation to better understand the lived experience and system dynamics of this compound disaster. The methods selected and specific approaches in each method come from a decade of collaboration with local partners in rural Haiti. These methods provide a community- and household-level approach to analyze changing livelihoods and adaptive capacities in natural resource-dependent communities.

Camp Perrin lies on Haiti's southern arm in the mountains forming the Rivye Sud Basin (see Figure 2.2). Farmers primarily rely on rain, and few have access to irrigation. This lack of irrigation partly comes from the region's historically high rainfall when compared with other regions of the country. Yet, rainfall variability and extreme weather events have increased with climate change, including a period of severe drought from 2014 to 2015. Interviews in the summer of 2016 reveal locally identified climate change effects, such as increasing cycles of unpredictable rainfall and drought interspersed with hurricanes.

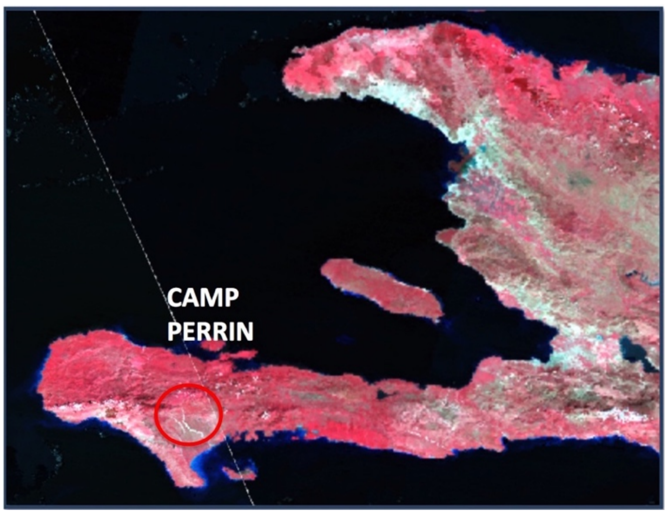

Figure 2.2 Study site, shown in false color for vegetation (red). Shown during January 2016, during a time of limited crop growth, to highlight tree cover. MODIS satellite sensor.

We randomly sampled traditional housing units (*lakou*) across two subpopulations to select 100 study participants. We selected the subpopulations (mountains and plains) based on preliminary satellite imagery that showed patterns of vegetation change before and after the compound disaster. This suggested different lived experiences with regards to natural resource availability. Flexibility of land tenure in traditional peasant societies of Haiti (Murray 1980) and lack of street addresses made it difficult to identify *jaden* (farmland) associated with all 100 study participants. We chose instead to identify *lakou,* traditional housing units with a few homes sharing a common fence or land boundary, house garden (*jaden lakou*), and smaller structures. Through satellite image analysis, we identified more than 10,000 *lakou* units for sampling across the two subpopulations.

We conducted eight focus groups of five to ten participants at public spaces and yards of participants. Core foci of these focus groups included the lived experience of participants through the compound disaster, adaptive strategies used, and locally identified variables indicative of heightened vulnerability to either hurricane or drought. The last focus led to a discussion of specific vs. generic adaptive capacity and adaptive strategies.

Adaptive strategies can either help or hinder future disaster response and future overall well-being (Adger 2001, Allison and Hobbs 2004, Maru et al. 2014, Wise et al. 2014). Participants collectively formed a list of strategies used in the two disaster events. We then collectively classified the different resource use decisions as forms of coping (help ameliorate the immediate need but produce insecurity or vulnerability in the future) or adapting (produce long-term security and reduced vulnerability in the future). These findings add to understanding of natural resource use decision-making after disasters, and they assisted in the formation of survey questions.

Our survey questions evolved from preliminary ethnographic research, focus groups, and an initial test survey with 20 participants. We then conducted 100 survey sessions molded as a joint survey and subsequent discussion. This format steers away from a typical, standalone survey, builds trust, and aligns with local customs. Survey questions highlighted livelihood strategies, household relationship with the landscape, social relationships, and how the compound disaster influenced all such components. For livelihood strategies, we asked about changing options for natural resource use, including farming, animal husbandry, and tree use. For relationship with the landscape, we asked about physical barriers to travel, slope of land, irrigation access, and how these factors influenced their experience with Hurricane Matthew and the following drought. Social relationship questions focused on connections with various actors (neighbors, local family, family abroad, farming groups, lending groups, non-profits, the government), and how such connections changed. Other data obtained includes spatial data (GPS points), researcher observations, and a post-survey mini interview with recorded audio for participants that wanted to continue the discussion.

As needed, we conducted semi-structured interviews in each stage of the process to remain grounded in local lived experience and better hone our findings on the dynamics between compound disasters, livelihood strategies, adaptive capacity, and system transformation.

The multiple components of this mixed methods research required different forms of analysis. For focus groups, we transcribed, translated, and coded responses. For survey data, we conducted descriptive statistical analysis. From other observation and audio data (such as post-survey discussion), we produced extensive notes that we analyzed for emergent themes and ethnographically supported explanations for patterns in survey data.

2.4 Results

In this section, we present the results of our mixed methods research across the timespan on the disaster lifecycle. We begin by laying out the key emergent themes coming from our initial qualitative methods. These results point to categories of system change that provide subsequent section headings in which we place relevant quantitative and other qualitative results. We examine these categories of system change and how their influence on livelihood strategies and adaptive capacity pointed us to apply the Second Impact Syndrome (SIS) framework in the Discussion section.

2.4.1 Emergent themes before and after a compound disaster

Initial ethnographic results from 2016, obtained just a couple of months before Hurricane Matthew, set a rare pre-disaster baseline for conditions in the study site. Across all zones of the community, people expressed pride in Camp Perrin as *yon ti kote apa*, "a little place apart." Popular explanations for this status stem from comparison to neighboring towns and the far-off capital city. Camp Perrin is relatively independent of non-governmental organizations (NGOs) and the Haitian government when compared to other towns. Other differences include a higher standard of living, higher adaptability to disturbances, fewer instances of crime, fewer protests, community-based environmental protection, and an emphasis on sustainable agroforestry practices. Our observations support this, with pre-disaster Camp Perrin standing out from all other towns we have seen or lived in across Haiti over the last decade.

Focus groups in 2018, two years after the compound disaster, reveal sustained changes in Camp Perrin. Table 2.1 highlights key emergent themes at different points in time: 1) pre-disaster, 2) during the compound disaster and its immediate aftermath, and 3) on-going. These emergent themes show an initial period of remarkable collective action followed by a series of system-wide changes: altered relationship with the environment, uncertainty of adaptive strategies, increased dependence on outside actors, and potentially permanent transformation of system dynamics.

Table 2.1 Emergent themes from different temporal points related to compound disaster onset

Pre-disaster (2016)	Disaster/immediate aftermath (2016-2017)	On-going (2018-2019)
High standard of living compared to other communities • Less crime and unrest • More reliable food access • Healthy ecosystem services	Extreme first impact (Hurricane Matthew) • Loss of lives, homes, roads • Loss of cattle, crops, trees, soil	Lasting influence on community • Persistent sense of loss • Reduced ability to respond to drought and future disturbances
High resilience and ability to adapt • Quick response to previous disasters • Farming groups supporting one another	Double shock to adaptive system • Extreme first impact followed by subtle, pressing drought • Collaboration of farmer groups, travelling far to seek help	Shifting livelihood strategies • Coping strategies: loans, cutting trees, selling most livestock • Confusion of adaptive strategy
Pride in local in independence • Little support from NGOs and government • Grassroots organizations	Remarkable community response to initial impact • Hundreds of families staying with neighbors for months • Local collaboration for emergency resource allocation	Increased reliance on outside groups • NGO influx • Relatives and friends abroad • Banks and loans
Community-based environmental protection • Sustainable agroforestry • Relative abundance of trees	Loss of stored natural capital • Fallen trees used for rebuilding • Loss of cattle, crops, trees, soil	Lasting effects on relationship with environment • Less natural capital • less trust in unpredictable rainfall patterns

2.4.2 System change

2.4.2.1 Altered relationship with the environment

Hurricane Matthew devastated household natural resource availability, and depletion of such resources continued through the drought that followed. Of note, 100% of survey participants lost trees on their property. These losses occurred primarily in the area surrounding homes, often leading to trees falling on structures. Concurrently, households lost crops and livestock they relied upon for sustenance and for sale in times of emergency. As seen in Figure 2.3, of the 80 individuals who said they did some type of animal husbandry, 94% lost animals in Hurricane Matthew. As seen in Figure 2.4, of the 86 individuals who said they did some type of farming, 95% lost crops in Hurricane Matthew.

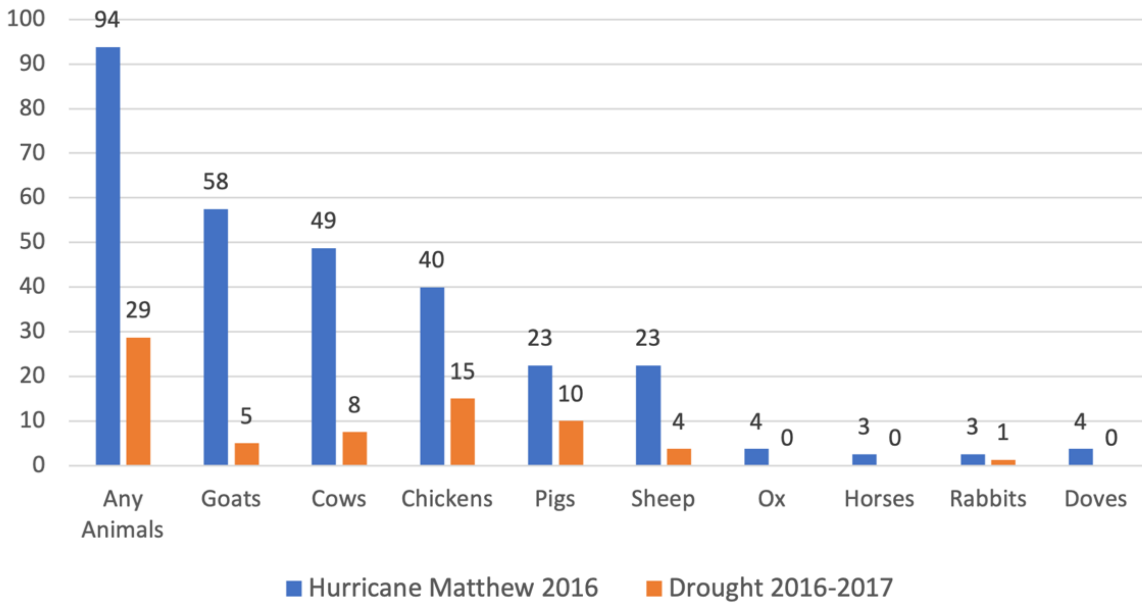

Figure 2.3 Percent of livestock owners losing animals, sorted by animal type and disaster event (n=80).

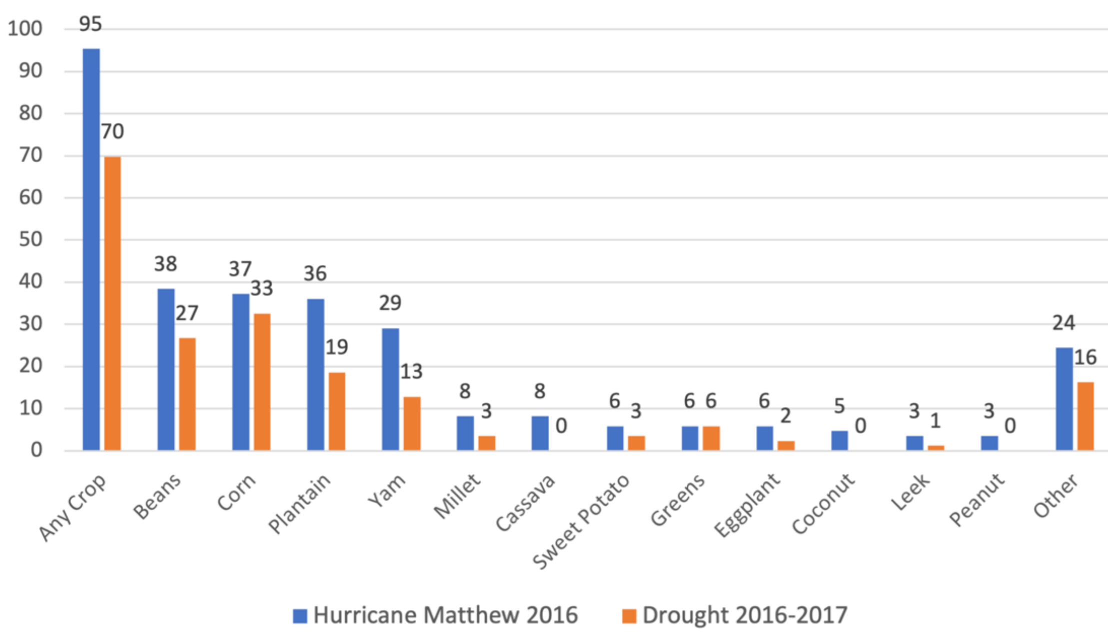

Figure 2.4 Percent of farmers who lost crops, sorted by crop type and disaster event, (n=86)

The second impact of the months-long drought further depleted other forms stored capital in crops and livestock. Despite planting them at reliably productive times, crops failed during the drought. Likewise, households lost livestock to starvation and dehydration during the drought. As seen in Figure 2.3, of the 80 individuals who said they did some type of animal husbandry, 29% lost animals during the drought. As seen in Figure 2.4, of the 86 individuals who said they did some type of farming, 70% lost crops during the drought.

Of those few households that did not wholly lose crops or livestock, many found no other option but to sell their remaining resources to rebuild homes, help support others, and pay for funerals or medical expenses. People pooled much of what remained for survival at spontaneous shelters forming in those homes not destroyed by Hurricane Matthew. The reduced time scale between disasters contributed to the social and ecological disruptions that make compound disasters so devastating: they inhibited the ability of households to respond, adapt, and rebuild and the ability of the ecosystem services to replenish before a second impact occurred.

2.4.2.2 Uncertainty of adaptive strategies

The second impact of an unexpected drought during what normally is a period of recovery produced widespread uncertainty on how to respond. Focus group participants, when asked about Hurricane Matthew, often spoke at length about the drought that followed, indicating that the two events were linked in their lived experience of the events. These participants chose to lead the conversation away from the most catastrophic hurricane in recent memory. Instead, they allocated time to what in most years would be an unfortunate but manageable event. Community members emphasized the influence of this drought on confusion, uncertainty, failure of previously adaptive strategies, lack of climate predictability, and futile pursuit of strategies to reduce future risk.

Focus group participants free listed coping mechanisms, actions participants or those around them used in ways that allowed households to address immediate needs at the expense of future risk and increased vulnerability. Commonly emphasized coping mechanisms include cutting young trees to make poles or charcoal for sale, cutting mature trees to produce boards, selling land, selling livestock, and taking out bank loans. The severity of the impact of these different coping mechanisms varies, some forming only a last resort. Participants lamented that they found no other option but to use natural resources in ways that would produce lasting damage.

The most common point of confusion, anger, anxiety, and fear surrounding this compound disaster was the uncertainty of when to plant crops. Farmers do not feel they can depend on local knowledge passed down through generations. Never before have they seen such extreme presence and immediate absence of rain. Even the most rural farmers, who later admitted to not having heard of global climate change, talked at length about the extreme changes in climate they observed over the last couple of decades culminating in this catastrophe.

Lack of irrigation access exacerbates this concern since 61% of households rely solely on rainfed agriculture. Still, those with irrigation access did not always fare well. One individual noted, "Water is the problem. During the drought, the canals did not even have water. Even the animals could not get water to drink." Another farmer responded to a question of his greatest worry for the future by saying, "I am most worried about having water to farm when even the canals run dry."

Pre-disaster data shows a recent shift in concern over water availability. Three months before this compound disaster, only 10% of participants selected irrigation from a list of 14 possible needs in their community. Moreover, none of the 100 participants in 2016 ranked irrigation as among the most important needs faced locally. Before the compound disaster, local knowledge of rainfall patterns, the presence of shade to retain soil moisture, and the abundance of rain in the region (albeit changing) made rainfed agriculture relatively dependable. While local people have long observed climate change, it was not until the compound disaster that reserve dipped below a point of ability to adapt to these changes.

Untested new strategies, which people rarely or never used, also emerged after the compound disaster. Participants expressed uncertainty or disagreement about how adaptive or maladaptive such strategies would perform. Camp Perrin residents did not commonly take out bank loans in 2016. Since Matthew, 32% of people took out loans. Two years later, more than half of those who have taken out loans had not paid them back.

Loss of reserve during the compound disaster has made it difficult to repay loans and help one another through traditional means. Over 70% of farmers lost crops from the drought's second impact and 29% lost animals. Combined with the 100% of households losing trees during the hurricane's initial impact, sellable resources diminished. In part to pay these loans, 34% sold their remaining livestock and 5% sold the land they relied on. With the loss of animals, crops, and trees, only limited or confusing options for adaptive strategies remained. Dependence on outsiders increased.

2.4.2.3 Increased dependence

We found dramatic shifts in household dependence on people and organizations outside of their community from before to after the compound disaster. Participants in 2016 lauded the local emphasis on sharing, with 99% saying they share with people outside of their household on at least a semi-frequent basis. Most common forms of sharing included food, tools, ideas, and money. Likewise, 93% said they could count on at least one person outside of their household in times of need, and 89% said they could count on at least three people in difficult times. For collective actions, 96% recalled recent communal events such as road cleaning, joint work parties, and local organization initiatives. Of these, 88% found the events effective. While not isolated from the rest of Haiti, the comparatively high values for sharing, networks of help in times of need, and effective community action set Camp Perrin apart from other towns in Haiti's Southern Peninsula

Table 2.2 Job approval and confidence levels of governmental and non-governmental organizations, 2016 survey (n=85).

Does this group do the role that it should?			Do you have confidence in this group?		
	Yes	No		Yes	No
NGOs	22%	78%	NGOs	59%	41%
Local Authorities	10%	90%	Local Authorities	23%	77%
State	9%	91%	State	20%	80%
Average	14%	87%	Average	34%	66%

Pre-disaster opinions of local authorities, the state, and NGOs further this self-reliant narrative, as seen in Table 2.2. While participants expressed relatively high confidence in NGOs, we must note that only 41% of the 85 participants that responded to this set of questions saw NGO presence in the town and only 16% met with an NGO before the disaster. These numbers pale in comparison to the overwhelming presence of NGOs in Haiti, often called "The Republic of NGOs" (Schuller 2007; Schuller and Morales 2012). This relationship and other relationships of dependence changed after the compound disaster.

Data from the first disaster impact (Hurricane Matthew) showed a continuation of local self-sufficiency and sharing of houses, food, and supplies. During 2018 focus groups and sample surveys, participants expressed a shift in dependence after the drought. In response, we explicitly looked at areas of increased dependence in our 2018-2019 survey.

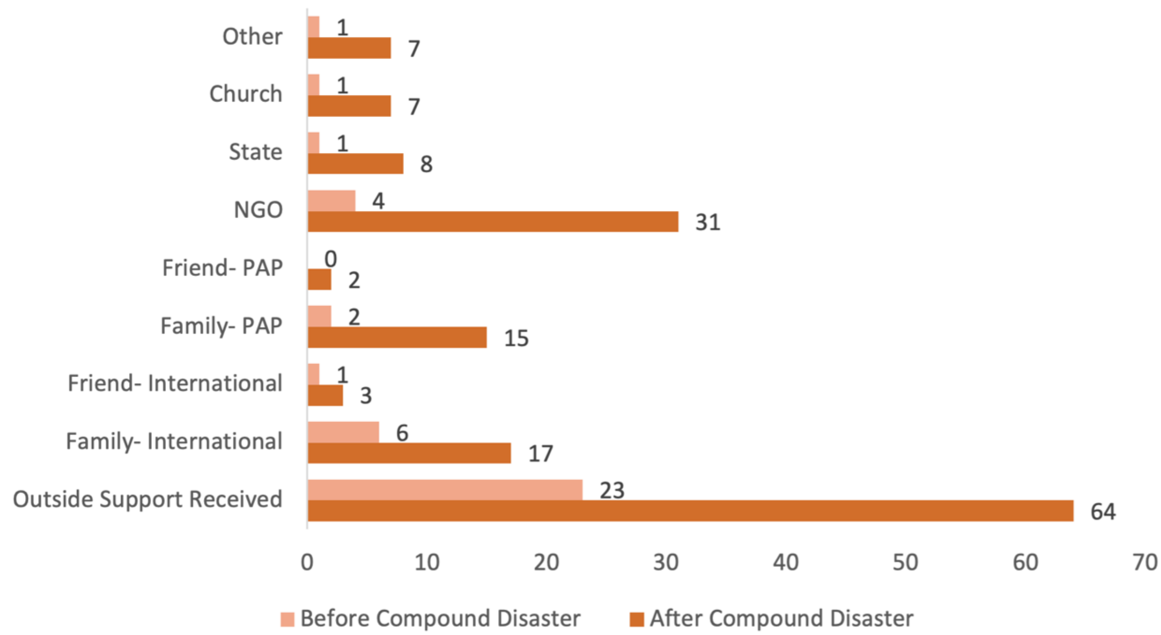

Figure 2.5 Percent of surveyed who received outside support from various sources, before and after compound disaster (Hurricane Matthew and following drought) (n=83).

As seen in Figure 2.5, overall reliance on outside support increased in Camp Perrin, shifting from 23% before the compound disaster to 64% afterward. The largest shift occurred with respect to NGOs, family in the capital city of Port-au-Prince (PAP), and family living abroad. Other towns of Haiti's Southern Peninsula typically rely on these sources of dependence. Interviews and observations explain this shift arising from a combination of increased coping strategies, loss of most or all livestock, complete loss of two rounds of crops (first in Hurricane Matthew and second in the drought), inability to pay off loans, and lack of natural resources. For the first time, outside entities began seeing Camp Perrin as a place of need when compared to other parts of the country. Increased dependence and other system changes remained present two years after experiencing Second Impact Syndrome. The reliability of an agrarian lifestyle has come into question, with many joining the largely undesired urban migration or beginning to consider it as their last option.

2.5 Discussion

2.5.1 Second Impact Syndrome: a social-ecological disease

When multiple disasters occur in one location in quick succession, here called compound disasters, the influence of these events surpasses the sum of these events occurring individually. Viewing such events individually ignores compounding interactions and can even hide a second, smaller disaster from the public eye. Compound disasters' heightened influence comes from a second impact arriving before a household has recovered from the first impact, producing Second Impact Syndrome (SIS). Compound disasters transform a system's typical progression of recovery and adaptation, with adaptive capacity and ecosystem services not replenishing in time for the second event. Even those households with much experience adapting to either disaster individually (e.g., hurricane or drought) cannot rely on their typical adaptive strategies.

Natural resource-dependent households exposed to SIS seek new forms of resource input (such as receiving aid from NGOs or family in the diaspora) and new forms of collaboration (such as spontaneous community shelters and community pooling of resources). These strategies support initial survival and new or strengthened networks of support, but the second impact prevents recovery. Initial loss of relied upon natural resources (e.g., storm-felled trees, crop loss, riverbank erosion) leads to resource user liquidation (e.g., selling animals, cutting trees, selling land). Ultimately, this process depletes resource reserve and undermines the adaptive capacity that such resources support.

SIS formation and its symptoms in social-ecological systems mirror SIS in the better understood neurological system. As seen in Figure 2.6, repeat brain trauma reduces the ability of the system to adapt to disturbances that can be commonly managed in isolation. This results in relationship changes, loss of cognitive function, maladaptive actions, reduced self-sufficiency, and possible system change beyond repair (Gavett et al. 2011, Stern et al. 2011). Repeat social-ecological disturbance follows an analogous pathway. Observed results on the system include altered human-ecological relationship, confusion over adaptive strategies, detrimental coping mechanisms, reliance on outside actors, and possible system transformation or collapse.

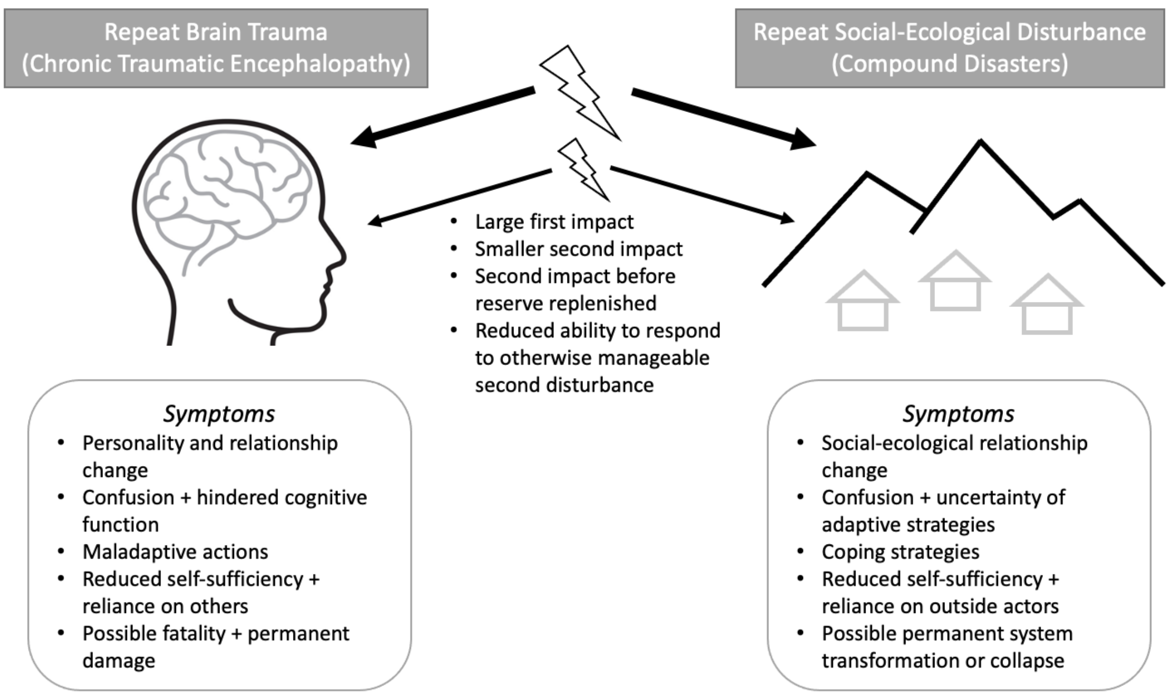

Figure 2.6 Mechanisms and symptoms of repeat brain trauma and repeat social-ecological disturbance

Further complicating the situation, climate change increases compound disaster frequency. Repeat stress on the system pushes needed reserve below a transformative threshold. Multiple concussions reduce self-reliance and the ability of a brain to successfully adapt by rerouting neural pathways. Compound disasters limit adaptive options to choose from and alter the landscape upon which households depend. Ultimately, detrimental coping mechanisms to meet urgent needs produce a net heightened vulnerability to coming disturbance. This sets the conditions for more destructive future disasters. As a result, livelihood systems in communities like the study site have transformed from dependence on sustainable agroforestry to dependence on outside entities. We visualize the SIS process producing this transformation in Figure 2.7.

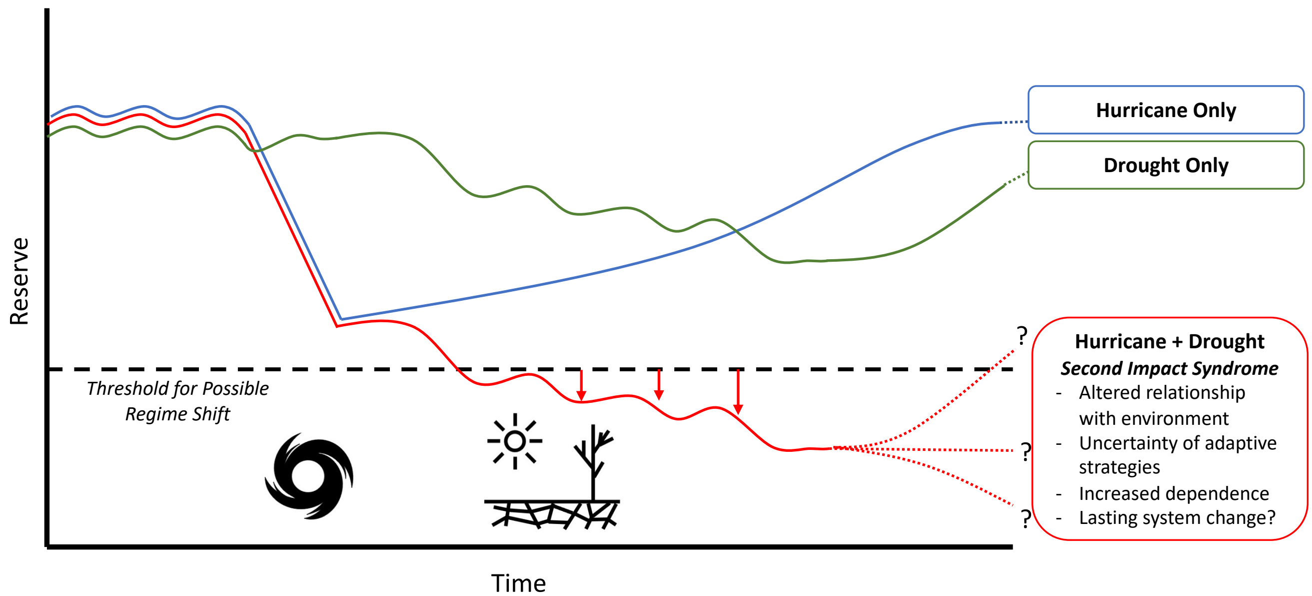

Figure 2.7 Comparative effects of simple and compound disasters on reserve and potential regime shifts through Second Impact Syndrome

Second Impact Syndrome may produce lasting system change. Our research, with data collected before and after the event, has witnessed this phenomenon of transformation. In it, natural resource-dependent communities lose livelihood viability and begin considering the largely undesired urban migration prevalent in other rural communities. In a way, this migration is a form of cascading risk permeating throughout the country. From the 1980s to the 2010 earthquake, population in the capital city of Port-au-Prince quadrupled from 700,000 to more than 3 million (Dupuy 2012). This rapid influx of population strained the city's infrastructure and contributed to unprecedented loss of life during the earthquake (Dupuy 2012, Schuller and Morales 2012). Of all homes lost, 86% were built since 1990 (Etienne 2012, Button and Schuller 2016). Such urbanization comes largely at the hands of rural livelihood destruction. This influence on disaster vulnerability reveals how SIS may then have cascading effects on other semi-connected systems in an increasingly connected world.

2.5.2 Long-term implications

Repeat disasters over a lifetime, even when not immediately close in time scale, produce lasting symptoms. Slower forming types of Chronic Traumatic Encephalopathy produce symptoms that seem to come about spontaneously. Often, patients and caregivers overlook the link to repeat brain trauma of the past. This idea reflects the experience of disasters in historically vulnerable countries like Haiti. Repeat, non-iconic impacts (drought, hunger, political unrest, disease, etc.) produce lasting damage larger than the sum of their parts. As long as the effects of one disaster increase vulnerability to a coming disaster, system transformation can occur without a noticeable compound disaster. Researchers can use understanding of SIS to tease out these symptoms. They can observe longer forms of reserve reduction in a system and examine how such processes can be altered, hopefully preventing loss of livelihood viability and halting permanent system change.

When looking at loss of livelihood strategies and decreased adaptive capacity, we cannot determine if natural resource-dependent communities like Camp Perrin, Haiti have crossed a threshold for permanent system change. Long-term research on other forms of compound disasters shows system-level changes remaining for a decade or more. Cascading risk from Hurricane Katrina led to levee breaks, inequitable changes in recovery across neighborhoods, and permanent changes in relationships across family groups (Browne 2015). Cascading risk from the 2010 earthquake has transformed power dynamics and the role of outsiders like non-governmental organizations in Haiti (Schuller 2016, Schuller and Morales 2012).

Alongside the people of Camp Perrin and similar communities, we hope lasting undesired change does not continue. Such towns have thrived through continuation of rural livelihood in close conjunction with the environment they depend on. In doing so, they have avoided the crowding, disease, unrest, and earthquake vulnerability of urban areas. But, as compound disasters become more frequent with climate change, reducing disaster risk will become increasingly more difficult. When coping strategies hold reserve below a point of return and local relationship with the environment erodes, these communities may join the more homogenous landscape of rural environmental deterioration and urban migration. We hope that with applied disaster risk reduction, small-scale natural resource-dependent communities like Camp Perrin may remain or return to their status as *a little place apart*.

2.6. Conclusions

This article explores adaptation and system change in the agrarian community of Camp Perrin, Haiti following the compound disaster of Hurricane Matthew and a months-long drought. Our study reveals a fundamental breakdown in the connection between humans and the environment caused by the compound disaster. Compound disasters reduce the time available for social components of the system to respond, adapt, and rebuild. They likewise reduce the time for ecological components of the system to replenish and regrow, blocking the ecosystem services necessary to respond adaptively to future disturbance. The result is a social-ecological disease analogous to the effects of repeat brain trauma: Second Impact Syndrome (SIS). Households facing SIS experience a loss of the natural resources they usually rely on for their livelihoods, a reduction in adaptive capacity, an increase in uncertainty, a disconnect with the environment, and a heightened risk to future disasters. The key advantage of the SIS systems approach is that it can explain such changes in natural resource-dependent communities as an observable system of feedbacks between households and natural resources, rather than random branching of damage from seemingly isolated incidents.

We recommend applying these findings and this framework in ways that can reduce disaster risk and facilitate rehabilitation. First, this framework can improve disaster risk reduction in the face of climate change and increasing compound disasters that climate change. Identification of SIS symptoms points to tangible areas of need to address at the household and community level. Instead of technocratic solutions used in other forms of compound disasters, SIS symptoms require repair at the interface between humans and the environment. Common NGO initiatives like rebuilding homes and providing emergency food shipments reduce suffering and provide shelter for the select of the community that receive aid. Yet, these practices do not repair the root problem. If natural resource-dependent livelihoods are to remain viable, lasting support must repair the human-environment connection essential for livelihood sustainability and adaptive capacity growth. Investment in locally informed ecological restoration and replenishment of household natural resource reserve will reduce future disaster risk.

Second, disaster risk reduction initiatives can expand adaptive options to combat the often overlooked long-forming disasters (drought, disease, hunger, unrest, etc.). Outside observes commonly think of disasters as isolated moments in time (Button and Schuller 2016). Yet, the effect of even “simple” disasters continues long after aid and media attention has moved on (Tierney et al. 2006, Browne 2015, Button and Schuller 2016). SIS reveals what can happen in the extended timeline of disasters, showing how the long duration of effects feeds into vulnerability to the next disturbance. Increased recognition of and funding to address these “everyday disasters” will prevent the depletion of natural resource reserve. While not as flashy as iconic disasters like hurricanes and earthquakes, they often make up the second impact in SIS, and their long duration of influence pushes households below a threshold of ability to adapt.

Third, SIS provides a medium to explain the complexity of disasters to an audience outside of academia. Developing simplified models of complex, non-linear disaster events produces representations that leave out unnecessary “noise.” In doing so, they offer a platform for mutual understanding between practitioners and affected communities (Kelly 1999). On this platform, local people and outsiders can present their understanding and agree or disagree with the mechanisms explained here. For natural resource-dependent communities, community-level disaster models move past simplistic narratives of the “helpless victim” of “natural” events (Flint and Luloff 2005). Communities can instead decide whether or not to accept and modify this model to portray their lived experience to outsiders.

Lastly, people suffering from the sudden onset of disasters or traumatic brain injury have found comfort in sharing their lived experience. Patients and families of traumatic brain injury patients have found peace in labeling and externalizing the complex mental processes and symptoms experienced (Trotter 2015, Shulman 2018). These patients also find comfort in self-realization and group discussion of personal experiences (Ownsworth et al. 2000). Similarly, increasing communication and sharing experiences with disasters has improved mental well-being following catastrophe (Kaniasty and Norris 2013, Norris et al. 2008). We hope the application of this SIS model provides a resource for those suffering after compound disasters. These households and communities may be able to label, externalize, and discuss an otherwise inexplicable phenomenon, as they see fit.

In this study, we maintained a scope of study to look at one compound disaster, two years of aftermath, and its impact on a community at large. This framing leaves room for future study on the topic. SIS head trauma and SIS social-ecological trauma send systems into a new, undesired state at a rapid pace, but our observations suggest this does not occur in a uniform manner. Heterogeneity of vulnerability across various households in a community provides a promising avenue of pursuit. Combining an understanding of SIS with spatially explicit agent-based modeling techniques and continued ethnographic field research can help us better understand variation and long-term outcomes from the system changing influence of Second Impact Syndrome.

Of note both for social-ecological systems and for neurological systems, is that this is a simplified version (as all frameworks are), here showing the average outcome. Yet, this is not always the case, and outcomes depend on reserve (in brain trauma) and its analogy of adaptive capacity in social-ecological systems. Those with higher levels of stored capital may not experience SIS at all. For example, a handful of the 100 participants said that they did not even notice a drought. These people tended to have additional jobs outside of agriculture that were not impacted. Ultimately, those most reliant on natural resources are those most likely to experience SIS in Haiti and other small island developing states.

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CHAPTER 3

COMPOUND DISASTERS, VULNERABILITY, AND CONSTRAINED LIVELIHOOD OPTIONS IN RURAL HAITI[2]

[2] McGreevy J. Submitted to *Economic Anthropology.*

Abstract

Disasters are increasing in frequency and intensity, disrupting all economic systems. In natural resource-dependent communities, this disruption often occurs by altering ecosystem services and livelihoods. Little is known about how these communities change when multiple disasters occur in quick succession. I address this issue through the use of qualitative, quantitative, spatial, and remote sensing methods to study damage from Hurricane Matthew and the drought that immediately followed in rural Haiti. Surprisingly, households with access to irrigation and with more desirable plots of land self-reported faring significantly *worse* in the drought than those with a reliance on rainfed agriculture and with lower quality farmland. I apply the Ecosystem Services and Livelihood Adaptation framework to assess these counterintuitive results and the processes producing them. I argue that economic loss from Hurricane Matthew and the severity of the drought that followed produced an altered portfolio of economic options available to households. This splits the two groups (access to irrigation vs. no access to irrigation) into different trajectories of disaster experience. Those households familiar with adapting to smaller droughts (i.e., those reliant on rainfall) recognized and put into practice community pooling of resources and other adaptive strategies that produced economic security in an otherwise uncertain time.

Keywords: Disaster vulnerability; livelihood strategies; ecosystem services; adaptive capacity; compound disasters; path dependency; drought; irrigation

3.1 Introduction

Increasing disaster frequency and intensity harms natural, social, and economic systems and sometimes does so in unexpected ways. In small-scale natural resource-dependent (SSNRD) communities where households depend directly on the natural world, climate change causes disproportionate harm (Thomas and Twyman 2005). More frequent disasters disturb the interface between humans and the environment by depleting necessary resources, increasing uncertainty, and leading to shifts in available livelihood options (Pelling and Uitto 2001). Changes in disaster patterns also make indicators of vulnerability unreliable across different types and intensities of disasters. Vulnerability to these changes does not fall equally across a landscape, with households experiencing different levels of physical damage, economic loss, and livelihood disruption (Aubrecht et al. 2012, van Zandt et al. 2012). Understanding the impact of diverse and complex disasters requires understanding variation in peoples' lived experience, a central focus of disaster studies (Delica-Willison and Willison 2013).

Disaster vulnerability is the outcome of the intersections and relationships between spatial, social, and ecological variables (Hilhorst and Bankoff 2013, Wisner et al. 2004; Button and Schuller 2016). Complex disasters can change or complicate these intersections, sometimes increasing longer-term mortality and economic destruction (Anttila-Hughes and Hsiang 2013). A rising form of complex disaster is the compound disaster, where two or more disasters occur in quick succession. Compound disasters produce more combined damage than if the events occurred in isolation (Kawata 2011, Eisner 2014). Increase of this phenomenon comes in part from increasing extreme weather events. Global communities of science, business, and economics rank extreme weather events as the single most inevitable of issues to come from climate change and among the most impactful (Future Earth and International Science Council 2021).

In this article, I analyze the relationship among spatial, social, and ecological variables amidst a compound disaster in rural Haiti. In 2016, Hurricane Matthew devastated Haiti's Southern Peninsula. Immediately after the hurricane rains ceased, a months-long drought began. Initial analysis of disaster outcomes produced counterintuitive results. Well-off households (i.e., those with access to irrigation, more productive land, high-value livestock, better building materials, family connections in the diaspora) had more resources to respond to either disaster occurring in isolation. Yet, these households ranked themselves as faring significantly worse from the second disaster event, the drought, than others in their community. This initial finding prompted the question: Why do households with better social, ecological, and economic conditions fare worse than less well-off households during a compound disaster?

Better-off households relied on a narrow range of typically durable livelihood strategies, such as cash crops and large animal husbandry. These livelihood strategies became damaged by the first disaster and pushed to the point where they could no longer be used after the second disaster. Less well-off houses also experienced damage that produced unviable livelihood strategies, but they had already experienced and responded to this type of damage in the past. When asked to self-assess damage, better-off households focused on what I call “phantom pathways.” Phantom pathways are well-worn connections between humans and the environment so relied upon that people continue to see them as the only economic option even after they become unachievable. Instead, less well-off households used past experiences with livelihood disruption to view a range of alternative economic opportunities when assessing their damage, and they altered pathways as needed.

3.2 Background

Anthropology provides useful avenues for studying the risk and resilience of impoverished communities in the face of disaster, including a better understanding of risk evaluation, uncertainty, and adaptation (Tucker and Nelson 2017). Of note for this study, disasters do not randomly produce different effects on different subpopulations. Instead, disasters expose underlying inequity and magnify system processes for us to see how society works (Oliver-Smith 1999, Wisner et al. 2004, Button and Schuller 2016). For example, Hurricane Katrina exposed long-standing disparities, racism, and environmental injustice in New Orleans and surrounding areas (Park and Miller 2006, Burton 2012). After Katrina, self-reliant families in less protected areas received less support and lost their tight-knit social connections, resulting in unequal outcomes that remained a decade later (Browne 2015). People of different economic statuses also view and respond to risk in different and potentially unexpected ways, especially in farming-based communities (Harthorn and Oaks 2003).

Disasters also expose the effects of ecosystem service loss through human modification of the environment, a loss that varies across landscapes and societies. Centuries of colonialism and neocolonialism led to widespread tree loss in Haiti compared to its neighboring countries (McGreevy 2013). Without ecosystem services provided by trees (e.g., wind, landslide protection), Hurricane Jeanne killed 3000 people in Haiti and 18 in the neighboring Dominican Republic (Felima 2009, Delva 2016). An abundance of natural resources and related ecosystem services contributes to economic well-being and decreases vulnerability to disasters. Yet, the increasing intensity and frequency of disasters caused by climate change produce less predictable results.

Various frameworks work to explain mounting complexity in the relationship between humans and environmental change through livelihood disturbances like disasters. These frameworks vary in focus and application. The Press-Pulse Dynamics framework acknowledges the more obvious Pulse disturbances (like hurricanes) that do much damage in a short amount of time, but it also brings light to the oft-overlooked Press disturbances (like droughts) (Collins et al. 2011). Contrary to media coverage and patterns of aid distribution, these slow-forming Pulse disturbances actually produce more harm to livelihood systems and more loss of life (Anttila-Hughes and Hsiang 2013). The SREX framework, inspired by the Intergovernmental Panel on Climate Change, emphasizes the relationship between development, climate change, and vulnerability to extreme weather events (Field et al. 2012). The IPBES framework comes from the Intergovernmental Panel on Biodiversity and Ecosystem Services, and it emphasizes direct and indirect drivers altering human well-being (Díaz et al. 2015). Pertinent for this study, these and other frameworks overlook the nuanced interface between ecosystem services and adaptive capacity (adaptive capacity here defined as the ability to adapt in a manner desirable to that household or community).

Combining theory on ecosystem services and livelihood adaptation helps examine the unequal influence of social capital and natural capital on human well-being (King et al. 2019). The Ecosystem Services and Livelihood Adaptation (ESLA) framework details how human and environmental domains co-produce a “choice portfolio” of available livelihood options. Households must recognize available options in the choice portfolio, perceive them as possible options, and enact them. This concept of choice portfolios provides one context through which to explain the differential influence of disasters on household economic well-being. In SSNRD communities, disasters can undermine typical natural resource strategies by constraining both the available livelihood strategies and the landscape-provided ecosystem services (Thomas and Twyman 2005, King et al. 2019). This loss results in a reduced and unfamiliar choice portfolio from which households must select. I am innovating with this framework to look at compound disasters, when two or more disasters strike the same community in quick succession.

A difference in path dependency vs. flexibility of strategies helps explain counterintuitive results in self-assessment of damage following a compound disaster. Well-off households rely on strong connections for extended periods of time without breaking, leaving them little need to prepare for adaptive alternatives. For example, previous one-off disasters did not break the bond between reliable irrigation access and a culture of productive cash crop/high-value livestock sales. Households with less dependable resources produce weaker but more varied connections between themselves and natural resources, such as relying on a variety of cash and subsistence crops and community pooling of resources in times of need. When looking at Haiti's 2016 compound disaster, those households with experience adapting to small disturbances find themselves in a better position than those who have not had to experience forced livelihood transitions.

3.3 Research design: study site and methods

The town of Camp Perrin sits in the Rivye Sud Basin near the tip of Haiti's Southern Peninsula. In one of the more remote parts of the country, the community experiences semi-frequent disasters but remains largely independent from governmental and non-governmental intervention. The center of the town separates the steep facing mountain slopes to the North from flatter, more productive farmland to the South. Outside of the concentrated town center, traditional housing units called *lakou* create patchworks across the landscape. In these *lakou,* a few houses of often related families share a common fence, house garden, and small animals. Farmland may lie adjacent to the *lakou* or up to a two-hour walk away.

Camp Perrin households rely primarily on farming, animal husbandry, and (to a lesser extent) selling goods in small stores. The types of crops grown, amount and value of livestock, and the emphasis on subsistence or market involvement varies highly from one household to another. The most common crops include beans, corn, plantains, yams/sweet potatoes, leafy greens, and millet. The most common livestock include chickens, cows, goats, and pigs, the last three of which serve as higher-value commodities. In times when cash is needed (such as the need for tuition and uniforms, medical bills, funerals, and disasters), households often sell livestock and may even sell land. Those fortunate enough to have more well-off family in the capital city and abroad may receive remittances as well. These times of need also see the cutting of trees and tree limbs to make boards and charcoal for sale. In Haiti, due to complex international forces including the mass slaughter of livestock by authorities, trees have taken on a role as an informal banking system to be liquidated as needed (Murray 1987).

Camp Perrin differs from other Haitian towns in its self-reliance, often called *yon ti kote apa*, or “a little place apart.” In my ethnographic fieldwork before the compound disaster, local peoples expressed pride in their relative abundance of trees, their community-based programs to support one another, and their lack of reliance on non-governmental organizations (NGOs) and the state. This is rare in a country often referred to as the Republic of NGOs, where outsiders attempt to fill the gap left by a turbulent government (Schuller 2007, Schuller 2016, Voltaire 2019). Yet, time and increasing disaster frequency have elevated NGO presence in Camp Perrin, with Haitian scholars criticizing the roles, relationships, and effectiveness of an influx of NGOs in the Southern Peninsula (Lamartinière 2019, Voltaire 2019).

Through data from ethnographic fieldwork in 2016 (interviews, surveys, participant observation), one month before Hurricane Matthew, I identified two subpopulations of interest: those in the mountains and those in the plains. I hypothesized that their differences would produce separate trajectories of household experiences in disasters. Those living at higher elevations and among steeper slopes had what the community generally referred to as less desirable land. The steep slopes left homes and farmlands more exposed to winds, landslides, and corresponding soil loss. Further distance from primary roads and public services left them more isolated from needed resources following a disturbance. Moreover, the livelihood strategy of eating more than they sell resulted in less cash income, which they need to pay for medical care and rebuilding. Households at lower elevations were more closely tied to the cash economy, selling more crops and high-value livestock. I strategically sampled from these two subpopulations to produce insight from two groups that interacted with the environment differently and were likely to have different disaster experiences.

Other factors, namely irrigation access, would ultimately produce a more accurate predictor of disaster outcomes and shift the subpopulations of interest. I adapted my analysis to focus on those households with access to irrigation (IRG) and those without access to irrigation but relied solely on rain for agriculture (RAIN). The areas high in the mountains often aligned with households that did not have access to irrigation, and the areas low in the plains often aligned well with households with access to irrigation. The new delineation of IRG vs. RAIN helped explain differences in experience along the cusp of these two regions, which has more variability in irrigation access and disaster experience.

Using mixed methods, I set out to identify pertinent variables related to household disaster experience, determine the relative strength and direction of correlation for each variable linked to household disaster experience, and then to assess ethnographic explanations for variable relationships. These data come from three months of fieldwork in 2016 and one year of fieldwork in 2018-2019. I worked closely with a Haitian research assistant who had worked with me since 2010. The formation of these study methods come both from training and a decade of experience studying rural Haitian livelihoods and their relationship with the environment, and they resulted in three steps of methods.

First, to identify pertinent variables that may explain differential disaster outcomes, I used findings from my 2016 study (before Hurricane Matthew) and eight focus groups conducted in 2018. I led four focus groups with the mountain subpopulation and four with the plains subpopulation. Participants and I collectively identified which social, spatial, economic, and natural characteristics could make a household 1) more or less vulnerable to Hurricane Matthew, 2) more or less prepared for future hurricanes, 3) more or less vulnerable to the drought of 2016-2017, and 4) more or less prepared for future droughts. We identified variables such as slope, elevation, distance to a river, access to irrigation, economic well-being before disasters, social connections with the diaspora, land quality, roof materials, quality of home construction, and many others. We produced categories and example variables, as seen in Table 3.1.

Table 3.1 Pertinent variables for assessing differential disaster outcomes and preparedness

Category	Pertinent variables
Disaster self-assessment variables*	relative damage from Hurricane Matthew relative damage from the drought relative preparedness for future hurricanes relative preparedness for future droughts
Housing variables	roof, wall, floor type construction quality
Spatial variables	distance to nearest road, river time to walk to farmland
Livelihood variables	have high value livestock sell more crops than eaten eat more crops than sold other income sources
Natural/landscape variables	access to water (irrigation or rain only) elevation, slope # trees observed on property
Social variables	part of farming group and/or lending group # living in household have family in Port-au-Prince, abroad
Livelihood damage variables**	trees, crops, high value livestock lost home damaged changes in vegetation presence (satellite imagery)
Disaster response variables	time spent in designated shelter time spent in impromptu house shelter rebuilt house took out loan/loan status

Note: For the sake of space, this list is not exhaustive but provides the variables hypothesized to have the most influence on lived experience and perceived vulnerability/adaptability. *These are important variables to get at the lived experience and perceived vulnerability/adaptability, the key focus of disaster studies (Delica-Willison and Willison 2013). I tested the relationship of these key variables with all other variables. **Broken down into hurricane-specific and drought-specific.

Second, to determine the relative strength and direction of variable correlation, I developed, tested, and revised a survey based on data from the 2016 study and 2018 focus groups. I sampled household locations from aerial image analysis and conducted surveys at 50 randomly selected mountain households and 50 randomly selected plains households in order to equally receive information from the two subpopulations hypothesized to experience disasters differently. Important for this article, I included in these surveys a series of questions asking for self-identification of how their household fared in the disasters compared to other members of the community. Participants responded whether their household and livelihood experienced more, the same, or less damage compared to other Camp Perrin households during 1) Hurricane Matthew and 2) the drought. They also responded whether they were more, the same, or less prepared for future 1) hurricanes and 2) droughts compared to other Camp Perrin households. These self-assessment questions served to indicate peoples' lived experiences with disasters, which should remain the center of disaster research (Delica-Willison and Willison 2013).

For other variables, I used aerial image analysis and spatial analysis. I determined change in NDVI (greenness/vegetation cover) before and after this compound disaster, during the time period most conducive to highlighting tree cover, a common form of stored capital in Haiti (Murray 1987, Jensen 2009, White et al. 2013). I also conducted spatial analysis for each household to determine slope, elevation, the direction the land faces, and distance to the nearest river.

To analyze the relationship direction and strength between the variables I used a combination of Pearson's correlation, two-tailed t-test, and chi-square test, depending on the type of data obtained for the variable. To visualize the relationship of all ethnographically supported variables at once and tease out those of highest correlative strength, I used Python software to produce a Pearson's correlation data matrix "heat map." I selected Pearson's for this initial data analysis because it allows for the use of "dummy variables," testing for the presence or absence of nominal variables simultaneously with other data types (Bernard 2017). I searched for expected and unexpected results, teasing out the most important and strongest relationships. After finding the key variable of concern for my study question (access to irrigation or rainfed agriculture only), I used SPSS software to test for statistical significance of the relationship with other variables. For those variables with continuous values, I used two-tailed t-test of means. For those variables with nominal values, I used Chi-square test (Bernard 2017).

Third, I assessed qualitative explanations for variable relationships by going back to local explanations of disaster damage. Certain variables (like irrigation access) produced strong relationships but in an unexpected and counterintuitive direction. I examined qualitative data from short interviews conducted after each survey and longer semi-structured interviews. This qualitative data on peoples' lived experiences explained otherwise puzzling results from the quantitative data.

3.4 Results

For this article, I focus on which factors influenced the lived experience of households in the two stages of the compound disaster (hurricane and drought). I get to this lived experience through survey questions that asked members of households to compare how negatively each of the two disaster events influenced their household and livelihood compared to other households in Camp Perrin. After testing relationships between lived experience and pertinent factors from focus group and ethnographic insight (variables shown in Table 3.1), the most significant relationship exists between perceived damage during the second stage of the compound disaster (the drought) and access to irrigation. Contrary to initial expectations of a significant difference between the plains and mountain subpopulations, access to irrigation had a much stronger relationship.

Below, I present the relationships between other variables and access to irrigation to better understand the two subpopulations and why irrigation access changes disaster experience. Important here is how these relationships can help explain the influence of Hurricane Matthew on drought response and experience, exploring how a compound disaster could produce more damage to livelihoods than both disasters occurring in isolation. I then triangulate these results with qualitative findings of local explanations for differing disaster experiences. Lastly, I look at to the phenomenon of spontaneous house shelter formation and resource pooling strategies, whose importance qualitative results supports. This last area of results helps link Hurricane Matthew's destruction and the different paths of social and economic strategies used by those with access to irrigation vs. those who relied entirely on rain. This highlights the complexity and far-reaching impact of compound disasters as opposed to simple, one-off disasters.

3.4.1 Relative strength and direction of variable correlation

Initial analysis of the Pearson's correlation data matrix heat map visualized all relations between variables in Table 3.1 and their strength of correlation at once, revealing expected and unexpected results. Some variables held strong relationships I had expected from observation and participant insight. Having a concrete roof was a strong indicator of faring better in Hurricane Matthew, both in physical destruction (roof/home damage) and self-reported well-being. Yet, mountain vs. plains populations did not provide significantly different results in lived experience. Instead, the strongest relationship producing different self-reported outcomes for the drought in two-tailed t-test of means was access to irrigation. That is, those with access to irrigation reported that they fared significantly *worse* in the drought than those that relied on rain-fed agriculture alone, as seen in Table 3.2.

Table 3.2 Household self-assessment of disaster experience compared to access to irrigation (n=66, 25 from IRG subpopulation and 41 from RAIN).

Comparative Disaster Experience	IRG average	RAIN average	p-value
Damage from Hurricane Matthew	0.08	0.10	0.924
Preparedness for future hurricanes	-0.29	-0.51	0.313
Damage from the drought	-0.42	-0.05	0.038*
Preparedness for future droughts	-0.48	-0.52	0.842

Note: IRG denotes households with access to irrigation. RAIN denotes households that do not have access to irrigation and rely only on rainfall for agriculture. "Comparative Disaster Experience" denotes self-assessment compared to other households in Camp Perrin on a scale of -1 (worse) to 1 (better). "Access to Irrigation" denotes average self-assessment for households with access to irrigation. "No Access to Irrigation" denotes the average self-assessment for households that do not have access to irrigation and rely only on rainfall for agriculture. For p-value from two-tailed t-test of means, *= statistically significant.

The variables differentiating households with access to irrigation (IRG) and households without access to irrigation that rely on rainfall only (RAIN) have implications learned through qualitative data, participant observation, and a wealth of ethnographic experience working with communities in rural Haiti. The first variable of statistically significant difference, as seen in Table 3.3, is whether households eat or sell more of what they produce, with RAIN households much more likely to rely on crops they produce for sustenance. Eating all or more of the crops produced rather than selling them results in less connection to the cash economy but also produces typically stronger bonds with neighboring farmers and sharing of crops when another household's crops fail or a particular type of crop fails for a season. These households grow a wider variety of crops, allowing for backup crops that may be more drought tolerant or pest tolerant when disturbances occur. Selling more crops than eaten typically means being more well-off financially and better able to pay for things as needed. Yet, this often results in more independence and less reliance on others in times of need. It also relates to having less variety of crops, since irrigation supports their selected cash crop productivity in times of reduced rainfall.

Table 3.3 Baseline comparison of households with access to irrigation or no access to irrigation, variables with nominal values (n=70, 27 from IRG subpopulation and 43 from RAIN).

Variable	IRG	RAIN	p-value
Food produced- eat all or more than sell	52%	90%	0.000**
Food produced- sell more than eat	48%	10%	0.000**
Family living abroad	78%	40%	0.001**
Family living in PAP	89%	100%	0.028*
Farming group participant	19%	23%	0.592
Have high-value livestock	71%	67%	0.562

Note IRG denotes households with access to irrigation. RAIN denotes households that do not have access to irrigation and rely only on rainfall for agriculture. Variable "Have high-value livestock" denotes having at least one cow, pig, sheep, goat house, mule, and/or donkey." For p-value from Chi-square test, *= statistically significant, **= highly statistically significant.

Geospatial variables also showed significant relationships. Higher elevation means less desirable farmland and cheaper housing, with IRG households at a lower elevation on average. Closer proximity to the nearest river may mean easier access to water, but too close to a river can mean flood hazard, with RAIN households having closer proximity to a river. Far distance to the farm means longer workdays and the possibility of getting caught in storms. Far away farmland is usually less expensive and usually in undesirable, highly sloped regions where erosion is prominent. RAIN households have a further distance from their farms, averaging nearly one and a half hours walk to reach their farmland. A higher slope means an increased risk of landslides and soil erosion, and RAIN households have a more undesirable slope of land.

Table 3.4 Baseline comparison of households with access to irrigation or no access to irrigation, variables with continuous values (n=70, 27 from IRG subpopulation and 43 from RAIN).

Variable	IRG average	RAIN average	p-value
Elevation (meters)	152	257	0.000**
Distance to farm (minutes' walk)	17	80	0.000**
Distance to nearest river (meters)	581	309	0.001**
Slope at household (%)	5.6	11.4	0.002**
Trees observed near house compound (#)	19	19	0.989

Note: IRG denotes households with access to irrigation. RAIN denotes households that do not have access to irrigation and rely only on rainfall for agriculture. "House compound" refers to traditional Haitian housing units, *lakou*. For p-value from two-tailed t-test of means, *= statistically significant, **= highly statistically significant.

Some social variables showed significant connections to the study populations. Money from family abroad produces some of the most consistent capital influxes in Haitian households (Orozco and Burgess 2011). This can provide support in times of need. IRG households have a higher percentage of family abroad. Family in Port-au-Prince (PAP) can provide capital increase, but usually much smaller than from family abroad. Alternatively, it can also be a sign that family left from failing rural livelihoods. RAIN households are more likely to have family members in PAP.

All other variables from Table 3.3 and Table 3.4 do not have a statistically significant difference, but they have some important lived contexts important to both subpopulations. Lending groups can provide opportunities for small business loans, but they have limits when the whole community is struggling, such as in times of disaster. While valuable for future research, I omitted lending group results due to question confusion about what constituted taking out loans vs. what constituted being a member of a locally-run lending group. Farming groups provide opportunities for pooling resources and services. Like lending groups, they can have limits in disasters, but they can produce collective adaptive strategies. Having high-value livestock of some sort can also provide stored capital and/or food in times of need.

3.4.2 Qualitative explanations for variable relationships

Interviews help explain some of the quantitative data, including the self-reported differences in drought influence between IRG and RAIN subpopulations. When asked to explain how the drought influenced their family and livelihoods, households with irrigation access focused on the inability to get water for drinking, planting crops, and livestock. More specifically, multiple households explained that even the canals had run dry, something not common in previous droughts. This resulted in loss of crops and loss of the few high-value livestock that were not taken by Hurricane Matthew. Linked to their strong connection with the market economy, IRG households emphasized the lack of money or credit available to buy the things they need.

Households without access to irrigation only rarely mentioned livestock, which had either been taken away by Hurricane Matthew or were of lower value and required less water. Instead, RAIN households talked about the loss of crops, the drying of springs depended on for drinking water, and the need to travel far to obtain water. Discussion of traveling long distances to obtain food and water tended to shift into stories of house shelters. People pooled what financial resources they had and traveled to municipalities over the mountains, which saw less damage from Hurricane Matthew.

3.4.3 House shelters and resource pooling: adaptations amidst a compound disaster

The combined explanations from focus groups and interviews demonstrate how Hurricane Matthew's damages prompted different responses, primarily in house shelter formation and resource pooling. Reciprocity and sharing commonly occur in times of scarcity and disaster, though the specifics and outcomes of these practices vary across households and communities (Jones et al. 2015, Brewis et al. 2019). During Hurricane Matthew's immediate aftermath, the initial and most beneficial response came from the people of Camp Perrin themselves. Community members with standing homes (typically concrete) formed spontaneous "house shelters" for others whose homes were destroyed. The practice was so widespread that community members housing and feeding one another was the most prevalent topic in all qualitative methods.

Smaller house shelters took in a few nearby neighbors, and larger ones sheltered hundreds of people. Of the 100 individuals surveyed, 71 were displaced by the hurricane, and 86% of those displaced went to house shelters. On average, each house shelter provided for 40 people over the span of 77 days. Only 14% of displaced individuals went to other shelters (churches, businesses, government buildings, etc.). While one church held as many as 3000 individuals, these shelters did not last long, averaging 9 days. Alternatively, some house shelters held up to 200 people and remained active two years later.

Data on the use of different types of shelter use show differences across IRG and RAIN subpopulations. RAIN households were more likely to stay at house shelters. The biggest difference lies in the time spent at house shelters. On average, RAIN households spent 95 days at house shelters, where they pooled resources and shared living space with others impacted by the compound disaster. IRG households averaged only 19 days. Another point of interest is that 12% of RAIN households had access to designated shelters, but they largely chose to engage with house shelters instead. IRG households had substantial alternative options at house shelters (50%), but they largely chose to spend time at designated shelters or to spend some but less time at house shelters, returning home in an attempt to rebuild and respond more independently. These designated shelters housed families for less time and had less pooling of resources.

3.5 Discussion and Conclusions

Factors predicted to influence outcomes of this compound disaster did so in the direction of influence that sometimes ran counter to common understanding. When facing climate change, improving irrigation access has decreased drought vulnerability for small scall farmers in Latin America and the Caribbean (Herwehe and Scott 2018). Yet, in this study, this adaptation failed significantly. Households with desirable pre-disaster conditions in the economic, social, and environmental domains and access to irrigation self-reported that they fared significantly *worse* in the 2016-2017 drought than those with less desirable conditions and dependence on rainfed agriculture. During smaller-scale, one-off disasters, households with more resources and infrastructural support (like irrigation) are likely to use their resources to benefit themselves and respond quickly. Yet, during compound disasters, normally less well-off households have more diverse strategies to rely on and a more collectivist mindset to respond in a collaborative and flexible manner. In the case of this study, the outcome of these strategies produced differences in perceived disaster damage.

3.5.1 Entering the adaptation domain: choice portfolio and livelihood enactment

The Ecosystem Services and Livelihood Adaptation (ELSA) framework brings together the human and environmental domains to visualize their interaction in the "adaptation domain" (King et al. 2019), adapted for this study in Figures 3.1 and 3.2. The human domain traces livelihood effects, agent wellbeing, policies & institutions, and how they form adaptive capacities that enter the adaptation domain. The environmental domain follows land use effects, localized ecological processes, landscape ecological processes, and how they form natural capitals that enter the adaptation domain. These components all combine to tell the story of human-environmental interaction in Haiti.

Figures 3.1 and 3.2 depict the adaptation domain of the ESLA framework simplified for the average IRG household (Figure 3.1) and the average RAIN household (Figure 3.2). At the top are the potential livelihood options, which were contributed by the human (blue) and natural (green) domains. These constitute the "choice portfolio," from which households recognize and engage in livelihood strategies. They then enter the livelihood enactment zone. I add to this a portion of the choice portfolio named the "emergency portfolio." Under non-emergency circumstances, these options are either undesirable (producing less than ideal outcomes) or culturally inappropriate (such as asking for assistance when other forms of production work well).

Figures 3.1A and 3.1B use study data to show the inner working of the adaptation domain among IRG households during normal, baseline periods (3.1A) and after the compound disasters of 2016-2017 (3.1B). The boldness of an outline roughly corresponds to the dependability of that option during baseline periods. The thickness of connections represents the relative dependence on and confidence in that relationship. As seen in Figure 3.1A, IRG households typically select natural/human pairings that imbed them in the cash economy, namely cash crops and high-value livestock. Productive farmland, productive pastures, and irrigation access provide reliable resources from which to form strong human/natural livelihood bonds. These strong bonds provide economic stability and resilience against smaller, isolated disasters. Such strong bonds promote a culture of self-reliance and limit the need to collaborate in adaptive manners. This also prevents the need for diversification of economic and subsistence options. Ultimately, farming households with consistent irrigation access tend to overspecialize and overlook other adaptive options.

That is not to say that the subpopulation with irrigation access does not share. Actually, 99% of all 100 people asked in 2016 surveys said they did share with neighbors and/or family. Rather, this means that, when in need, this population tends to work to get back to well-worn connections based on the cash economy more often than focusing on the collaborative pooling of resources.

I focus on these figures before and after the compound disaster instead of just the drought due to the influence of Hurricane Matthew and its relationship with the drought on livelihood decisions between the IRG and RAIN subpopulations. The drought itself does not produce the broken connections, but the preceding hurricane damaged the available resources to the point that it reduces a choice portfolio and leaves only a phantom pathway. For example, the loss of high-value livestock removes the one other recognized avenue for cash generation to fund needs, needs like rebuilding homes and paying medical bills, which the hurricane prompted.

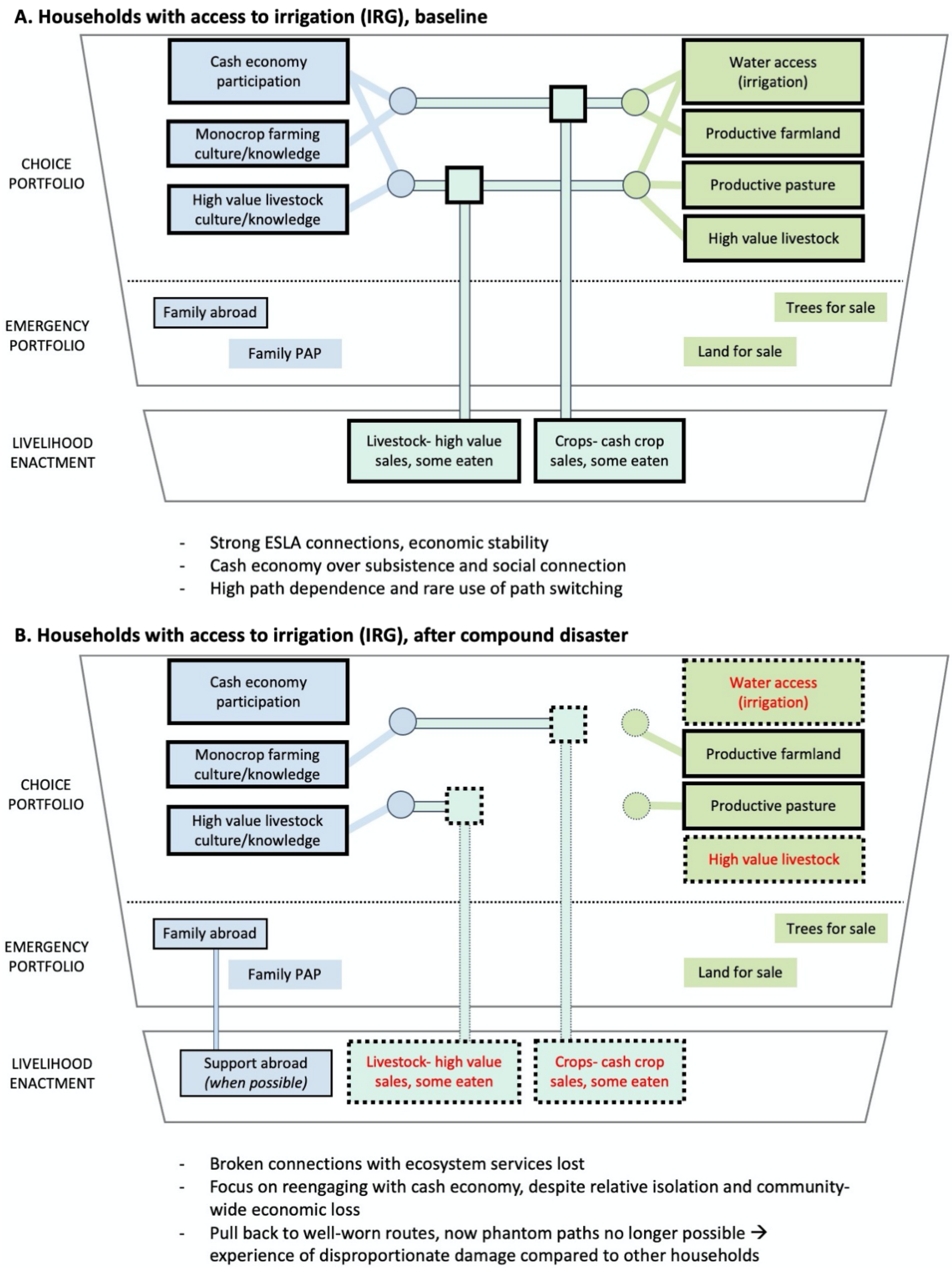

Figure 3.1 Choice portfolio and livelihood enactment before (A.) and after (B.) 2016-2017 compound disasters for households with access to irrigation (IRG).

As seen in 3.1B, strong ESLA connections produce collapse of all commonly practiced options for IRG households when a compound disaster event removes the resources and ecosystem services they rely on. Broken strong connections between ecosystem services and livelihood adaptations lead to what I call phantom pathways. Phantom pathways are a well-worn livelihood connection that remains the path that a household tries to get back to, even if the resources needed no longer remain. Phantom pathways distract those impacted by a disaster from recognizing new avenues for adaptation.

IRG households spent some time in house shelters or designated shelters, but they ultimately went back to the cash economy they knew best, gaining assistance from abroad and attempting to return to the phantom pathways that were temporarily not viable. These households have regained some of their livestock and way of life. Yet, two years after the drought, they still saw their family and livelihood as being damaged more than other members of the community.

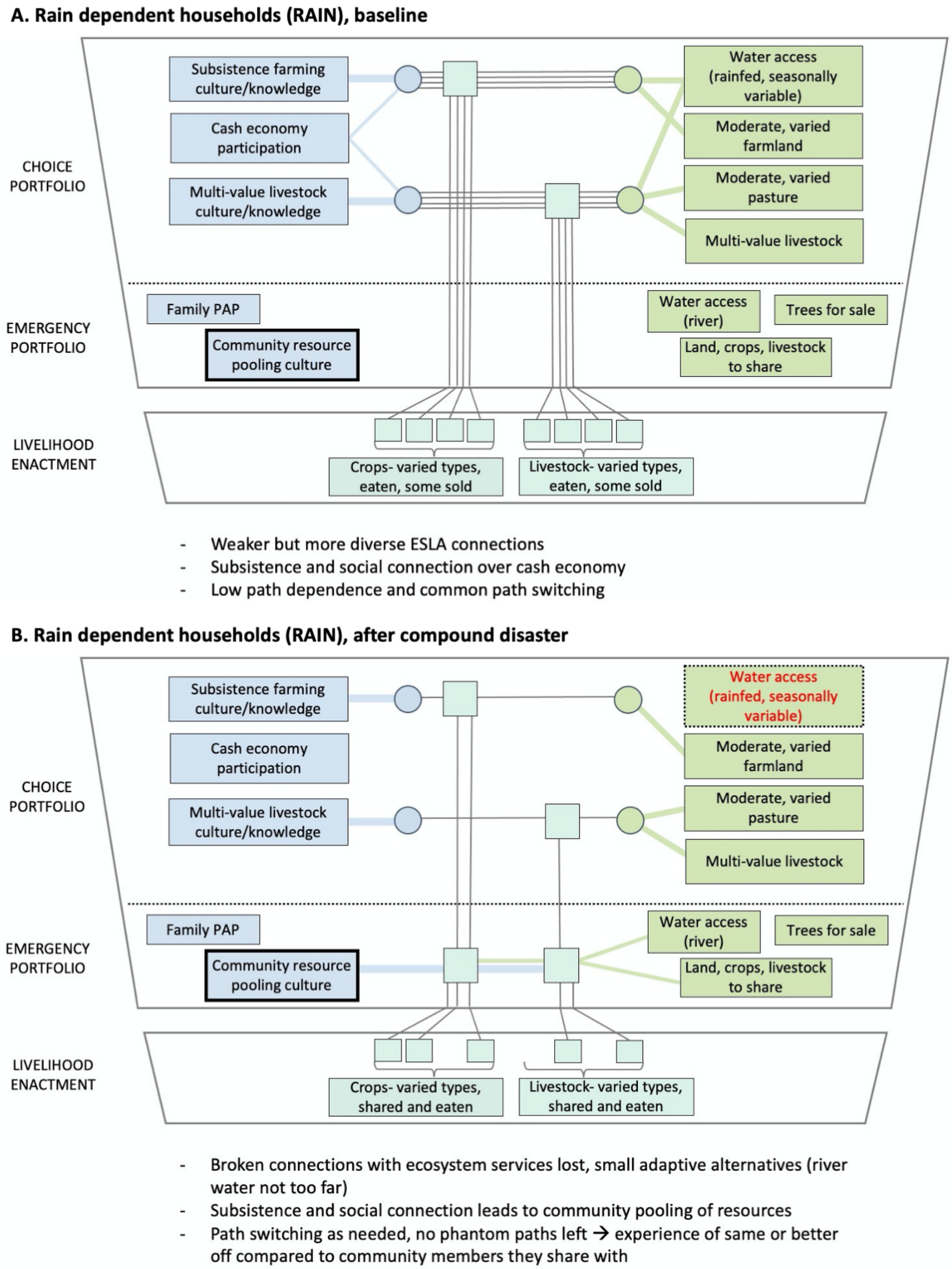

Figure 3.2 Choice portfolio and livelihood enactment before (A.) and after (B.) 2016-2017 compound disasters for households with rainfed agriculture only (RAIN)

Figures 3.2A and 3.2B use study data to show the adaptive domain from the RAIN household perspective. Unlike IRG households, they began with fewer ecosystem services. Their land sits largely on a high-altitude slope, far from the nearest roads, and with even more remote farmlands. This suite of factors results in less erosion protection, less soil moisture protection, more difficult farmland, longer working days, and dependence on changing rainfall patterns. To adapt to these pressures, RAIN households tend to plant a variety of subsistence crops at different times of the year. If one were to fail, their livelihood and their sustenance does not depend solely on that crop. Similarly, they tend to have lower value livestock such as chickens, rabbits, and sometimes goats, which require less resource input. Most importantly for this study, however, is the strong reliance on interhousehold bonds, sharing labor (forming *konbit* work parties), sharing food of various types when neighbor crops fail, and even lending money when possible.

The RAIN household subpopulation relies less on the cash economy. This can produce stress and vulnerability in times when families need cash to pay for school uniforms, tuition, medical bills, funerals, and other unforeseen expenses. Yet, as seen in Figure 3.2B, this proved advantageous after the unprecedented compound disaster of 2016-2017. RAIN households used path switching and relied on an established culture of resource pooling in disasters to fare better in the disaster's immediate aftermath. In no hurry to return to a self-reliant, cash-based livelihood option, RAIN households remained in house shelters, pooling resources and living in close proximity to other families, far longer than their IRG counterparts. Both IRG and RAIN households had access to house shelters and designated shelters. This suggests that IRG households spent less time at house shelters not out of availability but out of choice, returning home instead to attempt a more self-reliant livelihood strategy.

3.5.2 Looking forward: local adaptation and global responsibility

Application of the Ecosystem Services and Livelihood Adaptation (ESLA) framework (King et al. 2019) reveals disruptions in available livelihood options. It also shows path dependency, in the form of phantom pathways, on no longer viable options for those that depended on irrigation and the cash economy. It also shows spontaneous community resource pooling for those that depended on rainfed agriculture and a culture of rural cohesion, a social strategy amongst the less well-off in times of water scarcity and disaster (Jones et al. 2015, Brewis et al. 2019). These and related differences ultimately led Camp Perrin households down two avenues: one for those reliant on irrigation (IRG) and one for those reliant on rainfed agriculture (RAIN).

Ultimately, this study aligns with the copious literature that disasters indeed help reveal underlying relationships latent in a system (Oliver-Smith 1999, Wisner et al. 2004, Button and Schuller 2016). At the same time, it asks us to delve deeper into unexpected outcomes that go counter to intuition and academic understanding, such as irrigation access for small-scale farmers in Latin America and the Caribbean (Herwehe and Scott 2018). Instead, the impact of compound disasters can produce results that mirror but transpose the inequalities present in a system.

One last pair of factors ties together this story of unexpected disaster outcomes: local economic isolation and global environmental connectedness. In a country where the central government often does not show up or does not have the resources to assist following a disaster, communities rely on outside help. This help comes from non-governmental organizations, foreign governments, and family living abroad, to varying measures of success. Yet, the scale of the 2016-2017 compound disaster limited all forms of outside support. With roads blocked and electricity down, aid could not come either physically through materials and medical support or electronically through financial support. Households with access to irrigation that also have family abroad could not use this portion of their emergency portfolio. As with the earthquake of 2010, local people responded first and in culturally useful ways (Schuller et al. 2019). They formed house shelters and resource pooling that saved lives to a number we will not know.

Looking forward, climate change-induced extreme weather events continue to disproportionately harm the Caribbean specifically and small-scale natural resource-dependent communities in general (Pelling and Uitto 2001, Fischer 2018, Villanueva 2021). With the expected continuance of this trend, Haiti will likely face more compound disasters. They will likely also experience isolation in times of need, compounded by unrest and travel dangers in the capital city (Abi-Habib and Graham 2021, Oxford Analytica 2021). For less severe disasters and one-off "simple" disasters, those with access to irrigation will likely return quickly to their established livelihood pathways. For more severe and compound disasters, households need new forms of adaptation and adjustment from well-worn strong ESLA linkages. Extreme weather events remain the most inevitable of climate change symptoms (Future Earth and International Science Council 2021), their increase reducing the time between disaster events and prompting compound disasters. In preparation and response to mounting change, we need new approaches to climate change, the force causing breakdowns in economic systems and continued suffering.

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CHAPTER 4

HOUSEHOLDS, EXTREME WEATHER, ADAPTATION, AND LIVELIHOODS (HEAL): AN AGENT-BASED MODEL OF RECOVERY FOLLOWING EXTREME WEATHER EVENTS IN SMALL ISLAND DEVELOPING STATES[3]

[3] McGreevy J, to be submitted to *Natural Hazards*

4.1 Introduction

Climate change brings damage and livelihood disruption to agricultural-based societies around the world. Small island developing states (SIDS) find themselves disproportionately vulnerable to climate change compared to other nations. Reasons for this disparity include nation size, large coastlines with a small interior, histories of geopolitical subjugation, and a heavy reliance on spatially bounded natural resources (Pelling an Uitto 2001). Low economic diversification also makes SIDS more vulnerable to livelihood disruption following a disaster, but the nature of this effect varies from one type of event to another. For example, earthquakes (as seen in Haiti in 2010) cause loss of life and loss of home, but they do little to directly influence agriculture. Yet, climate-related disasters have a more direct and severe impact on typical SIDS livelihoods (Julca and Paddison 2010).

Extreme weather events are the most visible and often the most damaging of climate change related natural hazards, especially for island nations. Annual frequency of extreme weather event-based disasters has increased steadily in SIDS since the 1970s, and this trend has accelerated since 2000 (Julca and Paddison 2010). Different types of extreme weather events produce different outcomes in terms of livelihood disruption and household adaptation. For many, the last available adaptation choice at the household level is migration. The pattern of this migration differs between slow-onset disasters like droughts and fast-onset disasters like hurricanes. Fast-onset disasters cause immediate relocation that may become permanent (e.g., Hurricane Katrina), whereas slow-onset disasters (e.g., drought) produce worsening conditions that may lead to conscious migration decisions (Warner et al. 2010).

Looking at these differences in disaster impact too broadly misses agent decision making and lived experience that aggregate to produce broader trends. Research on natural hazard damage in SIDS typically occurs at higher levels, either nationally or lumping together multiple islands or island chains. This approach misses the nuance and heterogeneity of such countries, with community-level and household-level interactions remaining hidden (Meheaux et al. 2007). Instead, agent-based models (ABMs) specifically target the characteristics, actions, and adaptive behaviors of each actor in a system and how these components influence the system as a whole (Railsback and Grimm 2019).

This study examines household experience and response to fast-onset disasters (hurricanes) and slow-onset disasters (droughts) through the application of empirical data to an ABM in a farming community in rural Haiti. I introduce this empirically based ABM to reveal trends about how households in small island developing states respond to the increasing extreme weather events that threaten their livelihoods. Based on mixed method analysis of household recovery following disaster in Haiti in 2016, the "Households, Extreme weather, Adaptation, and Livelihoods" (HEAL) agent-based model traces different trajectories of households following disaster.

For this study, I more specifically ask the question "How do different adaptive approaches (pooling resources locally or seeking resources outside of the community) influence household recovery following extreme weather events?" I answer this question by applying the HEAL agent-based model through different scenarios: baseline, drought, hurricane, and a hurricane followed by a drought. The importance of this question comes from analysis in Chapter 3 showing the formation of two different typologies (or collectives, to use the ABM term) of farming households: 1) those with access to irrigation, who participate more in the cash economy and rely on cash and international aid in times of need, and 2) those without access to irrigation, who primarily farm for subsistence and rely on community resource pooling in times of need. The HEAL model reveals the effects of such subsistence and adaptive strategies amid disaster, setting the framework for further understanding of climate change, extreme weather events, and disaster recovery in other small island developing states.

4.2 Background

4.2.1 Extreme weather events in small island developing states

The characteristics making nations small island developing states (SIDS) are the characteristics that also make them more vulnerable to extreme weather events, and the study site in rural Haiti provides a prime example. The geography of Haiti's southern peninsula leaves it exposed to hurricanes, with a narrow sliver of flat land suitable for agriculture trapped between difficult to pass mountain peaks and the southern coastline where hurricanes land (Kijewski-Correa et al. 2018). Historical constraints from entering the international economy and foreign occupiers leveling forests for sugar plantations resulted in tree loss and loss of ecosystem services like protection against erosion, landslides, and wind (Mintz 1986, Murray 1987, Farmer 2006, Felima 2009, Oliver-Smith 2010, McGreevy 2013, Schuller 2016). A growing population with needs for fuelwood and finite farmland further constrained resources needed for survival (Murray 1987, White et al. 2013). A lack of available economic opportunities and policies centralizing resources produces communities dependent on annual harvest for the viability of rural livelihood, and in Haiti, this means farmers have left the countryside to seek the few jobs available in the crowded and earthquake-prone capital city (Trouillot 1990, Jean-Baptiste 2012, Schuller and Morales 2012). Lastly, geography and exposed infrastructure leave those on the southern peninsula unreachable after a disaster (Kijewski-Correa et al. 2018). Combined, these and other factors make Haiti a small island developing state that is most vulnerable to disasters. Even before the earthquake of 2010, the worst disaster in modern history, Haiti had a higher relative death toll from disasters than any island of more than 100,000 inhabitants (Pelling and Uitto 2001).

These characteristics influence adaptation and livelihood change in Haiti and similar nations. Key negative impacts of natural hazards on SIDS include geophysical components (landscape destruction, erosion, and soil salinization) and human components (loss of life, changing social structure, and agricultural impacts) (Méheaux et al. 2007). Focusing on the latter, agent-based models of extreme weather events predict increasing internal migration from more vulnerable areas (those exposed and sensitive to drought and cyclones/hurricanes) to less vulnerable areas in the country (Hassani-Mahmooei 2012). Yet, this migration increases population density and produces increased vulnerability to other forms of disasters. Haiti's earthquake of 2010 provides a cautionary tale of how internal migration (among many other factors national and international) produces disaster vulnerability. Of the structures destroyed during the earthquake, 86 percent were built since the 1990s, when rural livelihood viability decreased and farmers fled the countryside in the hope of wage labor (Etienne 2012, Button and Schuller 2016). The predicted increase in climate change-related urban migration and the links such trends have on future disaster vulnerability necessitate research on how remaining rural households experience and respond to disasters.

4.2.2 Adaptive capacity and vulnerability

The range of responses available to rural households is their ability to adapt, also known as adaptive capacity. Adaptive capacity works in conjunction with vulnerability to influence the outcomes of a disaster. Vulnerability is the susceptibility to the adverse effects of a disaster, with exposure, sensitivity, and adaptive capacity affecting the level of vulnerability to disaster (Adger 2006). Exposure consists of the frequency and intensity of natural hazards occurring in the community, such as the growing frequency and intensity of hurricanes as well as unpredictable rainfall occurring in the Caribbean (Taylor et al. 2012). Sensitivity in this context refers to the degree to which the natural hazard impacts the households in the community of Camp Perrin, Haiti. For example, surveys showed how some households did not even notice a recent drought while others reported severe livelihood losses, meaning people felt the influence of the same event differently. This alone questions the wide held narrative that disasters cause inevitable unfortunate events. Adaptive capacity in this context is the ability of a household to respond to a natural hazard in a manner desirable to them. Having higher levels of adaptive capacity allows households to push against the pressures of sensitivity and exposure, reducing overall vulnerability (Adger 2006, Engle 2011).

Adaptive capacity breaks down further into generic adaptive capacity and specific adaptive capacity, a nuance important for the assessment of specific variables contributing to the outcome of households facing a natural hazard. Generic adaptive capacity consists of variables that contribute to the outcome of any natural hazard (Eakin et al. 2014). For example, houses with a steady income source outside of farming would fare better in both a hurricane and a drought. Specific adaptive capacity consists of those variables that contribute to the outcome of a specific natural hazard, and some variables may improve adaptive capacity for some events but decrease them for others (Eakin et al. 2014). For example, having a tin roof in a hurricane results in roof loss and the lost opportunity to stay in that shelter. However, having a tin roof in an earthquake reduces the chances of injury or death and requires fewer resources to replace, saving capital for other needs.

When combined, specific and generic adaptive capacity influence the ability of a household to get back to a desirable state following a disaster. For this study and its application to an agent-based model, the desirable state involves "satisficing" or getting back to the minimum needed to be satisfied (Railsback and Grimm 2019). I simplify this as getting back to baseline state before the disaster, when Camp Perrin stood out as a wealthy community with stable livelihoods before the disasters of 2016.

4.2.3 Agent-based models (ABMs) and disasters

Traditional forms of modelling struggle with the integration of theories from different disciplines into one model of a social-ecological system. By linking different theories into the agent decision-making rules of an agent-based model (ABM), models test the collection of ideas rather than those ideas commonly isolated into silos (Schluter et al. 2017). The model in this study integrates science on disaster vulnerability, natural resource use, and adaptation with real-world data to better understand the complexities influencing household ability to recover from disasters across different scenarios.

ABMs are more of a theoretical approach than a tool (Bonabeau 2002). At the most basic level, they involve agents that make decisions based on internal characteristics and environmental characteristics. The observer watches the effects of these decisions and the interactions between agents, looking for emergent trends and expected outputs (e.g., amount of crops produced, change in location of the agent, and countless others). ABMs are a useful approach when interactions among agents are complex and nonlinear, when space is an important factor, when heterogeneity occurs, and when learning and adaptation occur, leading to the possibility of emergence (Bonabeau 2002, Railsback and Grimm 2019).

The complexity of modeling agent decision making varies dramatically, in some cases becoming too cumbersome to trace trends and causation. In streamlined modeling of human behavior, humans experience external events coming from the environment. Their perception of these events interacts with the mental state of the agent consisting of beliefs, desires, and intentions. Out of this mental state, agents make plans and act intentionally with the environment in what is called an "intentional system" (Balke and Gilbert 2014). This starting point is fit for incorporation into ABMs due to its ability to respond dynamically. Many variations and extensions exist from this basic mental model, extending to include cultural beliefs, deficiency needs, and stressors (Dignum et al. 2009). Adding insight from disaster studies and studies of vulnerability, resilience, and adaptive capacity in human-environmental interaction produces a model with the needed complexity to assess disaster impact without complicating the mental model beyond its usefulness as an ABM.

ABMs assist in quickly assessing how different scenarios, with social constraints and natural hazards, impact natural resource-dependent communities. As seen with the application of the DECUMA and SAVANNA models in Kenyan pastoral societies, they also connect household survey results to ecosystem understanding to provide insight into human-environmental interaction (Boone et al. 2011). Using Overview, Design concepts, and Details (ODD) protocol for studies on human interaction with the environment helps further the field by connecting individual-based modelers from ecology and similar disciplines with agent-based modelers more rooted in social sciences. This facilitates interdisciplinary connection for reviewing, replicating, and comparing models (Pollhill et al. 2008). For this reason, I provide a detailed ODD Protocol in Section 4.4.1.

Adaptive capacity analysis usually involves qualitative assessment (Hernández-Cruz and Davlia 2020). Assessing literature for the most referenced components of adaptive capacity (AC) provides variables to quantify and model. The most frequently cited variables of AC are broken down into the categories of socioeconomic attributes, access to resources, risk appraisal, adaptation appraisal, reliance on public assistance, level of preparedness, and social capital (Hernández-Cruz and Davlia 2020). Simplifying a model to a usable degree requires selecting from all available variables in these categories to focus on the most significant variables as perceived by local peoples and implementing them into ABM model formation. In doing so, this model reveals the trajectory of two subpopulations (those with access to irrigation and those without) as they practice different adaptive strategies in an attempt to recover from disaster.

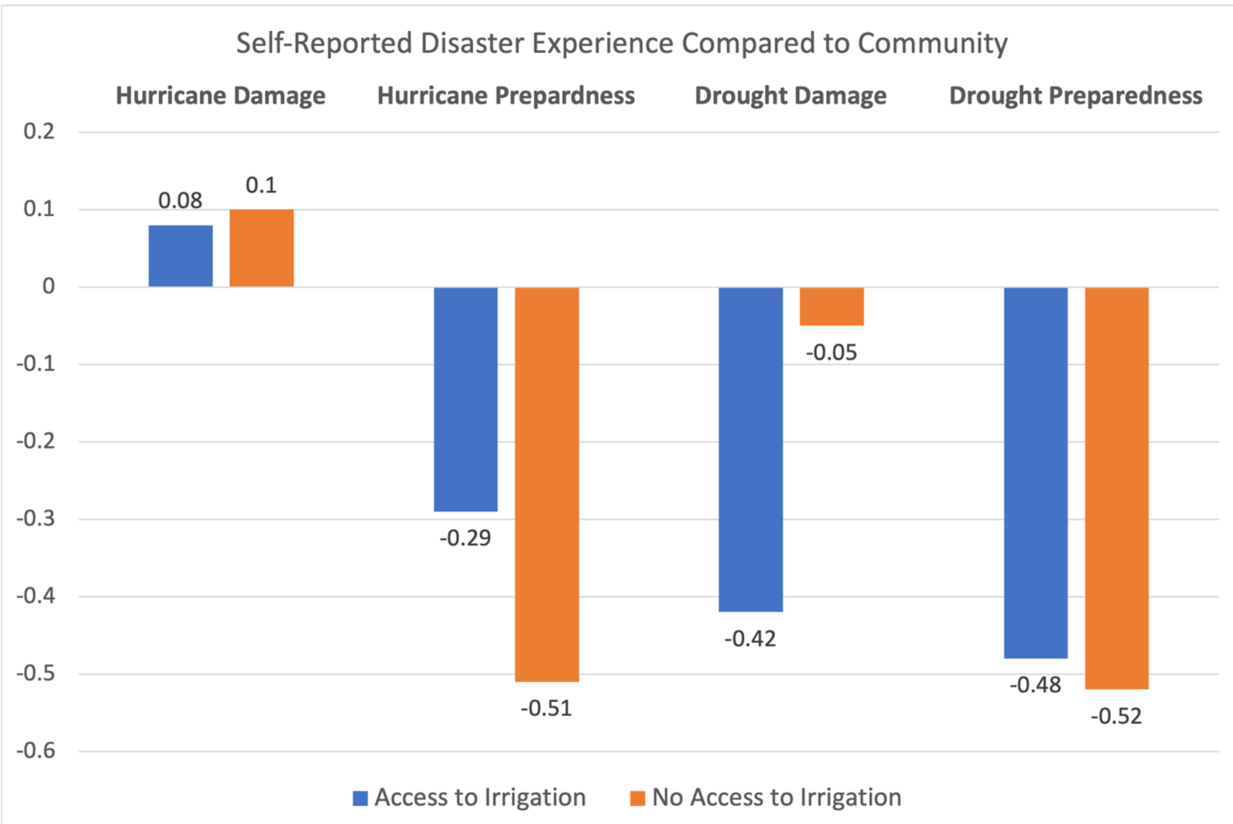

Figure 4.1 Self-reported disaster experience, comparing average responses for those households with access to irrigation and those households without access to irrigation. (n=66, 25 from subpopulation with access to irrigation (IRG) and 41 from subpopulation without access to irrigation (RAIN)). Respondents reported how they perceived their household fared in Hurricane Matthew compared to other households in the community, how prepared they are for future hurricanes, how the fared in the drought, and how prepared they are for future droughts. (-1 = worse, 0 = same, 1 = better).

A secondary purpose for this model is to better understand the causation behind households' self-reported experience in the 2016 hurricane and drought and their preparedness for future hurricanes and droughts, as compared to other households in the community. In preliminary analysis, shown in Figure 4.1, both subpopulations (those with access to irrigation (IRG) and those without access to irrigation (RAIN)) reported on average that they had roughly equal or slightly less damage from Hurricane Matthew. Analysis from Chapter 3 yielded the surprising result that IRG households reported faring significantly worse from the drought than RAIN households. Through model formation, I build on these findings to look more specifically at why the subpopulations reported low but varied preparedness for future hurricanes and low preparedness for future droughts. For example, even though RAIN households reported faring relatively equal to other households in the drought of 2016, they reported that they felt much less prepared than other households for future droughts. The ABM I present here runs through various possible scenarios to test outcomes that may explain these low levels of self-reported future preparedness.

4.3 Methods

4.3.1 Study area

Camp Perrin sits between the mountain peaks and coastal flats toward the westernmost portion of Haiti's southern peninsula. Residents speak about Camp Perrin as *yon ti kote apa*, a little place apart, holding pride for the relative independence of the town, the abundant natural resources, and the relative stability of rural livelihoods compared to other portions of Haiti. Farming and animal husbandry make up the majority of the economic activity in the town, but variability does exist. Some households have secondary income working as teachers, lawyers, construction professionals, and other wage labor, most of whom commuting to the nearby regional capital.

Agricultural production and animal husbandry also vary, separating the population into two roughly discrete groups. A little more than half of the town primarily eats more crops than they sell and possess mainly low and medium-value livestock (chickens, doves, rabbits and sheep and goats, respectively). These households more often reside in the less valuable mountainous land and generally do not have access to irrigation. A little less than half of the town engages more in the cash economy, growing and selling higher value but water intensive monocrops and raising high-value livestock (pigs, horses, cows, donkeys, and oxen). This subpopulation tends to live in the more productive and flat lowlands and has access to irrigation.

In 2016, Hurricane Matthew devasted Camp Perrin as it swept up from the south and over the peninsula. The infrastructure in Haiti's southern plateau led to differences in experiences during Hurricane Matthew. Roof construction would ideally be heavy corrugated metal, not the cheaper light metal, but most rural families cannot afford this. Thick concrete is also good, but it increases vulnerability to earthquakes. While the earthquake of 2010 certainly caused more loss of life and concrete structure damage, it did not disrupt natural resource-based livelihoods in the way Hurricane Matthew did: uprooting trees, destroying cropland, and eroding soil (Kijewski-Correa et al. 2018).

Immediately following Hurricane Matthew, rainfall ceased in the town for multiple months. Hit with a compound disaster, two or more disasters occurring in quick succession, the subpopulations experienced the events differently and responded to the events differently. Those with access to irrigation and more involved with the cash economy tended to share resources minimally and seek remittances from family and friends abroad. Those without access to irrigation and more involved in subsistence agriculture tended to pool more resources for longer periods. This model seeks to explain how these adaptive strategies led to different outcomes for the subpopulations, and how these strategies could impact the community under various other scenarios.

4.3.2 Data collection

I used a mixed methods approach to obtain qualitative and quantitative data related to disaster experience, factors hypothesized to influence disaster experience, and adaptive strategies used. With a research assistant, I conducted eight focus groups (four with women and four with men) in both the mountainous and plains regions of Camp Perrin. These focus groups identified variables most likely to impact vulnerability to 1) Hurricane Matthew, 2) the drought that followed, and 3) the combination of the two. Likewise, we collectively identified those adaptive strategies used by different subpopulations and the consequences (positive and negative) of different approaches. To quantify these factors, we conducted 100 surveys at randomly sampled households. To explore causal links and the lived experience of these disasters, we conducted brief post-survey interviews and longer semi-structured interviews. I obtained other pertinent geospatial data (i.e., slope, elevation, aspect, distance to the nearest river, etc.) through GIS analysis of the study area.

4.3.3 Data analysis

Modelling human behavior requires simplifying the world of the model to those variables that set the basic resources used by the actor and the agent-related variables that influence decision making (Anderies 2000). Because of this, I include in this model only those variables demonstrated through observation and survey data to produce different adaptive strategies and different disaster experiences across households, shown in Figure 4.2 in the following section. I conducted eight focus groups to identify potential factors influencing vulnerability, disaster experience, and adaptive strategies. For geospatial variables, I used aerial imagery to identify *lakou* traditional housing units and their exact location. From this, I determined potentially important variables like distance to nearest river and slope of land. To analyze the strength and direction of the relationship between variables, I produced a Pearson's correlation coefficient heatmap and focused statistical analysis on the strongest relationships. I did so through a combination of Pearson's correlation, two-tailed t-test, and chi-square test, depending on the type of data obtained for the variable. Lastly, I used qualitative data to better understand the process and reason behind the influence of these variables so as to best incorporate them into the agent-based model.

4. HEAL Agent-Based Model

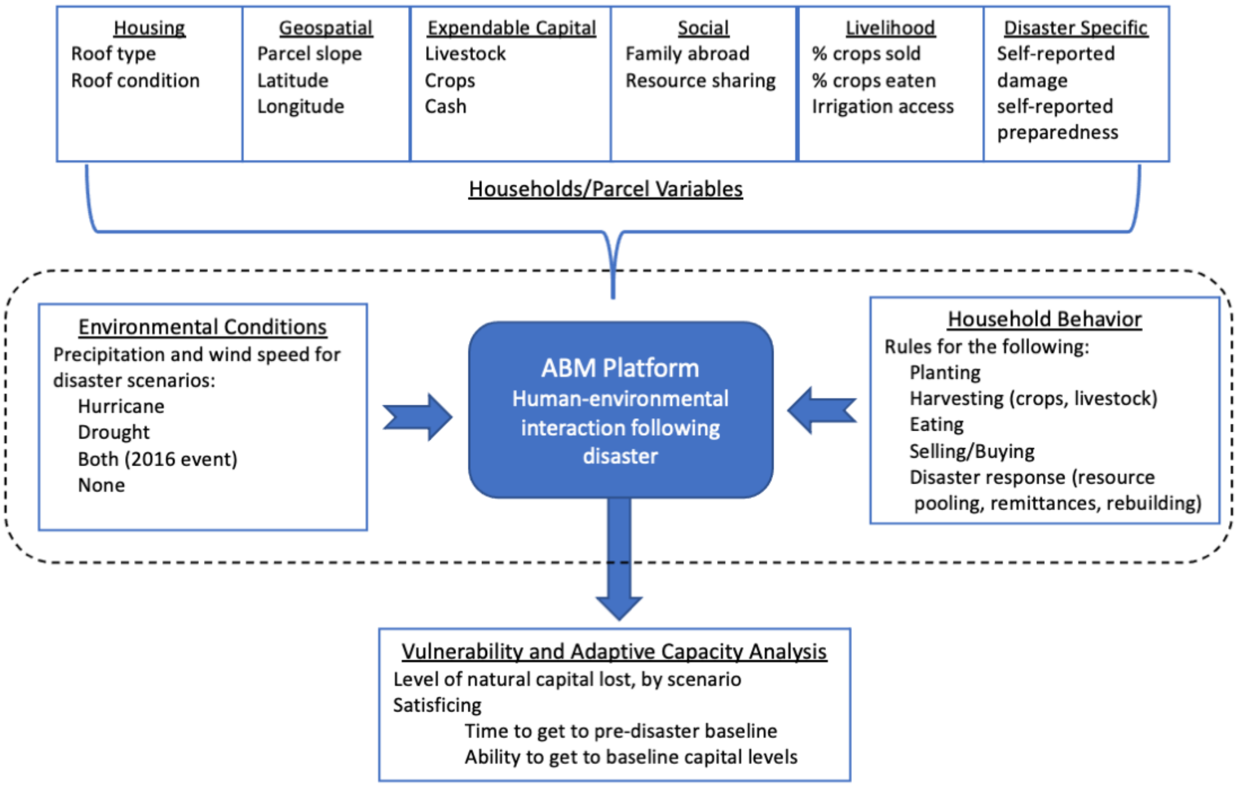

Figure 4.2 Input and output for Households, Environment, and Adaptation of Livelihoods (HEAL) interdisciplinary agent-based model for disaster study of rural livelihoods in small island developing states.

4.4.1 ODD protocol for the HEAL Agent-Based Model

4.4.1.2 Purpose

This model explores factors influencing heterogeneous disaster experience and difference in perceived preparedness for future disasters across a community. I do so by linking empirical data on social, natural, and economic variables to a household and the parcel on which that household is located, based on fieldwork in rural Haiti. I then evaluate changes in each household's expendable resources and the time it takes to return to pre-disaster levels after different disaster scenarios.

4.4.1.2 Entities, State Variables, Scales

Entities in this model include farming households, the environment of Camp Perrin, Haiti, and the "Global" environment acting evenly across the landscape. The households act as decision-making units for planting, harvesting, and adapting to disturbances. As also seen in Table 4.1, households and the parcels they sit upon harbor many variables, particularly those associated with farming, animal husbandry, and disaster preparedness and vulnerability. Static variables for households include roof type, family abroad, family in Port-au-Prince, percent of crops sold vs. eaten, other sources of income, and self-reported disaster experience compared to other households in the community. Dynamic variables for households include roof condition, stored capital (cash and food), and time since the last harvest.

Households sit on patches or land parcels that possess variables from the environment as well as for livelihood use. Static patch variables include elevation, slope, access to irrigation, and slope of the associated farmland. Dynamic variables include the number of livestock of different values (high, medium, and low), pounds of crops on the land if the current crops grow to completion, weeks of crop growth, crop growth status (growing or not), and the number of plantings in the current year. Other variables exist outside of the model but are associated with each household and each land parcel, for comparison with model exports.

Global variables relate to weather conditions and variations from normal conditions, particularly in the form of disasters (hurricanes and droughts). They include weekly precipitation, weekly average windspeed, presence of a Hurricane (highly elevated rainfall and hurricane force winds, presence of a mild drought (4 weeks with no rainfall), and presence of a severe drought (8 weeks with no rainfall). The temporal scale is two years' duration with time steps of 1 week, and the spatial scale is the area of the municipality of Camp Perrin.

4.4.1.3 Process overview and scheduling

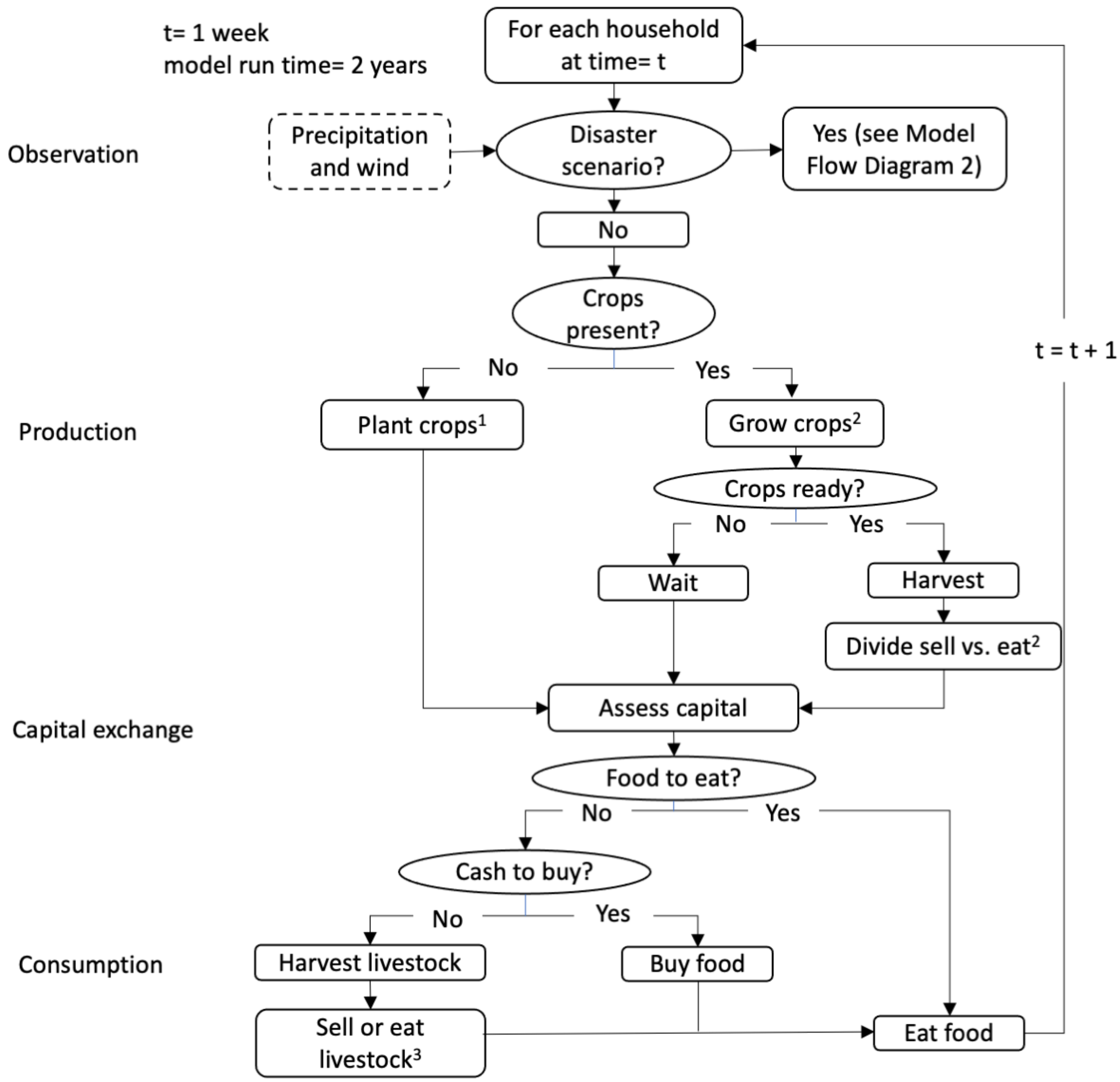

Figure 4.3 Model flow diagram 1: baseline conditions and core processes. [1]Ability to plant crops depends on time since last crop planting and number of crops planted per year (max 2). [2]Results depend on factors from initialization (i.e., Irrigation access, slope of land, and % eat vs. sell crops). [3]Livestock use depends on availability and value, with lowest valued livestock being sold or eaten first and medium and high value livestock retained for capital storage.

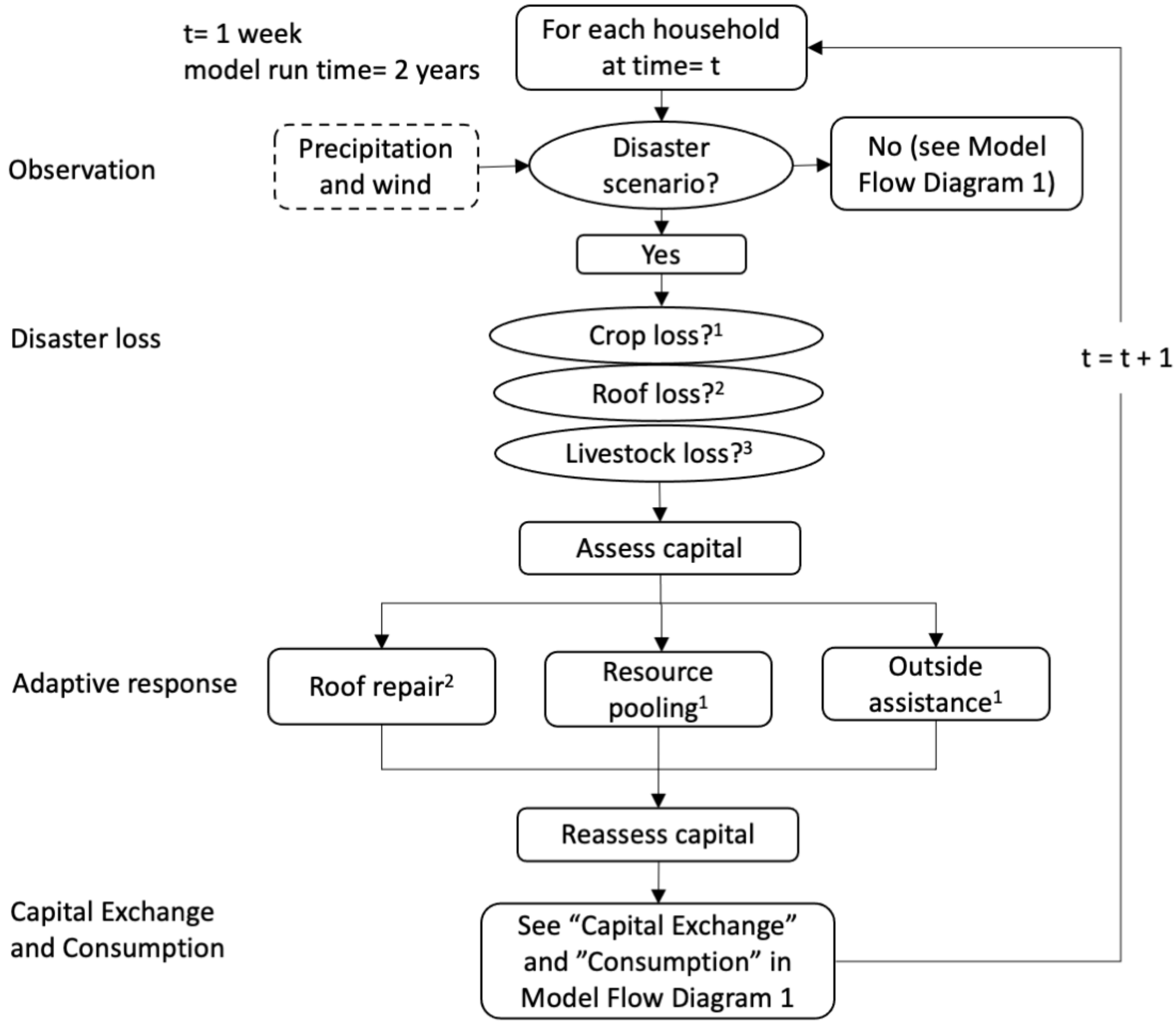

Figure 4.4 Model flow diagram 2: processes under disaster scenarios. [1]Results depend on factors from initialization (i.e., Irrigation access, slope of land, and % eat vs. sell crops). [2]Roof loss and need to repair depends on roof building material (i.e., concrete vs. other). [3]Livestock loss depends on availability and value, with lowest valued livestock being lost more easily in disasters.

Figure 4.3 visually depicts the flow of the model without any disturbance. Figure 4.4 expands on this process flow to include the impacts and responses to disturbances. A disturbance occurs at the beginning of all scenarios, sometimes multiple disturbances (except for the baseline scenario to compare to other scenarios). Each time step after this disturbance, the household moves through a series of sub-models: Planting, Consuming, Selling, Buying, Adapting

(Resource Pooling, Remittances, Rebuilding, etc.). Actions taken by the household depend on the state variables, variables linked to the parcel, and global variables like precipitation. The process continues until the household reaches its baseline of assets and house condition again after a disturbance, or two years, whichever comes first. For each household, the time it took to get them back to baseline was recorded.

4.4.1.4 Design Concepts

Basic principles: This model's basic principle is to explore how small-scale farming households fare differently across different types of disasters and different disaster frequencies. The model assesses the ability of households to return to pre-disaster levels of production along with the speed to accomplish this, and it provides the opportunity to assess these recovery timelines in comparison to variables from surveys, observation, and spatial analysis.

Emergence: Important model outputs include observation of the pattern of returning to pre-disaster capital levels. Forms of capital for this model include stored capital in household (food, cash, and rebuilt roof) and stored capital on the land (crop growth, livestock of low, medium, and high value).

Adaptation: As observed at the study site, households adapt to disasters by pooling resources (namely food) across collectives of households. Those households that eat more than they sell, do not have family abroad to receive remittances from, and do not have access to irrigation tend to pool more resources for longer periods than households more involved in the cash economy and those that have cash crops fed by irrigation. Other forms of adaptation include shifting to rely more on another income source, receiving support from family/friends in Port-au-Prince, and receiving support from family/friends abroad.

Objectives: The objective of agents is to take care of their household financially and subsistence-wise, repair home, and return to pre-disaster levels of capitals. Adaptation effectiveness is measured by the ability to and the time it takes to repair home and return to pre-disaster levels of capital. The state of the variables for the parcel and the household on the parcel determine the adaptive mechanism selected (e.g., households without irrigation access tend to pool resources, resources are sold off in the order of crops then low value livestock then medium value livestock then high value livestock).

Learning: Households embedded in the cash economy and with cash-crop supporting resources like irrigation, here named IRG households, tend to follow their same, tried and true adaptive strategies. From observation and survey data, they only deviate from their learned adaptation in the most extreme disturbances. Households reliant only on rainfall (RAIN) change some in their adaptation, increasing resource pooling as the severity of the disaster increases. Outside of that, households use their long-used strategies concerning planting and livestock use. This may produce part of the current shift from perceived normal: disasters occur in higher frequency and severity, and routine adaptation cannot fill the void of needs.

Prediction: From mixed-method analysis, households predict that the future will be like the past. For centuries, their families have been planting at the same time and have relied on predictable rainfall patterns. Yet, rainfall timing and frequency is changing in the Caribbean. The changes are unpredictable, resulting in some prediction but often inaccurate predictions based on unpredictable variation induced by climate change (Cashman et al. 2010, Taylor et al. 2012).

Sensing: Households sense how much capital they have, their stage of crop growth, the number of times they have planted that year, and the global variables like precipitation and wind speed. Based on prediction and wind speed, they can sense if they are experiencing normal conditions, a mild drought, a severe drought, or a hurricane, and they can respond accordingly.

Stochasticity: Model outcomes come from differentiation of starting variables and associated adaptive strategies with changes in global variable (precipitation and wind speed) during a scenario. In future analysis, I will include more stochasticity through probability distribution and sensitivity analysis.

Interaction: The main form of interaction in this model comes in the Resource Pooling sub-model. In this sub-model, all households resource pool but to different extents. IRG households do so for a week at most and only with a smaller percentage of their expendable capital. RAIN households average more resource pooling, more than a month in extreme events. They likewise pool a higher percentage of their resources, since they rely less on the more individualistic cash economy. In this sub-model, RAIN households spread their capital more, increasing those that have low capital and decreasing those that have more.

Collectives: Households form collectives that pool resources during the Resource Pooling sub-model. These collectives separate into a group of households with access to irrigation and a group of households without access to irrigation.

Observation: The outcomes to observe from this model are differences between scenarios and between different households and subpopulations that practice different adaptive strategies. More specifically, I observe the speed of recovery for different households and subpopulations and how their assets change over time following a disaster or series of disasters. The three assets of interest for this model's purpose are household capital stored as cash, food, and livestock of different value (low, medium, and high). Simplified for modeling purposes, once these forms of stored capital reach their pre-disaster level and their house is repaired, this model considers a household "recovered" from the disaster or series of disasters.

4.4.1.5 Initialization

Table 4.1 Model parameters. Providing more detail to model flow diagrams in Figure 4.3 and Figure 4.4, this table focuses on parameters in the model and some rationale behind them.

Parameter	ID	Value	Static or Changes	Influence and Rationale
Model Initialization				
Roof type	roof_type	1 (concrete), 0 (metal, tarp)	Static	From survey data. Influences loss during hurricane.
Farm slope	farm_slope	flat, mix, slope	Static	From survey data. Influences crop output: flat with 100 unit production, mix with 90, and slope with 80.
Crops sold (%)	crop_sell	0, 25, 50, 75, 100%	Static	From survey data. Influences % crop harvest going to cap_cash.
Crops eaten (%)	crop_eat	100 - (crop_sell)	Static	From survey data. Influences % crop harvest going to cap_food.
Irrigation access	irrig	0 (RAIN), 1 (IRG)	Static	From survey data. Influences crop survival in mild droughts and adaptive strategies.
Latitude	lat	latitude	Static	From GIS data. Determines location on visualization.
Longitude	long	longitude	Static	From GIS data. Determines location on visualization.
Roof condition	roof_condition	1 (present), 0 (absent)	Changes	Assumed all livable houses have roof. All start 1 (present).
Livestock- low value	cap_live_low	# animals	Changes	Initial value from survey data.
Livestock- medium value	cap_live_med	# animals	Changes	Initial value from survey data.
Livestock- high value	cap_live_high	# animals	Changes	Initial value from survey data.
Crops stored	cap_crops	# weeks worth of meals	Changes	Simplified from interviews and surveys. Changes with Production, Capital exchange, and Consumption.
Cash stored	cap_cash	cash equivalent to # weeks worth of meals	Changes	Simplified from interviews and surveys. Changes with Production, Capital exchange, and Consumption.
Global variables				
Precipitation	precip_wk	# inches per week	Observer changes	Changes with scenario.
Wind speed	wind_wk	0 (normal), 1 (hurricane force)	Observer changes	Changes with scenario.
Water presence in irrigation canals	irrig_full	1 (Yes), 0 (No)	Changes	From interviews about lack of water presence in canals after multi-month, severe drought. Depends on recent rainfall. If weeks since last rainfall > 8, switches to 1 (Yes).

At initialization, all households are rooted on the land parcel associated with GIS data collected during household surveys. All households begin with input data specific to them and starting conditions generic to all households, as seen in Table 4.1. The model starts at the beginning of a typical growing season, with crops already in the early stages of growth on the land parcel. Land parcels have variables ascribed from survey results with the household. All houses begin fully intact, with no roof damage.

4.4.1.6 Input data

I input a csv file with the pertinent survey results and GIS data for location of each household, as shown in Table 4.1. Some of these variables remain static (such as roof type, having family abroad, having access to irrigation, elevation, and slope, among others). Other variables change (number of livestock, roof condition, time since the last harvest, among others). Certain variables influence effects on capital and the actions taken by the household, such as access to irrigation influencing crop death in a mild drought and roof type influencing damage following a hurricane. Precipitation and wind variables change with each time step if a disaster develops. Otherwise, they stay at the annual average. Precipitation influences crop survival, animal survival, and flood/landslide damage. Wind influences house damage an animal survival.

4.4.1.7 Sub models

Table 4.2 Model processes and sub-models. Providing more detail to model flow diagrams in Figure 4.3 and Figure 4.4, this table focuses on specifics of processes in the model and some rationale behind them.

Process Name	Sub-Model	Process
Observation		
Sense scenario	sub_sense	If wind_wk = 1 (hurricane force), hurricane observed. If weeks since last rainfall > 4, mild drought. If weeks since last rainfall > 8, severe drought.
Production		
Plant	sub_plant	Due to lack of resources, people can only farm twice a year. Only plant after 26 weeks after harvest (half a year). If households lose all their crops, they will use all resources to plant again right away to make up for lost crops.
Grow	sub_grow	If crops planted and rain is present, crops grow each week until they reach harvestable level.
Harvest	sub_harvest	If crops reach 10 weeks growth or the equivalent after disturbed by a mild drought, they are harvested. The percent going to stored food and stored cash depends on crop_sell and crop_eat value for household.
Capital exchange		
Sell crops	*in* sub_eat	With enough to feed average household (3 people), eat 3 weekly potions. If needed, exchange cash for food. If not enough cash, enter sub_harvest_live.
Harvest livestock	sub_harvest_live	Harvest and sell livestock for cheaper food in stressful time, beginning with least valuable livestock. Reduce cap_live in category and increase cap_food by 10 (low value), 40 (medium value), 100 (high value).
Consumption		
Eat	sub_eat	Eat stored food from crops if available and reduce amount of stored food.
Disaster Loss		
Crops lost	*in* sub_grow	Mild drought: crops grow at half speed without irrigation and full speed with irrigation. All crops destroyed in a hurricane or severe drought.
Roof lost	*in* sub_rebuild	If a hurricane occurs and households have a non-concrete roof, roof is lost.
Livestock lost	sub_live	Mild drought: lose 20% of cap_live_low and 10% of cap_live_med. Severe drought: lose 60% low, 40% med, 20% high. Hurricane: lose 80% low, 60% med, 40% high. Higher value livestock is larger and less likely to get diseases or get injured/lost during disasters.
Adaptive response		
Resource pooling	sub_pooling	RAIN pool all food until severe scenario ends (severe drought, hurricane, compound disaster) or pool half of resources during mild drought. IRG pool during severe events with half of resources for half of the time.
Remittances	sub_remittances	IRG are more likely to have family abroad. Disasters that make the news (i.e., hurricanes) are more likely to produce remittances. Simplified here, IRG receive 100 cash units after hurricanes. This can only happen once per year.
Rebuild roof	sub_rebuild	If roof is lost, household must pay to replace it with 100 cash units. To reach this amount, they may need to sell food or sell livestock.

I show the suite of sub-models in Table 4.2 and provide more detailed explanation throughout this section. In general, all processes are simplified from surveys, interviews, and observations. Many other interactions exist between humans and the environment and across households. What I include in this model are the factors that significantly impacted disaster experience in the case study. Should these disaster frequencies continue, things like tree cutting and wood fuel use may result in loss of tree cover, but that is outside the scope of this model.

Sense: Households sense if a disaster has occurred, noting the condition as 1) baseline, 2) mild drought, 3) severe drought, 4) hurricane, or 5) combination of hurricane and disaster (compound disaster).

Plant: Crops are only planted if 1) nothing is currently in the field, 2) there have been less than two plantings in the past year, and 3) if the last harvest occurred more than 25 weeks ago. This setup accounts for the limited resources like seed, labor, and soil nutrients that limit the number of crops that can grow in a year. It also spreads planting out if a harvest occurred recently and the household has ample food levels. However, as seen observed in 2016, households will plant shortly after a disaster ceases, in an attempt to regain resources lost and return to pre-disaster levels.

Grow: Crop growth varies depending on precipitation and if the household has access to irrigation (IRG) or if they do not (RAIN). Crops grow by 1 "week of growth" each time step, making a crop ready for harvest in 10 weeks (10 time steps) if there is no disturbance (Westerfield 2019). If no precipitation occurs in a week, RAIN crops stop growing momentarily but IRG crops continue. If a mild drought occurs (4 weeks), half of the crops die for RAIN households but no crops die for IRG households who use water from canals. If an extreme drought occurs (8 weeks) all crops die for all household, since canals run dry, as seen in 2016. If a hurricane occurs, all crops die, with no variation in IRG and RAIN households.

Livestock: Livestock stay unless numbers decline from 1) a hurricane, 2) a mild drought, or 3) an extreme drought, with different outcomes for each. When a hurricane occurs, low value livestock with less weight get taken away more frequently than heavier medium value and high value livestock. When there is a mild drought, less sturdy low value and medium decrease, but the hardier high value stay the same. When an extreme drought occurs, all decrease but at differing levels.

Harvest: Once the crops grow fully (10 weeks under average conditions), households harvest them, switching crop capital from the landscape patch to the household.

Adapt- Resource Pooling: Surveys following the disasters of 2016 reveal different length and level of resource pooling depend on access to irrigation and corresponding reliance on cash economy. During a mild drought, households with irrigation access (IRG) rely on canals and do not pool resources. Households that rely on rain instead of irrigation (RAIN) share some of their available food resources. After severe droughts and hurricanes, IRG households begin pooling some of their available food resources for short periods of time. RAIN households pool all of their available food resources for long periods of time.

Adapt- Remittances: The opportunity for remittances only exists for households with family/friends abroad and, to a lesser extent, for those with family/friends in the capital of Port-au-Prince (PAP). From surveys, interviews, and observation, households of Camp Perrin pride themselves in self-sufficiency. Those with the opportunity to do so only seek external help in severe events. In severe droughts and hurricanes, those with the appropriate connections seek assistance outside of the local community. To better visualize these differences, I simplify remittances based on their category of IRG or RAIN, more clearly revealing the influence of a particular adaptive strategy.

Eat: The most basic need of households is to eat enough to sustain their household for that week. If food or cash is available, households eat. If the subsistence-related capital related to the household (cash and harvest crop) does not last a week, households seek out other methods, such as harvesting livestock, to achieve weekly sustenance.

Harvest Livestock: Due to valued stored capital of livestock, households only harvest and sell/eat livestock when have no other option or require additional capital to meet immediate needs. When selling or consuming livestock households move strategically from low value (chickens, rabbits, doves) to medium value (goats, sheep) to high value (cows, pigs, ox).

Rebuild- Home: If a household has basic food needs met, they move on to other priorities. If their roof is missing and they have the money to fix it, then they repair their roof.

Rebuild- Cash: If a household has a complete roof, a week's worth of food, and livestock levels equal to or greater than pre-disaster levels, then the household seeks to rebuild their cash to pre-disaster levels.

4.4.2 Model Analysis

I analyzed the trends of stored capital (cash, food, and livestock) available to each household before, during, and after each of the scenarios. I likewise analyzed the time it took for households to recover and return to a point of satisficing, here meaning that the household has reached their pre-disaster capital levels (for cash and food, livestock left out due to breeding complexity). I then compared these outputs to the adaptive strategy used by different subpopulations of households to assess the impact of different adaptive strategies in the face of different disaster scenarios.

4.5 Results

Model outcomes for 5 scenarios (1 baseline scenario and 4 different extreme weather event scenarios) produced different outcomes across the two subpopulations with different adaptive strategies. The results include graphs for each scenario and a spatially explicit plot of results, seen in the following sections and Figure 4.5 through Figure 4.9 contained within them. The first two graphs for each scenario chart changing levels of capital in the form of average units of crops (cap_crops) average units of cash (cap_cash), averaged across all households with access to irrigation (IRG) and all households with no access to irrigation (RAIN) through the 104 time steps (weeks) of the two-year model duration. The next two graphs chart changing levels of livestock of low value (cap_live_low), medium value (cap_live_med), and high value (cap_live_high) for IRG and RAIN households. The graphic plots for each scenario show locations of households cased on latitude and longitude, with the more mountainous region to the north and the flat floodplains to the south. The brighter the color, the higher the final level of combined cap_crops and cap_cash after the 2-year model duration.

Scenario 1. Baseline, no disturbance

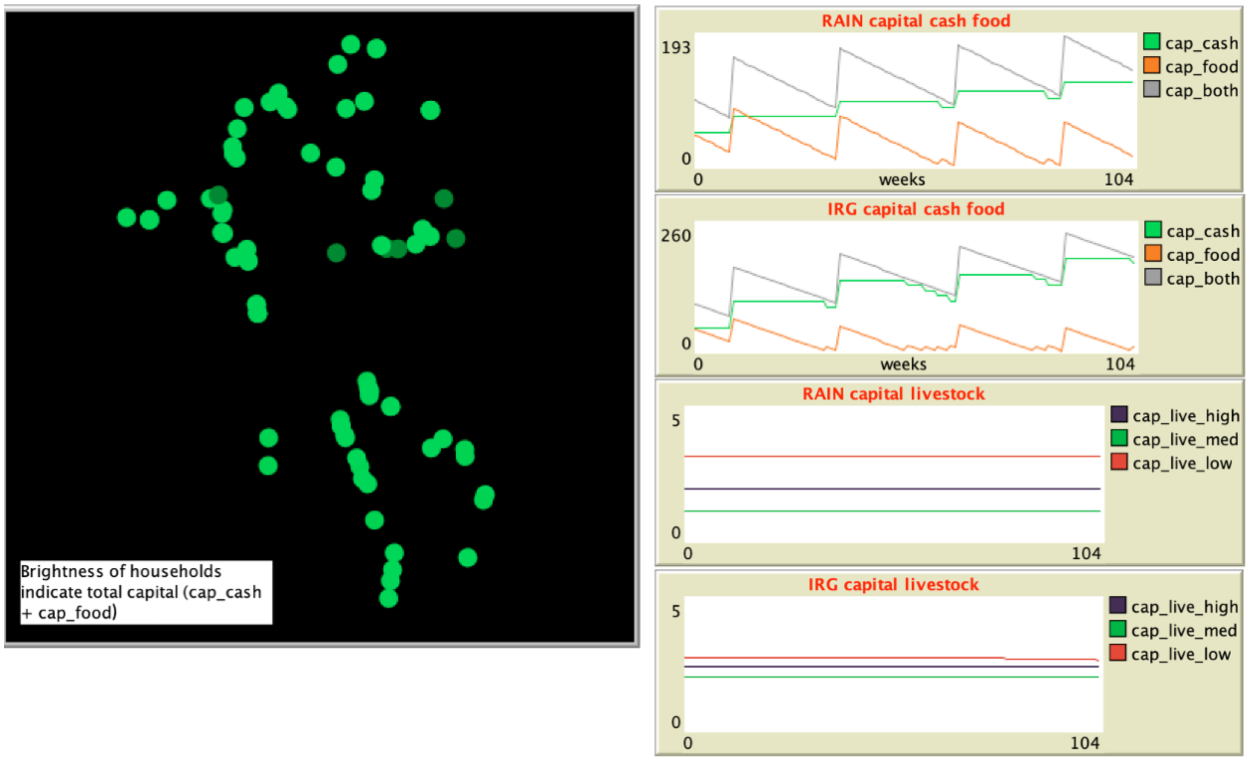

Figure 4.5 Model outputs for scenario 1: baseline, no disturbance. Left plot shows relative capital compared to other households at the end of model cycle (2 years) with the more likely to have irrigation plains households to the south (bottom) and less likely to have irrigation mountain households to the north (top). Right graphs show average level of capital stored for RAIN households and IRG households in forms of cash, food, both cash and food, and livestock of various values (high, medium, low) as the mode progresses through 2 years.

In Scenario 1, RAIN and IRG showed similar trajectories of growing, harvesting, eating, and buying crops as needed, as seen in Figure 4.5. Towards the beginning of each new harvest period, households begin to run out of stored food and exchange cash capital for food capital, which they then consume. The main differences include: 1) the higher cap_cash and lower cap_food in IRG households. This comes from the aggregation of how each individual household decides what percentage of crops to sell and how much to consume, data coming from surveys and implemented specifically for each spatially explicit household. This demonstrates the livelihood strategies for those with irrigation access to grow cash crops for sale mor than RAIN households. 2) IRG households end with a higher average final combined food and cash capital (cap_both). This may come from the higher productivity of IRG household farmland, which is more likely to have less of a slope. RAIN households tend to live in the mountains, with less productive lands. Yet, both groups increased their capital from their 100-unit baseline over the two-year period, when no disaster occurred.

Scenario 2. Hurricane

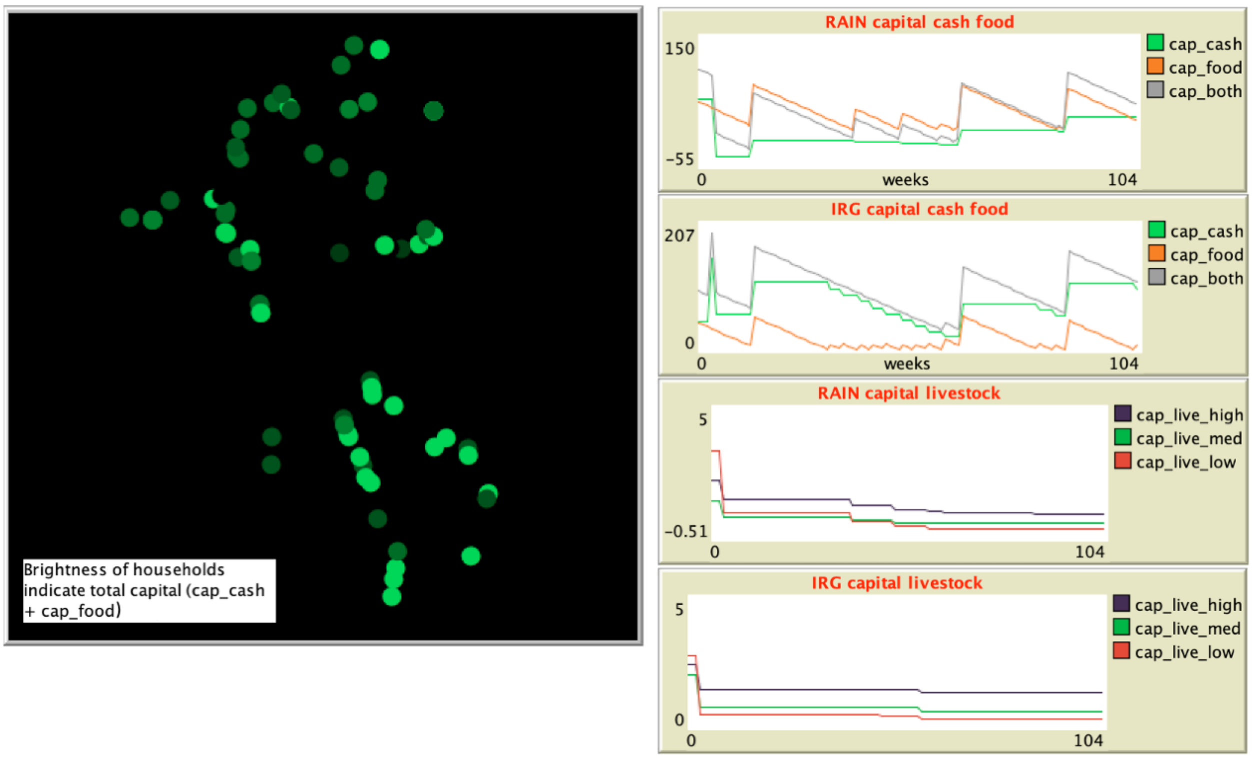

Figure 4.6 Model outputs for scenario 2: hurricane. Left plot shows relative capital compared to other households at the end of model cycle (2 years) with the more likely to have irrigation plains households to the south (bottom) and less likely to have irrigation mountain households to the north (top). Right graphs show average level of capital stored for RAIN households and IRG households in forms of cash, food, both cash and food, and livestock of various values (high, medium, low) as the mode progresses through 2 years.

In the hurricane scenario, IRG households saw a spike in cap_cash from reparations just after the disaster, as seen in Figure 4.6. RAIN households, more likely to have metal roofs, saw an average decline in cap_cash as many households needed to repair their lost roof. RAIN households also sold low, medium, and high value livestock in the between the first harvest period and the harvest occurring in the new year. During the same period, IRG households used their cap_cash, bolstered by remittances from family abroad to buy food until the next harvest period. IRG households saw livestock loss in the drought but minimal average loss in the year that followed, with some variability based on household. Most importantly for IRG households, they retained relatively high levels of high value livestock, which can be sold if more disturbances arise. RAIN households, who relied on resource pooling, prevented individual households from losing everything, but the average fell and rose with the crop cycles, ultimately ending slightly lower than their original cap_both and with less livestock. The associated plot shows the spatial distribution of household capital, with those in the lowlands to the south faring much better than those in the steep mountains to the north.

Scenario 3. Mild drought

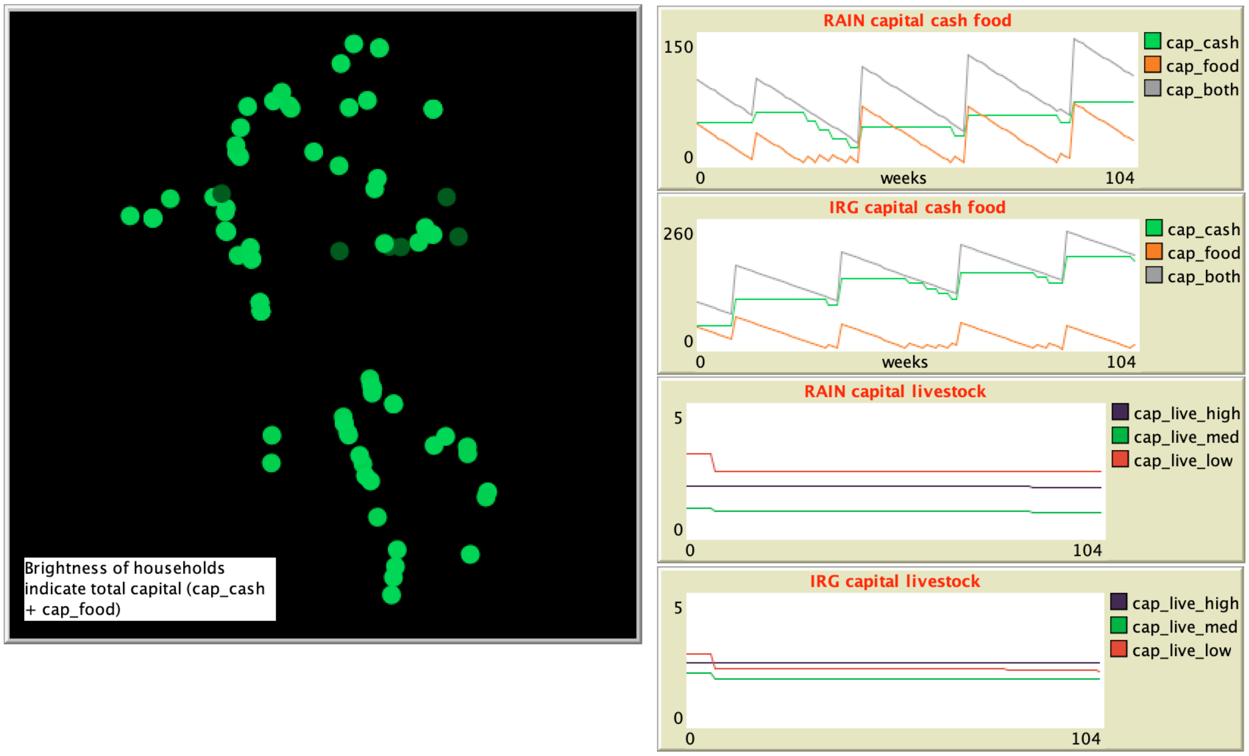

Figure 4.7 Model outputs for scenario 3: mild drought. Left plot shows relative capital compared to other households at the end of model cycle (2 years) with the more likely to have irrigation plains households to the south (bottom) and less likely to have irrigation mountain households to the north (top). Right graphs show average level of capital stored for RAIN households and IRG households in forms of cash, food, both cash and food, and livestock of various values (high, medium, low) as the mode progresses through 2 years.

The mild drought scenario showed a more equal pattern of capital dispersal across the landscape, as seen in Figure 4.7. This scenario quickly reduced RAIN household food levels, but IRG households remained relatively unchanged, only losing a limited amount of low and medium value livestock. Since water continues to flow in the canals during the more common, mild drought, IRG households ended up unscathed, increasing their stored capital. RAIN households returned to pre-disaster capital levels, but only after another crop cycle when rain fell again.

Scenario 4. Severe drought

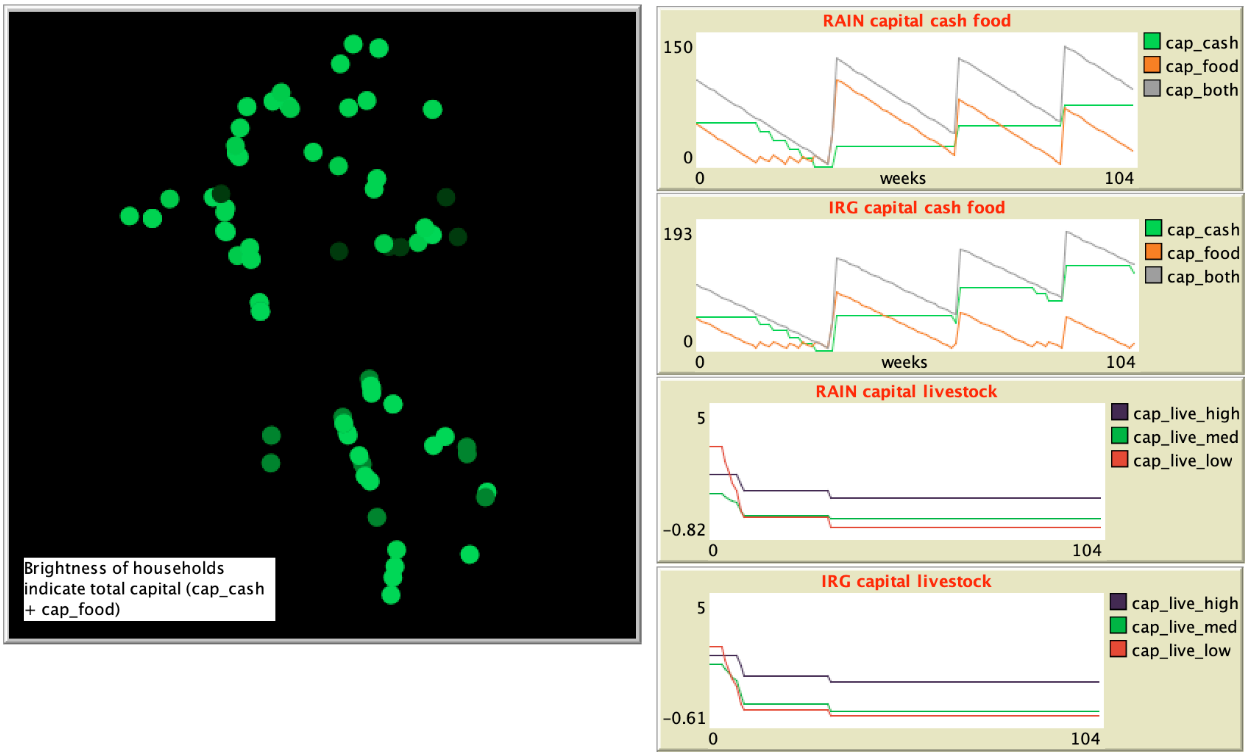

Figure 4.8 Model outputs for scenario 4: severe drought. Left plot shows relative capital compared to other households at the end of model cycle (2 years) with the more likely to have irrigation plains households to the south (bottom) and less likely to have irrigation mountain households to the north (top). Right graphs show average level of capital stored for RAIN households and IRG households in forms of cash, food, both cash and food, and livestock of various values (high, medium, low) as the mode progresses through 2 years.

The severe drought scenario produced similar results for both IRG and RAIN households, as seen in Figure 4.8. With no rain and with no water in the irrigation canals, both groups rapidly lost food capital and gained no cash capital until rains fell again. Both groups lost large amounts of livestock. IRG households ended up eventually doing slightly better than RAIN households, likely due to the aggregation of households with more productive farmland. Of note, spatial distribution of capital appeared more evenly dispersed in mild and severe droughts than with hurricanes.

Scenario 5. Hurricane then severe drought

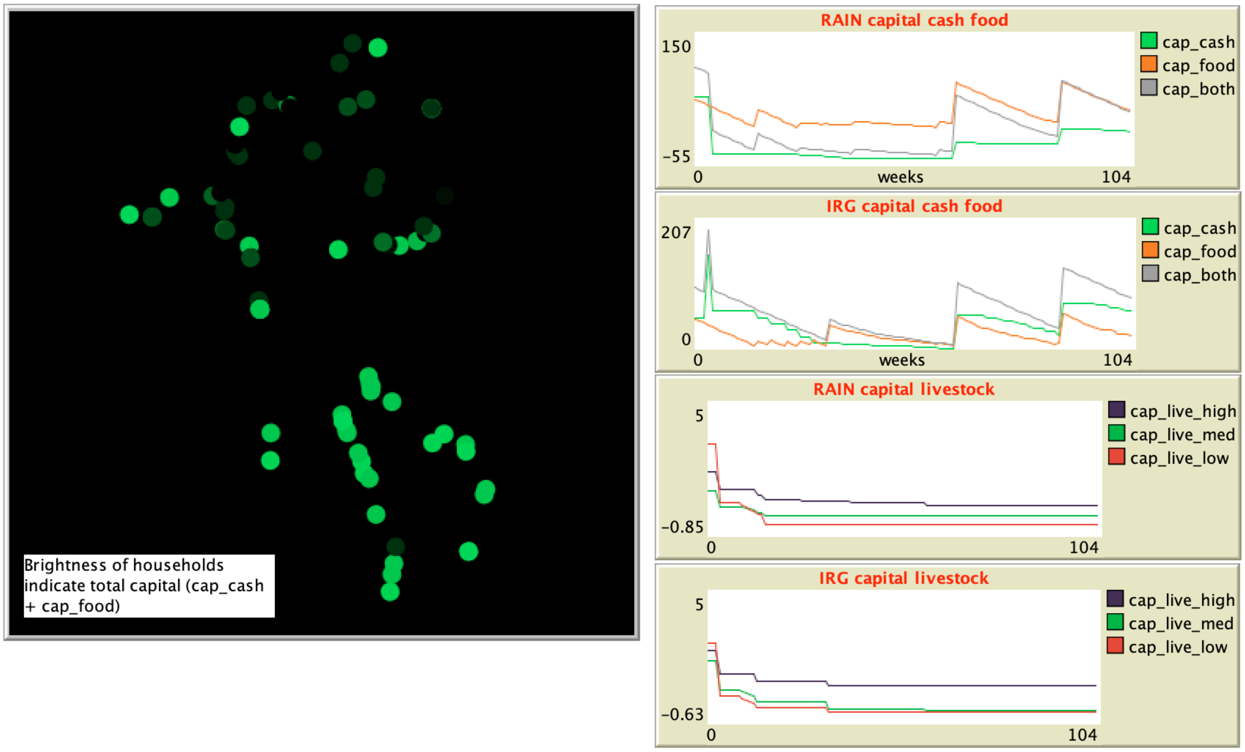

Figure 4.9 Model outputs for scenario 5: compound disaster (hurricane followed by severe drought). Left plot shows relative capital compared to other households at the end of model cycle (2 years) with the more likely to have irrigation plains households to the south (bottom) and less likely to have irrigation mountain households to the north (top). Right graphs show average level of capital stored for RAIN households and IRG households in forms of cash, food, both cash and food, and livestock of various values (high, medium, low) as the mode progresses through 2 years.

Differences in the compound disaster (hurricane and drought) scenario compared to others include the much longer time for both groups to recover (with RAIN not recovering in the 2-year duration and IRG peaking above the pre-disaster level but dipping down again) and the drastic loss in livestock, as seen in Figure 4.9. When considering adaptive strategies, the resource pooling of the RAIN households provides an adequate level of food for all across the most difficult time period. Yet, this pooling involved consuming much of the livestock, including those of high value. IRG households relied on less resource pooling and relied more on outside assistance through remittances. In this way, IRG households never went below 0 in their average capital. Yet, RAIN household did. In the context of this model, this means reaching a level that required intervention or assistance outside the scope of the adaptive strategies listed here. This could include non-profit assistance and possible outmigration to areas less impacted by the disasters.

4.6 Discussion

The HEAL agent-based model shows the outcomes of households having different adaptive strategies and different levels of vulnerability in the face of different disaster scenarios. It likewise questions common misconceptions about disasters and natural resource use in small island developing states. Seen in other agent-based models, farmers can be broken down into two types when considering water use and planting strategy: Type 1) those that stick to one crop type of high value which also requires high water input, and Type 2) those that that take more precautions by planting a variety of crops, including those with lower water needs, and the distribution of Type 1 and Type 2 farmers varies across locations based on policies and available resources (Yuan et al. 2021). Those households with access to irrigation in Camp Perrin, Haiti have the ability to be more "adventurous" or risk taking in their planting. They can plant high cash value monocrops with relatively high water needs. Those relying only on rainfall also tend to be those households that eat more of their crops than they sell. With annual subsistence dependent on crop production, they plant a wider variety of crops to cover a range of precipitation and pest issues. But, in doing so, they limit their potential cash yield from crops compared to their Type 1 counterparts. This setup maintains homeostasis throughout baseline times and mild droughts, but extreme droughts and compound disasters complicate the effectiveness of these strategies.

As seen in the DROP model (disaster resilience of place) (Cutter et al. 2008), when looking at the community level, resilience to disasters is dependent on many conditions, including the severity of the event, the time between events, and influence of other factors acting on the community. the combination of the event and the conditions at the time of the event can change the degree of damage caused, possibly exceeding the ability of the agent or system to absorb the blow without harming chances and speed of recovery. Adaptation following the event (such as improvisation and social learning) can likewise increase the degree and speed of recovery. But, when time between events diminishes, the starting condition (social, natural, and built) remain in a damaged condition, produce disasters that may slow recovery and leave the household or community more vulnerable to coming events.

Ultimately, this model questions two false narratives: 1) that local resource users tend to misuse the resources they depend upon due to ignorance, apathy, or short-sightedness, and 2) that disasters occur randomly and produce unfortunate events, isolated form other factors. When combined, the dual false narrative is that The HEAL agent-based model shows that natural resource use varies depending on the availability of resources of a particular type at any point in time. In small island developing states, the levels of available capital from these natural resources depend largely on the disturbances that destroy resources and increase the need for local peoples to use the resources available to them. As seen across the 5 scenarios, disasters influence natural resource use in different ways, depending on timing and severity. Local people respond in the ways they have learned to be useful through past disturbances that have previously led to full recovery over time. Yet, multiple disasters impede households to respond in an adaptive manner over long periods of time, not isolated to the event itself. These results question common narratives and invokes the need to address problems related to natural resource use and disaster vulnerability a) down to the root problems influencing resource use (not ignorance or apathy but system processes) and b) over long periods of time, as households may struggle for years from one or a combination of events.

4.7 Conclusions

The increase in disaster frequency caused by climate change necessitates new approaches to understanding and approaching disaster vulnerability and adaptive strategies. The HEAL model shows one method of manipulating scenarios to anticipate outcomes for those with different strategies. Another approach for future renditions of the HEAL model could be to change at which portion in the growing cycle that the disaster event occurs. Those events occurring when crops are growing may produce more influence on capital and recovery time than those occurring when crops are almost ready for harvest.

The influence of memory of past disturbances and the perception of what options households have available to them complicates the connection between adaptive capacity and action taken by agents. In this model, people respond using traditional knowledge of adaptive strategies, but the increasing frequency of disaster and linked decrease in time to rebuild and replenish resources complicates these strategies. Households increasingly rely on new strategies to increase capital in times where natural capital diminishes. Some options appear adaptive but produce long term livelihood damage. For example, remittances can help households in the short term, but overdependence on them can change local economies and reduce local production (Julca and Paddison 2010). If households with irrigation continue this adaptive strategy with increasing disaster frequency, the local independence that Camp Perrin is known for may change over time.

The HEAL ABM showed how individual behaviors in response to multiple disaster scenarios contribute to community-wide resilience in spite of repeat disturbance. Similarly, ABMs on disasters in other nations provide insight into other solutions that may avoid issues of locally untested strategies that produce short-term survival but increase long-term dependence or overall reduction of adaptive capacity. In one of the world's most drought vulnerable nations, Bangladesh, models depict a decrease in vulnerability to drought with increasing education levels and job diversification (Salam et al. 2021). Yet, the key distinction for the country of Haiti this job diversity and educational opportunities will only decrease disaster vulnerability if they occur in the rural and semi-urban settings. More jobs in Port-au-Prince or more education to fill jobs in Port-au-Prince only trades vulnerability from one type of disaster to other disasters and disturbances, like earthquakes, epidemics, political unrest, and gang violence. Instead, relocating alternative employment options outside of Port-au-Prince and to regional centers would reduce livelihood vulnerability and increase capacity in rural areas. As a rippling effect, this move would reduce resource strain and decrease vulnerability to disasters in the densely populated capital city. These and other system processes demonstrate the need for continued analysis and modelling of disasters in small island developing states, both more in depth to the systemic roots of the problem and over longer periods of time, so as to capture the long-term influence of disasters on livelihoods and natural resource use.

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CHAPTER 5

CONCLUSIONS: WHEN THE RAIN FALLS

"When the rain falls, it don't fall on one man's housetop. Remember that.
When the rain falls, it don't fall on one man's housetop."

- Bob Marley & the Wailers, So Much Things to Say

"Le lapli tonbe…"

- "When the rain falls…" (Haitian Creole)

Many of my conversations with Haitian farmers start with three Creole words: *Le lapli tonbe*, that is "When the rain falls…" People follow this phrase by expressing their frustrating and complex relationship with a changing climate. They share the longing to once again be able to predict rainfall, and they lament not knowing in what way the rain will fall again in the Haitian countryside. Will it take away everything or bring life? Will it last or cease? Will it create or destroy? In "So Much Things to Say," Bob Marley goes through problematic events, narrowing down the focus through the verses to small island developing state examples and those who sought to fight issues in the Caribbean. He then asks the audience to consider the interconnectedness of all human struggles and sufferings, centered around the same phrase heard throughout my field research: "So don't you forget, no you, who you are and where you stand in the struggle…. When the rain falls, it don't fall on one man's housetop. Remember that."

The dual false narratives explained in the Introduction ("The Naïve Local" and "The Unfortunate Poor") reveal how those outside of these nations may misunderstand the connectedness of foreign struggles to current and future international processes. Confronted with the loss of natural resources, livelihoods, and human lives from climate change-induced extreme weather events, we can assess where the wider world stands and how this is not just a Haitian problem. Contrary to "The Naïve Local" misconception that local people misuse natural resources out of ignorance, apathy, or short-sightedness, small-island developing states and small-scale natural resource-dependent communities cause very little environmental damage compared to the wider world. Instead, they respond through adaptive means to use natural resources in ways learned through the generations to produce sustainable results. Moreover, their immediate proximity to the changes in social-ecological systems causes them to feel the impact of environmental degradation sooner and to a much higher degree than nations further removed from the natural world (Julca and Paddison 2010, Méheux et al. 2007).

Contrary to "The Unfortunate Poor" false narrative, disasters do not occur as isolated points in time in which unfortunate and unavoidable catastrophes strike unlucky poor people. The people of Haiti and similar nations experience natural hazards differently because of the complex factors increasing their vulnerability and decreasing their ability to adapt in a desirable manner. Disasters constrain the ability to adapt by removing resources once available to vulnerable households, making them more vulnerable. As exposure increases with the increase in extreme weather events, it becomes increasingly apparent that what is happening in Haiti is not isolated. Instead, Haiti is an unwitting "canary in the coalmine" for what will continue advancing across the world (Villanueva 2021). The increasing frequency and intensity of hurricanes and droughts in the United States shrinks the buffer of technology and wealth that permits Western apathy toward climate change (Bender et al. 2010, Strzepek et al. 2010). With integrative social-ecological analyses like those in this dissertation, the Global North may help our neighbors of the

South while also preparing for the changes already occurring in our own nation. Extreme weather events, after all, do not just fall on impoverished rooftops.

My first recommendation to address the issue of misconceptions that prevent recognition of this connection is to increase awareness of the reinforcing power climate change has on false narratives. These narratives largely stem from the Western view of the world and our place in it. Politicians, some non-profits, and writings of popular books ultimately ignore the history of what brought countries to positions of poverty and vulnerability. Instead, they invoke a burden to do something about problems without first seeing our own role in these problems. Some of these narratives are easier to swallow then the truth, as seen in Madagascar and the Amazon, where small scale swidden agriculture is labelled "slash and burn," diverting attention from mass clear cutting and livestock production. Instead, governments and industries blame the local people and justify interventions to remove them. Haiti is no exception. It is much easier to blame supposed local ignorance, something that we can "fix" through environmental education rather than dealing with troubling facts. For example, the largest percentage of tree loss in Haitian history occurred during US occupation from 1915 to 1934, with forced work camps clearcutting the island for foreign sugar plantations. This tree loss, occurring before the current population existed, continues to increase Haitian sensitivity to disasters through events like landslides that have taken thousands of lives in recent decades (Felima 2009, McGreevy 2013). Yet, the common rhetoric around non-governmental organizations is that Haiti is poor, small-scale farmers cut down the vast majority of their trees, rural people need our help to recover from tree loss, and they the country as a whole needs our help when struck again by another unfortunate and isolated disaster.

The Western world has long viewed the rural poor, their natural resource use, and the disasters they experience through the lens of dual false narratives: naïve locals and unfortunate poor. These ideas combine to form the narrative of "The Naïve and Unfortunate Poor." In this misconception, local resource misuse and unfortunate natural events cause disasters. Climate change furthers this narrative. For example, with Hurricane Matthew, Camp Perrin saw vast tree loss. Each of the 100 research participants lost trees on their land during the storm. Households then strategically used the fallen wood to cook, rebuild, make caskets, or sell wood-based products to meet disaster-induced needs. Instead of praising local resourcefulness or drawing attention to the multifaceted issues that produced fewer trees in Haiti to begin with, the media used this snapshot of tree loss out of context to reinforce false narratives (Ho 2016).

As seen in Chapter 2, the increased frequency of extreme weather events, caused by climate change, reduces the time in which households can recover, producing compound disasters. These compound disasters do more damage than isolated events, and they can lead to system-altering outcomes. Places like Camp Perrin, once seen as "a little place apart" that once bounced back quickly from disasters and needed no outsider intervention, experiences new levels of destruction and resource loss. With enough damage, they can transition from examples that dispute these false narratives to examples that supposedly fit the mold of these false narratives.

My second recommendation is to break down these simplistic false narratives by revealing the complexity of causation in social-ecological symptoms. As seen in Chapter 3, disasters produce unexpected results, such as those with access to irrigation faring worse in a drought than those without access to irrigation. Complex interactions of wealth, degree of engagement with the cash economy, available natural resources, available infrastructure, relationships with family abroad, and past experience lead to different lived experience to disasters across a community. These complex interactions also lead to different choice portfolios from which households can choose adaptive strategies. Simple narratives become less palatable when exposed to the reality of complex causation.

My third recommendation is to properly diagnose what causes the symptoms we see in the social-ecological systems of Haiti and similar nations. Reduction in time between disasters produces worse outcomes to humans and the environment and provides less time through which both aspects of the system can regrow, replenish, and repair. As seen in Chapter 4, at some point, household adaptive strategies do not have enough time to return to pre-disaster stability before another disturbance occurs. The HEAL agent-based model highlights the importance of time and replenishment. Adaptive capacity is not unlimited, and as climate change shortens the time to rebuild adaptive capacity and replenish natural resources, it threatens long-term system change. Even seeking assistance outside of the system has its limits and cautions, with overreliance on remittances or outside organizations restructuring the system and reducing the long-term viability of rural livelihoods (Julca and Paddison 2010). While many people view disasters as isolated events, those experiencing them live with the long-term damage that disasters cause on natural use availability and potential adaptive options. Mental models from the Global North more often than not lump communities into the category of being unfortunately poor rather than understanding these communities as experiencing ongoing damage from previous disaster events.

Ultimately, slowing climate change produces the most wide-reaching benefit for small island developing states as well as for other countries less exposed and sensitive to climate change's impact. Still, strategic steps can contribute to reducing symptoms in countries that feel more burden than their neighbors. As places like Camp Perrin become less self-sufficient, aid has and will increase. Yet, if any hope exists for this avenue to produce long-term benefits, outside assistance must work to ameliorate the root of the problem and not only the more visible short-term issues. Quickly addressing symptoms brings more press and accolades. Sustaining rural livelihood viability in the face of climate change requires alternative income opportunities available in rural and semi-urban areas outside. Reduced rural livelihood viability leads to urban migration and increased vulnerability to other forms of disasters, like earthquakes (Dupuy 2012, Oliver-Smith 2012, Schuller and Morales 2012).

Lastly, most importantly, and most simply, long-term improvement requires listening. Occasionally, a single conversation with any member of the community is the difference between success and failure, between improvement or resources wasted. During one of my last days in Haiti, I walked around the remote regions of the area. On my walk, I stumbled upon a group of maybe 20 identical-looking houses with shiny new roofs. I thought to myself how the impressive sight and building layout must have cost an international non-profit and its donors a lot of time and money. A kind local family recognized me as an outsider and invited me in to see their home. Given the most comfortable of their chairs, I sat as we discussed their beautiful home, the kindness of others, the weather, and as much about the latest soccer matches as I knew (which wasn't much). As I got up to leave, I entered their kitchen, froze, and turned around. "You don't use this kitchen, do you?" No, they did not. The kitchen went straight up to the roof in an open design that spread out across all the bedrooms and the living room. As Haitians would know, this remote household obviously uses wood or charcoal to make cooking fires, and the smoke would inundate all rooms in the house. And no, no one in the 20 new houses used their kitchens, they all had to build detached structures to cook their meals.

This little example of a kitchen lacks the more visceral imagery of failed products that influence loss of life and livelihood, but it does show one thing: no one saw the need to ask a single resident about the design of their future homes. It reveals a distinctly Western outlook of people in developing nations. It again highlights the false narratives that outsiders should question each time they consider Haiti and similar nations. These people are not naïve farmers who do not know their land. These are not unfortunate poor people exposed randomly to disasters. Instead, these are intelligent people learned in traditional local knowledge. These are people worth listening to, whose livelihoods and adaptive strategies strain against the weight of climate change-induced disaster, a global issue they did nothing to cause.

I feel compelled to note that I never set out to study climate change. I actively avoided studying a topic that divides so many in the West. Instead, with some false narratives still guiding my line of inquiry, I originally sought to only study tree loss and what non-profits can do to help reduce deforestation. Climate change and its linked disasters were not something I focused on until I let go of my residual false narratives and listened with a more open mind to the people with which I studied. This new view of the lives of those in the most rural and isolated areas implored me to follow a different path of study. Opening myself to their experiences, I listened to what they considered the most pressing issue to them and adjusted my studies accordingly.

When discussing climate change, the lives of human beings often fade behind technical climate science analyses, leaving room for misunderstanding and politicization of an issue not yet felt in the daily lives of those living in the wealthiest nations. Integrative use of social science alongside natural sciences provides a discussion space to bring lived experience into the conversation. This approach can even depoliticize the issue through a focus on tangible lived experience over analyses distant from the average person in nation less sensitive to changes in natural systems.

With this approach, I invite all readers, including those skeptical of the scientific consensus on climate change, to consider the lived experience of Haitian farmers. Through the experiences of people in small island developing states, a window emerges of how climate change already impacts daily life. This view of daily life goes overlooked because the lives are of people that live in other nations. These small island developing states are too often seen as exceptional and not comparable to lives outside of developing islands. Instead, the provide invaluable insight.

Over the past decade, I have traveled to the most remote reaches of Haiti's arid Northwest, the heights of its landlocked Central Plateau, and the steep highlands of its rainy Southern Peninsula. I have had hundreds of conversations in the most remote of households. These discussions often begin by me asking people the most significant difficulties occurring in their life. The most common and pressing concern has been the changing climate, through altered rainfall frequency, increasing extreme weather events, and overall rainfall unpredictability. The climatic patterns relied upon by their parents and many generations prior no longer exist. Curious, I began following up in these discussions by asking if they have ever heard of the term "global climate change." The answer in these remote regions is nearly always "no." So, many Haitian farmers, well versed in the health of the natural world they rely upon, have never been exposed to the concept of global climate change or the political divide such a term produces in Western society. It is not political to them because these people simply state their experience: the climate is changing. The climate is changing in front of Haitian eyes, and it is producing tangible and drastic results, depleting natural resources, destroying livelihoods, and taking human lives.

With the integration of social and natural sciences, outside observers who otherwise would be less inclined to follow climate science analyses can choose to empathize with the lives of those in small island developing states. Western rhetoric of the struggle of the rural poor already prompts outside intervention. Unfortunately, it does so through popular but long-discredited false narratives. Realignment of these narratives and their momentum to address root causes of livelihood system breakdown amidst disaster and to prompt efforts at better understanding climate change vulnerability can help farmers maintain the viability of their rural livelihood and adapt to a changing world. Storms are not hitting only on rooftops of the rural poor in small island developing states. Some households have just experienced more persistent and complex forms of wear. A limited time now exists in which outsiders can learn lessons alongside people of more vulnerable states. Increasingly, climate change-induced natural hazards in wealthy nations will likewise become full-fledged social-ecological disasters.

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APPENDIX A

"HEAL" AGENT-BASED MODEL NETLOGO CODE

```
;; INITIALIZE ;;

;Load NetLogo extensions
extensions [csv gis]

;Global for weather events
globals [
  drought_len        ;Length of drought
  hurricane_time      ;Weeks since last hurricane
  drought_severe_time ;Weeks since last severe drought
  drought_mild_time   ;Weeks since last mild drought
]

;Variables for turtles (households)
turtles-own [
  id
  roof_type       ;0 = non-concrete, 1 = concrete
  fam_abroad      ;0 = no; 1 = yes
  fam_PAP        ;0 = family
  crop_sold
  inc_other
  h_dmg
  d_dmg
  h_prep
  d_prep
  roof_condition
  cap_cash
  cap_food
  time_harvest
  parcel_elev
  parcel_slope
  irrig
  farm_slope
  cap_live_low
  cap_live_med
  cap_live_high
  cap_crops
  crop_weeks
  ;crop_status
  crop_num
  crop_eat
  remittances_num
]
```

```
;; UTILITY FUCNTIONS ;;

;Irrigation canals full if not a severe drought
to-report irrig_full
  ifelse drought_len > 8 [report 1] [report 0]
end

;Hurricane occurs depending on wind strength
to-report hurricane
  ifelse wind_wk = 1 [report 1] [report 0]
end

;Mild drought if no rain for 4 days
to-report drought_mild
  ifelse drought_len > 4 [report 1] [report 0]
end

;Severe drought if no rain for 8 days
to-report drought_severe
  ifelse drought_len > 8 [report 1] [report 0]
end

;Pool resources for an irrig_val group by sharing the amount of split (0 to 1)
to pool [irrig_val split]

  ;Get all irrig or rain turtles
  let pooled_turtles turtles with [irrig = irrig_val]

  ;Find the mean amount of food
  let avg_food sum [cap_food] of pooled_turtles / count pooled_turtles

  ;Redistribute food based upon the split
  ask pooled_turtles [
    set cap_food avg_food * split + cap_food * (1 - split)
  ]
end

;Save output to csv
to save_results

  ;Print headers for output
  output-print "id,cap_live_low,cap_live_med,cap_live_high,cap_cash,cash_food"
```

```
  ;Sort turtles by id and print each row to output
  foreach sort-on [id] turtles [ the-turtle ->
    ask the-turtle [
      output-print csv:to-row (list
        id
        cap_live_low
        cap_live_med
        cap_live_high
        cap_cash
        cap_food
      )
    ]
  ]

  ;Save output to CSV
  export-output "output.csv"
end

;; SETUP ;;

;Reset everything and create households
to setup
  clear-all
  reset-ticks
  setup_turtles
  setup_weather
end

;Loads households from CSV file
to setup_turtles

  ;Set turtle shape to circle
  set-default-shape turtles "circle"

  ;Set map projection and envelope
  gis:load-coordinate-system "32618.prj"
  gis:set-world-envelope (list 617000 625000 2019000 2032000)

  ;Loop through CSV rows and add a household for each row
  foreach but-first csv:from-file "data200.csv" [ row ->
    let pos gis:project-lat-lon (item  2 row) (item  3 row)
    crt 1 [
```

```
    set color approximate-hsb 140 100 100
    set xcor          item  0 pos
    set ycor          item  1 pos
    set id           item  0 row
    set roof_type     item  4 row
    set roof_type     item  4 row
    set inc_other     item  5 row
    set crop_sold     item  6 row
    set farm_slope    item  7 row
    set irrig         item  8 row
    set cap_live_high  item  9 row
    set cap_live_med   item 10 row
    set cap_live_low   item 11 row
    set fam_abroad    item 12 row
    set fam_PAP       item 13 row
    set h_dmg         item 14 row
    set h_prep        item 15 row
    set d_dmg         item 16 row
    set d_prep        item 17 row
    set parcel_elev   item 18 row
    set parcel_slope  item 20 row
    set roof_condition item 23 row
    set cap_cash      item 24 row
    set cap_food      item 25 row
    set cap_crops     item 26 row
    set crop_weeks    item 27 row
    ;set crop_status   item 28 row
    set time_harvest  item 29 row
    set crop_eat      item 30 row
    set remittances_num 0
   ]
  ]
end

;Set weather initial states to indicate no weather yet
to setup_weather
  set hurricane_time -1
  set drought_severe_time -1
  set drought_mild_time -1
end

;; GO LOOP ;;
```

```
;Run each week (tick)
to go

  ;Stops after 2 years
  if ticks >= 104 [
    save_results
    stop
  ]

  ;Run weather subroutine
  sub_sense

  ;Run household subroutines part 1
  ask turtles [
    sub_plant
    sub_grow
    sub_live
    sub_harvest
  ]

  ;Resource pooling is not per turtle as it requires other turtles
  sub_pooling

  ;Run household subroutines part 2
  ask turtles [
    sub_remittances
    sub_rebuild
    sub_eat
    sub_color
  ]

  ;Trigger next tick
  tick
end

;; SUBMODELS ;;

;Detect weather events
to sub_sense

  ;Update drought length based on precipitation
  ifelse precip_wk = 0 [set drought_len + 1] [set drought_len 0]
```

```
  ;Increment weather event times
  if hurricane_time >= 0 [set hurricane_time hurricane_time + 1]
  if drought_severe_time >= 0 [set drought_severe_time drought_severe_time + 1]
  if drought_mild_time >= 0 [set drought_mild_time drought_mild_time + 1]

  ;Reset weather events when they occur
  if hurricane = 1 [set hurricane_time 0]
  if drought_severe = 1 [set drought_severe_time 0]
  if drought_mild = 1 [set drought_mild_time 0]
end

;Plants crops
to sub_plant

  ;Plant crops at most 2 times a year
  if crop_num < 2 and (time_harvest > 15 or hurricane_time = 1) [
    set cap_crops (ifelse-value
      farm_slope = "flat" [100]
      farm_slope = "mix" [90]
      farm_slope = "slope" [80]
    )
    set crop_num crop_num + 1
    set crop_weeks 0
    set time_harvest 0
  ]

  ;Reset annual crop limit
  if ticks = 52 [set crop_num 0]
end

;Grows crops
to sub_grow

  ;Only run if crops exist
  if cap_crops > 0 [

    ;Grow crops if there is rain and no irrigation is setup
    if irrig = 0 [
      if precip_wk = 1 [set crop_weeks crop_weeks + 1]
      if drought_mild = 1 [set cap_crops cap_crops * 0.5]
    ]

    ;Grow crops if there is irrigation
```

```
    if irrig = 1 [
      set crop_weeks crop_weeks + 1
    ]

    ;Destroy crops if hurricane or severe drought
    if hurricane = 1 or drought_severe = 1 [
      set cap_crops 0
      set crop_weeks 0
    ]
  ]
end

;Determines if livestock survives
to sub_live

  ;Kill animals if hurricane
  if hurricane = 1 [
    set cap_live_low cap_live_low * 0.2
    set cap_live_med cap_live_med * 0.4
    set cap_live_high cap_live_high * 0.6
  ]

  ;Kill animals if mild drought
  if drought_mild = 1 [
    set cap_live_low cap_live_low * 0.8
    set cap_live_med cap_live_med * 0.9
  ]

  ;Kill animals if severe drought
  if drought_severe = 1 [
    set cap_live_low cap_live_low * 0.4
    set cap_live_med cap_live_med * 0.6
    set cap_live_high cap_live_high * 0.8
  ]
end

;Harvest crops into cash and/or food
to sub_harvest

  ;Harvest after crops are fully grown
  if crop_weeks >= 10 [

    ;Sell crops for cash
```

```
    set cap_cash cap_cash + cap_crops * crop_sold * 0.01

    ;Transfer remaining crops to food
    set cap_food cap_food + cap_crops * crop_eat * 0.01

    ;Reset crops and harvest
    set cap_crops 0
    set crop_weeks 0
    set time_harvest 0
  ]

  ;Track time since last harvest
  if cap_crops = 0 [
    set time_harvest time_harvest + 1
  ]
end

;Pool households resources after disasters
to sub_pooling

  ;Pool resources for hurricanes
  if hurricane_time <= 4 [pool 0 1.0]
  if hurricane_time <= 2 [pool 1 0.5]

  ;Pool resources for mild droughts
  if drought_mild_time <= 2 [pool 0 0.5]

  ;Pool resources for severe droughts
  if drought_severe_time <= 4 [pool 0 1.0]
  if drought_severe_time <= 2 [pool 1 0.5]
end

;Gain resources from family after disaster
to sub_remittances

  ;Receive cash during hurricane
  if remittances_num = 0 and (hurricane = 1) [
    if irrig = 0 [set cap_cash cap_cash + 0]
    if irrig = 1 [set cap_cash cap_cash + 100]
    set remittances_num 1
  ]
end
```

```
;Obtains food and eats it
to sub_eat

  ;Eat food from crops if available
  if cap_food >= 4 [
    set cap_food cap_food - 3
  ]

  ;Buy food if enough money
  if cap_food < 4 and cap_cash >= 4 [
    set cap_cash cap_cash - 10
    set cap_food cap_food + 10
  ]

  ;Harvest livestock otherwise
  if cap_food < 4 and cap_cash < 4 [
    sub_harvest_live
  ]
end

;Harvest livestock if there is not enough food
to sub_harvest_live

   ;Harvest small livestock first
   if cap_live_low > 0 [
     set cap_live_low cap_live_low - 1
     set cap_food cap_food + 10
   ]

   ;Harvest medium livestock second
   if cap_live_low = 0 and cap_live_med > 0 [
     set cap_live_med cap_live_med - 1
     set cap_food cap_food + 40
    ]

   ;Harvest high livestock third
   if cap_live_low = 0 and cap_live_med = 0 and cap_live_high > 0 [
     set cap_live_high cap_live_high - 1
     set cap_food cap_food + 100
   ]
end

;Rebuild roof after hurricane
```

```
to sub_rebuild

  ;Rebuild roofs if the roof is not concrete
  if hurricane_time = 1 and roof_type = 0 [
    set cap_cash cap_cash - 100
  ]
end

;Color turtles based on capital
to sub_color

  ;Set brightness based on total cap
  let cap cap_crops + cap_cash + cap_food
  set color approximate-hsb 140 100 cap
end
```