Predicting Boko Haram's Impact on the Logone Floodplain in Cameroon: An Agent-Based Simulation Approach

Undergraduate Research Thesis

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Abstract

This study investigates the indirect impacts of Boko Haram on the Logone floodplain in the Far North Region of Cameroon. While the direct threat of Boko Haram attacks remains low on the Logone floodplain, residents face new economic pressures related to the disruption of the Northeast Nigerian economy and increased military activity in the region. This study aims to quantify the magnitude of these economic impacts on floodplain residents; identify which groups are most vulnerable to the current crisis; and determine whether or not the short-term disruption facilitated by Boko Haram could precipitate long-term changes to social and economic trends on the floodplain. In order to answer these questions, I present an agent-based model that simulates the economic and demographic behaviors of households on the floodplain. After testing the effects of nine different economic crises on the floodplain model, I conclude that the floodplain system is resilient to the short-term economic disturbance caused by Boko Haram. The simulations also provide valuable insights about the relative vulnerability of different household sub-populations, the possible short-term effects of the crisis, and the effect of family size on changes in household wealth.

1. Introduction

Since 2012, Boko Haram has killed thousands of people in Northeast Nigeria and in the border regions of Cameroon, Chad, and Niger. The growing body of reportage, strategic analysis, and academic literature on Boko Haram tends to focus on the endogenous development of the group itself (Cook 2014; Agbiboa 2013), as well as the direct impact of Boko Haram in the regions where it is currently active (Nfor 2015). However, in addition to areas where they are currently active, Boko Haram has exerted indirect pressures in surrounding areas due to the closure of the Nigerian markets and an increased military presence leading to intensified taxation and restrictions on mobility and economic activity. Efforts to manage and restore the region once Boko Haram is gone must account not only for the direct damage caused by the group, but also the long-term indirect impact on the entire region.

This thesis considers Boko Haram's effect on fishermen in the Logone floodplain in the Far North Region of Cameroon. The floodplain is a social-ecological system that was already undergoing rapid changes in the years before the rise of Boko Haram. Now, Boko Haram's presence in Cameroon, along with the subsequent reactions from local government and military forces, has exerted new and significant stresses on the floodplain that threaten to change it for decades to come. I will examine the indirect effects of Boko Haram, particularly the closing of the Nigerian border and its impact on fish prices, on floodplain households. Specifically, this study addresses the following questions: what is the magnitude of the pressure placed on floodplain households as a result of Boko Haram? Which households or groups on the floodplain will experience the strongest adverse effects? Finally, could this short-term pressure facilitate a shift in the floodplain system that outlasts the disturbance itself, permanently changing residents' behavior and livelihoods?

The remainder of this introduction provides historical and theoretical context for the current crisis on the Logone floodplain. I discuss how historical factors contributed to the floodplain's shifting social and economic dynamics in the lead-up to the Boko Haram crisis. I then introduce the concepts of complexity, resilience, and vulnerability as theoretical tools for understanding the long-term effects of disturbances on the floodplain. I discuss how Boko Haram has placed indirect pressures on floodplain residents and the potential threat of those pressures on the floodplain system.

In the Methods section, I discuss agent-based modeling as a tool to understand demographic and economic changes. I introduce the agent-based model used in this study, which links economic activity and demographic changes within floodplain households. I then describe the experiment used to simulate the potential impacts of Boko Haram on the floodplain. Finally, in the Results and Discussion sections, I discuss the results of the experiments and their implications for the economic prospects of floodplain residents.

1.1 The Logone Floodplain

The Logone floodplain is one of the major floodplains in the Lake Chad hydrological system (Lemoalle 2005), and is one of the largest and most fertile floodplains in Sahelian West Africa

(Drijver et al 1995: 30). Located in the Far North Region of Cameroon, it derives its name from the Logone river, which forms the boundary between Cameroon and Chad, and Waza National Park. Morphologically, the floodplain is characterized by extreme flatness; the only raised areas on the floodplain are human-made mounds upon which people build their houses and the banks of the rivers (Delclaux et al 2010).

Under typical climactic and weather conditions, the plain is flooded by the Logone river once a year, beginning in late August or September. During the three to four months of annual flooding, water on the plain can reach depths of up to two meters (Lemoalle 2005). By December, most of the water recedes into the Logone River and the El Bëid River, leaving only a few isolated depressions filled with water (Fernandez et al forthcoming). Over subsequent months, these depressions become smaller and swamp-like before disappearing due to evaporation (Acreman et al 2004: 63).

The inundation of the floodwaters serves as a rich nursery for a variety of vegetation and fish species (Lemoalle 2005). The floods deposit rich sediment onto the floodplain and support the development of vegetation; then, facilitated by a combination of available nutrients and habitat, the floodplain attracts spawning fish. By the middle of the twentieth century, the Logone floodplain was reputed to be “one of the richest fish-producing inland waters of Africa” (Drijver et al 1995: 30). The floodplain’s richness in both vegetation and fish is the basis of the local economy; however, its ability to sustain fish stocks, and therefore support a local community, is in turn based off of the extent of the flooding. In this way, the hydrologic, ecological, and social-economic systems of the floodplain are closely linked (Laborde et al forthcoming).

Local people make a living on the floodplain through a variety of activities. People plant floating rice during the early inundation period, fish on the rivers and in man-made canals during the late flooding season, and plant crops in the fertile soil or raise livestock that graze on the indigenous vegetation during the dry season (Drijver et al 1995: 30-31). While certain groups specialize in just one activity, others are generalists: “during the same season, the local populations are alternatively or simultaneously fishers, herders, and farmers, and each part of the floodplains is potentially a fishing ground, a grazing area and a cultured field, depending on the period in the flood cycle” (Béné 2003: 188).

While pastoralists from Fulani and Shuwa Arab ethnic groups bring their herds to graze on the floodplain during the dry season, they cannot live in the Logone floodplain all year, as the pastures are inundated during the flooding season (Delclaux et al 2010). My thesis will primarily examine Boko Haram’s potential impact on two ethnic groups, the Kotoko and the Musgum, who fish or farm on the floodplain year-round (Béné 2003). While the Kotoko have been fishing on the floodplain for centuries, the Musgum are a group of traditional farmers who arrived on the plain more recently (Acreman et al 2004: 55). The following section will briefly discuss the history of the two groups on the floodplain and its relationship to the changing social and economic dynamics on the floodplain.

1.2 Historical Context

The Kotoko trace their history on the floodplain back to the 15th century (Drijver et al 1995: 32). While evidence suggests that their ethnic group originally practiced pastoralism, they quickly switched to fishing as their primary economic activity after arriving on the floodplain (Acreman et al 2004: 55). The Musgum began to appear on the floodplain in the late 19th century. In many ways, the changing relationship between the Kotoko and Musgum is a microcosm of larger events in Cameroonian history. For example, the first streams of Musgum onto the floodplain from plains coincided with the advent of the French-British "colonial peace" (Seignobos and Fabien 2003).

The Kotoko originally allowed the Musgum to live on small, uninhabited islands in the floodplain under strict conditions (Acreman et al 2004: 62). However, a new wave of Musgum migrants came from the south following Cameroonian independence in the 1960s, and governance of the new group became much more fraught. Interviews with floodplain residents[1] suggested that this wave of migrants was seeking refuge from the Sultan of Pouss, who had begun to terrorize villages after they had refused to vote for his preferred candidate in the first post-independence elections. An older Musgum man recalled people having their property confiscated, being put into forced labor, and their village being burned to the ground. With the influx of new Musgum migrants, the traditional laws of the Kotoko became increasingly difficult to enforce.

Until the 1970s, consistent farming and fishing yields and a relatively small floodplain population kept conflicts and poverty on the Logone floodplain to a minimum; however, this was disrupted by drought and the implementation of a national rice-growing scheme directly to the south of the floodplain. Under the auspices of the Cameroonian national government, a state-owned company called SEMRY ("Societe d'Expansion et de Modernisation de Riziculture de Yagoua") dammed the area to create an artificial lake known today as Lake Maga (Delclaux et al 2010). The lake drew significant amounts of water from the Logone River, limiting the river's annual flooding capacity further downstream. To prevent the rice projects from being flooded, SEMRY also built a dike along the Logone River that extended kilometers downstream. The effects of the SEMRY project had reduced the annual extent of the floodwaters by up to 30 percent (Acreman et al 2004: 7). Several drought years in the 1980s exacerbated this problem, creating a time of scarcity when many households fell into poverty or were forced to leave the floodplain (Acreman et al 2004:23). After over a decade of privation, a reflooding effort led by the World Conservation Union began to restore the floodplain's capacity. The reflooding project was completed, partially restoring the floodwaters to the Logone, by 2000 (Acreman et al 2004).

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[1] Unless explicitly stated otherwise, all interview responses discussed in this study were transcribed from a focus group conducted by Sarah Laborde during November 2015 in Maroua, Cameroon. The four interviewees included Musgum, Kotoko, and Fulbe residents of the floodplain. This focus group is currently unpublished.

1.3 A Changing Social-Ecological System

But while the floodwaters have returned to the Logone floodplain, the practices used by local groups to manage and derive wealth from the floodplain have gradually shifted. This section discusses changes in practice over time, setting the social-ecological context for studying the Boko Haram-induced disturbance that is the focus of this thesis.

The practices in place at the turn of the 20th century were regulated by the Kotoko, and involved an assortment of restrictions and regulations based on tradition and social hierarchy that effectively maintained the floodplain's ecological resources over time. For example, the Kotoko would only begin their fishing season after observing the ritual of *moutwak*, which involves spotting a late-spawning fish in the water. This traditional ensures that most of the other fish species have completed their reproductive cycles and helps to maintain fish stocks over time (Drijver et al 1995: 37). After the floodplain had receded, some fish remain trapped in nearby depressions; fishing in those depressions used to be a strictly communal activity that required approval of a local spiritual authority (Acreman et al 2004: 63).

Fishing canals, known as *irari* in the Kotoko dialect, have received special attention due to their potential profitability as well as their impact on the hydrology of the floodplain. During the dry season, fishermen are able to dig canals in the floodplain that are 1-3 meters deep and up to several kilometers long (Laborde et al forthcoming). The canals can simply extend out into the floodplain, or they can end in a depression. When the floodwater recedes during the following flood season, fish are forced into the canal's channel. Then, the canal owner simply has to place a barrier and a net around the end of his canal and wait to catch what can be, in a well-maintained and well-located canal, enormous amounts of fish. Of all the fishing techniques, the canal is the most productive by far (Drijver et al 1995: 36); however, Kotoko fishermen had to receive permission from a local authority to build a canal, which itself could only occur once a resident had reached a certain status within their village, so only a few households had the wealth and influence to do build and maintain canals.

While these traditional regulations and restrictions were likely conceived in order to monopolize resources among the local Kotoko elite, they effectively managed the natural resources of the Logone floodplain for centuries (Drijver et al 1995: 37). In the heyday of the 1960s, fishers could earn the equivalent of up to 2,000 USD in a single season (quite a lot for the floodplain); meanwhile, the lucky few owners of fish canals could make four to five times as much money (Drijver et al 1995: 36).

For the first half of the twentieth century, when the Musgum were still a minority population on the floodplain, the Kotoko fishers placed strict restrictions on their ability to exploit wealth from the natural environment. For example, the Kotoko were allowed to fish with dragnets, while the Musgum were restricted to less-productive techniques such as fish-hooks (Landolt 2010). These restrictions were enforced by the Kotoko's superior numbers and long-standing traditional institutions on the floodplain. Additionally, coming from an agricultural background, the Musgum simply lacked the technical knowledge for some of the more advanced fishing techniques (Landolt 2010).

The arrival of new Musgum immigrants in the 1960s combined with the environmental change due to the Maga Dam and SEMRY dikes eroded the power of traditional Kotoko institutions. Throughout the 1980s, a 30% reduction in the flooding extent caused fishing revenues, agricultural yields, and the available of key natural products to plummet simultaneously (Delclaux et al 2010). Musgum residents then began to fish in new locations, at new times, and using new techniques that had been forbidden to them under Kotoko law. This caused an increase in conflicts between Musgum and Kotoko residents, leading to a further breakdown in the social order (Drijver et al 1995).

Today, the water has partially returned to the floodplain, but the social-ecological regime in both Musgum and Kotoko communities is still rapidly shifting. Fish canals, once a protected resource reserved for the lucky few, have spread across the floodplain in recent decades. A survey of canal locations and ages revealed that on a subsection of the floodplain, the number of fishing canals grew from 510 in 1980 to 1,172 in 2014. Because canals are now so prevalent, they are also individually less productive (Laborde et al forthcoming). Many depressions are now being drained by canals as the floodwaters recede, leaving no fish for community fishing in the dry season. Disagreements about community fishing resources and digging new canals have spurred conflicts, which can even spiral into violence: in 2007, a battle over Sifna Pond on the floodplain left 30 dead (Delclaux et al 2010). Many people are concerned that the fishing canals are reducing the floodplain’s productivity overall, and their continued growth could cause a collapse in fish stocks. But despite this, fishing canals continue to increase exponentially in number across the floodplain (Laborde et al forthcoming).

Resource management has been shifting in the last few decades from a strictly controlled regime to a “democratized,” individual regime. Fishing canals are growing at an increasing, potentially unsustainable rate. Tensions over fishing access and new canals have been slowly growing as fish catches begin to decrease. It is this already fraught historical, social, and environmental context that Boko Haram has further unsettled since 2013, indirectly disrupting the physical security, social relations, and economic well-being of practically everyone on the floodplain.

Aspects of both continuity and sudden change are apparent in the recent history of the floodplain. While the in-migration of Musgum households, the decline of a Kotoko-dominated system of governance, and the rapid growth of fishing canals since the 1980s are all well-documented trends on the floodplain, it would be a mistake to assume that any of these shifts were inevitable. Equally important to this study is the role of rapid, dramatic changes in social and economic conditions on the floodplain, instigated by events such as the construction of the Maga Dam. Understanding how these sudden changes interplay with longer-term patterns is a crucial step towards understanding how Boko Haram might permanently alter the floodplain. To do so, a theoretical framework is needed. In the following section, I will discuss the concepts of complexity, resilience, and vulnerability, three concepts that can help to clarify Boko Haram’s potential impact on the floodplain.

1.4 Complexity, Resilience, and Vulnerability on the Floodplain

One field of inquiry investigating the interplay between short-term changes and long-term shifts in behavior is that of complexity science. Complexity science studies systems where relatively simple rules for individual behavior or decision-making produces unintuitive, "emergent" properties at the system level (Wolfram 2002). The tenets of complexity can be applied to a diverse set of systems, and the Coupled Human and Natural Systems (CHANS) perspective applies aspects of complexity theory to human-environment interactions. CHANS can be defined as "integrated systems in which people interact with natural components" (Liu et al 2007: 1513). Common traits of CHANS include nonlinear processes; thresholds, or transition points between different states; surprising, sometimes detrimental, effects created by large-scale development or conservation policies; and legacy affects, in which human-natural couplings affect systems outcomes at a much later time (Liu et al 2007). Moritz et al argue that the Logone floodplain is well-suited to a CHANS approach because it can help to uncover potential *regime shifts*, in which a system moves from one sustained state (or regime) to another (Moritz et al 2016: 101). While the present study does not explicitly engage with human-environment interactions, it engages with similar concepts of couplings, also known as feedbacks; the concept of the threshold, discussed in more detail below, is also key to the current study.

Laborde et al (forthcoming) also make use of a complexity perspective to better understand the exponential growth of canals in the Logone floodplain over time. Laborde et al trace this transition in floodplain dynamics back to a set of positive social-ecological feedbacks that incentivize individual fishermen to build and expand more and more canals over time. These feedbacks include behavioral feedbacks, where fishermen hold out hope for a more productive catch next season, or where the canal becomes an important part of their identity; socio-economic feedbacks such as the development of a fish-commerce channel to Nigeria in parallel to the growth of canal fishing; and a hydrological feedback, where more canals on the floodplain reduce the flooding time, making non-canal fishing techniques less effective. Laborde et al suggest that these feedbacks might be altered to promote the growth of different, more sustainable techniques in the future. Finding new strategies for resource management on the floodplain is a critical endeavor, as the floodplain may already be in "overshoot," locked-in to a technology that the social-ecological system cannot sustain (Laborde et al 2010).

While feedback loops can help to explain long-term trends in the Logone fishery system, the system cannot be fully understood without considering how those trends relate to crises and other short-term, dramatic changes on the floodplain. This relationship can be explored using two key concepts within the literature on disaster response in complex systems: *resilience* and *vulnerability*.

Resilience describes the ability of a system to recover from disturbances and return to its original state (Cutter et al 2008: 599). A resilience perspective conceptualizes complex systems as existing on a "stability landscape" that tends to attract systems towards certain dynamic equilibria based on their current state (Gallopin 2006: 298). Using the metaphor of a ball being drawn into an indentation in the ground based on its current position and the slope of the ground, this perspective imagines "basins of attraction" in the stability landscape as ranges of conditions under which a system (the ball) will be drawn towards the dynamic equilibrium (the indentation). If a system is disturbed by a long-term shock, its behavior can generally change in one of two ways: either the system will remain in the same basin of attraction, pulling it back towards the original stable state, or it will be pushed into a different basin of attraction, which will draw it towards a different equilibrium state over the long term (Walker et al 2004). The point at which the system moves from one basin of attraction into another, changing its long-term behavior, is known as the threshold (Gallopin 2006: 298). In other words, resilience describes whether the system will remain within its original basin of attraction after a disturbance, or whether that disturbance will move the system into another basin of attraction, changing the system's long-term equilibrium state. Key aspects of the system's resilience include latitude, the maximum degree to which a system can be changed before losing its ability to recover; resistance, the ease or difficulty of changing the system; precariousness, how close the system is to the threshold before the disturbance; and panarchy, the effect of cross-scale interactions and feedbacks on the system state (Walker et al 2004; Cutter et al 2008: 601).

Vulnerability is a complementary method for conceptualizing response to disruptions. If resilience describes a system's ability to recover from disturbance, then vulnerability describes susceptibility to harm from a disturbance (Adger 2006: 268). While resilience is a holistic trait of complex systems, vulnerability can be investigated at different scales, from individuals and households to entire cities and nations (Smit and Wandel 2006: 282-283). Two key components of vulnerability research are pertinent to this study: first, *exposure* assesses the preexisting conditions that make people and systems sensitive to hazards (Cutter et al 2003). In response to a hazard, *adaptive capacity* describes the processes within a system that allow it to better adjust to or manage changing conditions (Smit and Wandel 2006: 282). The long-term goals of vulnerability research include identifying the most important variables in "a causal chain of vulnerability" to specific stressors (Adger 2006: 273), as well as merging the fields of vulnerability and resilience to create more holistic measures of system responses to disturbances (Smit and Wandel 2006: 289).

Previous research (Moritz et al 2016; Laborde et al forthcoming) suggests that the Logone floodplain is a nonlinear dynamical system suitable for resilience and vulnerability analysis (Gallopin 2006: 299). In resilience terms, we can understand the construction of the Maga Dam as a stressor that pushed the floodplain system from one basin of attraction, in which communal canal and river fishing were primary economic activities, to another basin, in which individual fishing canals have grown exponentially over time. It is important to recognize that this change is due to both long-term internal pressures within the Logone floodplain, such as in-migration of Musgum households, as well as the "external" disturbance of the dam. In-migration increased the precariousness of the system before the dam pushed it past the threshold.

A resilience perspective also lends itself to questions about the current state of the floodplain system. How precarious is the current system, and how resistant is it to current disturbances caused by Boko Haram? Can Boko Haram move the system towards a different basin of attraction that once again changes social, economic, and ecological systems on the floodplain? Are there any positive or negative feedbacks that will amplify or dampen the effect of these shocks on floodplain residents? Vulnerability analysis, with its emphasis on individual as well as systemic outcomes, can also inform the current investigation. Which individuals or groups are most vulnerable to dramatic changes on the floodplain, and why? Now that the disturbances are in effect, what behaviors are people and groups adopting to manage the effects of Boko Haram? In the following sections, I will discuss how Boko Haram's presence has instigated a number of short-term stressors on the system, then present the specific questions addressed by this study.

1.5 The Indirect Threat of Boko Haram on the Logone Floodplain

Boko Haram, whose name may be translated to "Western Education is Forbidden" (Agbiboa 2013: 145), publicly emerged in Northwestern Nigeria around 2002, led by a charismatic Salafist preacher named Mohammed Yusuf (Rogers 2012:1). The group's identity originally revolved around theology and a rejection of colonial influences, particularly Western-style education, in Nigerian culture. Boko Haram became significantly more militant in 2009, when the Nigerian military destroyed the group's headquarters and killed Mohammed Yusuf (Rogers 2012: 1). The next year, Boko Haram's remaining leaders organized a prison-break for its captured members; then, starting in 2011 and 2012, the group began carrying out large-scale attacks on civilians in Northeast Nigeria (Cold-Ravnkilde and Signe 2015: 21-22).

In recent years, Boko Haram's operations have expanded to include the other countries surrounding Northeast Nigeria: Cameroon, Niger, and Chad (Cold-Ravnkilde and Signe 2015: 23). Since the beginning of 2015, Boko Haram has killed more than 200 people in the Far North Region of Cameroon alone, primarily through bombing attacks on markets and public gathering-places (CrisisWatch). In response, the Nigerian, Chadian, and Cameroonian militaries have all mobilized against the group. The Nigerian-Cameroonian border is closed, while Chad's border with the Far North Region of Cameroon is under strict military control (Adams 2014; Salatou 2015). The Cameroonian government has also banned gatherings of more than seven people in the Far North Region in an effort to limit potential Boko Haram attacks, effectively banning open-air markets (Kindzeka 2016). While the floodplain has not yet been subjected to direct violence as the result of Boko Haram, the group's activities have indirectly impacted the floodplain through disruption of the Northeast Nigerian economy as well as the government-mandated security measures. I discuss these impacts in detail below.

Through lootings, direct attacks, and market bombings, Boko Haram has severely disrupted the economy of Northeastern Nigeria, displacing more than 2 million people and creating the conditions for a regional hunger crisis (Searcey 2016; Nfor 2015). A 2014 survey showed that more than half of fishers on the Logone floodplain had been selling fish to Nigerian traders; the sharp drop in demand from Nigeria, compounded with the closing of the Nigerian-Cameroonian border in late 2014, have depressed fish prices on the floodplain (Adams 2014). Additionally, the closed border has raised prices for fuel and food goods that used to be imported into Northern Cameroon from Nigeria; for example, within five months of the border closing, the price of sugar increased by 50 percent (Kindzeka 2014; Nfor 2015). As a result, floodplain residents can no longer make as much money selling their food products at market, and other foods from outside are now significantly more expensive.

The presence of new authorities on the floodplain have created new difficulties and expenses for residents, epitomized by the dispute over the Logone River. The Logone is not only the source for the annual floods on the region, it is also the national boundary between Chad and the Far North Region of Cameroon, as well as an important travel corridor that many residents to access local markets. In October 2015, the Chadian military took control of the Logone River and prohibited residents from traveling on or across it to prevent Boko Haram from entering Chad and reaching N'Djamena, the capital, by the river. According to an interview of floodplain residents conducted in November 2015, many people living on the shore of the Logone have assets on both the Chadian and Cameroonian sides of the river, such as their house, rice fields, or fishing canals. When the Chadian military prohibited travel across the river, these residents lost their investments. Additionally, residents who originally traveled on the Logone now have to find alternate routes to major towns in the area, for example through seasonal rivers and fishing canals, sometimes paying expensive tolls to do so. According to interviewees, some residents still attempt to travel on the Logone at night, but those who are caught face hefty fines (Salatou 2015). These taxes are only one example; in a 2016 survey, respondents identified five different institutions that had levied new taxes in the past year alone.

In addition to food insecurity, movement restrictions, and new taxes on the floodplain, many residents are living in fear of physical violence from both Boko Haram and the armies supposedly fighting them. One interviewee discussed how he felt safe from Boko Haram during the wet season, but when the dry season came, Boko Haram fighters could easily reach their village by motorbike. Another interviewee mentioned that he had been harassed by the Cameroonian military at a local market, even though he had his ID and all of the proper licenses. Others have fared much worse. Amnesty International accuses the Cameroonian military of unlawfully detaining political opponents in the Far North Region under the guise of counter-terrorism activities (Amnesty International 2013); and in late October 2015, the Chadian military sparked uproar by killing a local Cameroonian fisherman (Kazé 2015). As one interviewee put it, "we continue to live, but we have the fear in our bellies."

Although most floodplain residents have been insulated from Boko Haram's attacks, the group's presence and the subsequent military response have placed very real burdens on floodplain residents. Floodplain residents now face more obstacles to selling their goods in markets, receive less income for the products they do sell, pay higher prices for their basic necessities, and face a proliferation of new taxes. It is possible that floodplain residents have not seen a threat to their livelihoods of this magnitude since the Maga Dam was constructed in 1979. If so, these pressures might facilitate a shift in the coupled human and natural system that outlast the disturbance itself, similarly to the regime shift that is currently taking place on the floodplain.

In the following sections, I explore Boko Haram's short- and long-term effects with a quantitative model of fisher households on the Logone floodplain. This model presents a simplified picture of family dynamics and economic activity on the floodplain from 1978 to 2014, with an emphasis on the feedbacks between demography and wealth. I then conduct *in silico* experiments to determine how disturbances to household income change the long-term economic well-being of floodplain residents. While no model can capture the full array of multi-scalar processes governing the floodplain, this model will be useful for quantifying and comparing the long-term effects of different types of disturbances on both individual households and the floodplain economy as a whole.

2. Methods

2.1 Modeling the Economic-Demographic Relationship

This thesis aims to simulate changes in socio-economic variables in the Logone Floodplain during and after the disturbance of Boko Haram. Given the complexity of the floodplain as a coupled human and natural system, Boko Haram's indirect impact will be felt differently by different groups on the floodplain according to their existing wealth, income, investments, and costs. Examining these variables requires a model capable of capturing the connection between demography and economic activities in the floodplain.

The fields of demography and economics are increasingly dealing with the challenge of representing and predicting the outcomes of complex processes. The field of demographic modeling faces three key challenges today: the issue of scale, the issue of dimensionality, and the issue of complexity. Demographic analysis has to operate across multiple scales, representing individuals, analytically significant collectives such as villages or regions, and for some applications, even entire societies. Modern demographic problems are also multi-dimensional, adding both uncertainty and the need to incorporate heterogeneous data sources in a single model. Finally, demographers must grapple with the question of how complex their models should be to capture the most important features of demographic processes (Silverman et al 2013). The field of economics has grappled with the issue of macro-micro interactions: individual people make decisions that alter system-level economic conditions, which in turn change the parameters within which individuals make decisions (Tesfatsion 2003: 264).

Economics and demography have traditionally relied on statistical models that simulate aggregate processes; however, the emerging method of Agent-Based Modeling offers an alternative that can better cope with these complex problems. Agent-based models (or ABMs) retain the advantages of formal statistical modeling, in that their explicit assumptions lead to models of reality that can be readily tested and validated against empirical data (Epstein 2008). Additionally, ABMs offer more "natural" description of human systems by explicitly rendering individuals and their actions; larger scale demographic processes emerge from interactions between these individual agents and the model environment (Bonabeau 2002). As such, ABMs can model processes that are difficult to formally represent in the aggregate, including social interactions, geographical spread, nonlinear transitions, and stochasticity (Silverman et al 2013). In the context of this study, I chose an agent-based modelling approach to better capture the heterogeneous nature of the floodplain's economy: an agent-based model facilitates capturing diverse individual impacts on households, as well as their aggregate result on the floodplain economy.

The model presented in this study focuses on the relationship and feedbacks between economics and demography at the level of the household. On the Logone floodplain, the prestige of a household head is directly tied to his ability to marry and support a large family (Rhebergen 1998: 75); wealth, often stored in herds of cattle, is prized because it can pay for the ceremonies and expenses required for marriage (Béné et al 2000: 5). However, a large family size serves as a check on household wealth: more wives and children mean higher food and clothing costs each year, which decrease the household's ability to marry again or invest in additional productive assets. In the model described below, households engage in economic activities in order to marry additional wives and have more children; the needs of the additional family members then limit a household's total wealth. While this relationship is adapted for the specific purposes of the Logone floodplain economy, its general principles could be applied to other subsistence economies that place a high value on family size.

2.2 Creating the Agent-Based Model

For the sake of clarity and replicability, this paper uses the updated Overview, Design concepts, and Details (ODD) protocol outlined by Grimm and colleagues for model description (2006; 2010). The model is written NetLogo (Wilensky 1999).

2.2.1 Purpose

The purpose of this model is to examine the impact of market collapse on the economy and demography of fishing households in the Logone Floodplain, Cameroon.

2.2.2 State Variables and Scales

The fundamental unit of this model is a fishermen household. The model is initialized with parameters matching the estimated population distribution and canal ownership levels in 1978; it then progresses in yearly time steps, with household members aging one year, undergoing demographic processes such as childbirth and death, receiving income from fishing and investments, paying for living expenses, and then making key decisions about marriage and investment in fish canals and/or rice fields.

2.2.3 Agents

A household contains one male household head, who is assigned an age. Men may marry up to four times, in accordance with Muslim religious law; as such, the household can contain between zero and four wives. The current age of each wife, as well as her age at marriage, is simulated in the model. The model also includes arrays containing the ages of all boys and girls in the family, along with an array containing the ages of widows who have joined the family after their husband has passed away.

Each year, households earn money from fishing on the river and from tending to any canals and fields they may own. Households then spend money on local taxes, equipment and maintenance expenses, and feeding its members. Each household has an attribute called *total-wealth* that represents the total liquid assets of the household. In practice, these assets would be stored in cattle and small livestock (Béné 2003: 193), but for the sake of simplicity, the model represents the cash equivalents of the assets in the local currency, the Central African CFA franc (FCFA).
By spending their wealth, households can purchase canals or fields to supplement their annual income. The household must meet certain conditions, described below, in order to purchase new investments. The number of canals and fields owned by each household are represented by the variables *num-canals* and *num-fields*, respectively.

2.2.4 Landscape

Households exist within an idealized environment representing a section of the floodplain containing three major rivers: the Logone, the Lorome-Mazera, and the Logomatya. This section measures 21 km from East to West and 24 km from North to South, and is displayed as a raster with a 300 m resolution. Tiles are classified as “river,” “habitable” (less than 1 km from the river), “depression” (low-elevation regions filled with water, digitized from satellite imagery), and “background.” The eastern bank of the Logone River is located within Chad and is outside of the study area; no habitable tile was assigned for this region. Households can only be located within the habitable region of the environment, as an attempt to reproduce settlement patterns in the floodplain: villages tend to be located near rivers for access to water and because river banks are more elevated areas, so the habitations are less vulnerable to flooding damage during flood season (Delclaux et al 2010).

Beyond the unit of the household, the model makes use of two spatial levels of aggregation. The first level of aggregation, the village, guides the initial placement of population and canals onto the floodplain. To determine the extents of different villages on the floodplain, we geolocated each of the survey respondents on a map of the floodplain and then aggregated these locations based on the respondents’ self-identified village. However, for the purpose of analysis, the model considers economic and demographic changes within the study area as a whole. The model also applies changes in costs and revenues uniformly across the floodplain.

2.2.5 Input data

This model uses data from three surveys conducted on the floodplain in the dry seasons of 2014, 2015, and 2016. These surveys ranged from 9 to 15 pages long and contained numerical, multiple-choice, and short-answer questions about the household head’s family, assets, economic activity, and opinions about the floodplain. In conjunction with the Modeling Regime Shifts in the Logone (MORSL) research group at the Ohio State University, the Center for Support to Research and Pastoralism (“Centre d’Appui a la Recherche et au Pastoralisme,” or CARPA) in Northern Cameroon carried out the surveys in each of these years. In 2014, a MORSL-CARPA research team surveyed a stratified random sample that included 20% of all canal owners in the study area (n=212). Additionally, in each village where canal owners were surveyed, the team conducted the same survey with an equal number of randomly-sampled non canal owners from the same village (n=205). The 2015 survey was conducted using a subsample of this group that contained 121 canal owners and 120 non canal owners. The 2016 survey was conducted for the same subsample as in 2015.

The model initializes a set number of families within each village in the study area based on regional government census conducted from 1975-77 that lists population by village (Office National de la Recherche 1978). To initialize the canals existing prior to 1978, the model references a survey conducted in 2014 by the MORSL-CARPA research team listing the location and age of each canal on the study zone. All canals greater than 36 years old (built before 1978) were assigned to the village closest to their locations.

In addition to these surveys, the model adapts Life Tables from the World Health Organization to describe the lifespan of men and women across the floodplain. Life tables provide detailed characteristics for different age cohorts of men and women. For each cohort, typically in a five-year span, the table provides the probability that a member entering the age cohort will die before moving on to the next cohort.

The model uses life tables for the Far-North Region of Cameroon from 1991, approximately halfway through the time period of the study. Data from the life tables are used for the entire period from 1978 to the present. By assuming that mortality remains fixed for all of the years within the cohort, we derive the annual mortality rate using Equation 1, below.

$$R = 1 - (1 - m)^{(1/n)}$$

Equation 1: Deriving annual mortality rates from life tables

In this case, R is the yearly mortality rate, m is the mortality rate over the entire cohort, and n is the number of years in the cohort. Note that when n = 1, the yearly mortality rate is equal to the cohort mortality rate. Using this equation, annual mortality probabilities can be assigned for each of the mortality functions in the model. Death is then determined using a stochastic function.

2.2.6 Initialization

The model starts in the year 1978, cotemporaneous with the SEMRY project that constructed the Maga Dam. Based on the location and village identification of respondents from the 2014 surveys, the habitable region of the floodplain was subdivided into villages. Using 1975-77 survey data from the government of Cameroon (Office National de la Recherche 1978), I estimated the number of households occupying each village. The appropriate number of households were spawned in a random location within each village. Past research suggests that most floodplain households own a small plot of land that they use for subsistence farming (Béné 2003: 200; Acreman et al 2004: 65); to account for this, each household was initialized with exactly one field.

According to our 2014 survey, 267 families within the study area already owned canals in 1978. These canals were located in reference to the villages on the floodplain, and for each 1978 canal located within a village, one household in that same village is assigned a canal. All other families in the village begin with no canals. All households begin the model with a *total-wealth* of 0 FCFA. This allows for easy future comparison between households that have gained and lost wealth over time.

The household head’s age, wives, and children are then initialized for each household. The household head’s age is determined by a random-normal distribution that differs for canal-owning and non-canal-owning households, based on data from the 2014 survey. A linear regression with a stochastic component determines the number of wives in a household based on the household head’s age; this regression also differs for canal-owning and non-canal-owning households. A function based on the number of wives and their time living in the household then determines the number and ages of children in the household. The process of initializing demographic attributes is described in more detail in a previous agent-based model of the floodplain (Henry forthcoming).

2.2.7 Process overview

Each year, every household goes through three phases in the model: demographic changes, generating wealth and expenses, and choosing to spend extra wealth. At the beginning of each year, the household undergoes demographic changes: household members age, reproduce, leave the household upon entering adulthood, and die.

The household then generates income for the year based on river fishing and existing investments. The model then calculates the total change in wealth for the year by subtracting taxes, maintenance and fishing costs, and the family's cost of living from the year's income. The household head then estimates his income for the next year by averaging his income for different investments over the past three years.

Finally, the household head has the option to spend his accumulated wealth by getting married or purchasing a canal or field. As each of these three possibilities requires a major expenditure of time and labor, the household head can only choose to spend his money in one way per year. If the household has sufficient wealth and income to pay for a marriage and support another wife, the household head will get married; otherwise, depending on his wealth and other restrictions, he may buy another canal or field instead. Each of these yearly subroutines is described in Table 1 below.

Table 1: The functions performed by each household on the floodplain in a given year. Functions marked with an asterisk are described in further detail in the following section (Subroutines)

Process name	Description
update-ages	The age of each household member is increased by 1.
children-born	Each wife under the age of 50 may have another child. If so, the child is added to the family with an age of 0.
children-leave-household	Based on their ages, children may leave the household. When they leave their household, boys may leave the floodplain altogether, start a new household in the same village, or start a new household somewhere else on the floodplain. Because the model is based on the behavior of male agents as household heads, women disappear from the model when they leave their parents' households. They may reappear as wives, but this connection is not explicit in the model.
wives-die *widows-die* *children-die*	Family members die based on known annual mortality rates for their age cohort, provided by the WHO.
head-dies	Household heads die based on known mortality rates for their age cohort. If a household head dies, then all of the wives become widows. If at least one boy in the family is above the age of 18, he becomes the new household head and provides for the family; otherwise, the family members are transferred to another household on the floodplain.
*update-payoffs**	The household's annual payoffs for river fishing, canals, and fields are determined based on known distributions.

update-expected-payoffs	The household head adjusts his expected payoffs for each economic activity in the following year based on known payoffs over the past five years.
*update-wealth**	The household gains wealth from economic activity, and loses wealth to taxes, fees, and each family member's cost of living
*update-expected-income**	Based on the expected payoffs for each economic activity, the household head calculates his expected income for the next year.
*marriage-decision**	If a household has less than four wives, has sufficient wealth to pay for a marriage, and has sufficient income to support another wife, then the household head will get married.
*investment-decision**	If the household head does not get married, and other wealth and family conditions are met, then the household can purchase either an additional canal or an additional field.

2.2.8 Subroutines

Update-payoffs: Households on the floodplain can earn income by fishing in the river, growing food in fields, or fishing in canals. Based on data from our 2014 surveys, payoffs for river fishing and canal fishing were not uniform between different households. Instead, each of the activities followed a log-normal distribution – a distribution where the natural logarithms of the dataset values form a normal distribution (see Figure 1, below). In a log-normal distribution, most values are clustered near the low end of the spectrum, with a long right tail that encompasses a few large values. This type of distribution fits anecdotal evidence on the floodplain: each year, a few canals perform far better than the floodplain at large (Laborde forthcoming).

In order to model the payoffs for river fishing and canals, the mean and standard deviation for the river fishing and canal fishing payoffs were determined for 2014. According to the results of a two-tailed probability test, non-canal owners derive a significantly higher income from river fishing than their canal-owning counterparts ($P < 0.01$). This finding also matches known data on the floodplain: canal owning households have to spend much of the dry season maintaining their canals and much of the wet season watching them, leaving household members less time for river fishing. The means and standard deviations for these distributions are listed in Table 2 below. Because the survey data does not account for inter-annual variation in profits, each household receives a randomly-generated income based only on their current investments, without taking prior income into account.

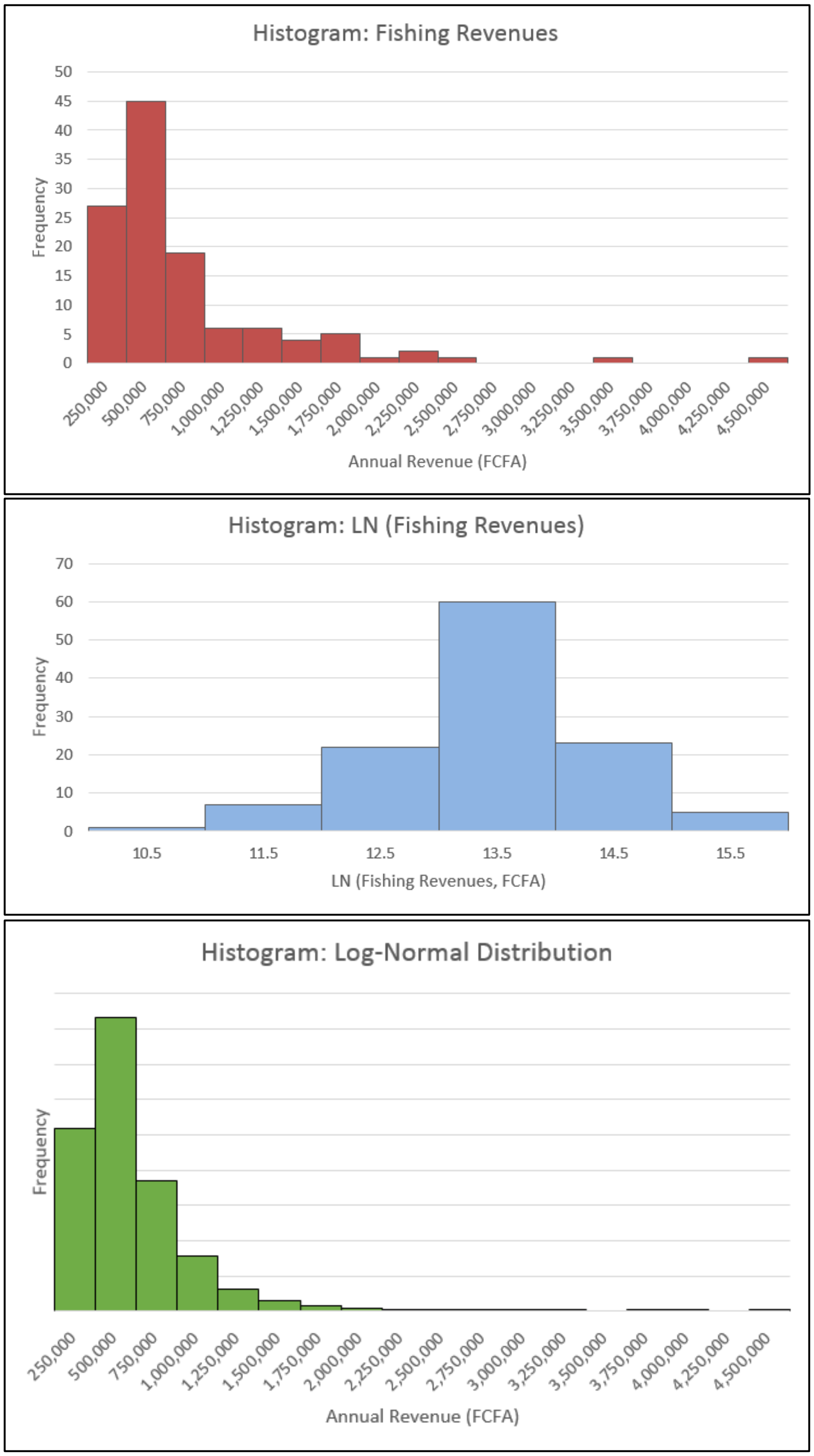


Figure 1: (*Top*) A histogram showing the distribution of river fishing revenue for non-canal owners; (*Middle*) A histogram showing the natural logarithms of the same values; (*Bottom*) A histogram showing an idealized log-normal distribution (n=10,000) with the same mean and standard deviation

Table 2: Means and standard deviations for canal and river fishing payoffs. Note that large standard deviations are common in log-normal distributions.

Value	Mean (FCFA)	Std. Deviation (FCFA)
River Fishing Payoff (Non Canal Owners)	461,000	321,000
River Fishing Payoff (Canal Owners)	202,000	289,000
Canal Fishing Payoff	571,780	556,762

Each household receives an expected payoff for river fishing along with each investment that they own. The log-normal distributions are generated using a *log-normal* function in NetLogo, using Equation 2 below.

$$\beta = \ln\left(\frac{\mu^2}{\sigma^2}\right)$$

$$x = e^{N\left(\ln(\mu - \beta/2), \sqrt{\beta}\right)}$$

Equation 2: A stochastic function that generates a log-normal distribution given the mean and standard deviation of that distribution (Railsback and Grimm 2015)

In the equation above, μ is the mean and σ is the standard deviation of a log-normal distribution. *N()* is the random-normal function, and *x* is a random value on the log-normal distribution.

According to socioeconomic survey data, a large majority (96%) of households engage in farming. Of these farming households, most primarily grow rice (88%), with smaller numbers growing millet, corn, and vegetables for personal consumption. Most household land holdings are broken up into parcels either 1 hectare or 0.5 hectares in area. Yearly income from agriculture is positively correlated with the amount of farmland owned by a household, with an increase in 1 hectare of land corresponding to an income increase of approximately 154,000 FCFA (see Figure 2). When a linear regression was created to estimate farming payoff based on farmland area, the regression's residuals were approximately normally distributed (see Figure 3). In the model, payoff from agriculture is based on a random-normal distribution with a mean of 154,000 FCFA per hectare of agricultural land owned.

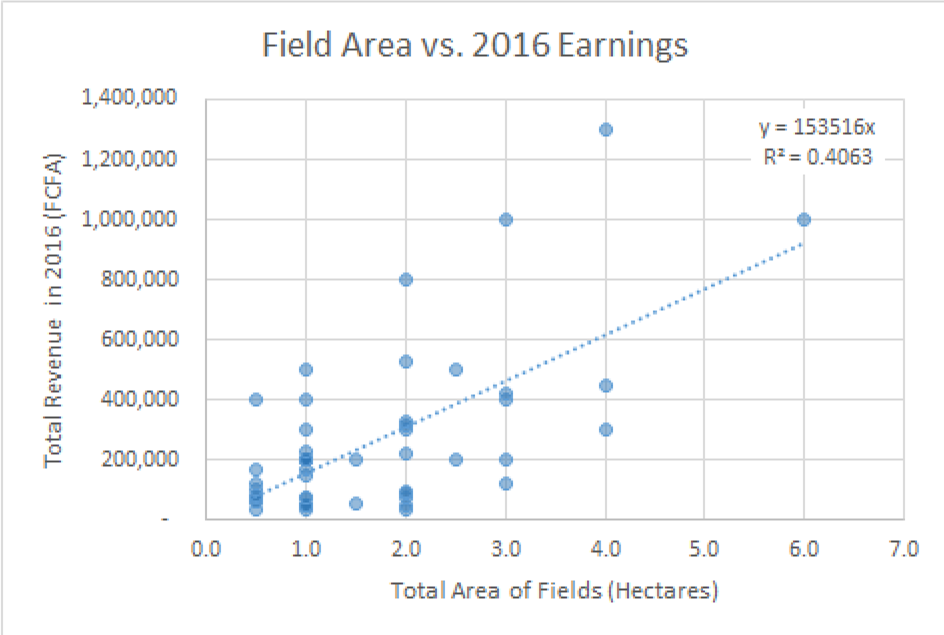


Figure 2: There is a positive linear correlation between a household's total agricultural land holdings and that household's revenue from farming.

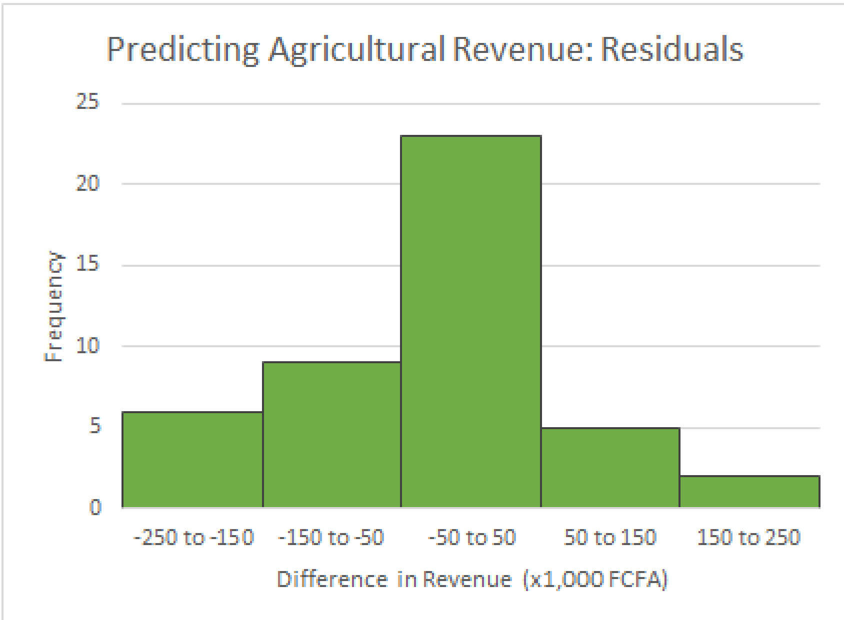


Figure 3: Residuals from a linear regression that estimates annual farming income from the total area of a household's agricultural land. The residuals are approximately normally distributed with a mean of 0 and a standard deviation of 113,000 FCFA.

Update-wealth: Once the household has earned a payoff from each of its activities and investments, it loses wealth to taxes, fees, maintenance costs, and providing for each family member. After subtracting annual costs from the year's income, the difference is added to the household's total wealth.

Canal maintenance costs, like the payoffs, follow a log-normal distribution with a mean of 169,000 FCFA and a standard deviation of 152,000 FCFA. The annual canal maintenance costs for each canal are set using the log-normal function described in Equation 2. Additionally, local authorities extract an income tax from each of the floodplain residents: both survey data and past studies suggest that until recently, the tax remained constant at approximately 10% of total income for all floodplain residents (Acreman et al 2004: 65, Béné 2003: 202).

Households must also feed and clothe their family members each year. Survey data showed a weak positive correlation between the number of family members in a household and that household's annual food and clothing costs (see Figure 4). A cost estimate that allocated 140,000 FCFA in food and clothing costs for each adult (ages 12-59) in the household, 70,000 FCFA for each child (ages 3-11), 35,000 FCFA for each infant (ages 0-2), and 70,000 for each elder (ages 60 and over) predicted more of the variation in household food costs than an estimate based on raw household size alone, so this estimate was used to predict household food costs in the model. These consumption estimates by age group correspond with the relative needs described by the Adult Consumer Equivalents (Moritz 2003: 85). However, socioeconomic surveys showed that approximately 5% of respondents reported skipping at least one meal per day in order to minimize their expenses. To account for this in the model, households whose total wealth falls below a certain threshold will consume only half of their predicted food and clothing costs for the year.

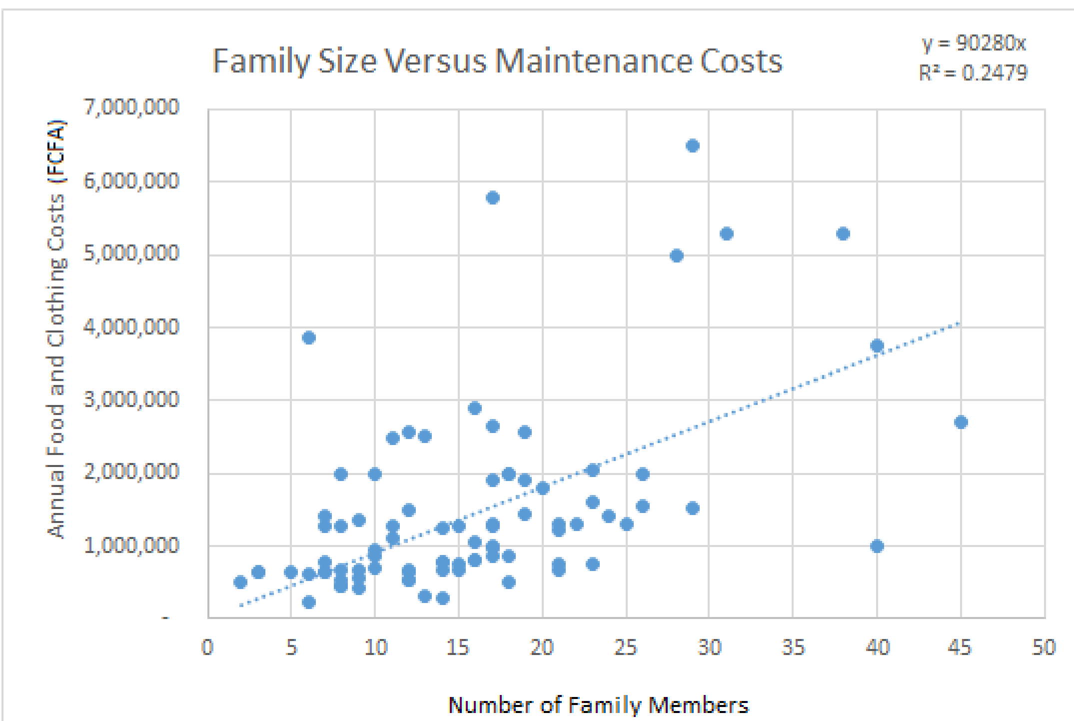


Figure 4: Relationship between the number of family members in a household and annual food and clothing costs.

Update-expected-income: Each household tracks its total income, minus maintenance costs and income taxes, over the past five years. This function averages those five values, taking into account changes in family size and new investments, to estimate the expected income in the following year. The household's expected income is used to make decisions about marriage each year.

Marriage-decision: A household head's social status on the floodplain is closely linked to his ability to support a large family (Rhebergen 1998: 73-75). Therefore, to maximize social status, a household head in this model will always take another wife if it is legally permissible, he can pay for another marriage, and he will be able to support her in the future.

In the model, these three requirements are formalized into the following constraints. In order to marry, a household:

- Must have less than four wives
- Must have an expected income great enough to support all current household members as well as one additional adult in the following year.
- Must have a total wealth that is greater than the cost of marriage (including both a dowry and the cost of a ceremony)

If these three conditions are met, then the household head will take another wife. The wife's age will be generated as a function of the husband's age at marriage (see Henry et al forthcoming). The household will gain one more wife, and will lose the amount of wealth equal to the marriage expenses.

If a household satisfies the first two conditions but does not have adequate wealth to pay for another marriage, it will perform a calculation to estimate whether it will be able to marry next year. This calculation is performed by adding the household's expected income to its total wealth, then subtracting expected food and clothing costs for the upcoming year. If the resulting wealth total is greater than the cost of marriage, then the household is likely to get married in the next year. In this case, a household will skip the *investment-decision* subroutine for the current year, as they are saving their wealth to get married.

Investment-decision: If a household has wealth left over after paying for the year's expenses, that household will determine whether or not it can invest in either of the model's two productive assets: fields and canals. The household first determines its eligibility to purchase either of the two resources. In order to purchase another canal, the household must satisfy the following conditions:

- The household must have sufficient wealth to pay for the canal's construction, set by the variable *canal-cost*
- Households must receive approval from the village chief and local elite before beginning canal construction; this requires that the household has achieved a certain status within the village community (Drijver et al 1995: 38). As a surrogate for measuring this status, the household's wealth must surpass a threshold (greater than the cost of the canal) in order to construct the canal. This threshold is measured by the variable *canal-ownership-threshold*
- Canal owners must expend significant effort maintaining their canal in the dry season and fishing from it during the wet season (Laborde et al forthcoming). Due to the intensive labor requirements, a household may own no more than two canals

Households also have the option to purchase a one-hectare field for farming each year. In order to purchase another field, the household must satisfy the following conditions:

- The household must have sufficient wealth to purchase the field, set by the variable *field-cost*
- Due to the labor requirements for maintaining and farming a field, a household may own no more than three fields

Households can only purchase one productive asset per year. If a household satisfies the requirements to purchase one type of asset but not the other, it will purchase the available asset. If a household satisfies the purchasing requirements for both assets, it will compare the expected payoffs for canals and fields (set by the *update-expected-payoffs* function) and purchase the asset with the higher expected payoff. If a household does not satisfy the requirements to purchase either asset, then it will move to the next year.

2.2.9 Design concepts

This model operates on the principle of *emergence*: while households make economic decisions based on their individual income, costs, and wealth, the model primarily measures the system-level trends that emerge from the aggregation of those individual decisions. The total number of fields and canals on the floodplain, distribution of wealth, and family sizes are controlled by no single household, but these measures are critical for understanding the effects of economic disturbances on the floodplain.

The model also relies on *stochastic* processes to determine many of the initial conditions, payoffs, and costs for each household. While households rely on a deterministic decision-making process for marriage and investments, the model's stochasticity more accurately reflects how wealth is distributed within the floodplain economy, as well as range of ways that economic disturbances would impact individual households.

Fitness-seeking behavior and *prediction* are two of the design concepts that characterize individual households. Instead of a single metric for fitness, households attempt to maximize their household size while still maintaining a high level of wealth, which takes the form of a large cattle herd on the floodplain (see Béné 2000). To accomplish this goal, households use their current knowledge to estimate future conditions. Households can predict whether or not they should save up money to get married next year; and given the choice between canals and fields, they will estimate the potential profitability of each by averaging payoffs from previous years.

2.3 Model Validation

The model was validated against known system-level trends on the floodplain. Two known indicators, growth in canals and average family sizes, were set as the criteria for validation:

- The number of canals on the floodplain grew at an increasing rate from 1978 to 2014
- By 2014, the average canal-owning household had a total of 11.99 family members, and the average non-canal-owning household had an average of 5.96 family members

The model replicated the increasing rate of growth in the number of canals on the floodplain between 1978 and 2014. While the model only covers a subset of the floodplain, and therefore overstates the total number of canals in 2014, the general trend of growth is evident.

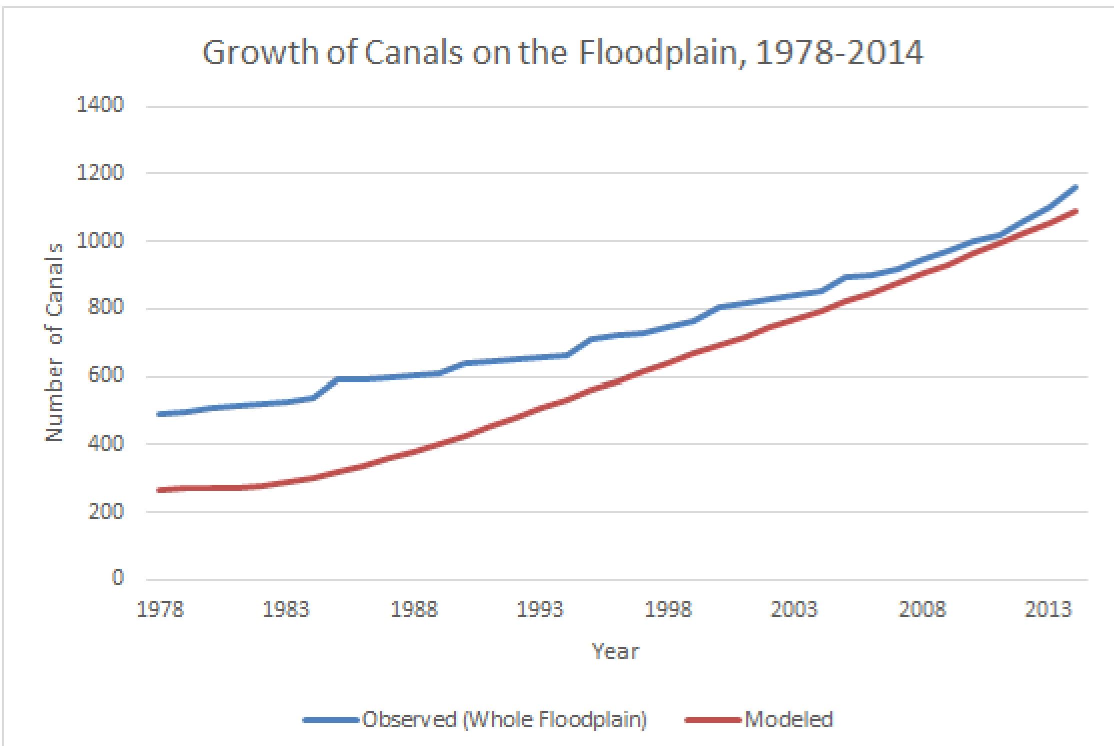


Figure 5: Actual increase in canals across the entire floodplain versus the modeled increase in canals on a subset of the floodplain

In terms of modeling average family sizes, the model's results fall within the 90% confidence interval for family sizes of both canal-owning families and non-canal-owning families, as determined by our 2014 socioeconomic survey of the floodplain. The results are summarized by Table 3, below.

Table 3: The mean household sizes for canal owners and non-canal-owners as determined a 2014 socioeconomic survey compared with the modeled result. In both cases, the modeled result falls within the 90% confidence interval for the actual mean household size.

Population	Sample Size	Mean HH Size	90% Confidence Interval	*Mean HH Size (Modeled)*
Canal Owning Households	208	11.99	[11.28, 12.70]	11.66
Non-Canal-Owning Households	205	5.96	[5.41, 6.51]	6.22

Because the model adequately replicated the pattern of canal growth over time and fell within acceptable limits for average household sizes, it serves as an acceptable approximation of actual floodplain conditions for the purposes of the economic experiments described in the following section.

2.4 Simulating Disturbances

In order to understand the long-term impacts of Boko Haram on the wealth, family size, and investments of floodplain households, I simulated disturbances to the floodplain's economy. I quantified the disturbance as a reduction in the profitability of economic activities: starting at the beginning of the disruption period, the income households derived from river fishing, canal fishing, and agriculture all decreased. As a result of this decreased profitability, the disruption reduces the ability of households to cover their living and maintenance expenses. After implementing the disturbance for a period of years, I revert the overall profitability to its original level and measure how important system metrics change over the following one to ten years.

I simulated nine different disturbances on the floodplain economy. Income could be reduced to 90% of its original levels (mild), 75% of its original levels (moderate), or 50% of its original levels (extreme); additionally, the disturbance could last for a period of one year (short), two years (medium), or five years (long). I began each disturbance in 1999, which allowed me to compare the results of even the longest disturbance (1999-2004) with data from the validated model up to ten years after the end of that disturbance (up to 2014). This testing timeline ensures that the experimental results are only tested against known, validated data on household demography and wealth.

In total, I ran the model under 10 different sets of parameters, including the nine disturbance states as well as a "null hypothesis" that experiences no outside disturbance. I simulated each set of parameters 100 times, then averaged the values from each of those runs to obtain my final data set. For each run, I took measurements for 38 different metrics each year. These metrics are broken down in Table 4, below.

Table 4: Metrics measured for each run of the model

Indicator	Measurement(s)	Scope(s)
Number of households	Total Count	All households Canal owners only Non-canal owners only
Number of canals	Total Count	Canal owners only
Number of fields	Total Count	All households
Fields per household	Mean	All households Canal owners only Non canal owners only
Wives per household	Mean	All households Canal owners only Non canal owners only
Number of family members per household	Mean	All households Canal owners only Non canal owners only
Expected income	Mean 25^{th} Percentile Median 75^{th} Percentile	All households Canal owners only Non canal owners only
Total wealth	Mean 25^{th} Percentile Median 75^{th} Percentile	All households Canal owners only Non canal owners only

In the following section, I describe the results of these experiments. In the “Discussion” section below, I explain the meaning of these results and their implications for the floodplain.

3. Results

3.1 Normal Conditions

The following section aggregates results from the 100 "null hypothesis" runs of the model, which simulate floodplain conditions without any disturbances. In this simulation, canals, households, and fields all experienced sustained growth from 1978 to 2014. Households grew at an approximately linear rate from 1978 until approximately 2002, when yearly household growth increased. The rate of canal growth quickened each year from 1980 until 1985, then became approximately linear for the remainder of the simulation. Field growth slowed slightly in the late 1980s, then increased again after 2000. These growth trends are charted in Figures 6 and 7; raw growth rates are summarized in Table 5, below.

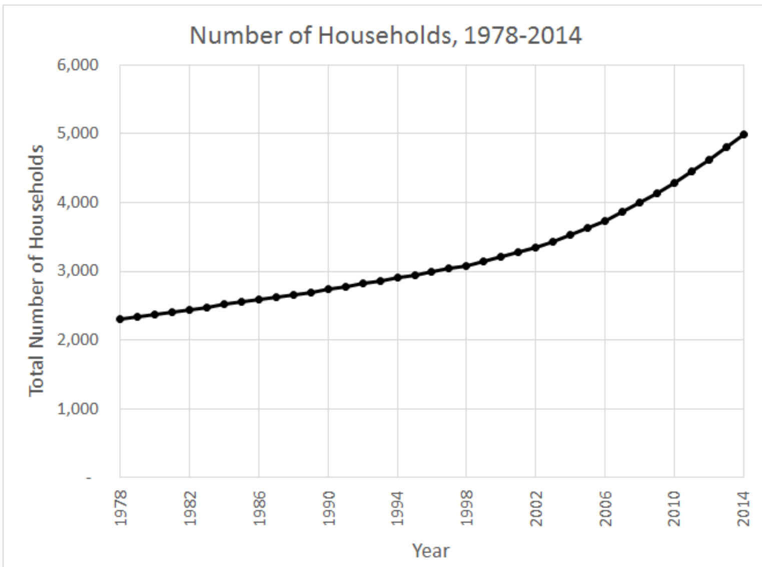


Figure 6: Simulated household growth on the floodplain in the absence of economic disturbances

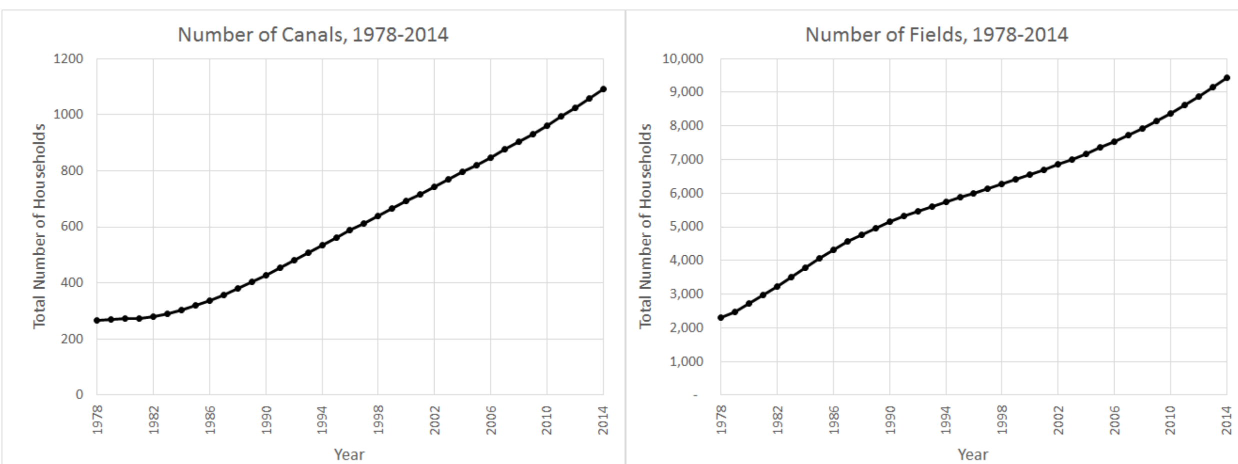


Figure 7: Growing numbers of canals (left) and fields (right) on the floodplain in the absence of economic disturbances

Table 5: Sustained growth in households, canals, and fields within the "null hypothesis" model

Stock	Count (1978)	Count (2014)	Growth: (2014)/(1978)
Households	2307	5175.9	2.243
Canals	267	1091.2	4.087
Fields	2307	9749.44	4.226

While the numbers of canal-owning and non-canal-owning households both experience sustained growth from 1978 to 2014, non-canal-owning households grow at a faster relative rate. On the whole, both canal-owning and non-canal-owning households grow in terms of wives, family size, and fields from 1978 to 2014, with canal owners experience higher levels of growth in both absolute and relative terms. However, all three metrics stagnate or decline slightly after the year 2000. As we shall see below, this may be due to a trend of stagnating income and increasing costs that begins around this time. Household growth, family size, and field investments from 1978 to 2014 are charted in Figures 8 through 11; growth for canal owners and non-canal owners is summarized in Table 6, below.

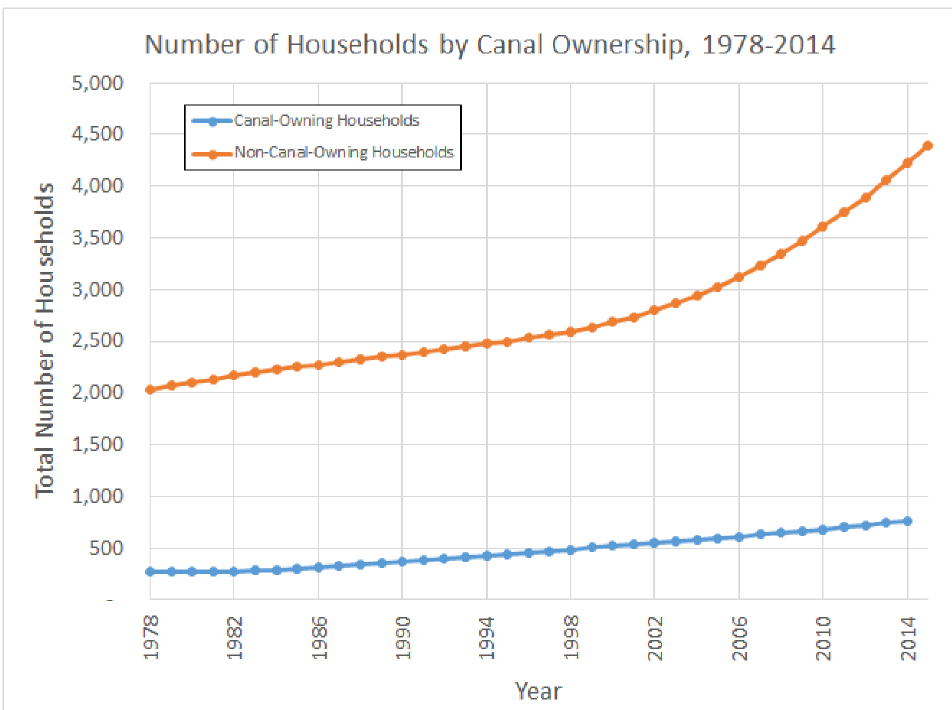


Figure 8: Increase in the number of households in the "null hypothesis" model floodplain from 1978 to 2014, divided by canal ownership

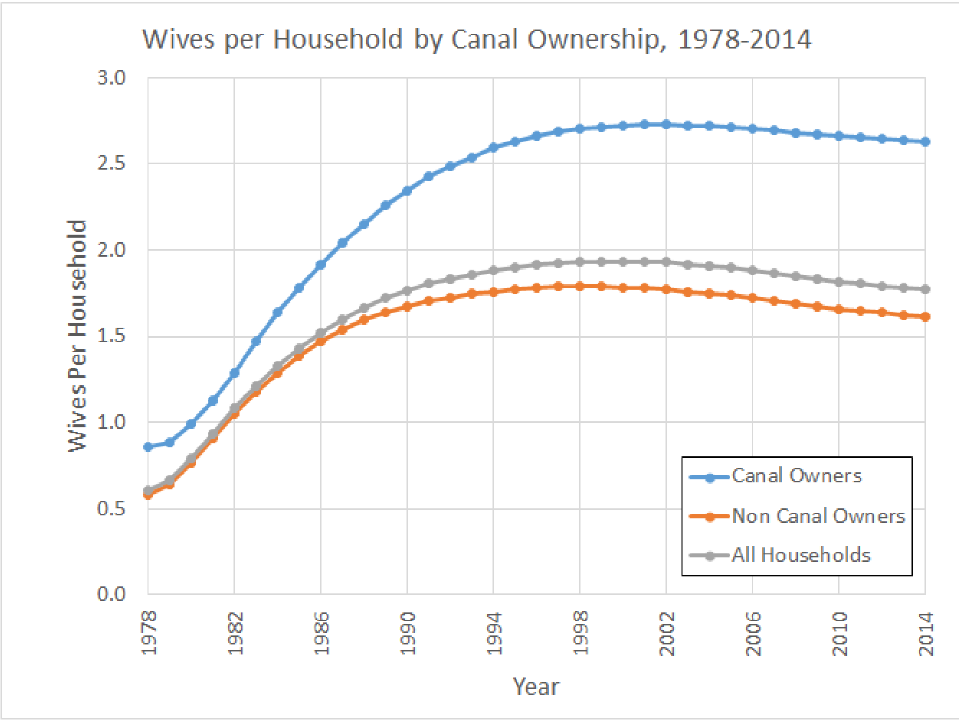


Figure 9: Change in the average number of wives per household over time in the “null hypothesis” model floodplain from 1978 to 2014, divided by canal ownership

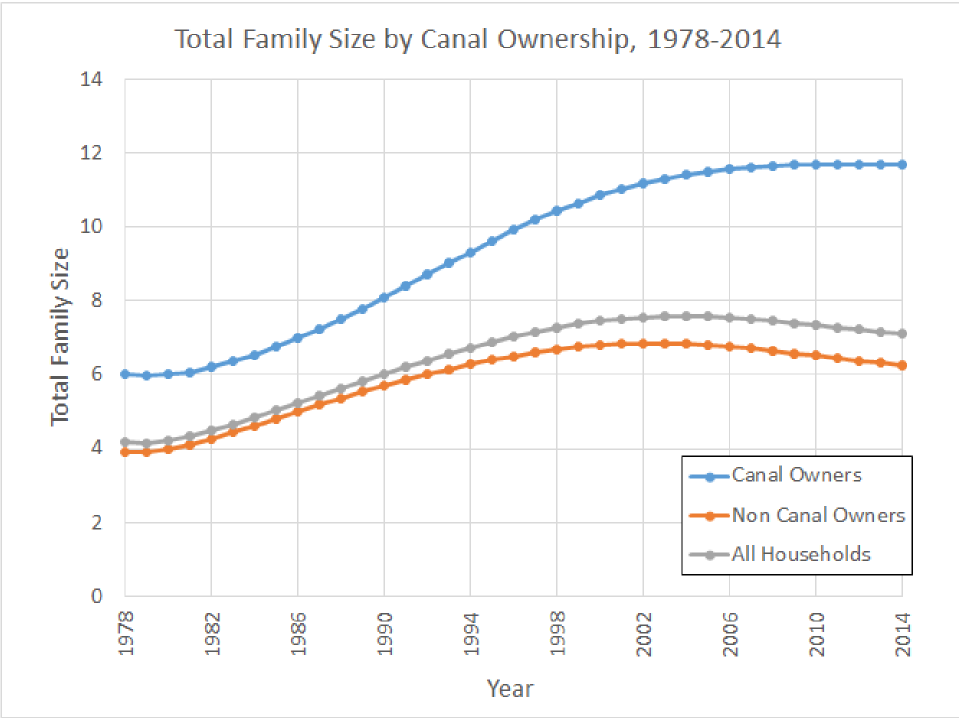


Figure 10: Average family size, including husband, wives, children, and widows, for households on the “null hypothesis” modeled floodplain

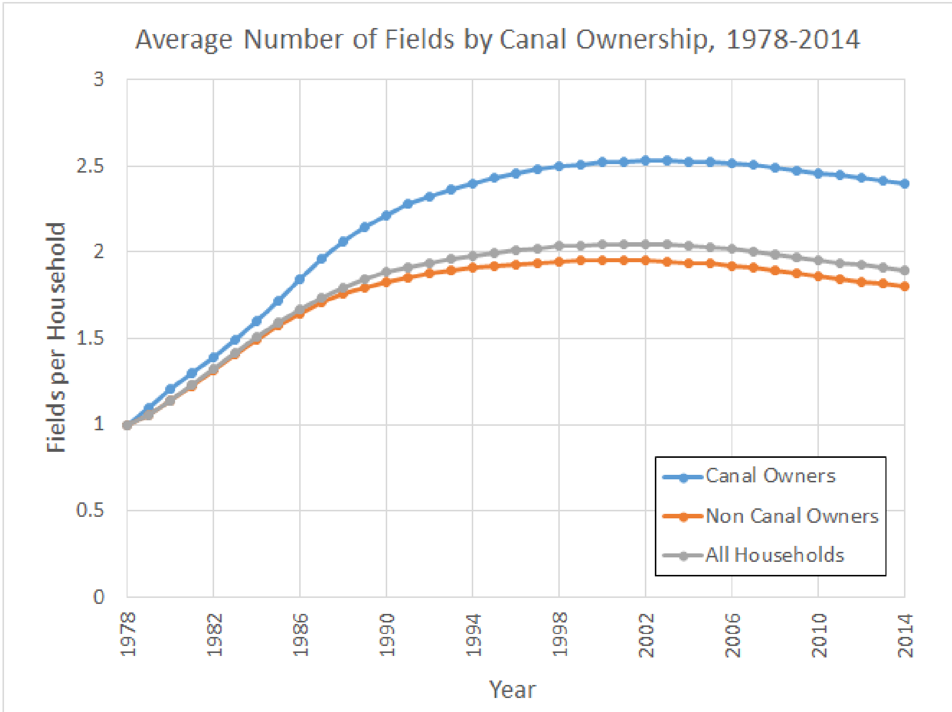


Figure 11: Average field ownership per household from 1978 to 2014 in the "null hypothesis" modeled floodplain

Table 6: Summary of average household characteristics for canal owners and non-canal owners in the absence of economic disturbance, 1978-2014

	Canal Owners (CO)			**Non Canal Owners (NCO)**			**Comparison: CO/NCO**	
Stock	*1978*	*2014*	*Pct. change, 1978-2014*	*1978*	*2014*	*Pct. change, 1978-2014*	*1978*	*2014*
Number of Households	267	783.6	+193.5%	2040	4392.3	+115.3%	0.131	0.178
Avg. Wives/Household	0.86	2.62	+205.5%	0.58	1.61	+178.2%	1.479	1.625
Avg. # Family Members	6.02	11.66	+93.8%	3.92	6.22	+58.6%	1.535	1.875
Avg. # Fields/Household	1	2.39	+139%	1	1.79	+79.4%	1.000	1.331

Plots of mean income over time suggest that the mean incomes of all household types increased from 1978 until the late 1990s, then stagnated from 2000 to 2014, even falling slightly in the case of non-canal-owners. Individual plots showing the ranked distribution of income for all households, canal owners, and non-canal owners show similar trends in income over the duration of the simulation. Note that because expected income is derived from an average of the past five years of earnings, it may understate yearly variation in income. Figures 12, 13, 14, and 15 show plots of income from 1978 to 2014.

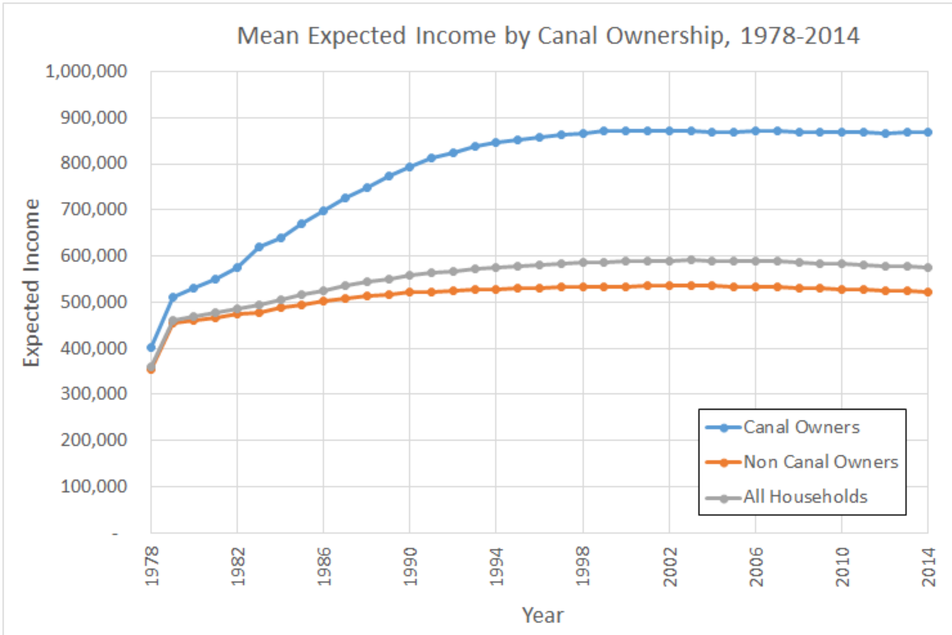


Figure 12: Mean expected income for different household groups on the floodplain from 1978 to 2014 in the absence of economic disturbances

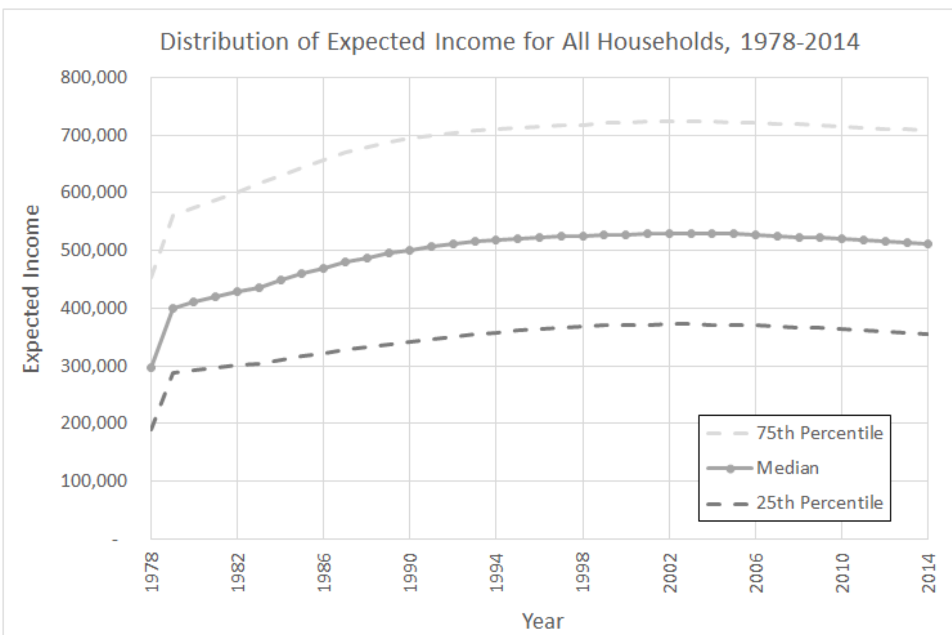
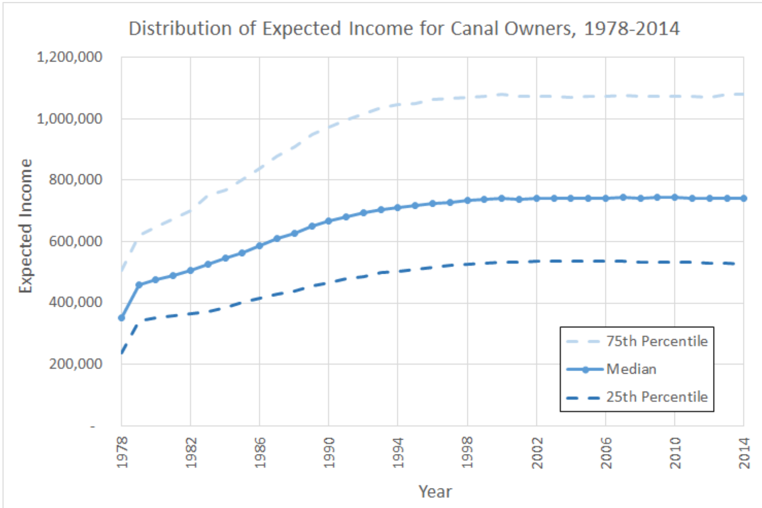
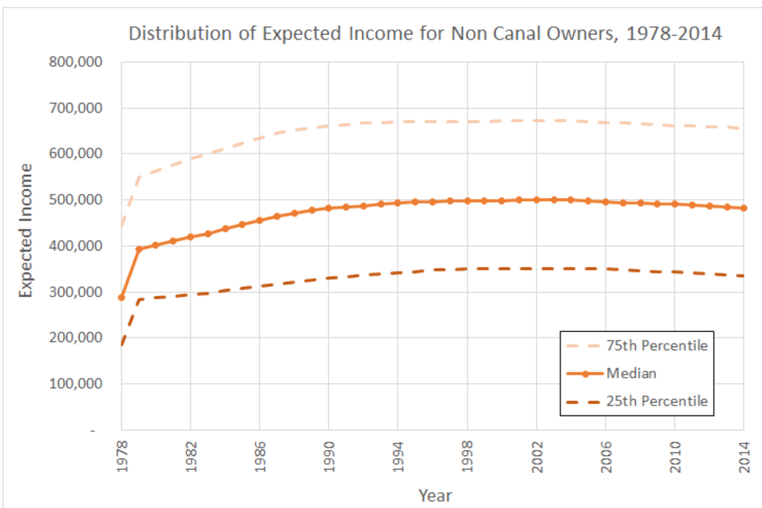


Figure 13: Distribution of expected income for all households on the floodplain from 1978 to 2014 in the absence of economic disturbances



<u>Figure 14</u>: Distribution of expected income for canal-owning households on the floodplain from 1978 to 2014 in the absence of economic disturbances



<u>Figure 15</u>: Distribution of expected income for non-canal-owning households on the floodplain from 1978 to 2014 in the absence of economic disturbances

Charts plotting changes in household wealth over time show the effects of stagnating income coupled with a larger household size. As average household size peaked in the late 1990s (see Figure 10) and average income stagnated (see Figure 13), it appears that more households had to spend their extra income on paying for family costs rather than investing in productive assets such as canals and fields (see Figure 11). As families continued to grow and new households appeared on the floodplain without inheriting assets from their parents, the average wealth of households decreased. Figure 16 shows the average wealth of household groups over time, while Figures 17, 18, and 19 show distributions of wealth across various household subgroups. Differences between the mean and median total wealth across incomes suggest that the mean wealth is being influenced by a few extreme values; as a result, median wealth will be the preferred metric used in subsequent sections.

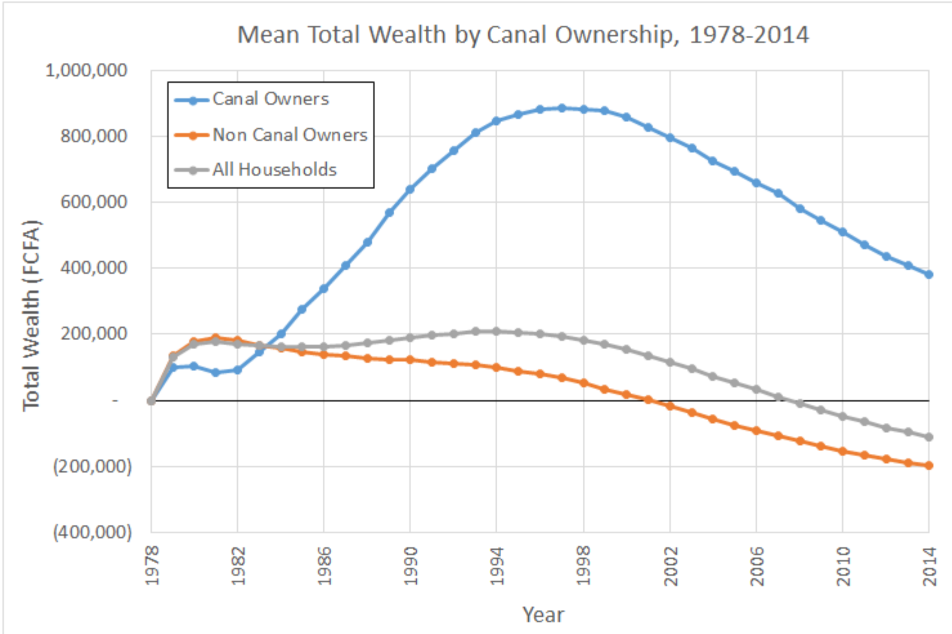


Figure 16: Mean total wealth for different groups of households on the floodplain, 1978-2014, in the absence of economic disturbance. Note that mean total wealth may be skewed by a few extreme outliers, so the figures showing wealth distributions below may be a better indicator of wealth changes for most of the population.

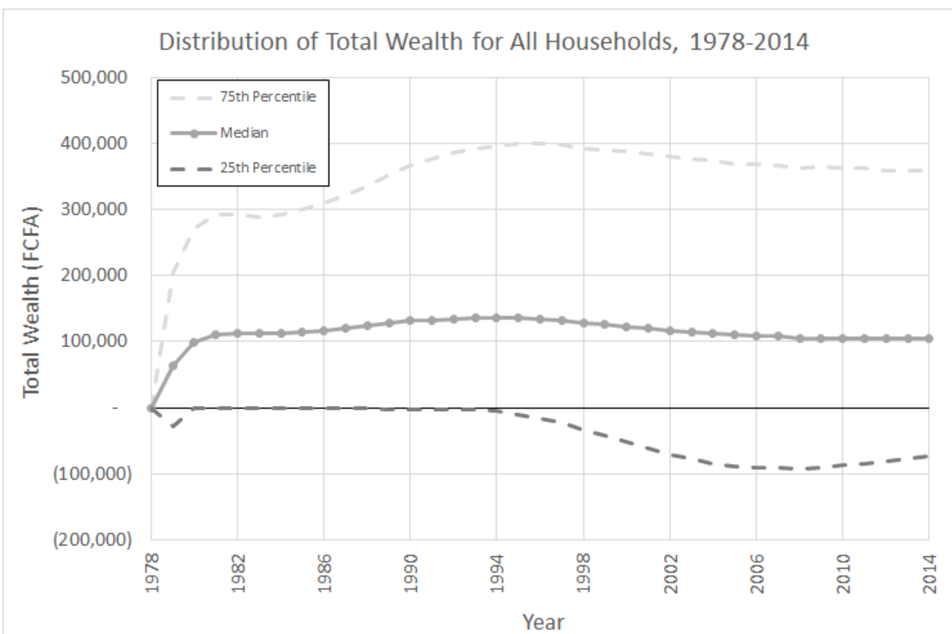


Figure 17: Distribution of total wealth for all households on the floodplain, 1978-2014, in the absence of economic disturbance

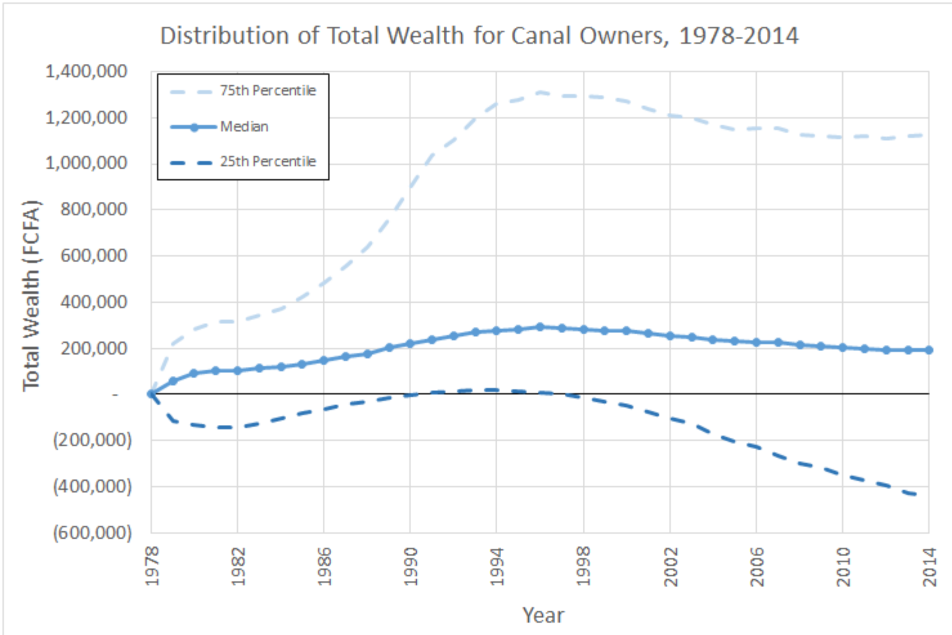


Figure 18: Distribution of total wealth for canal-owning households on the floodplain, 1978-2014, in the absence of economic disturbance

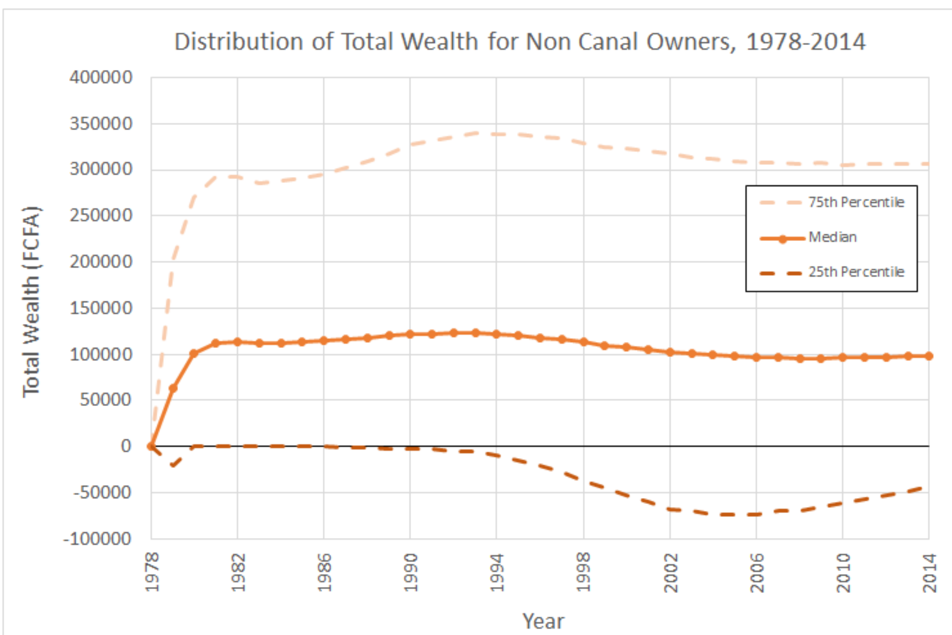


Figure 19: Distribution of total wealth for non-canal-owning households on the floodplain, 1978-2014, in the absence of economic disturbance

Table 7: Changes in wealth metrics for households on the floodplain, 1983-2014, in the absence of economic disturbance. Note that because all households started with 0 wealth, comparing with 1983 provides a more accurate measure of wealth change over time.

Metric	Group	1983	2014	Difference, 1983-2014
Mean	All	165,740	-110,042	-275,782
Mean	Canal owners	145,597	381,513	235,916
Mean	Non canal owners	168,276	-198,818	-367,094
25th Percentile	All	-15	-73,532	-73,517
25th Percentile	Canal owners	-124,674	-440,415	-315,741
25th Percentile	Non canal owners	640	-43,546	-44,186
Median	All	112,430	105,511	-6,919
Median	Canal owners	112,401	192,045	79,644
Median	Non canal owners	112,426	98,200	-14,225
75th Percentile	All	289,354	359,363	70,009
75th Percentile	Canal owners	344,149	1,129,139	784,990
75th Percentile	Non canal owners	286,038	306,425	20,387

3.2 Economic disturbances

The model was also run using 9 sets of experimental parameters that simulated economic shocks of varying severity and length. In this section, I discuss the effects of these shocks, which began in 1999, on the long-term family characteristics and assets of floodplain households. Before comparing the effects of the disturbances, I compared the 9 experimental results (each averaged over 100 runs) with the results from the "null hypothesis" before 1999, when all of the parameters should have been the same. I determined that there was no significant or unusual variation between results (all experimental results were within ±5% of the original results before 1999).

In order to analyze the effects of the economic disturbances, I charted the total number of canals, fields, and households from 1994 until 2014. Figure 17, below, shows the total number of canals over time in the original simulation as well as the nine experimental simulations. The nine economic disturbances have an easily recognizable impact on canal stocks: while canal growth slows down during the economic disturbances, and slows down more dramatically for the more severe economic shocks, the total canal count quickly resumes its original upwards trend. Even for the most severe disturbance, during which income decreased by 50% for five years, canal growth resumes its normal rate within five years after the end of the disturbance.

Figure 18, below, examines this pattern more closely by charting the change in canal growth rates during each of the nine economic shocks. Several trends become apparent from this figure: first, canal growth drops more rapidly during more severe economic downturns. However, even during the most severe economic downturns, floodplain residents continue to build canals. The downwards trend for the "extreme" set of disturbances suggests that if the disturbance continued, new canal growth would eventually reach zero. Finally, when each economic shock ends, the new canal growth rate steadily climbs back to the same rate as the undisturbed model.

Figure 20 shows the total number of fields in each of the 10 simulations from 1994 until 2014. The same stoppage in field growth is apparent throughout each economic disturbance, but field growth resumes its normal growth pattern even more quickly after the end of the disturbance. This may be due to the lower cost of fields relative to canals.

Figure 21 shows the total number of households for each of the 10 simulations. There is no significant difference, visually or statistically, between household counts for each of the 10 simulations as of 2014. This may indicate a time delay between the economic disturbances and their effect on population totals; it may also suggest that the maximum five-year duration of the economic shocks is still too short to impact patterns of marriage on the floodplain.

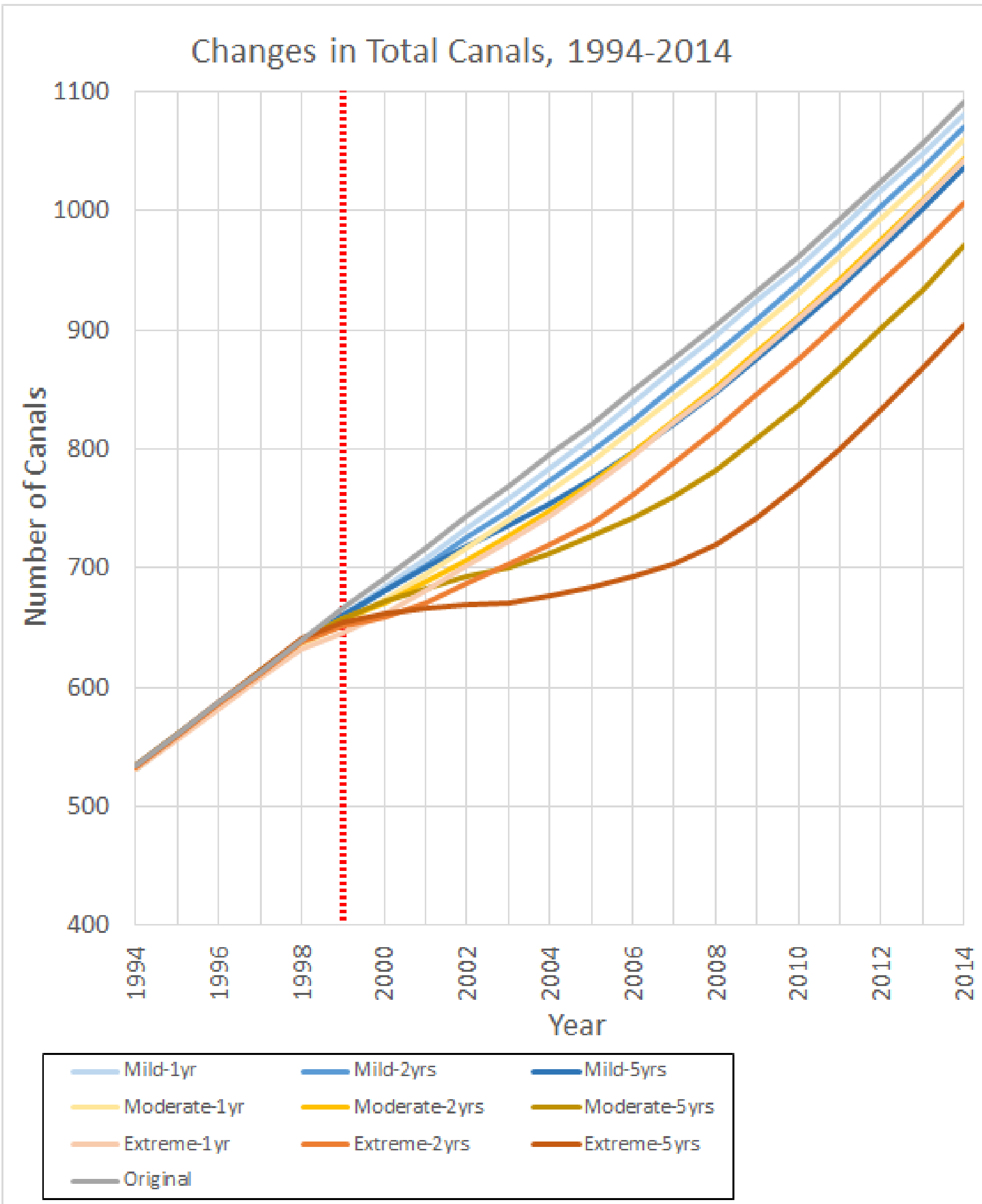


Figure 17: Changes in total canals as a result of nine economic shocks

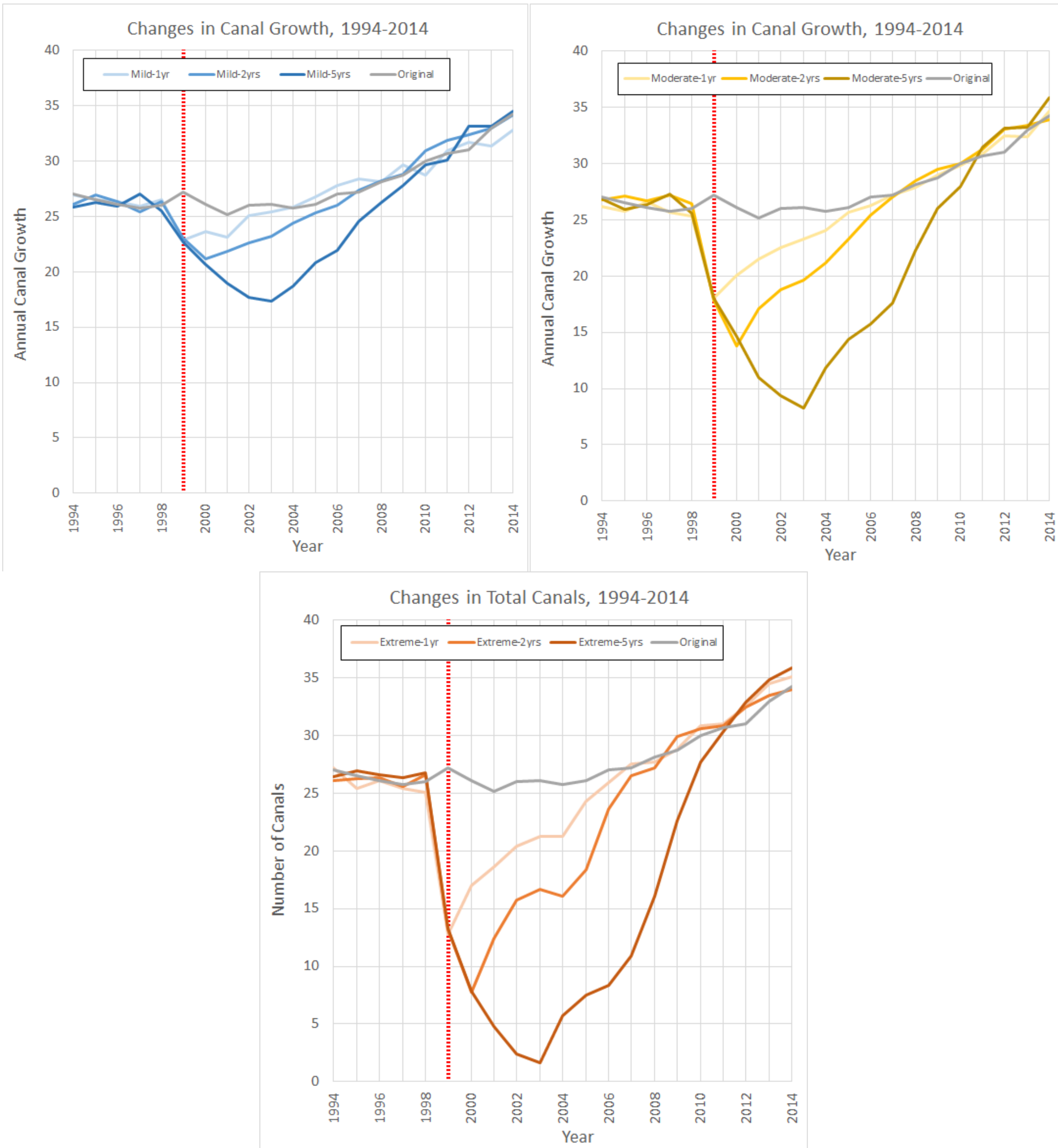


Figure 18: Changes in annual canal growth as a result of mild (top left), moderate (top right), and severe (bottom) economic shocks of five durations

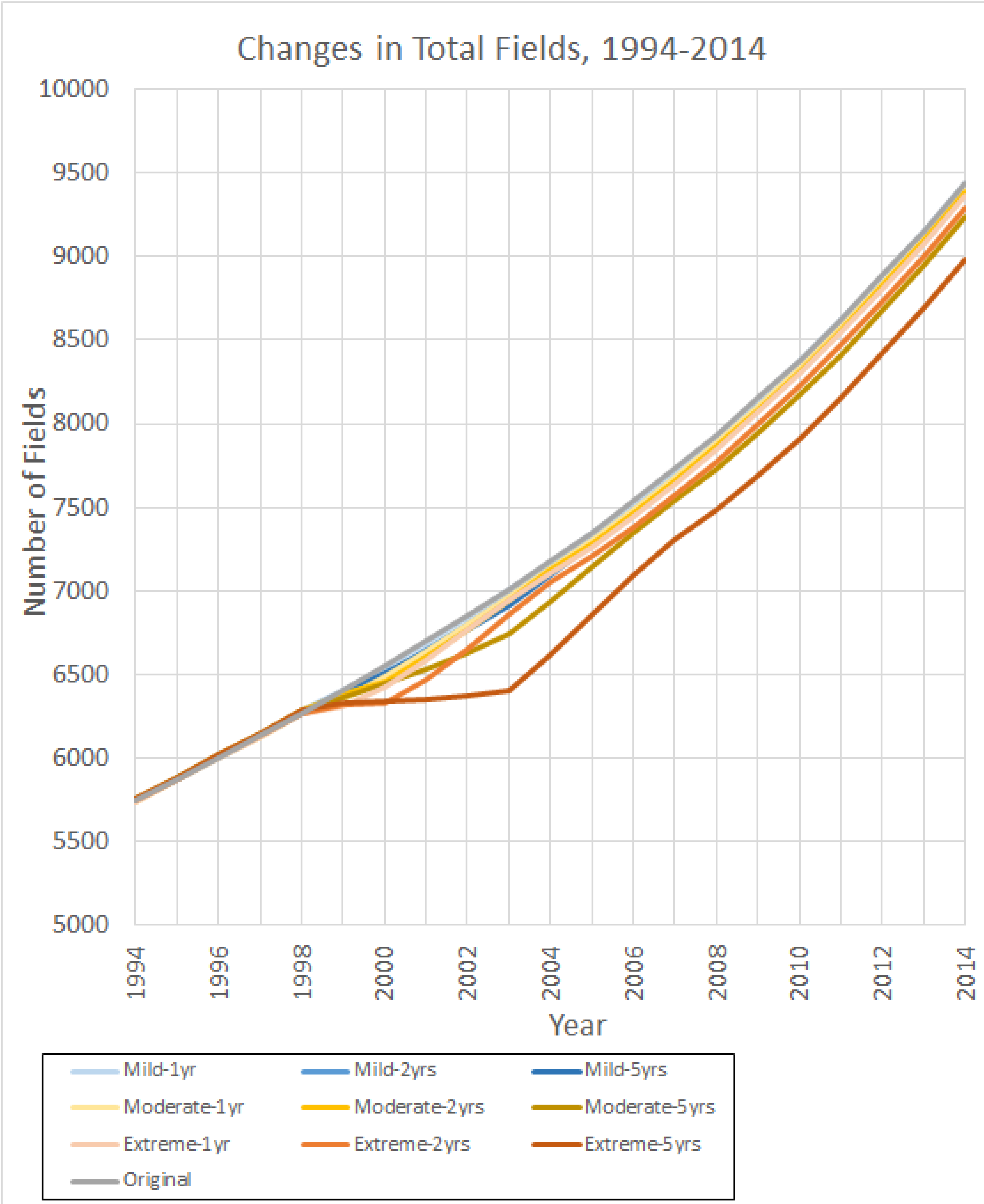


Figure 19: Changes in the total number of fields over time as the result of nine economic disturbances

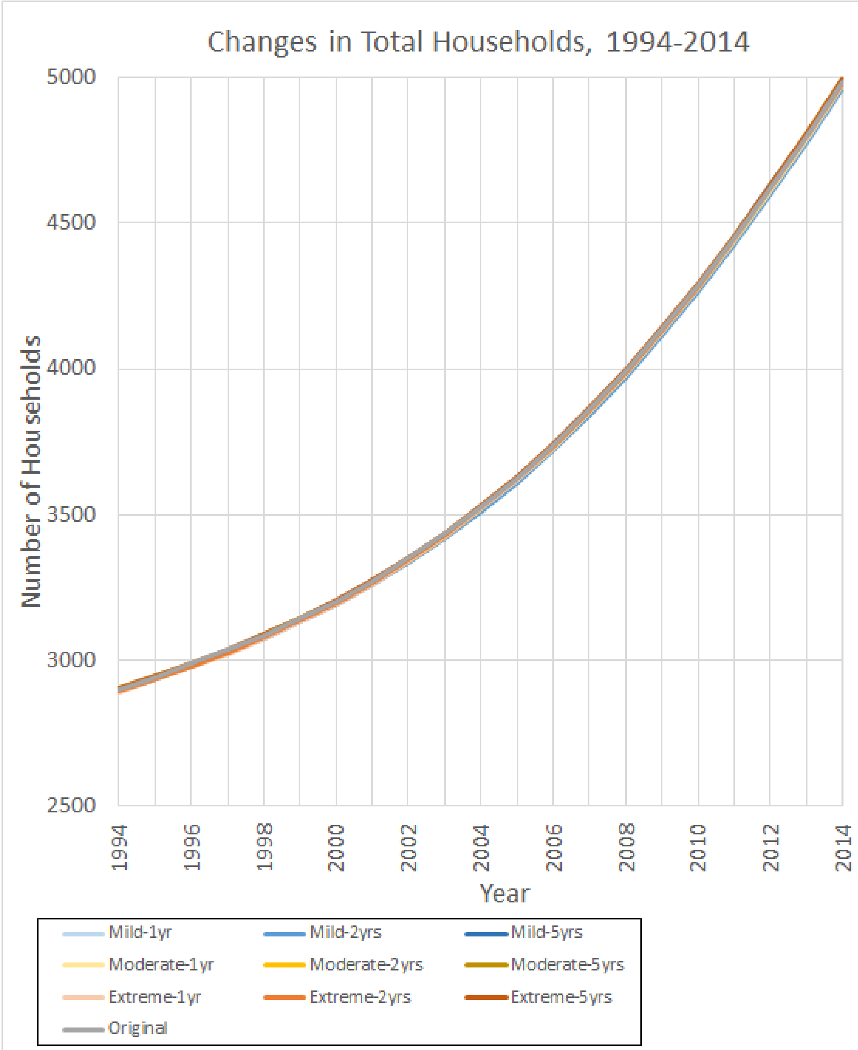


Figure 20: No change in total households as a result of nine economic shocks

Wealth comparisons across the ten simulations indicate dramatic short-term changes throughout and immediately after each of the economic disturbances, with a long-term pattern of reversion to the path of the undisturbed model. This is true for the mean wealth of all households (Figure 21) as well as diverse wealth demographics of canal-owning households (Figure 22), non-canal-owners (Figure 23), and the population as a whole (Table 8 and Table 9). By comparing median wealth values for experimental simulations with the original undisturbed simulation, Table 8 projects the effects of various economic disturbances on median household wealth years after the end of those disturbances. The numbers clearly demonstrate that while the disturbances cause significant short-term wealth losses for floodplain households, most of those losses are regained within 10 years after the end of the disturbance. Table 9, which examines the same trends for the bottom 25% of all households, displays greater short term losses: after five years of a severe disturbance, this subgroup is estimated to lose approximately 1 million FCFA more than they would have without the shock. However, the pattern of long-term reversion to the undisturbed state is clear.

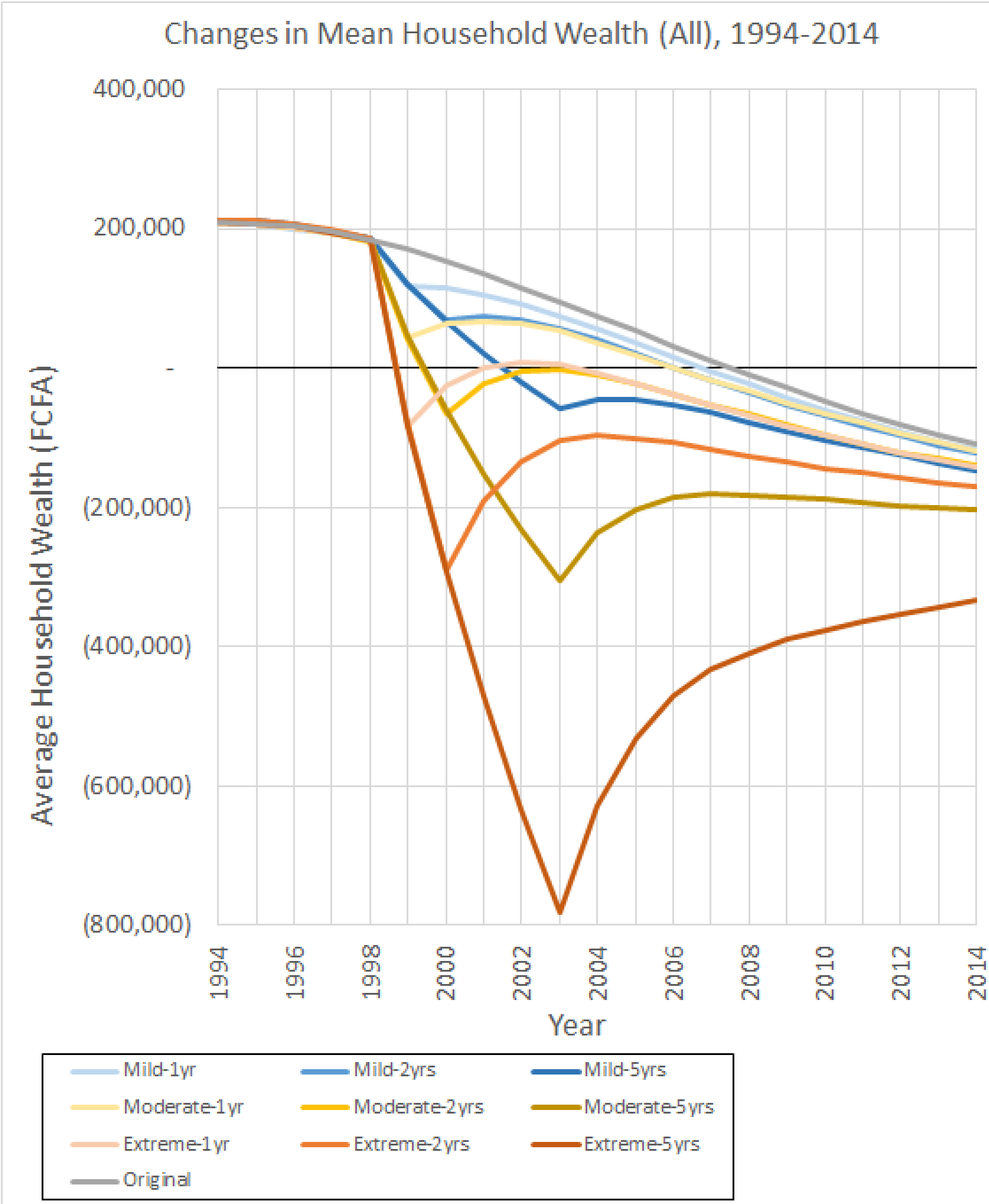
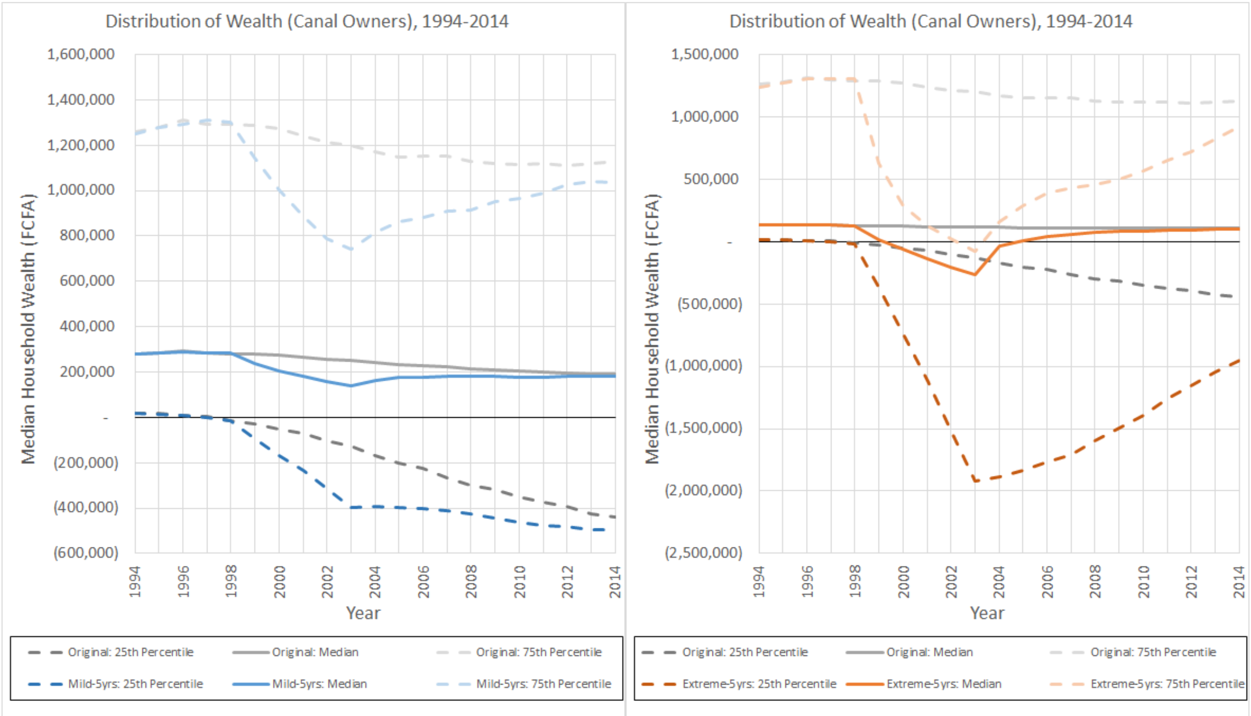
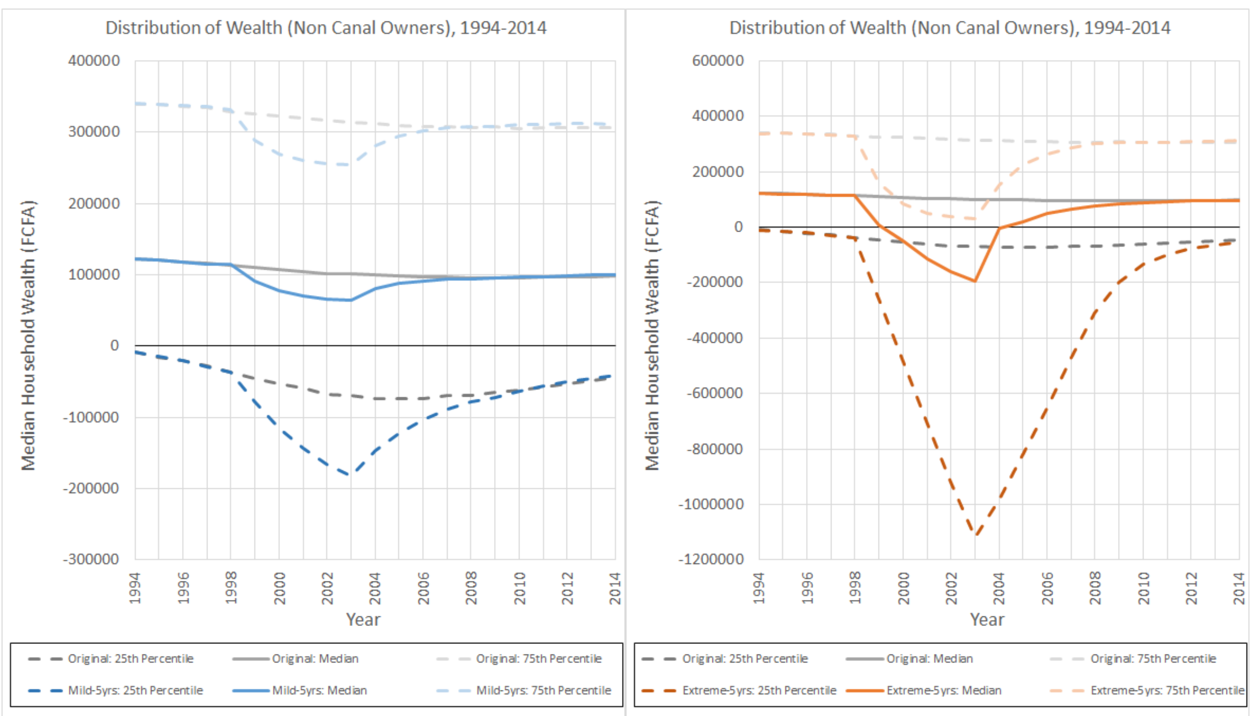


Figure 21: Changes in mean wealth of all floodplain households as a result of nine economic shocks



<u>Figure 22</u>: Losses in wealth for canal owners as the result of mild (left) and extreme (right) economic shocks lasting five years



<u>Figure 23</u>: Losses in wealth for non-canal owners as the result of mild (left) and extreme (right) economic shocks lasting for five years

Table 8: Differences between the median wealth of all households after experiencing an economic disturbance compared with the median wealth of all households in the undisturbed simulation, measured at four time periods after the disturbance (rounded to the nearest 10,000 FCFA)

Shock Type	End of Shock	1 Year Afterwards	5 Years Afterwards	10 Years Afterwards
Mild-1 Year	-40,000	-20,000	-10,000	0
Mild-2 Years	-40,000	-30,000	-10,000	-10,000
Mild-5 Years	-80,000	-60,000	-30,000	-10,000
Moderate-1 Year	-70,000	-50,000	-10,000	0
Moderate-2 Years	-110,000	-80,000	-30,000	-20,000
Moderate-5 Year	-200,000	-150,000	-70,000	-20,000
Extreme-1 Year	-130,000	-90,000	-40,000	-20,000
Extreme-2 Years	-220,000	-160,000	-70,000	-20,000
Extreme-5 Years	-830,000	-580,000	-160,000	-50,000

Table 9: Differences between the wealth of the bottom 25% of all households after experiencing an economic disturbance compared with the wealth the bottom quarter of households in the undisturbed simulation, measured at four time periods after the disturbance (rounded to the nearest 10,000 FCFA)

Shock Type	End of Shock	1 Year Afterwards	5 Years Afterwards	10 Years Afterwards
Mild-1 Year	-30,000	-20,000	0	0
Mild-2 Years	-50,000	-30,000	-10,000	0
Mild-5 Years	-90,000	-70,000	-20,000	0
Moderate-1 Year	-70,000	-50,000	-10,000	0
Moderate-2 Years	-150,000	-100,000	-30,000	0
Moderate-5 Year	-350,000	-260,000	-50,000	0
Extreme-1 Year	-190,000	-130,000	-30,000	0
Extreme-2 Years	-400,000	-300,000	-70,000	-10,000
Extreme-5 Years	-1,040,000	-890,000	-250,000	-20,000

Taken as a whole, the results demonstrate that the residual effects of short-term economic disturbances can remain on the floodplain for years after the end of the disturbance itself. However, these effects diminish over time, and no clear indicators point to the economic disturbances triggering a shift in the economic activities of households. These results and their implications for the Logone floodplain will be discussed in the following section.

4. Discussion

The simulation results paint a telling, if incomplete, picture of conditions on the floodplain as a result of Boko Haram. The exact magnitude of Boko Haram's impact on the floodplain will depend on how far fish prices drop, the duration of the price change, and the possible continuation of increased fees and taxation even after the threat of Boko Haram has passed; however, the model suggests that unless the situation on the floodplain becomes significantly worse, the system will return to its previous state within ten years after the disruption. In each of the nine experimental simulations mimicking Boko Haram's threat to the floodplain, economic activity was disrupted and wealth was destroyed during the disruption, but economic activity returned to its normal levels within five years, household wealth converged with the undisrupted wealth trends within 10 years, and there was no observable impact on long-term changes to family dynamics. In other words, the model predicts that the system is resilient to the change wrought by Boko Haram: while the floodplain will still face the previous internal threats of growing canals and lowered fish stocks, the current crisis will not push the system over a threshold or create long-term changes in the floodplain system.

While these conclusions seem reassuring, they must be taken cautiously as an incomplete representation of the entire floodplain system. By definition, no quantitative model can capture the myriad interactions, scales, and influences on the "panarchy" governing actual social-ecological dynamics on the floodplain. My quantitative model centers around a single feedback between two important components of life on the floodplain: economic activity and the family. As it turns out, this feedback serves as a negative feedback that dampens significant changes in wealth, making individual households resistant to economic crises like the price decrease modeled in this paper. To increase the size of their families, household heads must earn an annual income high enough to feed all existing family members, as well as to save up the money for another marriage; as a result, family size (the major determinant of annual costs for households) only increases slowly over time. However, when the household's wealth threshold falls below a certain level, family members can reduce their consumption by half, significantly lowering a household's costs without impacting annual income. In this way, households can quickly recover after economic crises once their annual income returns to normal. While this feedback may play a genuine role in disaster recovery on the Logone floodplain, it is only one of many feedbacks between individuals, households, institutions, and the environment that collectively determine the future trajectory of the social-ecological system.

While the model's portrayal of system resilience remains incomplete, the results also provide insight into the relative vulnerability of different subgroups on the floodplain. During each experimental simulation, the model captured the average debt load of various subgroups on the floodplain, their debt levels over time, and the amount of time it took them to return to zero wealth. A large portion of the floodplain goes into debt during the more severe and extended crisis simulations: for example, the model predicts that if income drops by 50% for a period of five years, approximately one-quarter of canal owners will exit the disturbance with more than 2 million FCFA (US $3,400) in debt. This amount is substantial, especially for families who have already reduced their consumption levels in an effort to save money. The model does not portray the negative consequences of debt, from compounding interest to the crushing psychological burden that accompanies it. For households in poverty, skipping meals to reduce costs would quickly take a toll on the labor capacity of family members, making them even more vulnerable than portrayed in the model. For government organizations and crisis relief groups working on the floodplain, this model can guide them in finding which groups and individuals to target for direct aid. After all, any effective response to Boko Haram must confront the poverty and lack of opportunity that are partially responsible for the group's genesis (Agbiboa 2013).

The model discussed in this paper has applications outside of the Logone floodplain. Agent-based modeling techniques can offer rich insight into the fields of economics and demography, particularly at the intersection of those two fields. In societies where marriage and wealth and linked, particularly in societies that practice polygyny, population dynamics cannot be understood without economic analysis, and vice versa. This feedback also links to a larger conversation about the links between family size, status competition, and the "embodied capital" of household in many small-scale societies (Shenk et al 2016). This model can serve as a testable and practical tool for understanding these types of integrated systems that might confound traditional dynamical models.

This model might also serve as the "human" component of a more integrated model of the Logone floodplain. Because the model's scope is currently limited to social and wealth-generating behavior, it currently relies on necessary assumptions about ecological and hydrological systems on the floodplain. For example, the model's current revenue functions are currently based on three questionnaires from 2014, 2015, and 2016; while they might approximate the distribution of wealth during those particular years, they cannot account for changes dating back to the beginning of the model in 1978. A more reliable revenue function might account for annual floodwater levels, the presence of nearby canals, and estimated fish stocks in the area. Not only would this provide households with a more accurate income each year, it could also serve as the basis for a spatially-aware canal building function that takes current wealth, nearby canal revenues, resource dynamics and diffusion of innovation into account.

5. Conclusion

In this thesis, I explored Boko Haram's indirect impact on the residents of the Logone floodplain in the Far North Region of Cameroon. The Logone floodplain has experienced large-scale disruptions in the past, such as the building of the Maga Dam, and is currently subjected to a number of internal pressures related to the rapid spread of a canal fishing technique. Now, Boko Haram's presence in the Far North Region has led to an increased military presence on the floodplain and has burdened floodplain residents with new taxes, lower annual incomes, and even the threat of violence. In order to determine how these burdens might impact the long-term behavior of the floodplain system, I constructed an agent-based model that simulated economic and demographic processes on the floodplain. After validating this model against known floodplain socio-economic trends from 1978-2014, I conducted a series of experiments that simulated economic disturbances of various magnitudes and durations on the floodplain.

According to the results of the experimental simulations, the economic disturbance caused by Boko Haram may lead many floodplain residents into debt, but it will not change the long-term behavior of the floodplain system. While this result comes with a series of caveats about the limitation of the model, it does reveal an interesting trend on the floodplain: a feedback between family size and income may make households resistant to dramatic changes in wealth. Additionally, the floodplain model can serve as the basis for a future integrated model of the floodplain, or else serve as the starting point for future investigations into economic-demographic interactions.

5.1 Acknowledgments

I conducted this research as part of the Modeling Regime Shifts in the Logone floodplain (MORSL) research group at The Ohio State University. I would like to thank the other members of the MORSL team for their comments, discussions, and insights, which have been foundational to my understanding of the floodplain. I am particularly indebted to the members of my Thesis Committee: Mark Moritz, Sarah Laborde, Ian Hamilton, and Ningchuan Xiao. Without their advice and continuing support, this research project would have been impossible.

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