Conflict in Complex Socio-Natural Systems: Using Agent-Based Modeling to Understand the Behavioral Roots of Social Unrest within the Mandera Triangle

Mark Rouleau, Mark Coletti, Jeffrey K. Bassett, Atesmachew B. Hailegiorgis, Tim Gulden, William G. Kennedy

Center for Social Complexity
Krasnow Institute for Advanced Study
George Mason University

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***Abstract*—Conflict resolution research relies upon a deep understanding of human behavior within highly complex socio-natural systems. Scholars must isolate the source of conflict among individuals reacting to the feedback of changing socio-natural conditions. Fortunately, the oft-obscured roots of conflict typically surface at critical points of change within the system. We use the Mandera Triangle region of East Africa as an example of this surfacing of behavioral drivers. Our research fuses a wide range of backgrounds to construct a simulation model of Mandera and to gain a better understanding of the roots of human behavior in relation to social conflict.**

***Key Words*—herder-farmer conflict, agent-based simulation, Mandera Triangle, East Africa.**

Introduction

The Mandera Triangle – an area of East Africa encompassing a generally triangular area bordering Somalia, Kenya, and Ethiopia – has served as the traditional home for several well-established nomadic herding groups. This zone and its populace were once coupled in a self-regulated socio-natural system developed over countless generations. The inhabitants of Mandera exhibit socio-natural evolution in the adoption of pastoralism as a response to their sparse and seasonally changing environment. Furthermore, the herders of Mandera have also constructed an elaborate social alliance structure to cope with various environmental shocks such as drought or flooding. However, this is the somewhat simplistic picture of Mandera before its relatively recent division into states and, with it, the introduction of new actors and governance structures. Herders in today's Mandera now face more socio-natural complexity in their lives marked by the advancement of government supported private landowners (i.e. farmers). Without sufficient time or resources (i.e. the low carrying capacity of the land) to evolve, this new socio-natural system has become highly conflict ridden.

Given the socio-natural complexity in the Mandera Triangle, our research uses Agent-Based Modeling (ABM) to gain a better understanding of herder behavior in response to the introduction of new actors (i.e. farmers), the feedback from these actors through the natural environment (i.e. land-use practices), and the resulting sources of tension and conflict. Our vastly multidisciplinary research team brings together knowledge from cognitive science, ethnography, political science, geography, and computer science to work towards the production of a high-fidelity model of conflict inspired by Mandera. The model's natural environment is constructed using data from Geographic Information Systems, including regional information on ground cover, resource variance, weather patterns, and hydrology. Agent decision-making within the model's social environment is supported by ethnographic research of social customs – mechanisms for alliance formation and conflict resolution – and regional studies of conflict mediation conducted by both political scientists and policy makers. The resulting model highlights the current socio-natural flashpoints in Mandera and provides the opportunity to experiment with future "what if" scenarios shaping the behavior of herders in response to land-use decisions.

Figure 1 – The Mandera Triangle study region in reference to its location in Eastern Africa.

Isolating the Roots of Conflict

It would be wrong to interpret the pre-colonial history of the Mandera Triangle as a stable, conflict-free socio-natural system evolving towards a steady equilibrium. In fact, conflict has been an ever-present feature of this region but one that has developed within its own institutional bounds over nearly three thousand years (Johnson 1983). For example, raiding is a common method of wealth redistribution used among pastoral groups during times of hardship. This behavior and other institutional and economic structures stem from the non-equilibrium dynamics that favored the survival of the traditional herder society found in Mandera today (Mace 1993). Pastoralism in Mandera was largely an adaptive response to both short- and long-term environmental cues. In the short-term pastoralism offered the greatest return on effort in a semi-arid region that was not especially hospitable to agriculture. In the long-term a mixture of agro-pastoralism, primarily dominated by herding, proved a flexible option for survival in a rather unpredictable and, at times, lean environment. Thus, societal evolution led the pastoralists of the Mandera Triangle to weave themselves into the fabric of the surrounding natural environment with its particular ebbs and flows (Smith 1984 and Smith 1992).

From this perspective it is possible to identify environmental restraints on survival, such as floods or droughts restricting access to grazing land, as potential triggers for conflict within these pastoralist groups. Consequently, institutional structures evolved to manage and accommodate these restrictions. One critical institutional development was the introduction of a customary system of shared resource access (Torry 1976 and Johnson 1988). This quasi-formal agreement among Mandera's pastoral groups permitted herders to mutually graze lands while traveling through one another's zone of influence or in times of desperation. Without this arrangement, pastoral life in Mandera would have been much more difficult if not impossible to sustain for all but a handful of groups (Mace 1993).

The sparse and seasonally changing landscape of this region meant that intrusion onto another's land was likely to occur in transit but particularly when marginal land faced adversity. Thus, mutual access agreements were implemented under the condition that common customs were respected – such as the grazing of cattle in the highlands and camel in the lowlands – and such rights were not abused. Although these agreements did not eliminate conflict among pastoralists, they did provide an authoritative framework for conflict resolution that centered upon a common understanding of socio-natural interactions (Torry 1976 and Wario 2006). When inter-herder conflict did occur, it typically took the form of a symbolic gesture of economic redistribution rather than an attempt to annihilate the other party (Torry 1976). This is how Mandera came to cope with its complex socio-natural environment for hundreds, if not thousands, of years. However, in the past number of decades, this picture has begun to change and, with it, the nature of conflict, as those in Mandera have traditionally known it.

The introduction of the Western-oriented state system has led to a number of unintended drivers of conflict within Mandera. The establishment of the state brought with it two social institutions – centralized power and land tenure – that did not fit well with the traditional system in place in this area (Bouh and Mammo 2008). It is the joint relationship between these two institutions developed under socio-natural circumstances entirely different than the Mandera Triangle that has done the most to upset the delicate social balance in this, at times, erratic and unpredictable environment. This change has come about primarily because it was facilitated by circumstances outside of the environmental restraints of the region it is currently impacting (Ensminger and Rutten 1991). Therefore, as the history of this change indicates, this is not a process that was likely to develop without external interference but one that was sure to have consequences once imposed.

The division of the Mandera Triangle into three separate states – Ethiopia, Kenya, and Somalia – has resulted in the concentration of power within three new power centers with political and economic demands that stretch far beyond the region. In this new market-oriented system, "survival" is no longer fixed to environmental change; rather it can be purchased through economic means in the form of global trade. In many ways, this has redefined the rules of the game in Mandera and has encouraged a rise in sedentarization for portions of the population seeking to participate in this new system (Ellis and Swift 1988). Sedentary societies are better able to contribute in the market system and, thus, the new power centers have come to favor individual farmers at the expense of nomadic pastoral groups (Ensminger and Rutten 1991). This is most apparent when property rights are at stake. Support for landowners has led to the enclosure of previously shared-access land to be used by farmers, national parks, and wildlife refuges, severely limiting outlets used by pastoralists to cope in desperate times (Scoones 1994)). Furthermore, much of this change has taken place without the consent of pastoralists and, most importantly, without a change in their methods for survival (Oba 2001). The result has been an increase in both the number and magnitude of conflicts in this region. These conflicts usually revolve around issues of trespassing but have the tendency to escalate beyond a single event (Wario 2006). It is this increasing incidence of escalating conflict that has drawn the interest of the global community.

The situation in the Mandera Triangle provides a unique opportunity to examine the behavioral roots of conflict. Given that conflict was historically "well-regulated" prior to the introduction of states, it is reasonable to speculate that the entrance of new actors, in the form of landowning farmers, has had a significant impact on the nature of conflict. The case of Mandera is a good example of the impact of institutional collision leading to the upset of a longstanding symbiotic socio-natural relationship. Moreover, it is possible to sift out behavioral drivers from these changed circumstances by observing differences between the new herder-farmer interactions and the traditional behavior of pastoralists attempting to meet the age-old demands of the natural environment. Our study seeks a better understanding of this change, its influence on herder behavior, the impact on the socio-natural system, and the complex feedback driving a new form of conflict in Mandera.

Prior Modeling Efforts

Our research team has chosen to model this dynamic relationship between herders and farmers in the Mandera Triangle as a means to investigate the behavioral roots of conflict in an experimental manner. We have constructed a platform for investigating the emergent macro-patterns of conflict as they come about due to changes in the socio-natural restraints imposed upon pastoralists in this region. This work is the first of its kind for the Mandera Triangle but it does build upon previous modeling efforts in three critical research domains: resource management models, pastoralist models, and herder-farmer conflict models. Therefore, it is important to first briefly describe these works and their influence upon the model we have developed.

Resource management, as a complex interplay between individual agents and their environment, is a fundamental theme of Mandera conflict and our modeling endeavor. One of the first ABM attempts to investigate the effects of micro-level decision-making within an environmentally constrained context was the Santa Fe Institute's Anasazi model of Axtell et al 2002. These researchers used the ABM framework to "retrodict" the rise and fall of the Anasazi civilization in response to climatic change and resource variance. The ABM approach permitted the researchers to overcome the aggregation techniques of system dynamic models and to produce resulting population dynamics that were much closer to reality. The key to this work was the simulation of interactions at the individual level where average values taken from population distributions would have washed out a number of critical socio-natural macro patterns such as the non-linear pressures of declining resources. This is evident in the importance of the spatial context of environmental degradation and its impact upon the Anasazi, something that could not be accounted for with ordinary differential equations. Since the Axtell et al. model, a number of researchers have been inspired by this approach and have used ABM to explore a wide range of socio-natural phenomena.

Current resource management modeling topics include: urban development, agricultural intensification, pollution, deforestation, water scarcity, food insecurity, and habitat conservation (Parker et al. 2001). These models range from highly abstract "thought experiments" conducted in a cellular automaton environment to high fidelity models grounded upon multiple scales of Geographic Information Systems (GIS) data. A strong emphasis on the complex feedback produced from individual land-use decisions underlies much of this work. The lesson learned is that a handful of individual actors can play a vital role in the overall future trajectory of a highly intertwined socio-natural system. Land can often be the indirect medium through which societies interact over a sustained period of time, providing the impetus for future changes in behavioral decision-making (Polhill in Parker et al. 2001). This was certainly the case in Mandera prior to, and after, the introduction of the state system (Wario 2006). Furthermore, it is important to understand that change to the environment -- such as the introduction of a small set of landowning farmers -- does not necessarily require or entail societal shifts at the same scale as the resulting macro patterns that are produced -- such as the rapid escalation of conflict (Parker et al. 2001). In other words, resource management models have helped to underscore the significance of seemingly minor environmental changes leading to major societal consequences. This is a feature that is undoubtedly critical to any ABM simulation of pastoralist behavior.

Only a few models exist that attempt to examine pastoralist behavior and its relationship with the natural environment. These models fall into two distinct categories. The first set of models explores the environmental conditions favorable to the adoption of pastoralism. This research argues that the decision to undertake pastoralism is environmentally dependent upon conditions that favor the raising of herd animals over the viability of crop production such as is found in the semi-arid and sparsely fertile region of the Mandera Triangle (Mace et al. 1993). It is also noted that the decision to undertake pastoralism is not entirely a one shot option. This research claims that a shift from pastoralism to some form of agro-pastoralism is likely in times of economic hardship, encouraging sedentarization in an effort to recoup wealth (Mace et al. 1993). However, this switch is highly contingent upon the availability of fertile land and the strength of conservative social pressure within the group to maintain a traditional lifestyle. Thus, a decision to switch from pastoralism to agropastoralism or farming is not likely to take place over the course of a single environmental event such as a drought. It will require sustained environmental pressure to break the pastoralists from their traditional ways. In conclusion, these models hint at the fact that pastoralists have incorporated flexibility into their short term decision-making regarding herd movements and kinship support to compensate for their reluctance to break close ties with their unpredictable environment (Johnson 1983 and Mace et al. 1993).

The second set of pastoralist models focus on strategic considerations regarding movement decisions. A particularly intriguing model for the Mandera study area is that of MacOpiyo et al. 2006. Their model uses a GIS informed landscape of southern Ethiopia and northern Kenya to explore the environmental drivers of herder movement in several pastoralist communities of this area. Although this model did not address issues of herder-farmer conflict, it provides an excellent example of herder movement patterns as they are linked to the sparsely populated grazing zones. It is argued that access to water plays a pivotal role in this form of decision-making. For example, MacOpiyo et al. show that herder movement patterns match the surrounding environment and remain relatively dispersed under normal circumstances. This behavior permits herders to avoid problems of overgrazing by continually moving in wide patterns to and from one grazing site to the next. In this way, the herders are able to take full advantage of an otherwise mediocre environment. However, the model of MacOpiyo et al. presents an entirely different picture in times of hardship such as during an extended drought. In these situations, herders find themselves tightly coupled in the zones of the greatest fertility, particularly those least disposed to desiccation. It is likely this complex socio-natural feedback that is responsible for the loose institutional regulation of land (Torry 1976). The sparse nature of the land discourages sedentarization and the wealth accumulation that comes in times of plenty. On the other hand, unpredictability forces relatively equally matched groups to coexist through common agreements in times of desperation (Mace 1993). This is not to suggest that conflict is never an option when these groups are forced into contact. The final set of models offer a clue as to when this may come about.

A number of herder-farmer models exist that suggest external interference has a hand to play in escalating conflict. For example, the NOMAD model of Kuznar and Sedlmeyer 2005, which models the ongoing ethnic conflict in the Sudan, highlights the importance of the herder-farmer relationship during environmental hardship. Although the situation in the Sudan differs from that of the Mandera Triangle, the NOMAD model does help bring to light the socio-natural impetus for conflict between pastoralists and a sedentary society. It is argued that herders, facing environmental barriers to survival, find themselves vulnerable and at the hands of farmers due to perturbations in resources. Greater perturbations lead to greater levels of desperation for both the herder and the farmer. As a result, the reluctance of farmers to trade or share the means to ensure survival leads inevitably to conflict. This argument is further supported by models such as Bah et al. 2006 that indicate little recourse is available, such as the drilling of artificial waterholes, to alleviate environmental pressures on pastoralists blocked from access to reliable rangeland. Finally, both of these models, as well as the model of Brockhaus et al. 2003, claim that the role of the state is crucial to the escalation of conflict beyond a single event. Poorly under funded and lacking institutional authority among the traditional pastoralists, the failure of the state to manage conflict combined with the support for land rights over grazing access results in a greater rate of conflict with a higher number of casualties.

Model Description

Our research draws two important parallels with the models previously described. First, we see herder-farmer disputes as the primary stage for conflict escalation within our region of study. Second, we believe that environmental hardship and ineffective land management drive this conflict. Therefore, as a first step, we have designed a platform to investigate herder-farmer conflict from these foundational principals. However, we are aware that no two herder groups, even those within the Mandera Triangle, are entirely alike. Thus, we have incorporated modularity into our model as a way to provide a plug-and-play environment for specialized conflict areas. Our ABM approach, implemented within the Java Object-Oriented modeling framework, makes this possible. We strive for modularity because it is our long-term goal to produce a generalizable model of conflict in all of East Africa. We have chosen the Mandera Triangle to guide model construction and will describe our initial modeling efforts from this perspective.

The Mandera Triangle model is developed within the MASON simulation environment. MASON is a multi-purpose simulation library for the Java programming language. MASON provides the necessary modeling tools, such as agent scheduling and visualization, for the development of customized ABM simulations. As is typical for ABM simulations, MASON models are dependent upon the implementation of three critical components: agents, the environment, and the rules of interaction. The Mandera Triangle model consists of two primary agents: herders and farmers. These agents are placed within a GIS-informed simulation environment meant to capture high-level environmental dynamics such as the fertility of the land, weather, and basic hydrology of a region approximately 150 km by 150 km. Finally, we will present a general set of interactions rules needed to produce the conflict behaviors outlined in the case study analysis above. The resulting architecture of the model is illustrated in Figure 2. In the final section of this paper, we offer a number of potential model extensions to this initial simulation core.

The Mandera Triangle model consists of two groups of agents with the potential for fundamentally opposed agendas contingent upon existing environmental conditions. The first type of agents is the farmer agent. To avoid overcomplicating our model from the outset, we have left the farmer agent as a relatively simple, passive actor. Farmer agents essentially occupy viable grazing land and increase the fertility of these parcels through their efforts. What is important to this behavior is the fact that farmers generally occupy parcels with a high fertility and, once occupied, farmers have a stake in defending these high-demand parcels from herder intrusions. Although this may seem to be quite simplified behavior, this simple occupy strategy is all that is needed to exhaust the herder agents' capability to overcome minor fluctuations in their environment.

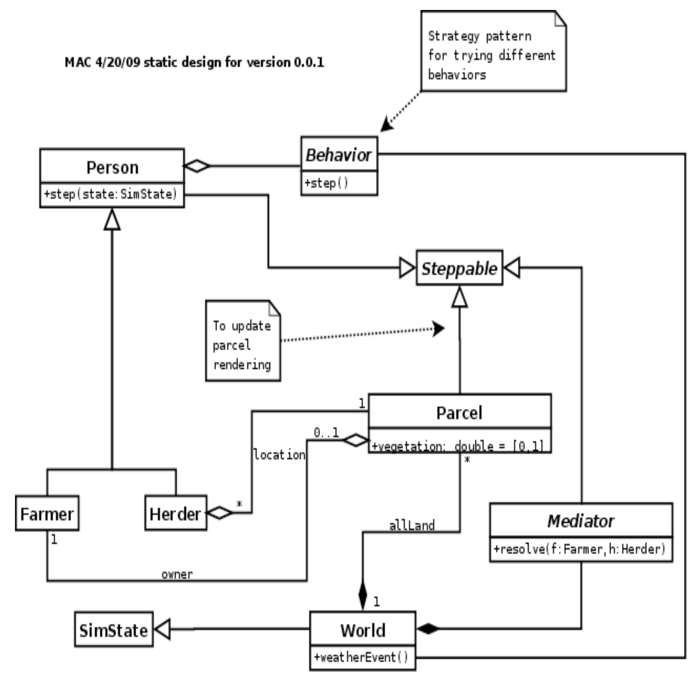

Figure 2 – High-level UML class diagram depicting the primary actors and their relationship to each other and their environment.

Herders, the other primary agent group, are the problem solvers in our model. A herder agent consists of a set of individuals -- the herder's family unit -- and a herd of animals such as cattle. Each herder agent can occupy only one grid cell or grazing parcel. The state of the herder agent's health is defined using a zero to 1.0 scale. Herder agents must manage their health through grazing. Grazing of a parcel depletes the resources in the herder agent's current location. Once the resource level of a parcel drops below a stressed threshold, herder agent's call on a movement function to determine the next appropriate parcel to engage. This movement decision strategy is one of the modular components of our model that can be removed and replaced as information from our study area dictates. Currently, the movement function presented in this article implements a simple local greedy search strategy. Herder agents exhaust the resources in their current parcel and move to the next nearest parcel with the greatest resource level. The only qualification to this movement decision is that herder agents prefer to avoid farmer agents whenever possible. Thus, herder agents will only move onto occupied parcels when their health is desperate, i.e., below another threshold. As will be shown below, the environment is the primary driving force behind this change in behavior.

We model the environment with two components: land, which is divided into a regular grid of 1 km^2 parcels, and weather. Land parcels are of differing quality, which is represented by the maximum amount of vegetation they can support in the absence of grazing and under optimal weather conditions. We estimate this maximum vegetation level using GIS data on land use and slope. Parcels grow vegetation according to a logistic function based on the parcel's maximum level of vegetation, its current level of vegetation, and the current rainfall. A minimum amount of rainfall is required to maintain the current level of vegetation – below that level the growth rate is negative and the grass dies off even in the absence of grazing. Farmed parcels are capable of producing a maximum level of vegetation that is twice what it would be in the absence of a farmer. These maximum vegetation levels are roughly calibrated using data from Keya (1998). We represent weather with the single variable of monthly rainfall. While we plan to test more elaborate specifications as the modeling effort progresses, we currently have specified weather such that it adjusts the rainfall level at the beginning of each month to reflect a typical yearly cycle as outlined in Keya (1998). See figure 3 for an example of the GIS environment with farmer locations and weather cycles.

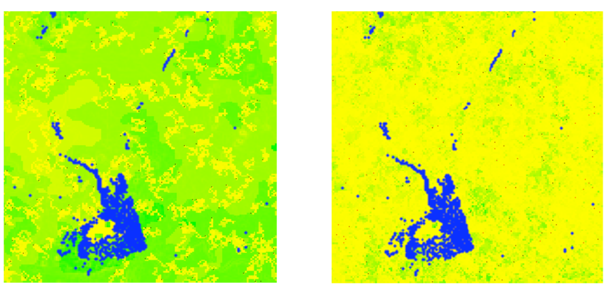

Figure 3 – The agent landscape during the rainy and dry seasons. The darkest circles note farmer agent locations while parcel viability is represented on a grayscale with lighter sections indicating low viability.

Once the agents and the environment have been defined, the simulation is then initialized and run while the resulting macro dynamics are recorded for analysis. Initialization of the model consists of placing herder and farmer agents onto the GIS-defined grid environment. Observations from GIS-data help to determine an approximate initial location for farmer agents. Herder agents are then randomly assigned locations throughout the grid, ensuring that no herder agent is placed on the same parcel as a farmer. The main simulation loop consists of herder agents adapting to the seasonally driven changes in the grazing environment. Seasonal changes in weather, in the form of rainfall, determine the current state of any given parcel according to that parcel's maximum fertility. Each time step is equivalent to a day and the herder agent's depletion of its current parcel is pegged to this time increment. As the environment permits, herder agents avoid farmer agents to move from parcel to parcel to maintain their health. Parcel re-growth occurs but at a much slower rate than the herders reap from them. This has the potential to drive herders onto farmer land during times of crisis. For example, if a herder agent's health reaches the desperate stage due to the lack of viable parcels, herder agents will then seek the nearest parcel with available resources regardless of the current landowner. It is these trespassing events that are entered into a conflict mediator and the results of the conflict are determined at the end of the round. This process is then repeated, varying the number of herders and recording the resulting conflict dynamics (see figure 4).

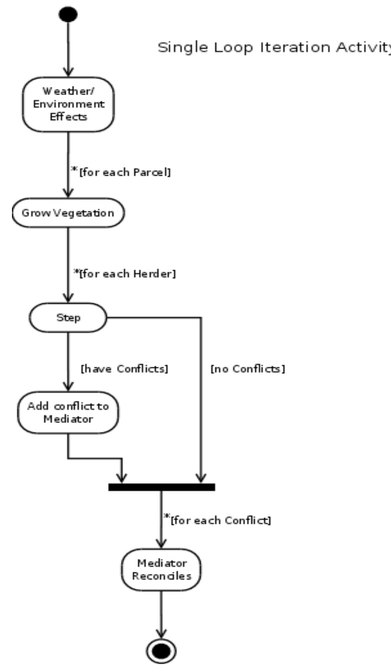

Figure 4 – UML Activity Diagram of the main simulation loop. First, weather events dictate the level of vegetation for each parcel. Next, herders attempt to graze. If herder agents cannot meet their grazing needs within a given parcel, herders then attempt to move. Herder agents will avoid farmer occupied parcels when moving to the best viable resource unless the herder agent health status is desperate. Finally, incidents of trespassing are passed to the conflict mediator and the results of conflict are determined at the end of a round.

Preliminary Results

From our initial modeling efforts, we have been able to replicate the generalizable features of herder-farmer conflict within the Mandera Triangle. Our model is able to demonstrate the significance of environmental change as a driver for conflict escalation. Given a small group of farmer agents and a high number of herders, seasonal variations in parcel viability result in greater incidents of conflict (see figure 6b). However, our model also highlights the potential for coexisting groups of herders and farmers with low levels of conflict (see figure 6a). This is possible when the herder population drops below the carrying capacity of the environment adjusted for the new farmer actors. On the other end of the spectrum, increases in the herder population lead to increases in conflict unrelated to fluctuations in resources (see figure 6c). This is quite an interesting result when considering the fact that conflicts per capita remain relatively constant regardless of herder population size (see figures 7a and 7b). The lesson here seems to be that farmers are destined to face conflict as the gatekeepers to the most reliable land. One of the intervening variables is certainly the size of the herder population. It is possible for herders and farmers to coexist relatively peacefully at a low population level. Efforts may be made to address conflict resolution through better state mediation but it is unlikely to resolve the herder's fundamental dependence upon the environment for its survival. Thus, herders and farmer will continue to be at the mercy of the weather until herders have had time to adapt to their newly introduced constraints. This is not likely to happen without a fundamental shift in the herder lifestyle.

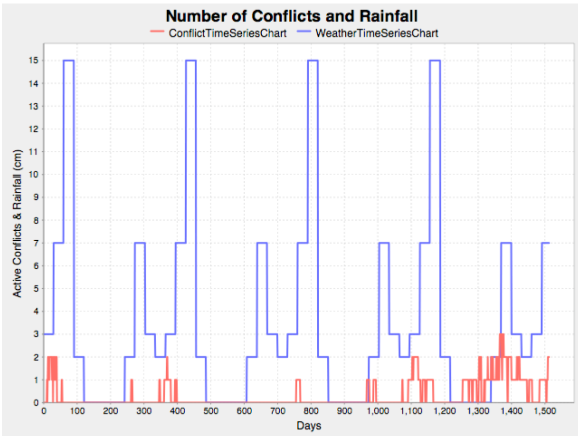

Figure 5a – Herder-farmer conflicts with 50 initial herder agents. Conflict is minimal with little to no escalation due to fluctuations in the natural environment.

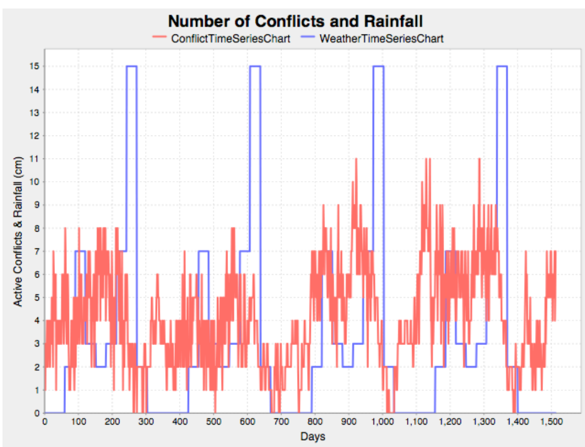

Figure 5b – Herder-farmer conflicts with 150 initial herder agents. Conflict is increased and it tends to follow the rainfall cycles.

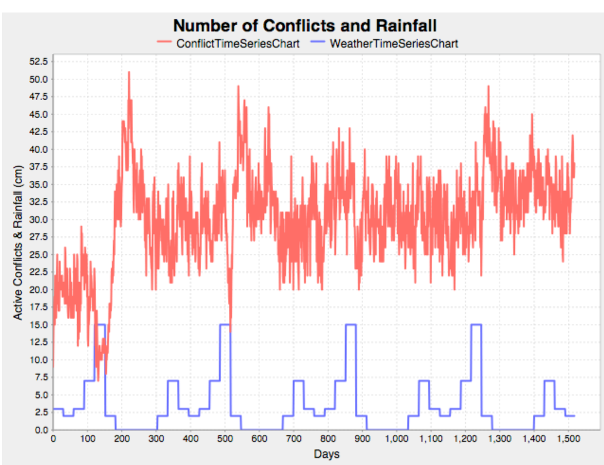

Figure 5c – Herder-farmer conflict with 1000 initial herder agents. Conflict is high and independent of rainfall.

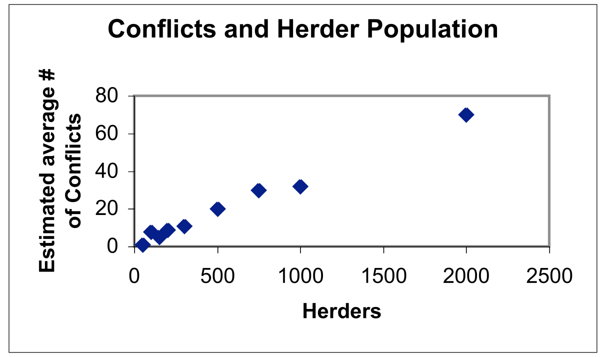

Figure 6a – The number of conflicts per the herder agent population.

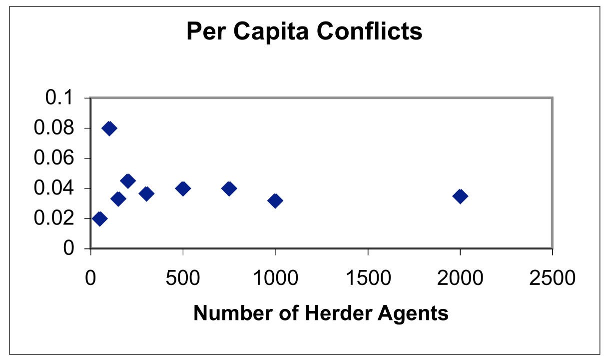

Figure 6b – Per capita herder conflicts based on the herder agent population.

Conclusion

The Mandera Triangle model is just the first step in a multi-year project to explore the socio-natural complexity of conflict in East Africa. The first stage of the model, presented within this article, involved the design and implementation of an all-purpose herder-farmer conflict platform. Many of the generalizable herder-farmer conflict features were drawn from our abstract interpretation of the ongoing struggles in the Mandera Triangle. Our initial model was intended to demonstrate the fundamental behaviors needed to replicate these conflict dynamics. We have found that much of the macro-patterns of conflict in Mandera can be simulated with a set of relatively simple actors with competing agendas. For example, when one actor is not bound to the limitations of the socio-natural system in the same way as another actor, conflict is likely to be pushed to a critical state. Whether through ignorance or devious intentions, this situation is able to build to a tipping point. All may seem calm until the tipping point is reached and conflict escalates rapidly.

This early modeling effort presents a number of opportunities for extension. Our next step is to introduce birth and death cycles into the model to gain a better understanding of the importance of the environment's carrying capacity. We will also look to introduce a primitive alliance formation structure to better represent the kinship networks herders rely upon both in hard times and in conflict. The model will continue to be updated with GIS data to ensure proper model validation. Finally, we plan to extend this model to other conflict zones in East Africa. This will require the utilization of new behavioral and environmental modules that will be grounded upon detailed case studies of the regions of interest. In the end, we hope to provide a platform that will permit researchers to draw generalizable conclusion from herder-farmer conflict to gain a better understanding of these dynamics in the context of East Africa.

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