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An Agent Based Model of Climate Change and Conflict among Pastoralists in East Africa

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Abstract: We present an agent-based model of human-environment interaction and conflict in East Africa using the MASON agent-based simulation environment. Our model focuses on the complex interaction of pastoral groups with their environment and other emerging external actors. Our model supports the observation that increased seasonal rainfall variability and droughts create tremendous stress on pastoralists groups and challenges their long-term resilience and adaptive response mechanisms.

Keywords: Agent-based model; conflict; climate change; pastoral.

1. INTRODUCTION

The pastoral system in most sub Saharan Africa faces many challenges attributed by two major changes that are considered as a major driver altering the equilibrium of the system. The first change is fragmentation of the natural system or grasslands of mainly induced by external actors. These changes occurred through alteration of the land use system or land tenure (i.e., agriculture, range land, natural conservation areas etc). Another major factors is environmental changes caused by climate variability(Galvin 2009). As pastoral livelihood is highly dependent on available pasture and water, climate variability affects the amount and distribution of pastures and water points. Recurrent occurrence of drought impose a restriction on the sustainability and use of the resource and custom that once highly regarded and accepted by different herder groups.

The Mandera Triangle, an area of East Africa encompassing a roughly 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 as a response to their sparse and seasonally changing environment. The herders of Mandera have constructed an elaborate social alliance structure to cope with various environmental shocks such as drought or flood. Herders in today's Mandera face more socio-natural complexity in their lives due to 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.

Our project focuses on understanding the complex human environment interaction in Mendera Triangle of East Africa by bringing together knowledge from cognitive science, ethnography, political science, geography, and computer science to produce a model of conflict inspired by Mendera. The focus of the project is to gain a better understanding of herder behavior in response to the environmental stresses and 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 using an Agent-Based Modeling (ABM).

Agent based approach is increasingly applied for understanding and modeling complex human-environment interaction (Parker and Meretsky, 2004). Application of ABM on pastoral system of sub Saharan Africa has been forwarded by many researchers. To mention few, MacOpiyo et al. 2006 delivered GIS based ABM to explore herder movement in southern Ethiopia and northern Kenya. Kusnar and Sedlmeyer(2005) developed NOMAD which models the ongoing ethnic conflict in Darfur, highlighting the importance of herder-farmer relationship during environmental hardship. Bah et al(2006) developed a participatory based ABM to model competition of natural resource and access to water in Sahel among different pastoral groups.

Our agent-based model (ABM) simulates interactions and conflict between herders with different ethnic identities and herders and farmers over the use of land resources in Mendera Triangle. The model mainly focuses on the tension between different herder groups over the utilization of the common grazing land and water resources and the emergence of conflict related to their use. In this paper, we want to experiment the influence of climate variability on the landscape. The experiment is designed to see the ever increasing conflict exhibited in recent decade following by recurrent drought. Our focus is to observe the impact of weather variability and intensity over period of time. In doing so we tried to see how pastoralists responses to environmental stress - weather they recover easily or engaged in more conflict.

2. MODEL DESCRIPTION

The model is developed within the MASON simulation environment (Luke et al. 2005). MASON is a multi-purpose simulation library for the Java programming language. The system 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. We model the environment based on 1km by 1km land parcels, each time step represents one day, and each agent represents a family unit.

The model includes two kinds of agents: herders and farmers (Figure 1). Because herders are the focus of this model, their behavior is represented in significantly greater detail. Each herder is represented as a single agent with the combined characteristics of the herder, the herder's family, and the herd animals. Two groups of herder agents who are ethnically different are represented by means of an arbitrary ethnic identity tag. Herders' relation with their ethnic group allows them to share scarce resources in time of need and to cooperate in time of conflict.

Herders are entirely dependent on their herds and manage their herds in each time step. They make decisions concerning their movement depending on the herd's level of hunger, thirst, the distance to the current water source, and the quality of grazing nearby. At any given time, each herder has a base camp near a water source. The herd must return to that water source to drink as its metabolism and movement priorities dictate. The herd continues to graze and water in the vicinity of this base until its needs for either food or

water are no longer met. When the herd runs short of either food or water, the herder shifts the base camp to a nearby water source.

Herders share the common resource if they belong to the same ethnic group and compete with other herders or farmers if they are of different groups. Herders minimize conflict by preferring to move to unoccupied parcels when they can. However, this is not always possible since the resources are limited. In such circumstance, they engage in conflict. The conflict can escalate by involving other herders within their ethnic group who share the burden through cooperation to increase their rate of survival.

The herders' knowledge to their environment depends on their vision, i.e., the range over which they can consider moving in a single day. Vision range can affect their success in surviving the environmental challenges. The availability of pasture and water determines the level of herd reproduction. If the environment is harsh, herds will be stressed by starvation or dehydration. Neither starving nor critically dehydrated herds reproduce. If they surpass a stress threshold, they will eventually die. When a herder agent survives and grows and the herd reaches a specified size, the herder and herd split into two, and a new herder family is introduced. The movement decision characteristics of the newly formed herder agent depend on parameter values of its parent with some noise introduced.

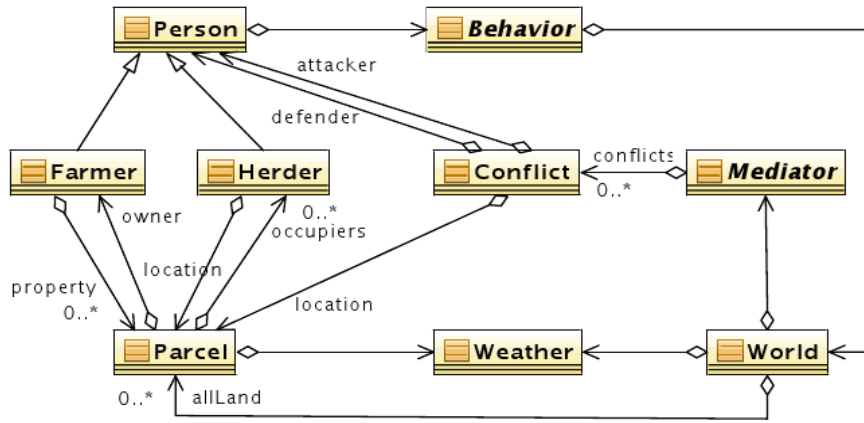


Figure 1: UML Diagram of Herders and Farmers

To avoid over-complicating our model from the outset, we have left the farmer agent as a simple, passive owner of territory. Farmer agents essentially occupy viable grazing land and increase the fertility of these parcels through their efforts. In this model, we assume that farmers are engaged in sedentary subsistence agricultural production and can produce enough food to meet the need of their family from their parcel land. What is important to this behavior is that farmers occupy parcels with a high agricultural fertility and, once occupied, farmers have a stake in defending these high-demand parcels from herder intrusions and can cause damage to herders. However, in this model, farmers will stay unaffected by any incident or conflict and their property will be inherited to the next generation with out any transformation or damage.

The environment has a spatial extent of 150 km by 150 km, and is comprised of 1 km² parcels, weather, and water holes. The parcel is the central feature of the environment, serving to consolidate the interactions between agricultural fertility, vegetation production, waterhole location, population density, and ownership. Land parcels are of differing quality, which is represented by differing maximum amounts 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 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 which the growth rate is negative and the grass dies off even without

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.

We represent weather over the entire region as a single variable amount of daily rainfall in millimeters using monthly averages for the study area. This rainfall information drives vegetation growth and re-filling of watering holes. Model runs start in January and use the same rainfall values each year. In addition to data driven monthly rainfall, we can change rainfall to simulate droughts by using a drought parameter. Waterholes are located in randomly assigned parcels. A waterhole can be exhausted with high herd consumption and refilled again based on rainfall.

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 the amount 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 utilized of its current parcel is calibrated to this time increment. As the environment permits, herder agents avoid other herders and farmers to move from parcel to parcel to obtain vegetation and water to maintain their health. Parcel regrowth occurs but at a much slower rate than the herders' grazing reaps 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 graze land or water, herder agents will then seek the nearest parcel with available resources regardless of the presence of another agent. It is these trespassing events that are considered conflict.

At each time step (i.e., day), we update the vegetation on each parcel (vegetation regenerates as a function of current level of grazing and rainfall); we activate each herder (in random order); then finally, we resolve conflicts. As previously stated, we update the weather monthly. Droughts can be programmed to occur in any of the years with a fifteen-year cycle. This process is then repeated, resulting in herd movements and conflict dynamics. Other processes will be activated under certain circumstances. For instance, splitting of herds and formation of new herder family depend on the success of the herder to accumulate a specified herd size. Severe thirst and hunger will result deaths of animals within herds. When all the animals have died, the herder agent is removed.

Conflict is defined to occur when herder movement results in a trespassing incident. We consider an incident as a combat (or opportunity for combat) between a herder and either another herder or a farmer. Conflict is modeled as two agents in the same parcel at the end of the movement part of a time step. Incident(s) can grow over time and potentially involve multiple herders and farmers. Consequences of an incident depend on participants. When it is between two herders of the same clan, the incident is resolved peacefully by averaging hunger and thirst values between both herders. We call this phenomena as cooperation between the same clan. Otherwise, the incident is considered as conflict. When the conflict is between herders of different clans, the defender's herd size is reduced by a damage ratio (a parameter) while the attacker's herd is increased by that number of animals. The attacker's hunger is also reduced based on the captured resources. However, both the attacker and defender thirst is not changed. In the farmer and herder situation, the farmer is unaffected by conflict and only the herder's herd size is reduced by a damage ratio.

3. EXPERIMENT DESCRIPTION

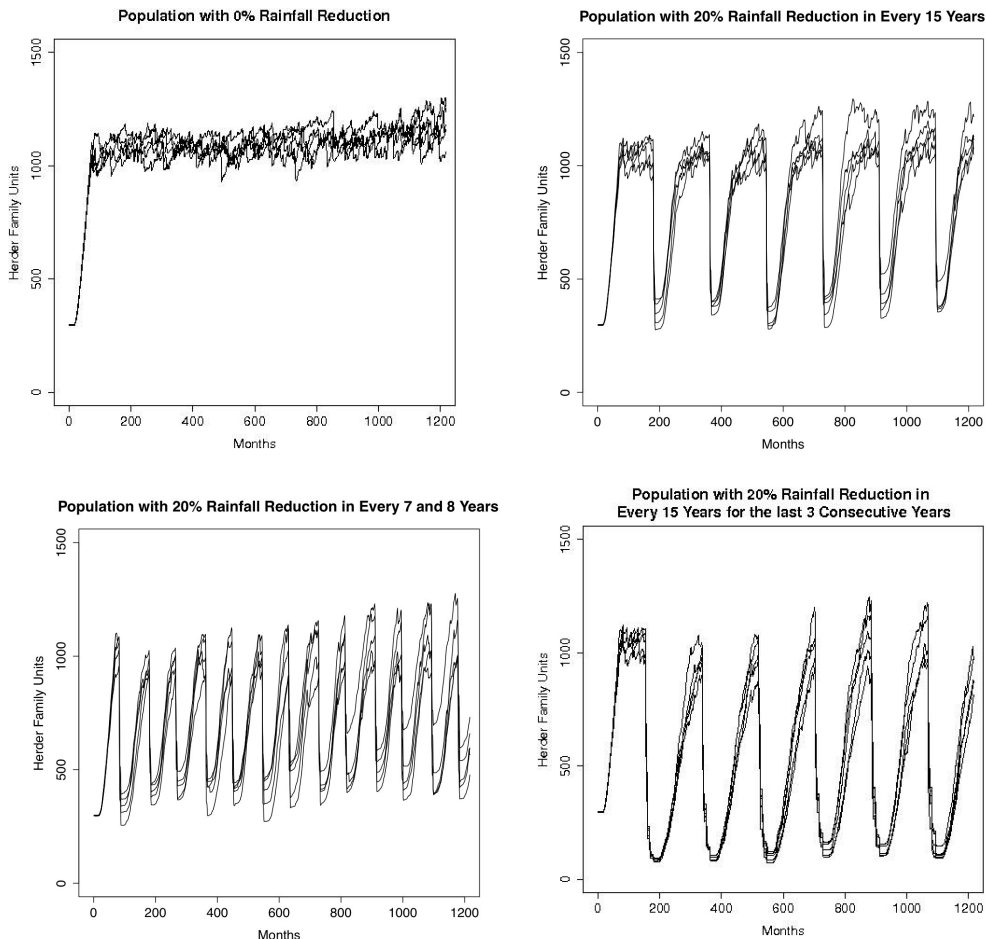
We perform a series of experiments to explore the fidelity and robustness of the model. Prior to this paper, we undertook experiments to understand the relationship between the number of watering holes, the total population, and the level of dominance of one ethnic group by varying the number of water holes in six steps between 50 and 300 (Kennedy et. al. 2010). Our parameter settings for the current paper rely on this previous work. Here, we experiment with the impact of climate change by varying the intensity and frequency of drought in five scenarios. Given the limitation of data on extreme climate event(IPCC

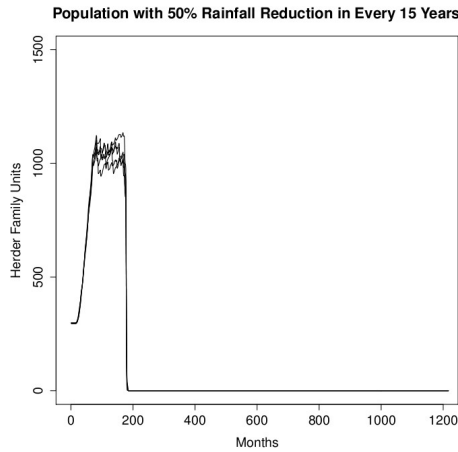
2007, Paeth, et. al. 2009), our experiments focused on the linkage between climate variability and conflict (Nordas and Gleditsch, 2007, Meier, et. al. 2007, Oba, 2001). In the first experiment we introduce a 20% reduction in annual rainfall in one of every 15 years. In the second we increase the frequency of drought to two of every 15 years with the same 20% reduction. In the third experiment we examine the impact of consecutive drought years. We introduce a 20% reduction in annual rainfall in the 12th, 13th and 14th years of the 15-year cycle. In the fourth experiment, we increase the intensity of droughts to a 50% reduction in the 14th year of each 15-year cycle. For each of these experiments, we conduct five 100-year runs. In this sequence of experiments, we omit farmers. We start each run with total of 300 herders that are randomly assigned to one of the two tribes. For every experiment, we set the number of water holes to 200 and vision, which is the maximum distance from the current location that a herder can move in each step, to 10km. The placement of water holes in the landscape is random with the probability of their placement in a given parcel proportional to the fertility of that parcel.

4. EXPERIMENTAL RESULT

4.1 Climate Change and Carrying Capacity

The base run has no drought occurrence. It begins with 300 herders and the number increases steadily in the first 120 months (10 years) until the population reaches the environmental carrying capacity imposed by limited water and vegetation and occurrence of conflict. In the first three experiments, the herders are able to recover from the impact of drought at different rates. Occurrence of drought separated by long time periods gives better opportunity for adaptation and recovery than when drought events occur separated by short periods or in sequence. However, when the intensity of drought increases, survival of herders comes into question as is shown in the fourth experiment (Figure 2d). In a fifth experiment (figure 2e), there were no survivors in any runs with a single year of 50 percent rainfall reduction.

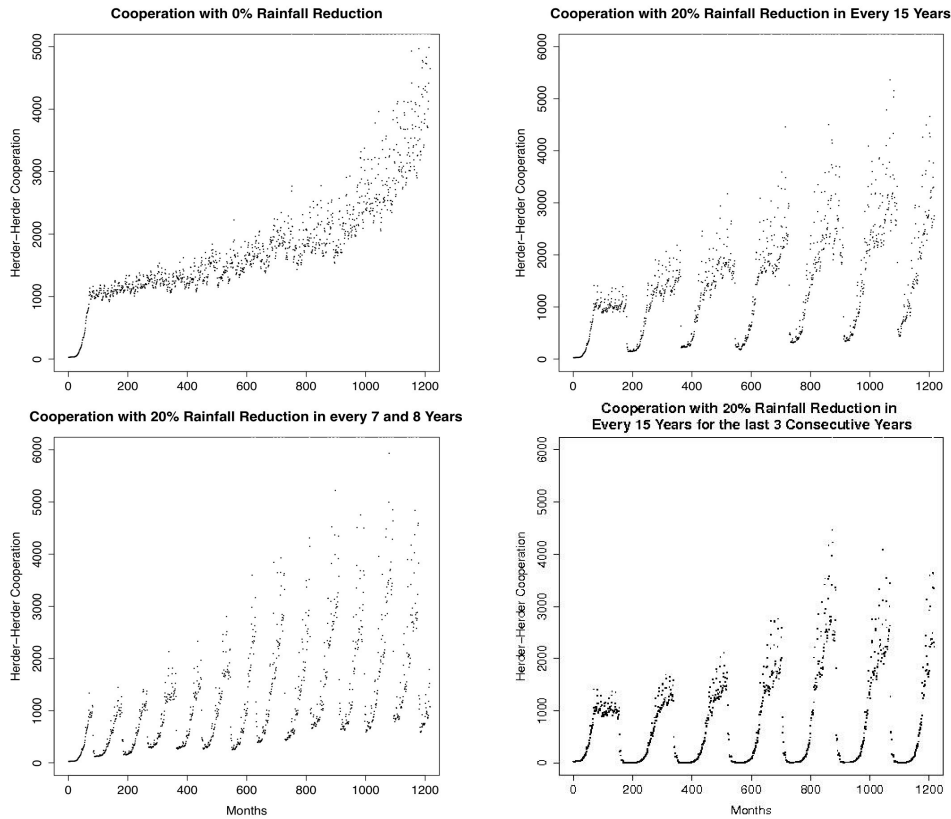




Figures 2 a, b, c, d, e. Population with different level of drought frequency and intensity

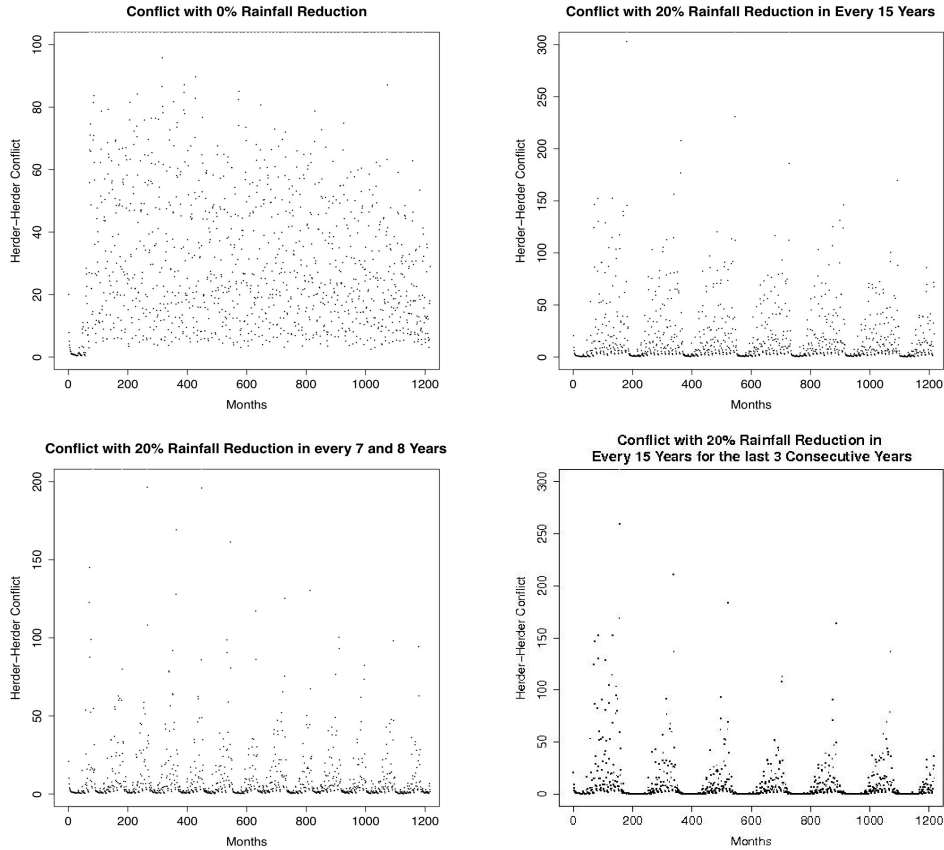
4.2 Cooperation and conflict

We also collected data on cooperation and conflict for each experiment. The rate of cooperation (i.e. collocation of members of the same group that results in sharing of resources) in the default run increases steadily over time. Especially after 800 months (around 67 years), cooperation increases sharply. With the reduction of rainfall, however, the rate of cooperation shows a punctuated pattern.



Figures 3 a, b, c and d. Level of cooperation with different levels of drought frequency
The climate change impact causes also significant change on the level of conflict in the system. In the base run with no drought, more sporadic conflict was observed. However, as

the occurrence of drought event increases in subsequent experiments, significance level of conflict occurred only on the recovery stage where more herders dwell in the system.



Figures 4 a, b, c and d. Level of conflict with different level of drought frequency

5. DISCUSSION

Climate variability influences the equilibrium of an otherwise relatively stabilized landscape. Specifically, the carrying capacity in the model is immediately affected by droughts and the herders' population adjusts to the new carrying capacity. Without droughts, cooperation increases with time and conflict appears completely random. With the significant reductions in population caused by all of the drought patterns, cooperation and conflict are minimized. Cooperation and conflict increase dramatically with the population's recovery. Therefore, the population's relation to the carrying capacity seems to be the major factor affecting cooperation and conflict.

This reasonably simple model of pastoral livelihood demonstrates the sensitive dependence of herders on rainfall and also, though its limitations, underscores the resilience of such people in reality. Though the model abstracts highly from the details of the behavior of people and, the nutritional needs of animals, and the ecological dynamics of the weather and landscape, the broad parameters relating to movement, nutritional needs, and environment are calibrated to real data. Even in this simplified form, the model manages to capture the strongly non-linear relationship between rainfall and carrying capacity. A shortfall of 20% in annual rainfall does not sound (on the face of it) like a major problem – but in this marginal land it can be catastrophic. In our model, the number of viable herds falls by over 60% in a single year when rainfall is short by 20%. After three such years in succession, the population has fallen by almost 90%.

Droughts of this severity and duration are by no means uncommon in Mandera – and they pose major threats to the pastoral peoples of the area. Such droughts do reduce the number of herder family units, not so much by killing people (though this can happen) but rather through consolidation as extended families pull together to survive hard times and destock their herds to make them more viable on marginal pasture. That said, a drought year does not reduce the number of herds as sharply our model indicates. This is because the people of Mandera have a host of social network and alternative coping strategies that we do not currently model, such as calling on distant relations in areas where the rains have been more bountiful. The current model captures some of the essence of the biophysical vulnerability of pastoralists in the dry savanna, but is (at this point) less successful in representing their resilience and coping abilities in the face of this vulnerability. We look forward to representing some of these more essentially human parts of the system in future iterations of the model.

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