An Agent-Based Model of Conflict in East Africa and the Effect of the Privatization of Land

William G. Kennedy[1], Tim Gulden[1], Atesmachew B. Hailegiorgis[1], Jeffrey K. Bassett[1], Mark Coletti[1], Gabriel C. Balan[1], Meghan Clark[1], & Claudio Cioffi-Revilla[1]

[1] Krasnow Institute for Advanced Study, George Mason University,
4400 University Drive, Fairfax, VA, 22030, USA
wkennedy@gmu.edu, tgulden@gmu.edu, ahailegi@gmu.edu, jbassett@cs.gmu.edu, mcoletti@gmu.edu, gbalan@cs.gmu.edu, mclarkk@gmu.edu, ccioffi@gmu.edu

Abstract. An agent-based model of conflict among herders and between herders and private farmers of east Africa is presented using the MASON agent-based simulation environment. Herders survive by keeping their herds fed and watered in the inhospitable environment with some of the land becoming unavailable due to privatization. Our model develops realistic population and conflict dynamics. With only basic behaviors, herders come into conflict with other herders and farmers over the limited resources. However, the introduction of farmers did not have severe effects on the herder carrying capacity and, when farmers are included in the overall carrying capacity, adding farmers actually increased the capacity by almost a factor of two. The introduction of farmers appears to have provided a separation between the two modeled herder clans reducing the trend toward hegemony seen without farmers.

Keywords: agent-based modeling, MASON, conflict modeling.

1 Introduction

The traditionally nomadic people of East Africa have been surviving in a semi-arid region for hundreds, if not thousands, of years. With the establishment of nation states came the institution of private land ownership. As a result, the challenge of survival in the already inhospitable region could be made much more difficult by the development of state-supported property holders and resulting restrictions on the accessibility of traditionally open grazing areas and watering holes. We are using Agent-Based Modeling (ABM) to gain a better understanding of the region's response to the introduction of farmers. The responses we are concerned with are the carrying capacity of the region and rise of violence between herders and farmers and among herders. Our multidisciplinary team consists of researchers from the fields of ethnography, geography, political science, cognitive science, and computer science. The team has come together to apply this diverse knowledge to building a model of resource-driven conflict in East Africa. In previous publications, we have described experiments showing the effects on carrying capacity, conflicts, and the rise of hegemony due to the number of watering holes [1] and droughts [2].

1.1 Area of Interest: East Africa

Our first step in modeling the area was to select a representative region. The countries of Somalia, Kenya, and Ethopia meet at a corner near the city of Mandera. The area around the city is known as the Mandera Triangle. We chose a 150km by 150km area approximately 300km west of the city of Mandera to be the geographic reference for our model. It is in the Mandera Triangle but far enough away from the city to be populated primarily by herders and farmers. Figure 1 shows this area.

Figure 1. Reference 150km by 150km area near the Mandera Triangle
(Source: the authors)

This area has been the home of several well-established nomadic herding groups. The populace and the region were a self-regulated socio-natural system with traditions developed over countless generations in response to the sparse and variable environment. Effective social supports have been developed to deal with various environmental shocks, such as droughts. In recent years, the herders face more socio-natural complexity in their survival efforts due to the introduction of government-supported privatization of land. Due to rapid change in the political environment, the people of the area have not had sufficient time to develop new systems to deal with the limited resource and the area has become conflict ridden.

Over the ages, the pastoralists of the region adapted to the natural environment [3][4]. The pastoralists' (herders') way of life in East Africa was primarily an adaptation to both long- and short-term environmental factors. To address the long-term unpredictability and sometimes severely stark environment, herders developed a predominately hearding mix of agro-pastoralism. In the short term, pastoralism provided the most successful strategy for the semi-arid region that was not conducive to agriculture.

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 [5][6], it is reasonable to speculate that the entrance of new actors, in the form of landowning farmers, would have 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.

1.2 Modeling Background

To ground the model in real data, we represented the natural environment using data from Geographic Information Systems. These systems provided information on ground cover (vegetation), weather patterns, hydrology, and resource variance over time [7][8][9][10]. To model the decision-making of herders and farmers in the region, we used ethnographic research on social customs [6][11][12]. We also considered alliance formation and conflict resolution mechanisms [13][14]. Finally, we used information on regional studies by political scientists and policy makers on conflict mediation [15][16][17][18][19][20].

2 Model Description

We simulated interactions and conflict between herders with different ethnic identities and between herders and farmers over the use of land resources using an agent-based model (ABM). The model focuses on the tension between different herder groups over the use of the common grazing land and water resources and the conflict that emerges related to their use. The following description of the model focuses on those aspects that are pertinent to this experiment. A more complete description of the model can be found in a previous paper [1].

The model was developed within the MASON simulation environment [21]. This system is a multi-purpose simulation library written in the Java programming language and provides the necessary modeling tools, such as agent scheduling and visualization, for the development of customized ABM simulations. As is typical for ABM simulations, our model is dependent upon the implementation of three critical components: agents, environment, and rules of interaction.

Our model's environment represents a specific 150 km by 150 km area and is comprised of 1km by 1km land parcels, a single weather system, and a number of water holes. Each step represents one day and each agent represents one family unit. The parcel is the center of focus consolidating interactions among agricultural fertility, vegetation production, waterhole location, population density, and ownership. Land parcels differ in quality representing the maximum amounts of vegetation they can support in the absence of grazing and under optimal weather conditions. We estimated these maximum vegetation levels using GIS data. Parcels grow vegetation based on the parcel's maximum vegetation, its current vegetation, and current rainfall.

The model has two kinds of agents: herders and farmers (see Figure 2). Because herders are the focus of this model, their behavior is represented in significantly greater detail. Each herder agent represents the combined characteristics of a herder, the herder's family, and the herd animals. Two groups of herder agents who are ethnically different are represented. Herders' relation with their ethnic group allows them to share scarce resources in time of need.

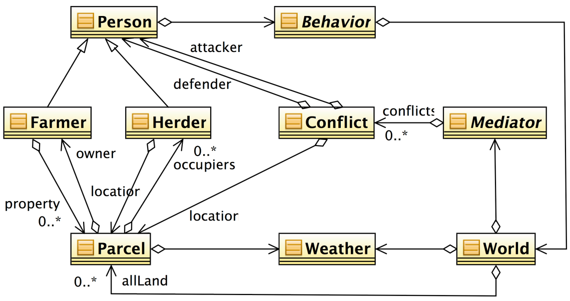

Figure 2: UML Class Diagram of the MASON HerderLand model. Source: the authors.

Herders are entirely dependent on their herds and manage their herds in each time step. Herders decide on their movement depending on the herd's level of hunger, thirst, distance to the current water source, and quality of grazing nearby. Herders evaluate visible parcels' pasture and water availability with respect to their herd's needs. Each herder has a base camp near a water source to which the herd returns to drink. The herd continues to graze and water near this base until its needs for either food or water is no longer met, then it shifts the base camp to a nearby water source.

Herders share the common resource if they belong to the same ethnic group and conflict with other herders or farmers if they are of different ethnic groups (clans). Herders minimize conflict by preferring to move to unoccupied parcels. However, this is not always possible and when necessary, they engage in conflict.

If the environment is harsh, herds will be stressed by starvation or dehydration. Neither starving nor critically dehydrated herds reproduce. If they surpass a threshold, they will eventually die. As a herd survives, it grows in the number of animals in the herd. When the herd reaches a specified size, the herder and herd family unit split into two, and a new herder family unit is introduced.

To avoid overcomplicating 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 produce enough food to meet the needs of their family from their parcel of land. What is important to this model 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 cause damage to invading herders. However, in this model, farmers will remain viable independent of any incident or conflict and their property is inherited by the next generation without any transformation or damage.

The main simulation loop consists of herder agents adapting to the seasonally driven changes in the grazing and watering environment. In each day's step of the model the herder agent's use of its current parcel is calculated. As the environment permits, herder agents avoid other herders and farmers in their movement to obtain vegetation and water. This process has the potential to drive herders onto farmer land during times of survival crisis. For example, if a herder agent's health reaches the desperate stage due to 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, herder or farmer. It is these trespassing events that are considered potential conflicts and the results of all these events are determined at the end of each day.

At each time step, we update the vegetation on each parcel (vegetation regenerates as a function of current level of grazing and rainfall); process each herder (in random order); then finally, resolve any conflicts in the execution of simulation events. We update the weather (rainfall) monthly. This process is then repeated, resulting in herd movements, which result in conflict dynamics. 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 in deaths of animals within herds. When all the animals have died, the herder agent is removed.

Incidents are modeled as two agents in the same parcel at the end of the movement part of a time step. Such events 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 helping one and hurting the other. When the incident is between herders of different clans, it is counted as a conflict and the defender's herd size is reduced by damage ratio (a parameter) while those animals increase the attacker’s herd. In the farmer and herder situation, the farmer is unaffected by conflict and only herder's herd size is reduced by a damage ratio. With this model we have conducted experiments exploring possible scenarios.

3 Experiment Description

In previous experiments, in which we increased the number of watering holes [1], we examined the effect of reduced environmental stress. That resulted in increased carrying capacity of the region, as expected. However, it was not as simple as expected. The model included two clans of herders and important inter-clan dynamics were seen. When the survival stress was higher due to fewer watering holes, one clan came to dominate the other faster than when there were more watering holes. In the present experiment, we have addressed another source of environmental stress, the introduction of farmers. Farmers occupy the best land reducing the total grazing land available. We ran six experiments (30 runs each) varying the number of farmers, from 0 to 1,000 in increments of 200. The lower limit anchored this experiment with previous and the upper limit was based on our interpretation of the GIS data of the reference area.

4 Experimental Results

The resulting total populations of herders are shown in Figures 3 and 4 for the two extremes of our experiment. Both figures show results from 30 runs (gray) and their averages (black). Each run begins with 300 herders and ran for 100 years of simulation time. Because all runs began by randomly placing herders and watering holes in the represented landscape, there is an initial transient. After that, there is a general trend toward increasing carrying capacity as the herders adapt to the environment. Between these extremes, we ran 4 other experiments, which produced results consistent with these figures. To show the primary results, Figure 5 contains the average ending populations for the independent variable's range and the total populations of herders and farmers for each experiment.

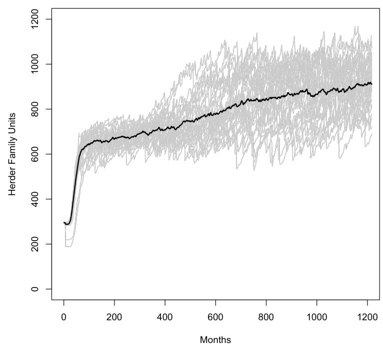

Figure 3. Herder Population with 0 Farmers

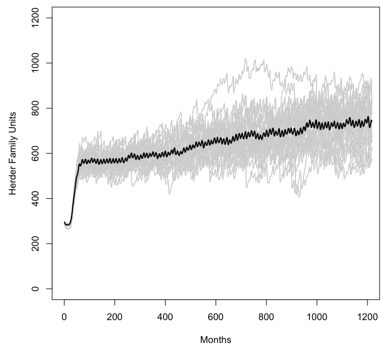

Figure 4. Herder Population with 1,000 Farmers

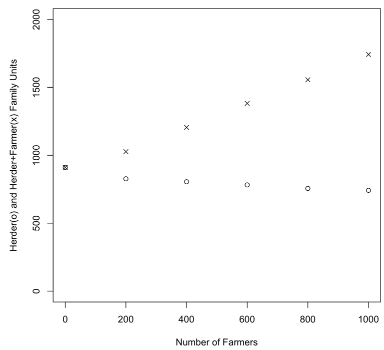

Figure 5. Carrying Capacity after 100 Years

The observed monthly counts of herder-inter-clan conflicts showed annual weather-driven oscillations and similar magnitudes across all experiments. The runs show higher conflicts during drier seasons than during wetter seasons. Mean monthly conflict peeks started at a little less than 50 per month and declined over the 100-year runs. Individual runs rarely spiked near 500 conflicts per month.

Herder-farmer conflicts were far less frequent than herder-herder conflicts: less than 10 conflicts on average per month throughout runs with 200 farmers and approximately twice that with 1,000 farmers. Individual runs rarely exceeded 100 conflicts per month.

The development of hegemony, the rise of one clan to complete dominance, was very different from our previous experiments. In previous experiments without farmers, the herders, who were initially placed randomly, became involved in frequent conflict near the scarce watering holes and with fewer watering holes, complete hegemony occurred earlier than when there were enough watering holes for both clans to regularly water their herds separately. In new experiments (still starting with randomly placed herders throughout the region), now with increasing numbers of farmers, hegemony was delayed and changed. Unlike the situation with no farmers in which hegemony occurred in some runs by year 30 and in nearly all runs by year 100, with 1,000 farmers hegemony does not occur for any runs until after year 65 and at year 100, there is still a full range of ratios of the populations of the two clans of herders. This appears to be due to the presence of farmers, who are located in a broken and incomplete line from the northwest toward the southeast of the region, thus breaking up the landscape and dividing the two clans.

5 Conclusions

Although the number of watering holes had a marked effect on carrying capacity, as previously reported [1][2], these new experiments with the introduction of farmers had different but also dramatic effects. Adding farmers did not affect the carrying capacity for herders very much. However, if we consider the farmers in the population of the region and presume their family units are similar to herder family units, the carrying capacity was dramatically increased, almost by a factor of two. With 100 watering holes, the carrying capacity without farmers was approximately 900 herder family units, *in our model*, and with 1,000 farmer family units, the population of herders only decreased to about 750 resulting in an overall carrying capacity of about 1,750 family units. We also found that the conflicts between the herders and farmers were approximately 10 percent of the conflicts among herders. Therefore, we did not see a great impact on the scale of conflict by the privatization of some land. Finally, the introduction of farmers appears to have reduced the likelihood of total hegemony by effectively dividing the region. These results confirmed the expectations of the ethnographers on our team. Of course, the results of our model, while data-driven, are certainly subject to modeling inaccuracies.

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References

1. Kennedy, W.G., Hailegiorgis, A.B., Rouleau, M., Bassett, J.K., Coletti, M., Balan, G.C., and Gulden, T. An Agent-Based Model of Conflict in East Africa and the Effect of the

Privatization of Land. Proceedings of the 19th Conference on Behavior Representation in Modeling and Simulation (2010) 274-281
2. Hailegiorgis, A. B., Kennedy, W. G., Balan, G. C., Bassett, J. K., and Gulden, T. (2010) An Agent Based Model of Climate Change and Conflict among Pastoralists in East Africa. Proceedings of the 2010 International Congress on Environmental Modeling and Software Modeling for Environment's Sake (2010)
3. Smith, A. B.: Environmental Limitations on Prehistoric Pastoralism in Africa. The African Archaeological Review, Vol. 2 (1984) 99-111
4. Smith, A. B.: Origins and Spread of Pastoralism in Africa. Annual Review of Anthropology, Vol. 21 (1992) 125-141
5. Torry, W. I.: Residence Rules Among the Gabra Nomads: Some Ecological Considerations," Ethnology, 15(3) (1976) 269-285
6. Johnson, G. A.: Decision-Making Organization and Nomad Camp Size," Human Ecology, 11(2) (1983) 175-199
7. Keya, G. A.: Herbaceous layer production and utilization by herbivores under different ecological conditions in an arid savanna of Kenya". Agriculture, Ecosystems and Environment 69 (1998) 55-67
8. Lenhart, L. and Casimir, M. J.: Environment, Property Resources and the State: An Introduction. Nomadic Peoples, 5(2) (2001) 6-20
9. Little, P. D., McPeak, J., Barrett, C. B., and Kristjanson, P.: Challenging Orthodoxies: Understanding Poverty in Pastoral Areas of East Africa. Development and Change, 39(4) (2008) 587-611
10. MacOpiyo, L. et al.: Use of GIS and Agent-Based Modeling to Simulate Pastoralist Mobility in the Rangelands of East Africa," GSDI-9 Conference Proceedings (2006)
11. Bah, A. et al. An Agent-Based Model to Understand the Multiple Uses of Land and Resources around Drillings in Sahel. Mathematical and Computer Modeling, Vol. 44, (2006) 513-534
12. Johnson, D. H. and Anderson, D. M.: The Ecology of Survival: Case Studies from Northeast African History, I.B. Tauris (1991)
13. Ellis, J. E. and Swift, D. M.: Stability of African Pastoralist Ecosystems: Alternate Paradigms and Implications for Development. Journal of Range Management, 41(6) (1988) 450-459
14. Ensminger, J. and Rutten, A.: The Political Economy of Changing Property Rights: Dismantling a Pastoral Commons," American Ethnologist, 18(4) (1991) 683-699
15. Bouh, A. M. and Mammo, Y.: Indigenous Conflict Management and Resolution Mechanisms on Rangelands in Somalia Regional State, Ethiopia. Nomadic Peoples, 12(1) (2008) 109-121
16. Kuznar, L. A. and Sedlmeyer, R.: Collective Violence in Darfur: An Agent-Based Model of Pastoral Nomad/Sedentary Peasant Interaction. Mathematical Anthropology and Cultural Theory, 1(4) (2005)
17. Mace, R. et al.: Transitions between Cultivation and Pastoralism in Sub-Saharan Africa. Current Anthropology, 34(4) (1993) 363-382
18. Mahmoud, H. A.: Seeking Citizenship on the Border: Kenya Somalis, the Uncertainty of Belonging, and Public Sphere Interactions". Council for the Development of Social Science Research in Africa (CODESRIA), 12th General Assembly, Yaounde, Cameroun (2008)
19. Saqalli, M.: Populations, Farming Systems and Social Transitions in Sahelian Niger: An Agent-Based Modeling Approach. PhD Thesis, Université Catholique de Louvain (2008)
20. Scoones, I. and Graham, O.: New Directions for Pastoral Development in Africa". Development in Practice, 4(3) (1994) 188-198
21. Luke, S., Cioffi-Revilla, C., Panait, L., and Sullivan, K. MASON: A Java Multi-Agent Simulation Environment. Simulation: Transactions of the Society for Modeling and Simulation International, 81(7) (2005) 517-527