

An Agent-Based Model of Conflict in East Africa And the Effect of Watering Holes

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Abstract: *An agent-based model conflict between herders in east Africa using the MASON agent-based simulation environment is presented. Herders struggle to keep their herds fed and watered in a GIS-based, spatially diverse environment with data-driven seasonal cycles. The model produces realistic carrying capacity dynamics and basically plausible conflict dynamics. With the rather basic set of behaviors, herders come into conflict over limited resources and one clan is eventually eliminated. We find that greater environmental scarcity leads to faster domination by a single group. At the same time, we note that there is tremendous variability from run to run in the rate and timing of the transition from a conflict-prone, multi-clan environment to hegemony of a single group.*

1. Introduction

The Mandera Triangle of East Africa is a complex environmental and human social area. Our research uses Agent-Based Modeling (ABM) 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. Our multidisciplinary research team brings together knowledge from cognitive science, ethnography, political science, geography, and computer science to produce a model of conflict inspired by Mandera. The model's natural environment is constructed using data from Geographic Information Systems, including information on ground cover, resource variance, weather patterns, and hydrology (Keya 1998; Lenhart & Casimir 2001; Little, McPeak, Barrett, & Kristjanson 2008; MacOpiyo et al 2006; Parker 2001; Weinstein et al 1983). Agent decision-making within the model's social environment is supported by ethnographic research of social customs (Axtell et al 2002; Bah et al 2006; Johnson & Anderson 1988; Johnson 1983; Marshall 1990; Oba 2001), mechanisms for alliance formation and conflict resolution (Ellis & Swift 1988; Ensminger & Rutten

1991), and regional studies of conflict mediation conducted by both political scientists and policy makers (Bouh & Mammo 2008; Brockhaus 2003; Kuznar & Sedlmeyer 2005; Mace et al 1993; Mahmoud 2008; Saqalli 2008; Scoones & Graham 1994). 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.

This paper describes one of a series of experiments: the impact of changing one environmental variable, the number of watering holes. Water is a vital resource in the subject region and building wells may be one way to improve the areas carrying capacity and reduce conflict. The research question is whether adding wells improves conditions. For this work, we define improving conditions in terms of increased carrying capacity and reduced incidents of conflicts.

2. Background

The Mandera Triangle – an area of East Africa encompassing a roughly triangular area bordering Somalia, Kenya, and Ethiopia (see Figure 1)– 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 flooding. 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.



Figure 1. Area of East Africa Modeled

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 constraints 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 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.

2. Model Description

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. 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.

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 consists of two kinds of agents, herders and farmers (Figure 2). Because herders are in the focus of this model, their behavior is represented in significantly greater detail. Each herder is represented as a single agent with combined characteristics of the herder, 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 and to cooperate in time of conflict.

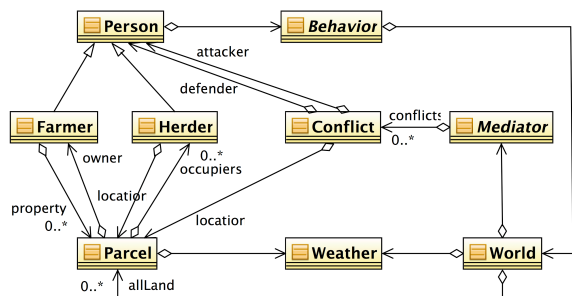


Figure 2: UML Diagram of Herders and Farmers

Herders are entirely dependent on their herds and manage their herds in each time step. They make decisions considering their movement depending on the herd's level of hunger, thirst, the distance to the current water source, and the quality of grazing nearby. Herders evaluate visible parcels' pasture and water ability to satisfy the needs of their herds. 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 the herd's 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 different. Herders minimize conflict by preferring to move to unoccupied parcels when they can. However, this is not always possible since the resource is 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, in km, 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. Starving herds don't reproduce, nor do critically dehydrated ones. If they surpass the 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 in to two and a new herder family is introduced. The movement decision characteristics of the newly formed herder agent depend on parameters values of its parent with some noise 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 can produce enough food to meet the need of their family from their parcel on 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 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. We model the environment with three components: land, which is divided into a regular grid of 1 km by 1 km parcels, waterholes, and weather. 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 address 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 pegged 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 and the results of all the conflicts are determined at the end of each day.

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, specifically every 30.4375 days. 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, resulting in 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. Deaths of animals within herds results from thirst and hunger and when all the animals have died, the herder agent is removed.

Conflict is analyzed by checking herder movement and detecting of occurrence of 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 helping one and hurting other. When the conflict is between herders of different clans, the defender's herd size is reduced by damage ratio (a parameter) while the attacker's herd is increased by those animals. In the mean time, the attacker's hunger is also reduced based on the captured resources. However both the attacker and defender thirst is not changed. In farmer and herder situation, farmer is unaffected by conflict and only herder's herd size is reduced by a damage ratio percentage.

Escalation of conflict occurs only between herders and farmers when the incident persists over a specified number of steps. As all herders track their last combatant, and the duration (number of steps) that the most recent combat has persisted uninterrupted, which is when (if) the duration reaches a specified number of steps, escalation of conflict is initiated. Consequently all allied herders within a specified range are identified. The resources (hunger and thirst) of all allied herders are averaged.

In the current design of our model, only a single previous combat/combatant is remembered. This works well with herder-farmer conflicts since a herder can never fight more than one farmer at a time. If we model herder-herder escalation, we will need to consider that a herder can fight several other herders in a time step. Similarly, if we model farmer sharing of resources, we will need to consider that a farmer can fight several herders in a time step. However, at this stage of our model, we prefer to consider very simple behavior.

3. Experiment Description

Our model is runs and provides us the ability to experiment with different parameters to see the fidelity of the model in relation to real world phenomena. To start simple, we have limited our experiments to the relationship between the number of watering holes, the total population, and the level of dominance of one ethnic group. For this experiment, we omitted farmers. We did vary one parameter, namely the number of watering holes, in six steps between 50 and 300. For each number of watering holes, we conducted five 100 year-long runs.

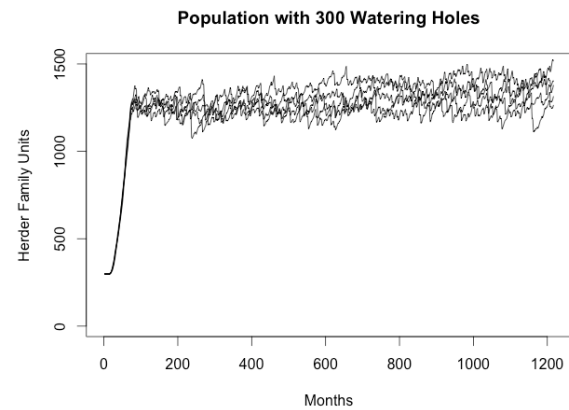
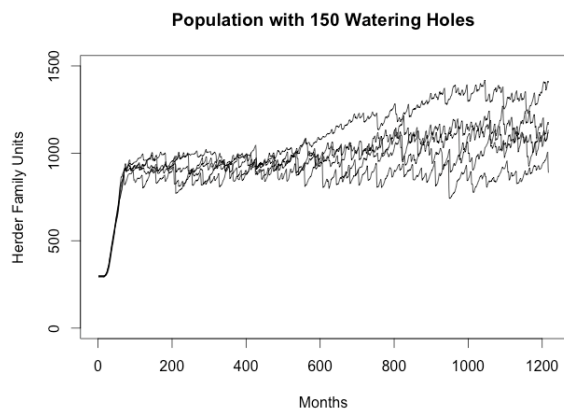
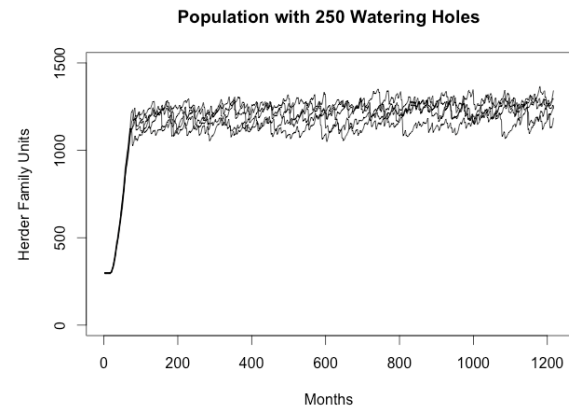
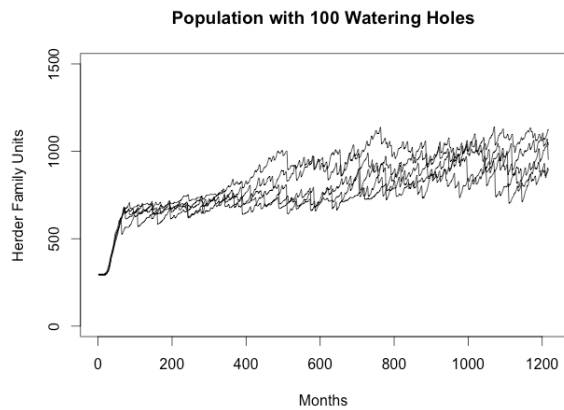
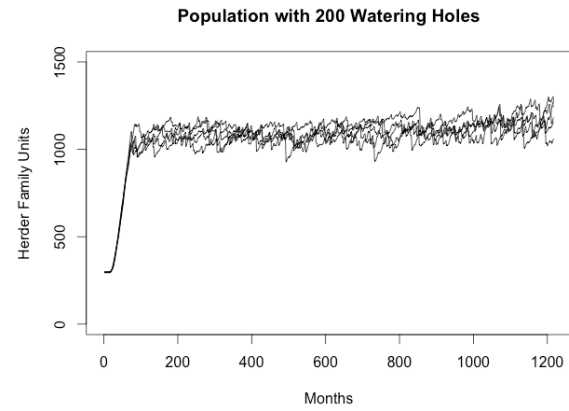
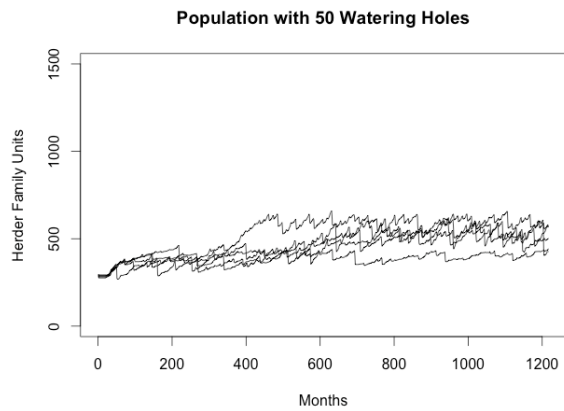
We started each run with 300 herders randomly assigned to one of the two tribes. Visibility was set at 10 km. This set the maximum distance from the current location that was considered at each step. Waterholes were placed randomly in each run, with the probability of their placement in a given parcel proportional to the fertility of that parcel

4. Experimental Results

4.1 Watering Holes and Carrying Capacity

Starting with 300 herder family units, the number of herders grows steadily for about the first 5 years (60 months) as the population reaches the environmental carrying capacity as seen in Figure 3a through e. Increasing the number of watering holes increases the carrying capacity, though not in a linear manner.

While in the lower ranges (between 50 and 100, for Population with Watering Holes example) the increase is nearly proportional (from around 400 to over 700), the proportionality breaks down with higher numbers of water holes. In going from 150 to 300 water holes, the initial carrying capacity increases from 900 to only around 1,300 – an increase of only about 50% as opposed to the 100% increase in watering holes. This fall off in the rate of increase in carrying capacity is because water is not the only limiting resource. When



Figures 3a, b, and c. Population with Watering Holes

Figures 3d, e, f. Population with Watering Holes

the number of watering holes is small, each new watering hole opens up grazing land that was previously too far from water to be useful. As more watering holes are added, however, their areas of influence begin to overlap and grazing land starts to become an additional limiting factor.

4.2 Ethnic Hegemony

Figure 4 and 5 compare two representative runs from the case with 100 watering holes (cf. Figure 3b). Both of these runs show four distinct phases: 1) a short period of initial growth toward carrying capacity characterized

by low levels of conflict and little change in ethnic composition, 2) a period of coexistence and competition for resources where the ethnic balance is relatively stable, 3) a period of relatively rapid and essentially monotonic increase in one clan at the expense of the other, and 4) a period of complete hegemony once the dominant clan has eliminated the competition.

The monotonic nature of the transition here is striking, as is the variability in its timing. Once one clan gains the upper hand, it almost always wins out. Though it may suffer setbacks lasting a few years, the progression

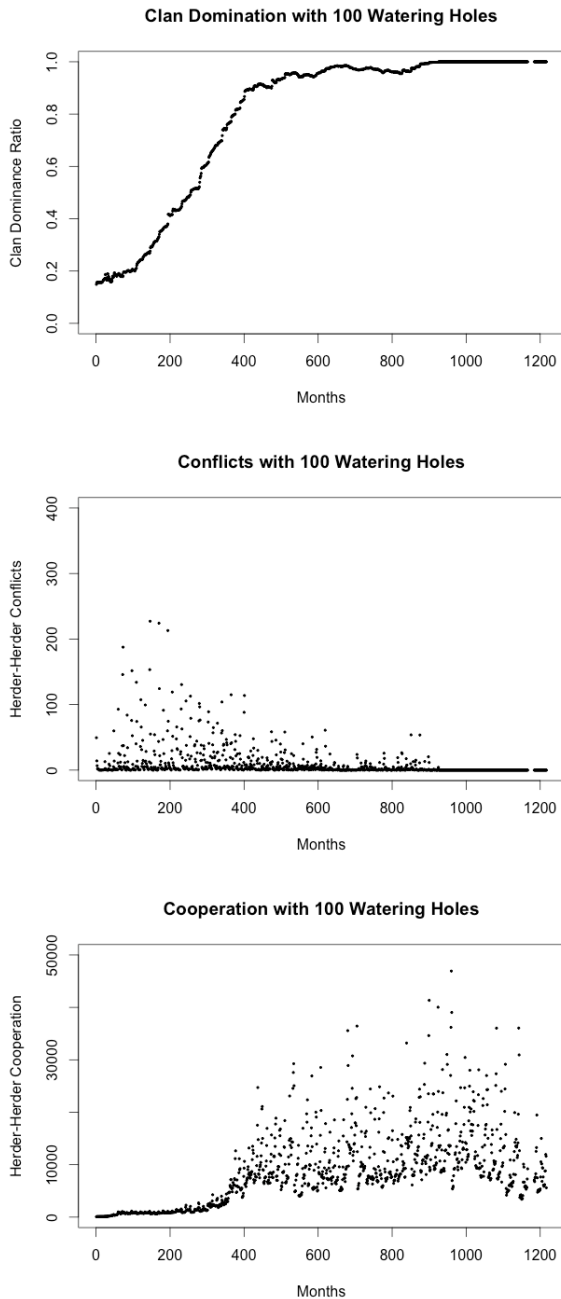


Figure 4. Run C with 100 Watering Holes

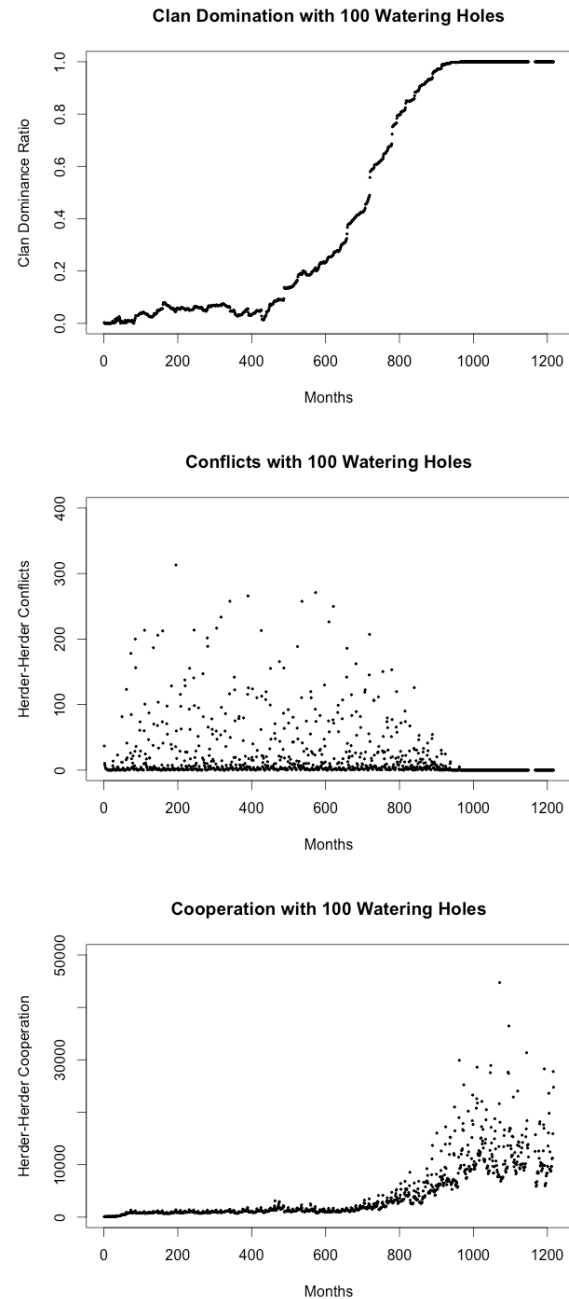


Figure 5. Run D with 100 Watering Holes

to dominance by the larger group is almost never reversed once the ratio goes beyond a tipping point. The timing of the transition is much less certain. In runs differing only in their random seed (resulting in slight differences in initial population ratio and major differences in the placement of watering holes), the transition may begin almost immediately and be essentially complete by month 400, or may not begin until approximately month 400 and not be complete until nearly the end of the 100 year simulation.

5. Conclusions

Although the large number and types of agents and phenomena included complicate our model, increasing the number of watering holes increases the population, as expected. However, considering only the total population plots misses the fact that there is competition between the two modeled clans. With the stress of fewer watering holes, one clan comes to dominate earlier than when there are more watering holes. Along the way to this hegemony, conflict between clans continues until one clan is eliminated. After total hegemony, inter-clan conflict ceases (by definition) but cooperation between members of the same clan increases dramatically

We can also draw conclusions concerning the behavior representation in modeling and simulation. In our work, the data-driven modeling of behavior has shown that environmental resources can result in disproportionately large variations in the frequency of conflict and cooperation.

Even the simple rules described here result in interesting macro-level behavior. We therefore find that this agent-based modeling framework is a rich approach for exploring the various complexities resulting from the interaction of purposive individuals in a spatially and temporally diverse natural environment. As a result, we believe agent-based modeling is the most effective modeling approach for the study of potentially chaotic systems.

Acknowledgments

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