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Collective Violence in Darfur: An Agent-based Model of Pastoral Nomad/Sedentary Peasant Interaction

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Abstract

The genocide in Darfur, Sudan is the first major humanitarian crisis of the 21st century. Over 2 million people have been displaced and tens of thousands have been killed. Popular explanations of the conflict root it in racism and prejudice orchestrated by the Sudanese government and abetted by the world community's negligence. While the complicity of the Sudanese government is evident, a closer analysis of the sequence of events suggests that the crisis is rooted in local conflicts over material resources brought about by an ecological crisis. Standard social theory has proven inadequate for analyzing the grass roots nature of the Darfur crisis. We have developed a flexible agent-based computer simulation of pastoral nomad/sedentary peasant interaction (NOMAD) that can be adapted to particular environmental and social settings. Our focus on how environmental and material factors condition individual agent response allows us to model how collective behaviors (mass raiding, genocide) can emerge from individual motives and needs. Many factors influence the conflict in Darfur (ethnicity, global politics, Sudanese politics). However, our simulations reinforce the analyses of some social scientists that argue the Darfur crisis is the inevitable result of the breakdown of land use in the face of growing populations, marginal habitats, and an unprecedented ecological crisis.

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Abstract: *The genocide in Darfur, Sudan is the first major humanitarian crisis of the 21st century. Over 2 million people have been displaced and tens of thousands have been killed. Popular explanations of the conflict root it in racism and prejudice orchestrated by the Sudanese government and abetted by the world community's negligence. While the complicity of the Sudanese government is evident, a closer analysis of the sequence of events suggests that the crisis is rooted in local conflicts over material resources brought about by an ecological crisis. Standard social theory has proven inadequate for analyzing the grass roots nature of the Darfur crisis. We have developed a flexible agent-based computer simulation of pastoral nomad/sedentary peasant interaction (NOMAD) that can be adapted to particular environmental and social settings. Our focus on how environmental and material factors condition individual agent response allows us to model how collective behaviors (mass raiding, genocide) can emerge from individual motives and needs. Many factors influence the conflict in Darfur (ethnicity, global politics, Sudanese politics). However, our simulations reinforce the analyses of some social scientists that argue the Darfur crisis is the inevitable result of the breakdown of land use in the face of growing populations, marginal habitats, and an unprecedented ecological crisis.*

Introduction

The Darfur crisis is a poignant reminder of the violence that can erupt between pastoral nomads and sedentary agriculturalists. We present a simulation, NOMAD – Darfur, designed to capture some of the essential elements of the conflict and provide insights into the nature of pastoral/peasant interactions. The simulation's parameters are derived from data gathered by social scientists and anthropologists who have worked in Sudan, providing a degree of fidelity to the Darfur context. The simulation models some aspects of Darfur traditional subsistence in detail, especially regarding local ecology, livestock and crop production, family demography, and interpersonal conflict. In order to keep the model within tractable limits, we have not incorporated supra-household phenomena such as lineage organization, the specific role of the Sudanese government, the impact of refugees, or international political pressure. Our primary aim is to demonstrate how individual family responses to ecological phenomena can produce conflict on a massive scale (Suliman 1996, 1997, 1998). While we acknowledge the selectivity of our analysis, we maintain that it nonetheless focuses on a vital piece of the elephant that is the Darfur crisis (Leaf 2004:291). Policy use of our model would require a more thorough specification of all influences on the current crisis. Nonetheless, our preliminary results suggest some of the fundamental variables that need to be addressed to mitigate the current crisis and ameliorate its underlying causes.

Tension between pastoral nomads and sedentary peasants is at least as ancient as written records; ancient Mesopotamians recorded such contention (Simon 1981), the ancient Greek Herodotus described Scythian nomad depredations (Herodotus 1972[4th C. B.C.]), and medieval scholars recorded contention and conquest between nomads and city folk (Ibn Khaldun 1967[1381]). More recent scholars have recorded the history of troubled interactions in Africa, the Middle East, and China (Barfield 1989, Lattimore 1951[1940], 1979). Anthropologists have recorded continued volatility between pastoralists and agriculturalists in the 20th century (Berntsen 1976, Goldschmidt 1979, Parkington 1984, Secoy 1992[1953]). However, raiding, homicide and rape are not necessarily foregone conclusions; anthropological observations are replete with examples of symbiotic trade between pastoral and agricultural populations (Barth 1969[1956], Dyson-Hudson and Dyson-Hudson 1980, Simon 1981). Facile generalizations are clearly not valid for characterizing the relationships between nomads and agriculturalists.

The data may not be as hopelessly contradictory as they may at first seem. It is possible that there are underlying, but competing, forces that tip pastoral/agricultural systems into different states of raiding and trading. It is difficult to identify the underlying mechanisms of such processes ethnographically since ethnographic research is typically too short in time span to allow full appreciation of the long-term consequences of observed mechanisms. Archaeological data provide a much longer time-depth, but suffer from archaeologists' inability to observe actual mechanisms as they play out. We use an agent-based modeling (ABM) approach to bridge the gap between observed mechanisms and long-term process relevant to trading and raiding between pastoral nomads and sedentary agricultural peasants.

Agent-based Models (ABMs) provide a means for modeling conflicting forces in scenarios that capture more real-life complexity than possible through verbally stated theories or simplified mathematical models. ABM simulations allow researchers to program theoretical processes, and test whether or not these processes lead to observed phenomena in the context of simulated social systems (Epstein and Axtell 1996). Anthropologists use ABM simulations to explain the rise and fall of civilizations (Axtell et al. 2002, Dean et al. 2000, Lazar and Reynolds 2002), to model the emergence of ethnic groups (McElreath, Boyd, and Richerson 2003) and cultural complexity (Read 2002), to study irrigation systems (Lansing and Miller 2005), to model the impacts of tourism on arctic communities (Berman et al. 2004) and colonization on Amazonian ecosystems (Deadman et al. 2004), and to explain the creolization of languages (Satterfield 2001). ABMs are also used to understand the emergence of social unrest, rebellion and terrorism (Kuznar, Sedlmeyer, and Frederick 2005, Lustick 2002, MacKerrow 2003, Srbljinovic et al. 2003). We have developed an ABM called NOMAD to model the essential dynamics of pastoral nomad/sedentary peasant interaction in a generic setting (Kuznar, Sedlmeyer, and Kreft in press). In this paper, we adapt NOMAD to the environmental and social conditions typical of Darfur in order to produce insights into the nature of conflict between pastoralists and peasants in this region.

Pastoral Nomadism/Peasant Agriculture

Pastoral nomadism does not exist as an independent economic system, but as an economic specialty linked to peasant agriculture (Dyson-Hudson and Dyson-Hudson 1980). The history of relations between the people pursuing these alternative lifestyles is characterized by dynamic tensions and mutually beneficial interactions. The earliest analysis of these interactions was provided by the Medieval scholar Ibn Khaldun (1967[1381]), in his analysis of urban/Bedouin interdependencies and conflict. Twentieth century anthropologists commonly note similar dynamics anywhere nomads and peasants coexist (Barth 1969[1956], 1973, Bates 1971, Berntsen 1976, Dyson-Hudson and Dyson-Hudson 1980, Kuznar 1995). The following relationships are typical:

1. Pastoral nomadism as an economic specialization exists only in conjunction with sedentary agricultural societies, so that nomads must acquire the primarily grain crops they need for food as well as other goods necessary for their existence (Dyson-Hudson and Dyson-Hudson 1980).
2. Pastoralism is characteristically volatile, with much variance in livestock holdings from year to year due to environmental hazards (drought, disease, snow), and social risks (raiding, theft) (Barfield 1993, Goldschmidt 1979: 20, Kuznar 1991b, 1995).
3. Pastoral nomads mitigate risks by maximizing the size of their herds (Downs 1972, Dyson-Hudson and Dyson-Hudson 1980, Goldschmidt 1979: 23, Grandin 1988, Kardulias 2000, Kuznar 1991a, b, 1995, 2001, Mace 1993, Mace and Houston 1989).
4. Pastoralism requires constant vigilance to protect flocks from predators and thieves, and mobility to seek adequate forage for animals. Mobility and familiarity with weapons creates a military pre-adaptation (Irons 1965, 1972, Salzman 1979:439). Pastoral/peasant interaction varies from raiding to extortion to trading, based on the relative military and political strengths of nomads and villagers (Asad 1973, Berntsen 1976, Irons 1972, Swift 1979).
5. The volatility of pastoralism and pastoralists' dependency on their own capabilities reinforces a set of personality traits and behaviors, including: aggression, use of violence, and capacity to suffer physical hardship (Goldschmidt 1979: 24).

Actual pastoral/peasant interactions can be quite varied based on contextual factors such as local government, environmental differences, migrations, etc. (Barfield 1993, Dyson-Hudson and Dyson-Hudson 1980, Goldschmidt 1979). However, the patterns enumerated above are general and flexible enough to provide insights into specific instances of pastoral/peasant interaction (Barfield 1993: 4, Barth 1973, Gellner 1973, Goldschmidt 1979). Their flexibility derives from the fact that they are relationships and processes whose parameters researchers can alter to fit particular circumstances. The parameters that particularize these relationships include species of crops and livestock, variances in production, amount of mobility, availability of weapons, etc. We review the relevance of these patterns to Darfur, and tailor their parameters to that region.

Pastoral Nomadism And Peasant Agriculture in Darfur

Darfur is the westernmost province in Sudan, the largest country in Africa. The environment of Darfur is typically dry, and much of the region consists of flat scrub, steppe, and desert lands that typically receive 200-500 mm rain annually (Suliman 1996: Table 2). The Jebel Marra massif occupies central Darfur, and this high altitude area receives more rainfall (500-700 mm) and has better soils for farming. Two traditional economies exist in Darfur, cattle or camel pastoralism in the dry flatlands, and subsistence millet farming centered in the Jebel Marra (Suliman 1996). Generally, peasant agriculturalists take on the Fur ethnicity, and are considered the original African inhabitants of this region. Most pastoral nomad groups claim descent from Arab invaders from the 14th Century. Although, so much intermarriage has occurred in ensuing centuries, and ethnic adoption and change is so variable, that any biological differences among the region's populations have been blurred (Haaland 1969, Suliman 1996). In general, cattle herding nomads in Darfur and Western Sudan are referred to as Baggara, and consist of ethnic groups such as the Arab Rezeigat, Irayqat, Mahamid, and Beni Hussein tribes (Suliman 1996, Teitelbaum 1984). One camel nomad group, the Zaghawa, is considered non-Arab. The relationships between pastoral nomadism and peasant agriculture in Darfur parallels the five patterns enumerated in the previous section.

1. Haaland (1969: 59) makes clear that Fur peasants provide the millet that forms the staple grain in Darfur, and Baggara supply necessary milk and livestock; making the two populations interdependent. Nonetheless, peasants often have small livestock holdings (Haaland 1969), and nomads plant seasonal fields to supplement their pastoral diets (Teitelbaum 1984:56).
2. The climate of Darfur is extremely variable, leading to wild fluctuations in livestock numbers, and widespread displacement of pastoral nomads (Suliman 1996: Table 1, Tobert 1985).
3. It is clear from descriptions of pastoral nomadism in Darfur that pastoral nomads in this region are constantly striving to increase the size of their herds (Haaland 1969, Suliman 1996, Tobert 1985). Other authors note this maximization behavior of Sudanese pastoralists in general (Ahmed 1973, Mustafa 2004, Teitelbaum 1984).
4. The history of pastoral/peasant relations in Darfur has always been tinged with tension. In times of relative peace, there can be substantial cooperation and social

mobility between peasants and nomads. Haaland (1969) describes how peasants who acquire cattle make contracts with nomads for the animals' care, and how impoverished nomads sedentarize and wealthy peasants sometimes nomadize. When this occurs, the parties not only change lifestyle, but also ethnic affiliation. Even religious affiliation can be very flexible and contingent on economic lifestyle (Teitelbaum 1984:57). At other times, extremes of violence erupt between peasant and nomad groups, leading to raiding, homicide, displacement and slavery (Suliman 1996).

5. Despite both Darfur peasants and nomads adhering to the same religion, Islam, Haaland (1969) describes a characteristic difference in bearing, attitude and religious practice between peasant and nomadic sectors. Fur peasants gain access to land through patrilineally held lands, prefer sedentary village life, drink millet beer, and generally view nomadic life as barbaric (Haaland 1969:62,65). In contrast, nomads maintain a haughty bearing, flaunt their martial tendencies, prefer the freedom their mobility affords and feel that milk is a preferred and necessary beverage (Haaland 1969:66, Suliman 1996).

Environmental fluctuations influence production, herd maximization is pervasive, prosperity and poverty influence mobility, and people's ethnicity changes *subsequent* to changes in economic behavior (Haaland 1969, Teitelbaum 1984). These patterns indicate that any useful analysis of pastoral/peasant interaction in Darfur requires consideration of ecological and material factors.

Darfur – Pastoralism, Drought, and Crisis

Pastoral nomad/sedentary peasant interactions have always been tinged with tension in Darfur (Suliman 1996), just as with any other part of the world (Barth 1973, Berntsen 1976, Khazanov 1994[1984], Kuznar 1995). However, these tensions erupted into full-scale war, leading many to call it genocide (Powell 2004). Many media reports have referred to the crisis' rooting in religious, ethnic, or racial prejudice. However, analysts close to the conflict and with access to data on actual behavior have pointed out that these characterizations can be misleading (Suliman 1996, 1997, 1998). There is a long history of intermarriage between indigenous African groups and Arab colonists (Suliman 1998:6) and ethnic boundaries tend to be very fluid in times of peace (Haaland 1969). The factors that are most consistently related to conflict within the Darfur region are the occurrence of drought and the degradation of land productivity (Suliman 1996). Once these conflicts emerge, ethnic fault lines are solidified, and at that point ethnicity begins to have a more causal effect on perpetuating violence (Suliman 1997:2).

From 1982-84, a severe drought afflicted Darfur. This drought had an especially severe effect on the people because it was the worst in half a century, and it was accompanied by a shift from subsistence to market production in a context of increasing ecological degradation (Suliman 1996). The low-lying plains where pastoral nomads live were hardest hit by the drought. Groups like the Zaghawa were particularly hard hit, causing many to fail as pastoralists and seek a living as peasants (Tobert 1985). Pastoral nomads migrated into the Jebel Marra region of Darfur where rains are typically higher (Suliman 1996). Some came to settle, and others for forage. These trespasses intensified conflict between peasants and nomads (Teitelbaum 1984:59). Given the irreversible effect of drought on declining environmental productivity, the conflicts continued.

The majority of pastoral nomads claim Arab descent and affiliation, while the majority of peasants claim indigenous African affiliation. Note that these claims belie historic intermarriage and ethnic fluidity. Nonetheless, once droughts created a crisis over land, these economically originated social distinctions became the fault lines along which conflict emerged. Nomads created an alliance against *Zurga* or "black" Africans, and horse-borne raiders called *janjaweed* would raid sedentary settlements and Zaghawa livestock. Sedentary peasants created their own local political organizations, and allied with the Sudanese rebel group SPLA (Sudan People's Liberation Army). These conflicts resulted in the deaths of at least 5000 Fur and the destruction of tens of thousands of homes (Suliman 1996). Through 2003, the environmental and climatic conditions of Darfur had not improved, and the conflict intensified even further. The Sudanese government, based in Khartoum, allied with the *janjaweed* militias and assisted raids by providing arms and aerial bombing. The result has been the displacement of approximately 2 million people, half of Darfur's population, and the deaths of scores of thousands (Powell 2004).

In light of the Sudanese government's involvement in Darfur, blame for the conflict has shifted to Sudanese politics, Islamic fundamentalism, and Arab ethic and racial prejudice (see Suliman 1996 for a critique). However, these explanations fail to take into account the origins of the conflict in local interactions between individual peasants and nomads. It is understandable that, given a phenomenon as vast as the displacement and genocidal war against millions of people, that analysts would focus on the effects of high-level phenomena such as governmental policies, or a pervasive force of racism. There may even be the seduction that, if a lynch pin at a high governmental level could be pulled, the conflict would be resolved. However, these hopes are either immeasurable (the force of racism) or fail to recognize the grass-roots nature of this conflict. Agent-based modeling provides precisely the analytical tool that allows understanding of such conflicts.

Simulating Pastoralist/Agriculturalist Interaction in Darfur

Agent-based models are computer programs that allow individual agents to interact with their environment and other agents according to programmed rules (Epstein and Axtell 1996). Researchers test theories of environmental influence or social interaction by programming these conditions and rules into the model, and then seeing if the model produces life-like results (Kohler 2000, Sallach 2003). These models provide for more realistic behavior than formal mathematical models because programming allows individual agents to behave in a more discrete fashion. The problem with traditional formal models is that, often, individual behaviors are aggregated as rates and averages, obscuring unexpected non-linearities and path dependencies that often emerge in social systems (O'Sullivan 2004). In ABM models, the same rates become probabilities that influence the discrete actions of agents, preserving the possibility for non-linear interactions to shift the model into varied and unexpected states as in real-life systems (Axelrod 1997, Terna 1998). It is useful to note, however, that an ABM captures these discrete effects only to the extent that individual agent behaviors are disaggregated. Our ABM makes use of the Java-based ABM programming framework called Swarm (Terna 1998) that facilitates the programming of independent agents, the assignment of behavioral rules, and the graphical display of agent behavior. The various components of the model that must be specified include: time, environment, productive resources, the human element, and behavioral rules.

Time. Since agrarian and pastoral rhythms ubiquitously occur on a seasonal basis, an iteration of the simulation represents one season. The seasonality of rainfall in Sudan is typically divided into rainy and dry seasons, but temperature fluctuations further sub-divide the seasonality of climate. Since each season differs in effect on environment, the simulation monitors four seasons with different effects on pasture and harvest.

Geography The central region of the simulation contains high quality agricultural land, modeling the central location of the Jebel Marra. Pastures are scattered about the landscape. Each land type needs a productivity, hazard rate, and hazard effect in order to model environmental fluctuations that impact both agriculturalists and pastoralists.

Agricultural Land. Suliman (1996: Table 1) provides rainfall data for a 27 year period in Darfur. Average rainfall is approximately 400 mm/year, and about 40% of years are below average and 18% below 1 standard deviation. We use a conservative hazard rate of 12.5% for all lands in Darfur (representing a substantial drought greater than 1 standard deviation below normal rainfall). This figure is consonant with drought figures for other African dry lands which vary from 10% (Dahl and Hjort 1976:116) to 15%-30% as in the Malian Sahel (Diarra and Breman 1975). Mustafa (2004:41) provides figures for average sorghum and millet productivity in Sudan; combined, they yield about 250 kg/ha. Sixty percent of years have below average agricultural production, and 20% are below one standard deviation. We use a conservative hazard effect rate of 50% loss felt during a fall harvest season, reflecting the decreased yield experienced during harvest time after a drought, consistent with figures provided by Dean et al. (2000:187) for decreased yields in arid lands.

Pastures. An artifact of the Swarm framework is that agents can only inhabit one cell at a time. African cattle pastoralists typically graze their herds over large areas and multiple pastures (Fratkin 1991). To model this effect, we assign an artificially high pasture productivity of 5000 kg/ha to a single cell (effectively acting as a number of cells across which a herder would graze his herd). Since pastures are growing at the beginning of the rainy season (spring), they typically do not achieve full productivity at this time. Consequently spring productivity is reduced by 20%, summer productivity is 100%, and fall (harvest) and winter productivity amounts to vegetation left over after grazing, following data from Sahelian Mali (Diarra and Breman 1975). Since the key periods of stress are spring and summer, we divide hazard rates evenly between these two seasons.

Hazard effects for pastures are often high ranging from 50% animal loss in Iran (Barth 1961:7), to 80% dry matter loss for US western range desert-prairie (Cook and Sims 1975), and more moderate 51%-57% dry matter (DM) loss (severe drought compared to moderate drought) in Mali (Diarra and Breman 1975). Given the more severe effect of drought on pasture, we use 65% for the pasture hazard effect.

Simulating a Major Drought Event. Once the ABM has stabilized to a dynamic equilibrium representing normal conditions for Darfur, we introduce a major and sustained drought event, like the drought that occurred in 1982/1984. This is modeled by increasing the hazard rate to 100% for pastures.

Herd Dynamics. The primary livestock in the Darfur region is cattle (Haaland 1969, Suliman 1996, Tobert 1985). Cattle need about 2.5% of their body weight in dry matter forage daily (Iannelli 1984:93). Herd mortality rates (mostly from disease and predation) amount to 8% in North Africa (Dahl and Hjort 1976:265). Since we are modeling a herd based on African cattle, the standard live bodyweight per animal is roughly 160 kg, and the standard meat take-off is 80 kg/per animal (Fratkin 1991:53), providing 118,400 Kcal and 17,600 g Protein per head. Fratkin (1991:53) and Dahl and Hjort (1976: 142) estimate an expected milk production of 1liter milk per cow per day during approximately 6 months lactation for 180 liters per year per cow, resulting in yearly milk production of: 126,000 Kcal/yr. and 6840 g Protein/yr per cow. However, much of that milk goes to calves and is otherwise lost, and milk does not entirely substitute grain as a source of carbohydrates in East Africa; we appropriately adjust the amount of available milk as a fraction of the milk cattle normally produce. The herd reproductive rate, only assessed during the spring season, should average about 1 calf per cow per year (Dahl and Hjort 1976:33-37).

The Human Dimension: We have instantiated an environment with resources and have characterized seasonal and random variations in those resources. Now we must create human agents to populate and interact in this environment. Some agent attributes are common to all agents, such as basic nutritional demands. Others are specific to pastoral or agricultural ways of life, such as fertility rates, mortality rates, and life spans. Also, economic factors are specific to ways of life including labor demands, access to resources and raiding mortality rates.

Basic Nutrition. We adopt the basic nutritional demand figures used by Kohler et al. (2000: 160) in their ABM of the rise and fall of Anasazi civilization in a dry land environment. Nutritional demands are broken down to two basic requirements: Kcal and protein. Nutritional protein demands are 63 g/day for males, 50g/day for females and children. Nutritional Kcal demands are 1872 Kcal/day for males, 1560 for females, and 1000 for children. Other biological and economic attributes are different for agricultural and pastoral populations.

Peasant Demography. Sedentary, agricultural peasants tend to have higher fertility than mobile pastoralists (Roth 1986). We use a Total Completed Fertility (TCF) rate of 6 children/female as commonly observed for sedentary agriculturalists (Thomas 1973: 147). Comparisons of morbidity and mortality between peasant and pastoral populations in Mali indicates that the peasant disease rate should be about 3%, and the childhood (age 1-5) mortality rate should be around 25% (Fratkin, Nathan, and Roth 1999:157, rough composite estimate of 3% from diarrhoea/fever in Figure 7.3, Strassmann 2000:53).

Pastoral Demography. Recorded TCF rates in pastoral societies in Africa range from 3.2 (Himba) to 4.7 (Pokot) (Fratkin and McCabe 1999:8). We use a pastoral TCF rate of 4. Pastoral disease rates among Sahelian pastoral groups are closer to 2% (Fratkin, Nathan, and Roth 1999:157, estimated 2% from figure 7.3). Pastoral childhood mortality rates are around 40%, as (Fratkin, Nathan, and Roth 1999:154, Gray et al. 2003: S8, Roth 1986: 71).

Peasant Labor. Each peasant household operates as a corporate entity that farms land to produce grain for consumption, tax payments, and trade. A reasonable labor rate for arid land peasant farming would be 1 ha per adult and ½ ha per child, as suggested by figures presented by Hillman and Davies (1990:169).

Pastoral Labor. Labor is a constant constraint on pastoral production (Dyson-Hudson and Dyson-Hudson 1980, Kuznar 1991a, Swidler 1972). Reliable labor rates for Darfur are difficult because very large herds that can tax a herder's abilities are uncommon. Considering Barth's (1961) estimate of 300 small stock per herder, we think a limit of 100 cattle per herder would be reasonable.

Raiding Mortality Rates. Raiding mortality has been directly observed among East African pastoral communities. Gray et. al. (2003) provide detailed demographic data on raiding mortality among the Karimojong during different periods of raiding intensity and weapon use. In the1950's, an escalation of cattle raiding among Karimojong led to violence accounting for 22% of all male deaths (Gray et al. 2003:S15). It was 12% in the two previous decades. Since 1970's and the introduction of firearms, it has gone up to 33%. Unfortunately, they provide no data on the number of raids a man does in a lifetime. However, a man's raiding lifespan is probably not more than 20 years and is probably intense while trying to acquire bridewealth (Gray et al. 2003:S18). Assuming one raid per year (probably more during 20's, less after married), we divide the mortality rates by 20 to get probability of death on a raid. During the peaceful period using spears, the annual probability of dying on a raid was therefore 0.006. During the intense period of raiding using spears, the mortality rate would increase to 0.011. Finally, the introduction of automatic rifles has increased the mortality rate to 0.0165. A reasonable long-term raiding death rate would be somewhere in between intense and peaceful with spears (0.0085). These raiding data were derived from armed herders attacking other armed herders. The rate for a herder raiding a relatively unarmed peasant would be lower. We assume that the mortality rate for pastoralists is half as much when attacking a peasant, and the peasant's mortality rate from being attacked is twice as high (note that pastoralists can die in a raid, and therefore peasants are not totally helpless). Therefore, the per capita death rates per raid are adjusted to the following: pastoral rate, 0.00425, peasant rate, 0.017. We maintained these low rates for NOMAD – Darfur to provide a conservative test of the role of weaponry. One reviewer encouraged us to conduct contrasting model runs with different access to weapons of different lethality. While the suggestion is welcome, it is beyond the scope of this paper's preliminary model.

The Rules of the Game

We have instantiated an environment, resources, and agents with essential attributes. Now, these various entities must interact, and therefore we must provide them with rules that govern their interactions. The rules can be divided into demographic rules, movement rules, and social rules (inheritance, trade, raiding).

Demographic Rules. For simplicity's sake, we use straightforward demographic rules. We already noted the childhood mortality rates. Adulthood for agents begins at age 20. All agents die at age 65, unless already dead. If an adult agent dies, agent's household disappears, since it is no longer viable. Women have a 20-year reproductive lifespan (age 20 to 40), and their probability of conceiving in any year is their TCF rate/20.

Pastoral Movement Rules. Since pastoralists are the only agents who are mobile, only they are impacted by movement rules. Each pastoral agent has a vision of 10 grid squares, allowing the agent to know what is nearby his or her location. Once 80% of pasture production is consumed, the agent moves in the direction (determined by vision) of increased yield. If there is no better direction, the agent moves randomly. If an agent has a metabolic need (Kcal store is at 2 seasons minimum yearly resource level for family), the agent moves toward a peasant for trading or raiding. Under severe drought conditions however, nomads cannot simply move back to pastures since there are none. In that case, the nomad remains on the nearest field to his trading partner/raiding victim. However, we presume, as observed in the Darfur case, that peasants will not tolerate this intrusion, and that further violence will continue. Therefore, while pastoralists cannot move, they will necessarily raid their peasant neighbors.

Interaction: Trade or Raid?

Trade Rule. In order to determine whether two agents would trade, and at what rates of exchange, we use the trade rule developed for the Sugarscape agent-based model (Epstein and Axtell 1996). Trade occurs when mutually beneficial to both parties. If not, either the pastoralist attempts a raid, or if unsuccessful in the attempt, goes without. This procedure models the risks agents incur in holding out for a better price, with the possibility of retribution. Agents choose the nearest neighboring potential partner, and each estimates his own marginal rate of substitution (MRS) for the goods potentially traded. In our model the two goods at issue are Kcal and Protein. An agent's MRS of Kcal for Protein is simply calculated as Kcal stored/Kcal needed for a family per year divided by Protein stored/Protein needed for the year (Epstein and Axtell 1996:103). In our case, if a pastoralist's MRS for Kcal is greater than a peasant's MRS for Kcal, then a trade can occur.

MRS's establish a range of feasible prices (quantities that can be exchanged). If we have two agents, P (pastoral nomad) and A (agriculturalist peasant), the range of prices at which they trade is [MRS_P, MRS_A]. While these may be theoretically agreeable prices, they will not normally be considered "fair" since an agent wealthy in one good may "gouge" another who is needy for that good. In order to limit the effect of such price gouging, we follow Epstein and Axtell (1996:104) and use the geometric mean of the endpoints of the feasible price range, or:

Equation 1. $$p(MRS_P, MRS_A) = \sqrt{MRS_P MRS_A} .$$

The amount exchanged is equal to p units of Kcal if $p > 1$ and $1/p$ units of Kcal if $p < 1$ where MRS_P: pastoralist's marginal rate of substitution; MRS_A: agriculturalist's marginal rate of substitution. Altering MRS's by taking this geometric mean was important in the model because there emerged a great deal of price gouging that would probably not be tolerated in any culture, reinforcing Epstein and Axtell's general intuition.

One reviewer rightfully points out that different price schemes, such as traditionally set prices, might be modeled. For instance, among Aymara Indians in Andean Peru, highland pastoral and lowland peasant families maintain traditional barter arrangements and front one another in times of hardship (Kuznar 1995). Unfortunately, we do not have similar data for Darfur, and so cannot at this time incorporate normative pricing in our model. We would like, however, to point out that in times of extreme stress, Andean trade relations break down, and in times of prosperity trade partners cheat on one another to strike more favorable terms of trade (Casaverde 1977). Also, trade does not preclude theft and rustling when opportunities present themselves in the Andes (Kuznar 1995). Therefore, there exists a great deal of back-door negotiation, even when customary prices seem to be the norm. The contentious history of land conflict in the Sudan indicates a similar weakness in the stability of trade norms (Ahmed 1992, Suliman 1998), leading us to favor a more individually negotiated form of pricing for now.

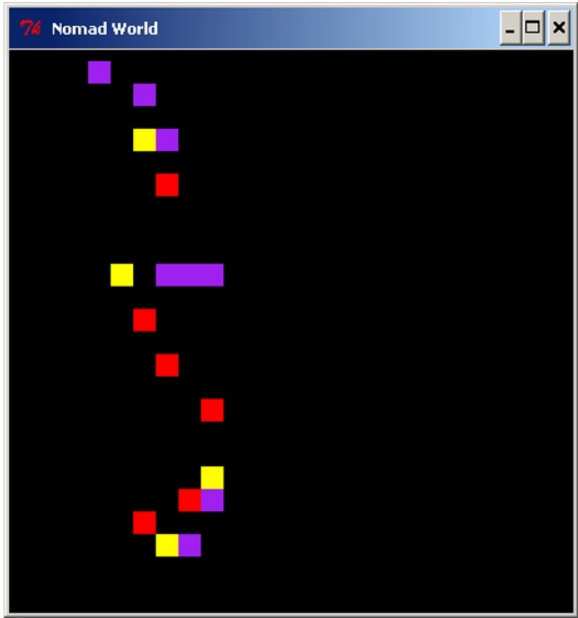
In Epstein and Axtell's simulation, if mutually beneficial terms of trade are not possible, agents seek other trading partners. In our simulation, we more realistically model the harsh constraints of satisfying need in the short-term; sometimes, trading partners cannot be found. Consequently, people either suffer resource depletion, starve, or use violence to obtain what they need. Berntsen (1976) provides a description of just such raiding where Maasai choose to raid agriculturalists too poor to trade.

Raid Rule. If a nomad has a nutritional need, yet cannot trade, then the nomad may raid an agricultural household. In most tribal societies, raids are considered unsuccessful if a member of the party is killed (Chagnon 1992). If any raiders die, then the raid is unsuccessful and nothing is gained. If the raid is successful, then the raiders divide the spoils equally.

Model Runs and Results

Twenty model runs were performed to explore the range of resulting histories and to test the sensitivity of the model's parameters (Figure 1).

Figure 1: *Screenshot of NOMAD - Darfur. Red – Peasant households not interacting with nomads, Yellow – Peasant households raided by nomads, Purple – Nomad households raiding peasants. Season is during harvest, when nomads and peasants are in close proximity.*

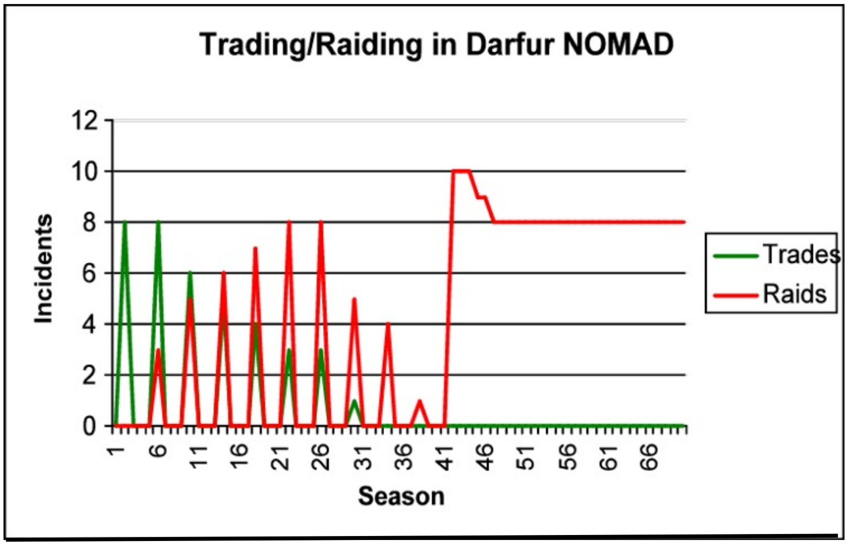


This particular screenshot portrays a spike in the raiding cycle. In earlier exercises we found that 20 or so runs were sufficient for covering the range of system responses in NOMAD (Kuznar, Sedlmeyer, and Kreft in press), and this number is consistent with other similar anthropological simulation exercises (Barreteau et al. 2004:268, Deadman et al. 2004:703, Huigen 2004:17, Kohler et al. 2000:164). Comparison to our earlier use of NOMAD to model Middle Eastern small stock pastoralism and wheat peasant agriculture is instructive (Kuznar, Sedlmeyer, and Kreft in press). The NOMAD - Smallstock model typically stabilized to a combination of trading and raiding, with raiding being more common. We also uncovered an intriguing necessity that peasants maintain small level protein sources and pastoralists maintain independent small level carbohydrate sources (mainly through milk production) (Kuznar, Sedlmeyer, and Kreft in press). This is because, while each livelihood represents a specialization, if one is totally lacking in one necessary good, one's trading partner can charge an infinite price for what one needs. This potentially explains the importance of milk production for pastoral nomads, and the pervasiveness of small-stock owning among peasants (Martin 1980, McCorkle 1990). Most runs resulted in an equilibrium seasonal harvest season raid/trade pattern. NOMAD - Smallstock therefore modeled the characteristic tensions between nomads and peasants, but also the interdependency based on trade that many scholars have noted (Barfield 1993, Dyson-Hudson and Dyson-Hudson 1980, Ibn Khaldun 1967[1381]). NOMAD - Darfur exhibits a more volatile picture.

In NOMAD - Darfur, under normal environmental circumstances, there is a definite tendency for seasonal raiding (Figure 2). We conducted sensitivity analysis by altering input parameters and tagging herder decisions to identify the underlying cause of this volatility. The increased volatility is the combined result of lower agricultural productivity in Darfur compared to the Middle East, and the greater wealth and volatility of wealth in a pastoral sector based on cattle herding. In contrast, successful cattle herds represent greater quantities of wealth, although since each cow is so valuable, stochastic shocks (disease, drought losses, poor reproduction) have a greater effect on nomad wealth. The net result is that peasants who trade with successful nomads suffer an imbalance in the terms of trade, and often do not have enough millet to trade with a nomad. The result is that the nomad simply raids the relatively impoverished peasant as recorded among Maasai cattle herders in Kenya and Tanzania (Berntsen 1976). In contrast, a nomad down on his luck is likely to have lost so much wealth with each of his lost cattle that he cannot trade with a comparatively wealthier peasant, and he will raid. However, under normal environmental circumstances, the next season likely will provide the nomad with an adequate pasture. The nomad would then return to the pasturelands and the violence would cease. In such a case, a seasonal pattern to hostility should emerge. The NOMAD - Darfur ABM under normal conditions therefore models the characteristic tension between peasants and nomads that Suliman (1996) describes as normal for the region.

Frequent seasonal raiding may be closer to historic reality for Darfur but it does not reflect the sustained genocidal warfare that threatens nearly all peasants in Darfur today. At this point, some analysts may interject that it requires state intervention on a massive scale to create such a genocidal war, as suggested by the U.S. State Department (Powell 2004). While the Sudanese national government is involved in the crisis, we think that it is premature to focus on government as a root cause. Analysts first need to consider whether or not local conditions are enough to produce a crisis of this magnitude.

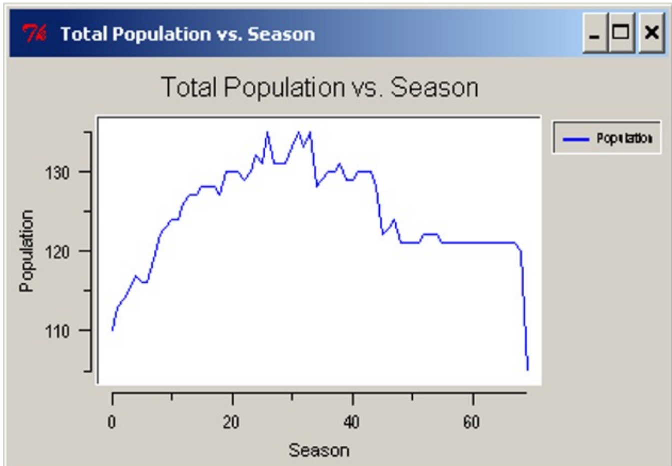
Figure 2: *Raiding/Trading Pattern from a Typical Run of NOMAD -Darfur*



The NOMAD - Darfur program typically stabilizes into seasonal raiding and some trade around iteration 20 (5 years) (Figure 2). After iteration 40, we enact the severe drought scenario, and the model in about 1-2 years duration (4-8 iterations) goes from seasonal to sustained, continuous raiding (Figure 2). This time lag models accurately the 1-2 year time lag Suliman (1996) records between major droughts and social unrest in Darfur historically. The effect of the individual nomad agents' not being able to return to pastures predictably results in their forced cohabitation and conflict with peasants. In the NOMAD - Darfur model, this results in higher mortality among peasants, but also in a state of de facto slavery in which peasant productivity is appropriated, not purchased, from peasants. The net effect is an eventual decrease in population despite the conservative mortality rates we used.

The model depopulation of course mirrors the depopulation in Darfur today (Figure 3, next page). This is curious given the historic persistence of slavery in Sudan. In the real-life situation, the martial superiority of nomads results in persistent victimization of peasant populations. The key result is that sustained, genocidal warfare need not be organized and precipitated by national governments; it can easily emerge from the interactions of individual, unconnected individuals out of extreme environmental circumstances and competition over resources.

Figure 3: *Population Growth and Decline in NOMAD - Darfur*



CONCLUSIONS AND POLICY SUGGESTIONS

The NOMAD - Darfur ABM models several aspects of pastoral/peasant interaction in the Darfur region of western Sudan. Our model omits other relevant factors (effects of marriage, movements between pastoral and peasant sectors, influence of national economies and governments). However, its lack of supra-family control represents the lack of state control of violence that has been typical of the Darfur crisis. The model's emphasis on basic environmental features and small-scale family economics in a setting where the state actively neglects the peace provides insights into several important dimensions of economy, land use, and ethnicity in Darfur. First, the combination of environmental unpredictability, volatility in cattle herding, and low agricultural productivity in Darfur results in volatile model outputs. These outputs indicate that, while trade does occur between the economic sectors, the potential for nomadic raiding is always high, although seasonal. Environmental fluctuations that improve range quality and seasonal increases in forage have historically alleviated some of the competition between nomads and peasants in the region.

However, a series of sustained droughts and land degradation in the late 20th century created conditions that led to a phase shift from seasonal raiding to sustained warfare. The NOMAD - Darfur ABM clearly demonstrates, as analysts in the region have been arguing, that the root cause of the Darfur crisis is ecological and emerges out of the individual needs, interactions, and responses of peasants and nomads in Darfur. We do not mean to indemnify the Sudanese government of responsibility for the crisis; they have aided and abetted the *janjaweed* militias, and their historic lack of effective state control in Darfur certainly created the political environment where local forces could willfully attempt to exterminate one another. However, as long as political responses to the crisis focus on the actions of national governments, the crisis will continue. The predicted impotence of political responses is due to the fact that government policies did not create the Darfur crisis; therefore, change in those policies will not resolve it. If Khartoum ceased all support for the *janjaweed*, the effect would merely be decreasing the efficiency with which the *janjaweed* conduct raids. Even if one could disarm the *janjaweed*, the killing could continue on a massive level; the recent genocide in Rwanda was largely carried out with machetes, not AK-47's and helicopter gunships. Unfortunately, evil leaders, multi-national cabals, or bad policy are not required for genocide; in this case policies don't kill people, people kill people.

We are not policy experts, but we think that the NOMAD - Darfur ABM suggests policy directions for consideration. First, people are killing people, and this violence begets more violence in the form of retaliation. Given the fundamental material cause of the violence, appeals to religion and brotherly love are unlikely to reduce violence. Likewise, regime change will likely be ineffective because any new government will face the same root causes and will find it difficult if not impossible to resolve the conflict no matter what form (theocratic, democratic, dictatorial) that government takes. Clearly, outside peacekeeping forces willing to enforce a peace are required, as was done in the Balkan conflict during the 1990's. As of 2004, the African Union deployed 305 peacekeepers, an anemic response at best. Second, a genuine long-term plan for changing the economy of Darfur to sustainable agricultural and industrial pursuits is necessary. Given the damage to the environment, a simple reversion to traditional economic practices is not feasible; traditional practices already failed and facilitated the crisis. Clearly, a suite of alternative livelihoods that take advantage of local resources and that can be spread widely across the population of Darfur is necessary. What that suite of livelihoods should be we do not know. However, more extensive and realistic modeling and simulation of Darfur's environment and population by area experts can provide an invaluable tool for exploring the possibilities.

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