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Author
Rogers, J. Daniel

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Introduction

Nomadic pastoralism has been a basic economic feature of Inner Asia for at least the last 5,000 years. While extensive archaeological, historical, and contemporary ethnographic work has done much to interpret this important way of life, many fundamental questions still remain, especially when analyzing change over time. This is in part true because mobility and the relatively ephemeral character of many types of pastoralist habitation sites leave few traces. The absence of a broad spectrum data set provides challenges to the diachronic study of adaptation, demography, the emergence of new technologies, or complex forms of social organization. While it has been possible for archaeologists to study the monuments, tombs, and material culture of pastoralism it has been far more difficult to investigate the dynamics of change within these social systems. In some instances the picture can be filled in by simply taking a much closer look, through systematic and intensive surface survey, or by stepping back to broaden the gaze to include a more comprehensive vision of pastoralism as a range of adaptations and landscape uses. Recent research in Mongolia, and surrounding areas, for instance, has used the detail-oriented approach of systematic surface survey to expand our perspectives on how the local both defines and is defined by the global. New information and new ideas continue to reorient our understanding of the diversity of pastoralist social systems (Allard, 2006; Chang et al., 2002; Fitzhugh, 2009; Frohlich et al., 2008; Frachetti, 2008; Houle, 2009).

In spite of the advances produced by systematic survey and more comprehensive visions of the economics of pastoralism, many regions have yet to supply much archaeological evidence of the day-to-day habitations and lives of common people. Observations of pastoralists today offer important insights on many fundamental practices, but also present the limitations of ethnographic analogy, both in terms of scope and time depth. An alternative analytical approach has emerged through the development of computational social simulations using the techniques of agent-based modeling (Epstein and Axtell, 1996).

Agent-based simulations developed thus far by the joint George Mason University-Smithsonian project have focused on both small-scale household social and economic interactions, as well as processes associated with the emergence of complex hierarchies evident in early states and empires. The simulations essentially offer a laboratory in which to experiment with the dynamics of social organization (Epstein, 2006; Kohler and van der Leeuw, 2007:5). Recently developed models have focused on long-term social change and pastoralist adaptations in Inner Asia, including southern Siberia, Mongolia, northern China, and eastern Kazakhstan (Cioffi-Revilla et al., 2007; Rogers and Cioffi-Revilla, 2009; Rogers et al., 2012).

Archaeological, historical, and ethnographic information are used to identify and validate the parameters hypothesized to be essential to the operation of pastoralist societies. It is not possible, or even desirable, to entirely engineer an artificial society that replicates the nearly infinite variability in human behavior. Nor is it the goal of this study to recreate the specific history of the target social system. Instead, the focus is on identifying the essential characteristics that account for the majority of the behaviors under study. Given the importance of local interactions for understanding broader implications, one central question is identified: which forms of pastoralist social structure have the greatest impact on mobility and use of landscape resources at the scale of decades and centuries?

Simulation Parameters and Procedures

The Software

The agent-based model, HouseholdsWorld (v.1.6.3) functions as an experimental platform designed as a modular interaction space. This model is the initial social simulation in a progression of models aimed at interpreting the rise and fall of polities in Inner Asia over a long time span. HouseholdsWorld is a spatial agent-based model of pastoral nomads living in a socio-natural system, as shown in the heuristic in Figure 1. The model is coded in Java utilizing the MASON (v. 14) simulation tool kit (Luke et al., 2005). Computational aspects of the model are described in detail in Cioffi-Revilla et al. (2010).

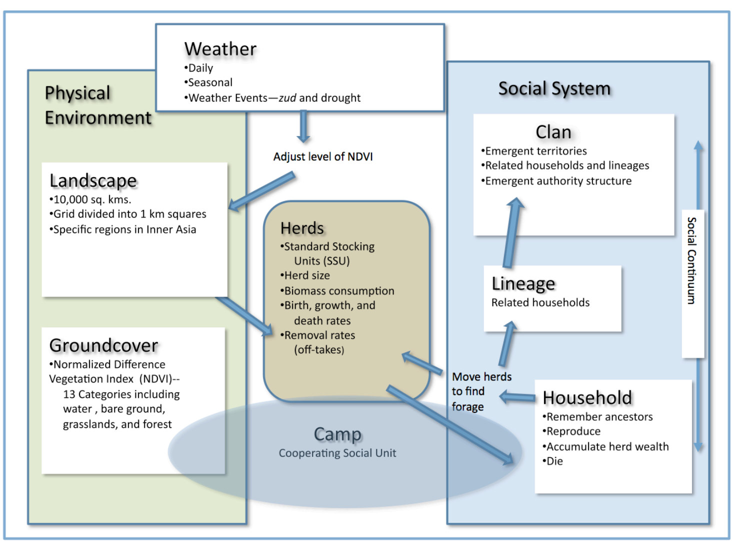


Figure 1. The structure of the HouseholdsWorld model, including the physical environment, weather, herd dynamics, and the social system. A larger version of Figure 1 is found at the article website as supplementary material.

Social Organization

The basic social units in the model are households, representing nuclear families belonging to lineages and clans (see Figure 1). Households have a life cycle

(Goody, 1971), produce offspring households (marriages of children), accumulate herd wealth, evaluate the landscape for suitable pasture on a daily basis, remember their routes to favorable grazing from year to year, form camps with other lineage/clan households, and interact with other clans depending on avoidance preferences and endogamous/exogamous kinship norms. Marriage partners are identified based on clan affiliation and kinship norms about degree of relatedness. A dowry of herd animals is given by the parent households to the newly formed household.

The logic supporting these characteristics is based on our understanding of pastoralist social organization empirically observed over the last 5,000 years of Inner Asian history. Pastoralists, whether in the distant past or the modern day, do not simply herd animals, but also gather, hunt, fish, sometimes practice agriculture, trade, engage in wage labor, and in other pursuits as part of the market economy, as either routine or risk buffering activities (Cooper, 1995; Honeychurch and Amartuvshin, 2007:36-37; Salzman, 1972:67). Within the model these alternative economic pursuits are implicit, but are not individually modeled. Both archaeological and historical evidence indicates the existence of households and larger social formations, like lineages and clans, with increasingly complex hierarchies documented before 1,000 B.C. (Fitzhugh, 2009; Frachetti, 2008; Frohlich et al., 2008; Honeychurch and Amartuvshin, 2006; Rogers, 2007, 2012). While the social system within the model operates on kin-based relationships, it is also known that in many instances clans and tribes described in the early Chinese historical sources (e.g. Sima Qian, 1961) actually incorporated elements of corporate and hierarchical organization, termed "aristocratic lineages" by Sneath (2007).

Herds

The target herd structure consists primarily of sheep, followed by different proportions of goats, horses, yaks, cattle, and camels. These animals are used today and documented archaeologically. The key herd dynamics in the model include herd size, biomass consumption, animal birth rates and growth rates, starvation rates, miscellaneous animal death rates due to routine hazards (e.g. predators or disease), herd grazing efficiency, and the off-take of animals for consumption by humans and for trade. Together, these parameters provide a herd mortality and survivability profile verified by field observations and experimental results (Begzsuren et al., 2004; Cribb, 1991; Dahl and Hjort, 1976; Natsagdorj and Dulamsuren, 2001; Redding, 1981; Skees and Enkh-Amgalan, 2002).

Landscapes

Households "live" on realistically rendered landscapes from specific regions: the Egiin Gol forest steppe region and the Baga Gazaryn Chuluu (BGC) desert steppe region of Mongolia (Figure 2) are used in this specific study. These regions offer distinctive environmental contrasts and both have been studied extensively archaeologically (Amartuvshin and Honeychurch, 2010; Honeychurch and Amartuvshin, 2003; Wright et al., 2007). Each landscape is 100 x 100 km, using a 1 x 1 km grid. Landscape characteristics are defined using normalized difference vegetation indices (NDVI) and specific land cover attributes (Hansen et al., 1998, 2000). Monthly NDVI rasters were computed from atmosphere corrected bands in 500 m resolution. The landscapes are classified into 14 land cover types and exponential regressions calculated to produce approximations of edible biomass for the relevant landscape types. Coefficients for biomass are calculated using the methods outlined in Kawamura et al. (2005).

Figure 2. The location of the two 100 x 100 km study regions, Egiin Gol and BGC, (cross-hatched boxes) in Inner Asia.

Weather

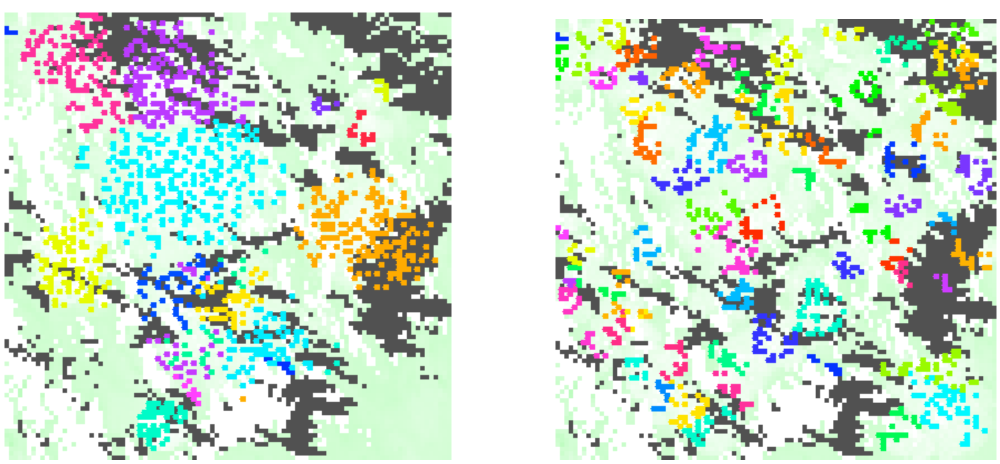
As with agricultural societies, pastoralists are strongly dependent on favorable weather cycles for the maintenance and increase of production. However, unlike primary agriculturalists, who typically store excess production, pastoralists use alternative strategies to buffer against unfavorable conditions. This means that the growth and loss of herds may occur far more rapidly, with devastating consequences (Cribb, 1991:24; Spooner, 1973). The modern era of herd insurance, governmental, and NGO intervention has changed the role of more traditional practices. Without modern safety nets pastoralists typically must survive the consequences of unfavorable years by either moving or relying on other households for support. Severe weather conditions over large regions may render mobility and sharing ineffective. Rogers et al. (2012) utilized the HouseholdsWorld model to study severe winter storms and droughts, and their effect on the resiliency of pastoralist social systems. For purposes of the present study, however, the weather is restricted to month-by-month seasonal variations as experienced in a "typical" year, based on modern monthly NDVI means for a five-year period.

Analysis: Three Experiments

The Egiin Gol, and BGC landscapes represent two distinct environments within Mongolia. A series of results were accumulated from multiple runs of the HouseholdsWorld simulation with output snapshots illustrating selected characteristics of landscape use, social, and demographic dynamics taken at 60 years (3 generations) from the beginning of the simulation. Collecting data at the 3 generation interval allowed the simulation to fully implement the kinship ancestry that serves to define marriageable partners, among other things.

Experiment 1

Clan affiliation creates restrictions and opportunities through simple concepts of inclusion or exclusion that generally form the foundations of a descent group (Fox, 1967:41). Clan leadership may also assert "rules" that affect household movements. In this experiment, on a periodic basis clan leadership was given the option of emphasizing one or another of the five different aspects of the group structure—memory of previous camp locations, knowledge of grazing availability, camp cohesion, clan cohesion, and avoidance of non-clan members. At Egiin Gol, giving clans the authority to change the degree of emphasis on one or another of the social rules produced distinctive clan territories (Figure 3). These territories emerged because clan leadership placed more emphasis on clan cohesion and avoidance of non-clan members. The number of households also decreased by 410 (Figure 4). With clan leadership setting the rules individual households could not move as often or as far. Some clans fared well, while others became poorer and less populated. The emergence of clan territories is a distinctive outcome of the simulation and one that has potential for comparison with the results of archaeological surveys in the region (see below).



(3a) (3b)

Figure 3. Comparison of the winter Egiin Gol landscape (100 x 100 km at 1 km

resolution) showing the distribution of households with and without clan leaders deciding rules: (a) With clans deciding rules; (b) Without clans deciding rules.

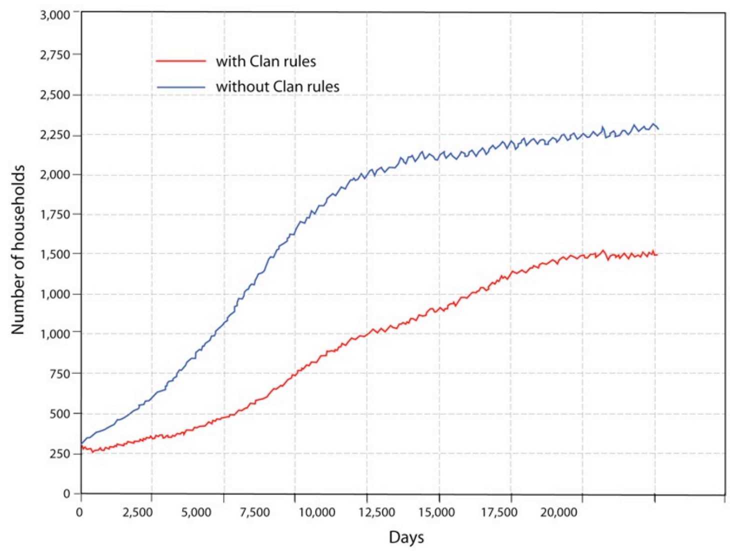
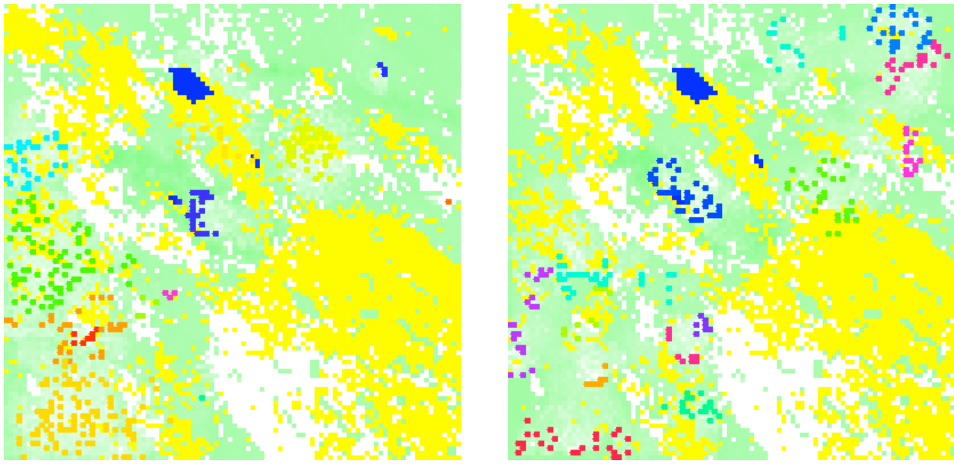


Figure 4. Comparison of winter count of households at Egiin Gol with and without clan leaders deciding rules. Population levels were substantially higher when decision making was locally controlled.

The results from BGC contrasted with those from Egiin Gol (Figure 5). Allowing the clans to set the rules did not produce more distinctive clan territories, but it did significantly reduce the frequency and distance moved by households. Less movement is often associated with overgrazing, but in this case the relatively sparse population density produced more options for short movements that actually resulted in an increase in the population under clan rules, from 450 to 510 households (Figure 6). The opposite happened at Egiin Gol, probably as a result of the denser populations. The implication is that landscape differences play a huge role in the outcomes of social decision making. At BGC, like Egiin Gol, some clans were far more successful than others, with a wider disparity of wealth between clans.



(5a) (5b)

Figure 5. Comparison of the winter BGC landscape (100 x 100 km at 1 km resolution) showing the distribution of households with and without clan leaders deciding rules: (a) With clans deciding rules: (b) Without clans deciding rules.

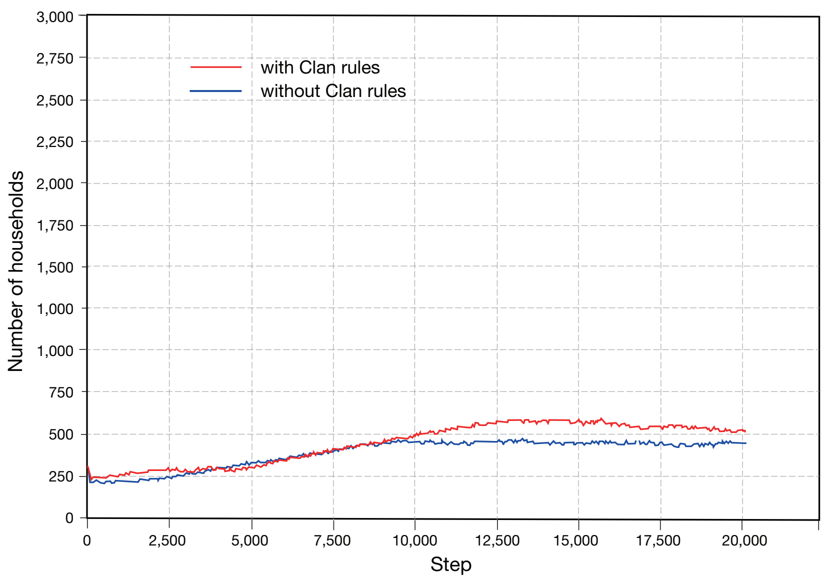


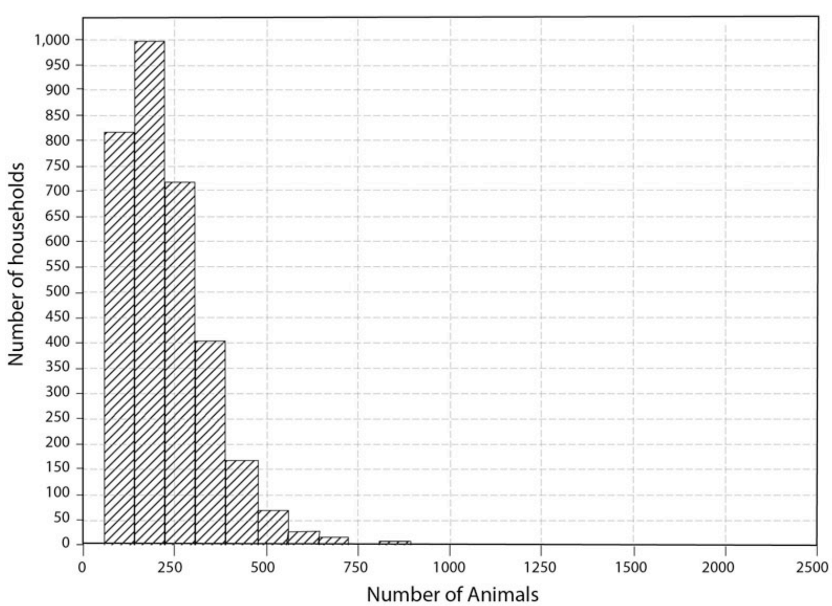
Figure 6. Comparison of winter household counts at BGC with and without clan leaders deciding rules. Unlike Egiin Gol, population levels were higher when the clan leaders made decisions.

Experiment 2

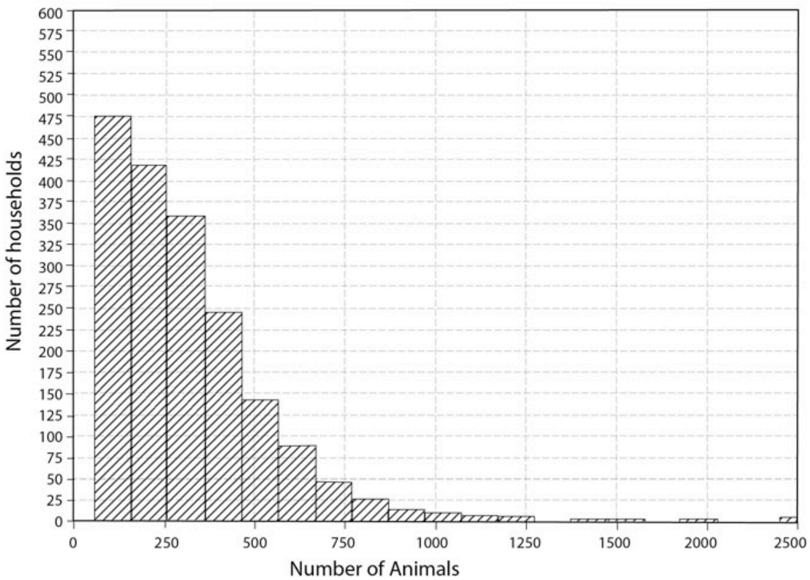
There are numerous aspects of social organization and demography that affect mobility and use of the landscape, however, the emphasis here is on how collective actions at the clan or camp levels impact individual households. Within clans, households form camps at different times of the year. These camps offer some benefits to the individual members, such as sharing opportunities. Local social networks also represent an important coping strategy during difficult economic times (Fernández-Giménez et al., 2012:7; Templer et al., 1993). Under Experiment 1 the maximum sustained camps might be as large as 12 households. In Experiment 2 camp size was reduced to no larger than 6 households.

The results show that when camp size is reduced, clan territories become more clearly defined. This result illustrates how local camp actions may serve to affect the role of clans. Reducing local camp size limited small-scale social networks, which allowed clan membership to become the primary social affiliation, at least concerning mobility and spatial distribution. With households more widely spaced in the smaller camps the possibility of overgrazing was reduced, with herds growing larger over time. This effect resulted in a population explosion at both Egiin Gol (3,200 households) and BGC (900 households).

How did individual households fare with the different camp size rules in a densely settled landscape? This can be measured by comparing the herd wealth of households at Egiin Gol. Figure 7 compares the distribution of herd animals among households in mid-summer using the small camp rule and the large camp rule. Under the small camp rule there were fewer wealthy households and many more near the starvation level. This is almost certainly a consequence of a densely populated landscape being overgrazed. While at first it appeared that large camps might produce overgrazing, keeping camps small actually resulted in increased population and overgrazing. In the end, individual families were more successful at establishing their children in new households, but many of them lived near the threshold of survivability.



(7a)



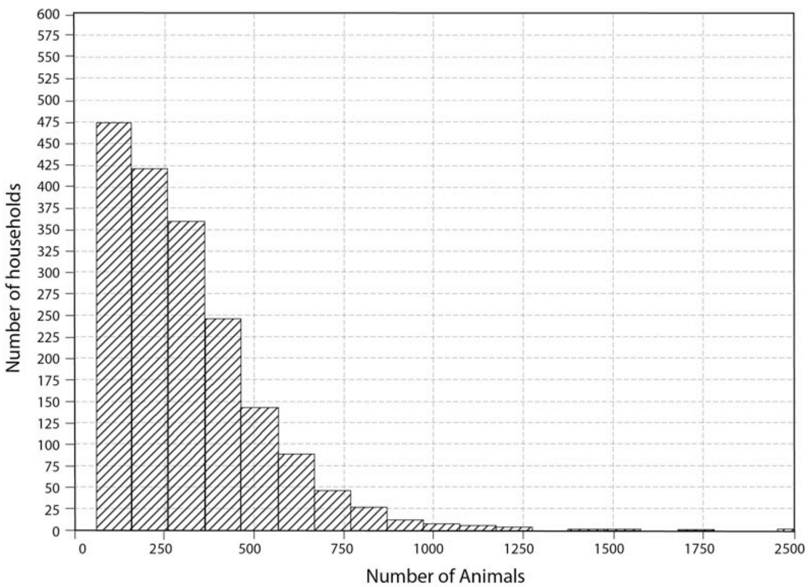
(7b)

Figure 7. Comparison of the effects of camp size at Egiin Gol on summer household herd wealth: (a) Small camps: (b) Large camps.

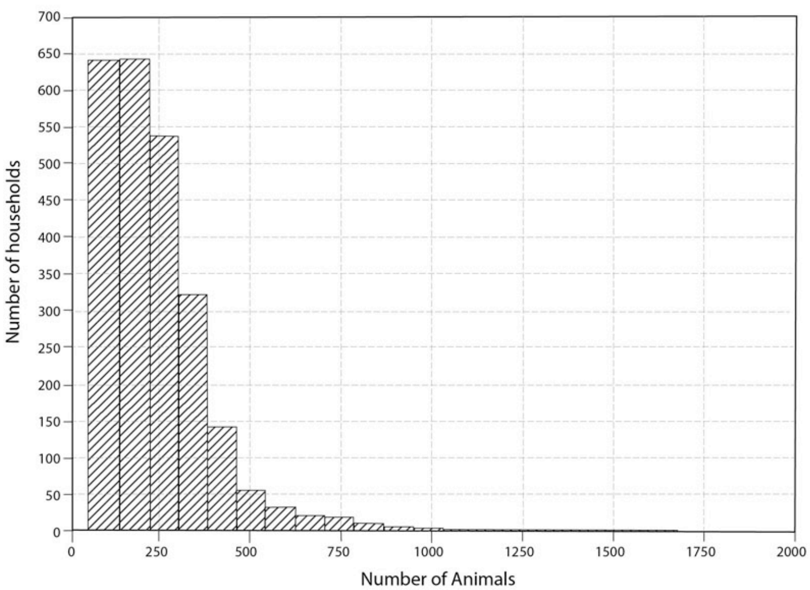
Experiment 3

Within the parameters of the simulation it is possible for households to expand their local knowledge when considering where to move herds, as well as recognizing where relatives, camp mates, and clan mates are located. Expanding local knowledge within the simulation is the equivalent of increasing local information sharing and for pastoralists is an aspect of what Borgerhoff Mulder (2010:38) calls *embodied wealth*. This kind of wealth refers to the degree of knowledge of the landscape and social ties held by an individual or family. If spatial knowledge is expanded households are hypothesized to be better able to find the best grass, grow their herds, and be less constrained by rules governing social behavior. From year-to-year such benefits are compounded as herders accumulate knowledge and further social contacts. In the highly productive range lands of Egiin Gol, with its dense populations, knowledge of a wider range of surrounding territory for a household would probably be less useful than at BGC where there are more movement options. If the vision range is increased at BGC then households should be able to increase their herd sizes and eventually the number of households would also increase. For the experiment the vision range radius in both regions was increased from 5 to 7 km.

Using the large camp parameter at Egiin Gol and increasing the vision range from 5 to 7 increased the mean monthly travel. When households have an expanded knowledge of the landscape, they take advantage of it. The total number of households expanded from 1850 to 2400. Rather than being relatively unimportant at Egiin Gol expanded knowledge allowed households to implement their personal interests more effectively, but how was the overall increase in herd animal numbers distributed among households and clans? Figure 8 presents histograms for household wealth distribution.



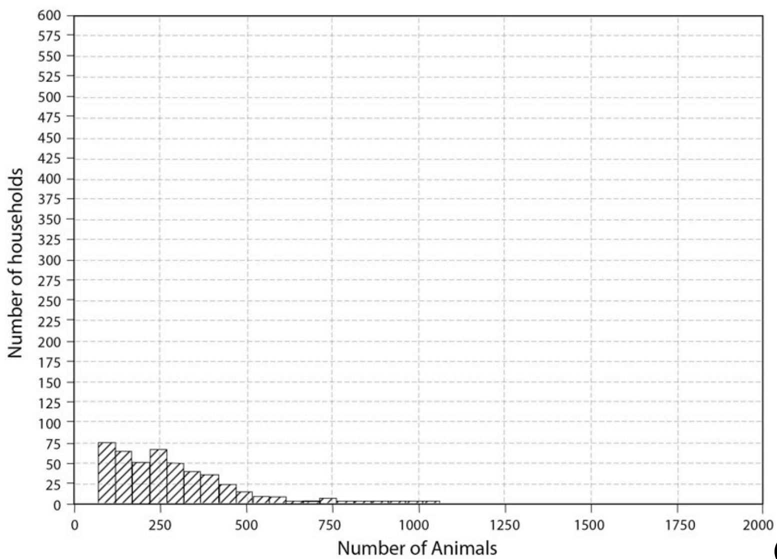
(8a)



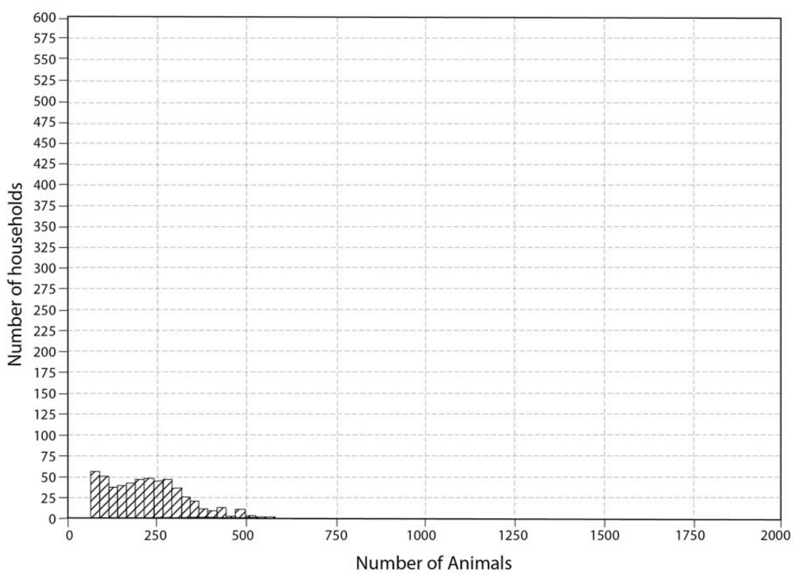
(8b)

Figure 8. Histograms comparing vision (landscape knowledge) ranges at Egiin Gol during the summer: (a) Vision range 5 km; (b) Vision range 7 km.

While increasing the vision range encouraged the growth in the number of animals and households, the largest growth was in the proportion of poor households, further skewing the wealth distribution. Greater knowledge of the landscape allowed individual households to be more reproductively successful, but not more affluent. In the much drier environment of BGC herd size at both the household and clan levels took on different dimensions (Figures 9). The wealth profile for households was different for a vision range of 5 km versus 7 km, but there continued to be a wide range of poor to middle-range. Increasing the vision range did have the effect of eliminating outlier wealthy households and increasing the middle-range of the reshaped wealth distribution.



(9a)



(9b)

Figure 9. Comparison of vision (landscape knowledge) ranges at BGC during the summer: (a) Vision range of 5 km; (b) Vision range of 7 km.

Connections and Implications

In the Bronze Age of Inner Asia, archaeologists have identified aspects of habitation and differential social status through study of burial mounds and other monuments that embody several of the patterns noted in the simulation (Frachetti, 2012; Frohlich et al., 2010; Houle, 2009; Kohl, 2007). Comparisons with the Bronze Age are particularly relevant for this study, since, as in the model, there is little evidence for multi-regional control hierarchies like those in later empires (Rogers, 2012).

Archaeological settlement data tends to conflate time periods and provides a partial and composite image of land use. Not all sites leave identifiable traces and many of those that do can only be dated to a wide range of years. Even with these caveats, archaeological evidence still reveals distinctive patterns. During the Bronze Age and Early Iron Age (late second to mid-first millennium B.C.) in Egiin Gol, archaeological study of site locations show five clusters, primarily centered on small tributaries to the Egiin River. In the simulation by comparison, when clan leadership exercised authority ten distinctive clusters were generated, primarily in the main river valley. The distribution of these population clusters is hypothesized to represent two different forms of social organization. The archaeological evidence reflects a pattern of distinct groups separated geographically, but not directly focused on access to the best grazing. Although research is continuing on this issue, currently the distribution of archaeological sites and monument clusters suggests that regional partitioning of lands was taking place either by strong social avoidance rules or by an overarching social hierarchy (Honeychurch and Amartuvshin, 2007:51-52). Kinship-based avoidance patterns alone are generally insufficient to produce the distinctive archaeological patterning. It is more likely that aristocratic lineages with strong authority over households were directing habitation and focal areas for the construction of monuments. In later time periods, after 200 B.C. (Xiongnu empire), site locations shift to the main river valley, apparently related to an emerging emphasis on agriculture and possibly the consolidation of local interests under the authority of a centralized administration.

The archaeological evidence at BGC is more difficult to interpret in relation to the simulation results because of the different kinds of sites present. The simulation generates habitation information, but for the Bronze Age and Early Iron Age at BGC the great majority of the sites relate to burial structures and monuments (Amartuvshin and Honeychurch, 2009; Wright et al., 2007). These constructions tend to represent a continuum from slopes and higher elevations down onto low-lying areas with pasture. The simulation by contrast shows habitation concentrated in the largest grassland areas. This is to be expected, since the simulated herders do not build burial monuments, but simply live where the herds can be grazed. In the archaeological data, habitation sites are conspicuous by their absence in the low-lying areas, except in the much earlier Epi-Paleolithic periods. It is a strong possibility that Bronze Age and Early Iron Age habitation sites in the grazeable areas simply did not leave sufficient evidence to be discovered.

Camp size and localized knowledge were explored in Experiments 2 and 3 in the simulation, but archaeologically there is little or no comparative information. Ethnographic information, however, is instructive for interpreting how localized knowledge of the social and environmental landscape might be advantageous. It is widely acknowledged that better social and landscape information is beneficial to effective herd movements and related decisions. This is confirmed in a broad sense through ethnographic observations on local social groups termed *khot-ail* in Mongolian, usually consisting of 2 to 12 households (Bold, 1996:75-79; Fernández-Giménez, 1999:320).

Conclusions

The three experiments provide quantitative observations from the histories of households and clans that exist only in an artificial world. This simulated world contains the key social, behavioral, economic, and environmental parameters that allow investigation of both general and very specific questions about how pastoralist societies in Inner Asia *may have* operated. The model is essentially an elaborate hypothesis that can either be accepted or rejected with empirical data. The model, however, also allows discovery of potential relationships for which no real-world comparative data is available. While the model incorporates many aspects of a functioning socio-environmental system it is far from comprehensive. It serves only for analysis of very local relationships, since there is no market economy, no wars, no forms of labor beyond herding, and no movement beyond the boundaries of the 100 x 100 km study landscapes. These and other limitations served to maintain the focus on the fundamental relationships between landscape, herds, and people.

The primary question addressed in this study focused on identifying basic forms of social structure that had the greatest impact on use of landscape resources. The results illustrate the emergence of sustained inequality based on differential wealth, emergent traditions of land use, the role of information networks, and centralized authority as it impacted the fate of entire clans and individual families. Differences were explored on two distinct landscapes and the benefits of various decisions were considered both in terms of how they affected wealth and the movement of individual households. In some cases, outcomes that benefitted households ran counter to those favoring clan elites and vice versa.

In Experiment 1, clan leadership was given the ability to change emphasis within a set of five social norms on a periodic basis. The clans changed, or did not change rules on a random basis, but with no ability to assess which rules were more effective at producing optimal outcomes. Even with blind leaders, the results produced a kind of self-organizing social landscape remarkably similar to what is known empirically. Archaeologically, at Egiin Gol distinctive settlement clusters existed that may represent social group territories. When the social rules were held constant, clan territories were less distinct and there were far fewer differences in size and wealth between clans.

In Experiment 2, local versus more collective clan-oriented decision making was explored further by considering the role of household membership in camps. The impact of households forming large local camps versus small local camps was compared on the two study landscapes. The results showed that the larger camps, in effect, kept decision making at the local level, which allowed individual households to become wealthier. Again, priority given to local action and control helped individual households to increase their herds, but did not help to increase the overall population.

In Experiment 3, the role of mobility was addressed directly by giving households an expanded ability to move a greater distance if they judged it to allow them to find better grass or more effectively implement the various social norms. It was hypothesized that because of the high quality rangelands of the Egiin Gol region, mobility would be less important than in the semi-arid BGC region on the edge of the Gobi Desert, considering that it would be necessary to move herds more frequently in light of the sparse edible biomass. The hypothesis was not supported, and instead Egiin Gol households used greater mobility to expand their herds dramatically, while at BGC the relatively sparse population was not benefited greatly by expanding potential movement. The principal restriction to movement was the presence of other households, especially those of other clans. At Egiin Gol households could use their expanded vision to find ways around both social and landscape obstacles, while at BGC the social movement restrictions were already sparse and not particularly restrictive. Households at BGC were already able to find the best grass, even if it was scarce.

Mobility and the nature of social controls are important issues in understanding pastoralist societies, whether involving individual families or the organization and expansion of great empires (Allard and Erdenebaatar, 2005; Fernández-Giménez et al., 2007; Honeychurch and Amartuvshin, 2007; Kerven et al., 2006; Rogers, 2007). Expansive social networks and long-distance seasonal movement for herd management, trade, warfare, religious, and other reasons greatly expanded after the domestication of the horse and the development of riding technologies. The importance of movement is evident in 20th century landscape histories of Central and Inner Asia, in which efforts to manage pastoralism by tying herders to large-scale collective farms, to expand production, resulted in partitioned lands in Russia and northern China and severe overgrazing. In Mongolia the landscape was less partitioned and pastoralists were freer to move in search of better pasture. As a consequence the pasture lands of Mongolia were under far less stress from overgrazing (Humphrey and Sneath, 1999; Sneath, 1998).

The simulated pastoralists in HouseholdsWorld try to maximize their herds, within the limits allowed by the potential of the landscape and their social world. Together these two aspects chart the adaptive capacity of the pastoralist system. With emergent clan territories and expanding populations the landscapes became increasingly complicated to navigate while providing a glimpse of the conditions that arguably led to the formalization of inequality and an emergent political community associated with the rise of empires (Honeychurch, 2012; Rogers, 2012). At Egiin Gol populations expanded, but people became poorer. Such an outcome may benefit the agenda of leaders, but not the wellbeing of individual families. At BGC expanding the potential for movement increased the mid-range of the wealth distribution without creating new levels of poverty. The very different outcomes between Egiin Gol and BGC are tied to differences between the two landscapes rather than the actions of leaders. The importance of environmental conditions cannot be overlooked and provides a clear example of the interactive quality of socionatural systems.

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