Environmental variability, wealth inequality, and empire: Agent-based simulation of nomadic pastoral complexity

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Table of Contents

Abstract

This dissertation uses agent-based computer simulation to examine general processes that generate patterns of social organization among nomadic pastoral populations in Inner Asia. Of particular interest are processes related to the formation of nomadic states and empires, such as those of the Mongol (1206 – 1368 CE) and Xiongnu (209 BCE – 48 CE) periods. Three main topics are addressed. First is the development of wealth inequality and hierarchical social networks among nomadic pastoralists, particularly in relation to environmental variability. Second is the effect of large fixed urban centres on livestock herding network dynamics and wealth inequality. Third is an exploration of the factors of nomadic pastoral livestock production, and how these factors generate spatial features of social organization. Findings are threefold: first, inequality develops rapidly under heterogeneous environmental conditions, due to the differential effects of natural disasters. This inequality can easily lead to hierarchical networks among herding households as an adaptive response. The size and resilience of these hierarchical networks increases in more favourable environmental herding conditions, characterized by increased biomass. Thus, large complex hierarchical societies such as states and empires are more likely to form in periods or regions with increased biomass. Second, the provision of disaster relief to herding households via urban centres increases the size and resilience of hierarchical herding networks during environmental downturns. Third, the extensive nature of nomadic pastoral food production exerts unique requirements, generating significant features of social organization. While many features exhibit a significant range of variation through time, the demands of food production generally lead to striking spatial continuities in Inner Asian nomadic pastoral social organization.

The results of this dissertation contribute to a growing body of knowledge emphasizing the internal capacity for the development of complex social organization among nomadic pastoral populations.

Abrégé

Cette thèse utilise la simulation par ordinateur pour examiner les processus généraux qui génèrent des modes d'organisation sociale parmi les populations pastorales nomades en Asie intérieure. Les processus liés à la formation d'États et d'empires nomades, tels que ceux des Mongols (1206 – 1368 ap. J.-C.) et des Xiongnu (209 av. J.-C. – 48 ap. J.-C.), présentent un intérêt particulier. Trois sujets principaux y sont abordés : le premier est le développement de l'inégalité des richesses et des réseaux sociaux hiérarchiques parmi les populations pastorales nomades en fonction de la variabilité environnementale. Deuxièmement, l'effet des grands centres urbains sur la dynamique des réseaux d'élevage et l'inégalité des richesses. Troisièmement, une exploration des facteurs de production pastorale nomade et comment ceux-ci génèrent des caractéristiques spatiales dans l'organisation sociale. Les résultats sont triples : premièrement, les inégalités se développent rapidement dans des conditions environnementales hétérogènes, en raison des effets différentiels des catastrophes naturelles. Cette inégalité peut facilement conduire à des réseaux hiérarchiques entre éleveurs pastoraux en tant que réponse adaptative. La taille et la résilience de ces réseaux hiérarchiques augmentent dans des conditions environnementales plus favorables, caractérisées par une augmentation de la biomasse. Ainsi, les grandes sociétés hiérarchiques complexes telles que les États et les empires sont plus susceptibles de se former dans des périodes ou des régions présentant

une biomasse accrue. Deuxièmement, l'assistance en cas de catastrophe aux éleveurs pastoraux via les centres urbains accroît la taille et la résilience des réseaux hiérarchisés d'élevage pendant les périodes de déclin environmental. Troisièmement, la nature extensive de la production pastorale nomade exerce des exigences uniques, générant des caractéristiques significatives de l'organisation sociale. Bien que de nombreuses caractéristiques présentent une gamme importante de variations au fil du temps, les exigences de la production pastorale conduisent généralement à des continuités spatiales frappantes dans l'organisation sociale pastorale nomade de l'Asie intérieure. Les résultats de cette thèse contribuent à un corpus croissant de connaissances mettant l'accent sur la capacité interne à développer une organisation sociale complexe parmi les populations pastorales nomades.

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Contributions of authors

Chapter 3 of this manuscript-based thesis is a paper co-authored with Andre Costopoulos. I was responsible for the original concept, design, execution, and analysis of the computational model, and writing the paper. Andre Costopoulos provided guidance and editing throughout this process. All other chapters are my own.

Chapter 1: Introduction

Research problem

An important question in scholarship on nomadic pastoral societies in Inner Asia is how they created such large and powerful states and empires. A related question concerns the relationship of nomadic pastoralists to sedentary agrarian civilizations - were they antagonistic, complementary, independent, or dependent? Scholars initially placed nomadic pastoralism between hunting and gathering and agriculture on the scale of progressive linear cultural evolution (Smith, 1776; Huntington, 1907; Grousset, 1970). Nomadic pastoral society tended to be portrayed as antagonistic to and dependent on settled agrarianism. As a result, theories of nomadic state and empire formation have focused on external variables as causes – reactions to climate, and reactions to neighbouring sedentary civilizations.

Both these causes are tied with notions of nomadic economies functioning around a subsistence level, presenting little opportunity for surplus and social hierarchy. This mirrors initial ethnographic reports by western anthropologists of relatively egalitarian nomads in the Middle East and Western Asia (Dyson-Hudson, 1980). As such, the hierarchies and social inequalities characteristic of states and empires were seen as created and sustained by acquiring the necessary surplus energy from sedentary agrarian neighbours. This process could manifest as a reaction by nomads to climatic downturns depriving them of subsistence (Huntington, 1907; Toynbee, 1934; Lattimore, 1938), an antagonistic response to the creation of sedentary states and empires (Yü, 1967; Barfield, 2001; Di Cosmo, 2002), or an inbuilt desire for conquest and plunder in militarized nomadic societies (Oppenheimer, 1907; Smith, 1776; *Muqqadimah*).

In recent years, increased international archaeological research in Mongolia has led to a reassessment of these theories, resulting in new emphasis on the indigenous capacity for complexity among Inner Asian nomads (Honeychurch, 2014; Houle, 2010; Waugh, 2010). Additionally, new climate data has indicated more favourable and productive herding environments during the formation of nomadic states, in contrast to previous climate theories, and further suggesting internal drivers of complexity in nomadic society (Pederson, Hessl, Baatarbileg, Anchukaitis, & Di Cosmo, 2014; Putnam et al., 2016; Wu, Ge, Zheng, Zhou, & Hu, 2009).

Nevertheless, precise and parsimonious explanatory mechanisms that can generate observed archaeological outcomes (nomadic complexity and a correlation between a productive climate and increased complexity), are underdeveloped. Rather than seeking out and analyzing patterns in the archaeological or historical sources, this dissertation is concerned with general processes, explored via computer simulation, which can generate observed outcomes. Explanations for the generation of large-scale patterns thus emerge from the (simulated) actions of individual herding households, and these mechanisms can then be compared with the empirical record.

The dissertation avoids issues of defining nomadic states or empires, or whether these historical polities meet formal definitions of states and empires. It simply explores generative mechanisms related to the formation of actual historical phenomena, however they may be classified. These phenomena include in particular the Mongol (1206 – 1368 CE) and Xiongnu (209 BCE – 48 CE) empires (see Appendix B for a broad overview of these periods). The general dynamics assumed to be relevant to these phenomena include the generation of sustained wealth or social inequality, and the formation of hierarchical networks in social organization. The dissertation is chiefly concerned with internal dynamics and social organization of nomadic pastoral societies. As such, empirical data on nomadic polities are considered mainly from periods prior to the incorporation by conquest of large areas of sedentary civilization and resulting hybrid societies, economies, or governing structures.

Questions

There are three main questions related to the generation and maintenance of complex hierarchical social relations that this dissertation seeks to answer. First, how does environmental variability affect the generation of wealth inequality, and the resulting formation of hierarchical social networks? This question assumes that inequality and hierarchical networks or social structures are crucial components in the development of complex social organization, states, and empires. Second, how does the addition of urban, or large permanent sites, into a nomadic pastoral context, affect the dynamics of question one? The appearance of such sites during periods of known nomadic states and empires is a feature of the archaeological record, but the role these sites played within pastoral economies and nomadic social organization remains poorly understood. Third, how do environmental variables influence the method of food production (i.e. nomadic pastoralism) in nomadic society, and how does this method of food production influence social organization, particularly its spatial component? This question addresses the critical issue of diachronic patterns in nomadic society. Understanding systemic continuities over time by creating richer diachronic datasets drawing on archaeological, historical, and ethnographic sources is crucial for the development of future quantitative computational models.

Contributions to knowledge

First, studying the organization of nomadic pastoral polities increases our knowledge of the full range of complex social organization generated by our species. As anthropologists have primarily focused on the path from hunting and gathering through to agrarian chiefdoms, states, empires, and modern nation-states, this addresses relative gaps in knowledge. Second, the relation between inequality, hierarchy, and social organization is fundamental to understanding cultural evolution in a variety of complex social systems. The focus of this dissertation on these themes adds to a general understanding of dynamics with applications beyond nomadic pastoral systems. Similarly, the effects of environmental variability and change on human society have become valuable subjects of study in their own right. Third, the application of agent-based modeling approaches to historical and archaeological research questions advances complex systems and emergent phenomena approaches in these areas. This helps bring archaeology and history in line with methodology and theory in other rapidly developing disciplines like evolutionary biology, ecology, computer science, economics, and physics. An agent-based approach also re-introduces micro perspectives and individual agency to quantitative and computational methods, potentially bridging the divide in the social sciences and humanities between particularistic and generalist approaches to studying the past. Finally, nomadic states and empires are inherently interesting phenomena. Examples like the Mongol Empire have long fascinated observers around the world due to their unique military strategies, lifestyles, and organization. The question of how such societies created the largest land empire in history is a natural extension of basic human curiosity.

Outline of the dissertation

Chapter 2 consists of two literature reviews. The first traces theories of nomadic pastoral empire formation from pre-modern scholarship, through the development of modern anthropology and history, till the present day. Major shifts in the literature include a focus away from external factors and dependency on sedentary neighbours to the internal capacity of nomadic pastoralists for the generation of social complexity. The second review traces the development of computer simulations and related quantitative models of wealth and social inequality in anthropology and related disciplines. The major development relevant to this dissertation has been a shift away from top-down analytical models that analyze the properties of large-scale patterns. These have increasingly been replaced by the development of agent-based models that simulate individual behaviour (such as the actions of herding households in this dissertation) that can generate large-scale phenomena like wealth inequality and hierarchical networks.

Chapter 3 is the core of this dissertation, and reports its major findings. It presents a simulation exploring the relation between environmental variability, wealth inequality, and the formation of hierarchical networks among nomadic pastoralists. In this simulation, herding households grow their herds and suffer occasional environmental disasters. If significant inequality in herd size between households develops, rich and poor households form patron-client networks as an adaptive response. The degree of wealth inequality and the size and duration of patron-client networks are recorded under different environmental parameters. These parameters include the carrying capacity of pasturelands, the frequency of environmental disasters, and the growth rate of herds. The goal is to understand 1) if heterogeneous environmental conditions can result in significant wealth inequality and the beginnings of complex hierarchical social organization, and 2) whether different environmental parameters increase or decrease the degree of wealth inequality and the probability of large and long-lasting network formation. This latter question serves to test theories linking climate to the formation of historical nomadic empires. Simulation results are compared with environmental, archaeological, and historical data for the Mongol (1206 – 1368 CE) and Xiongnu (209 BCE – 48 CE) empires. The chapter also expands on the theoretical approach to simulation used in this dissertation, and its potential applications to empirical cases. This includes how internal and external socio-political variables can interact with and confound the relationships in the simple computational model presented. It is made clear that even though multiple case studies fit well with these results, the modeled relationship between climate and network formation is not a necessary or exclusive driver of the multivariate phenomenon of nomadic empire creation. The chapter outlines methodological difficulties in gathering empirical evidence for processes governing the emergence of phenomena like nomadic empires, and emphasizes the potential of agent-based simulation in contexts of empirical data scarcity.

Chapter 4 adds the presence of 'urban' centres to the simulation described in chapter 3, in order to test their effects on dynamics of inequality and network formation. The presence of newly constructed urban, or large fixed settlements, in nomadic territory during periods of known nomadic states and empires is a characteristic feature of the archaeological record in Mongolia (Danilov, 2011; Pohl et al., 2012). Despite this, their role within a nomadic pastoral mode of food production is not well understood. This simulation takes inspiration from historical sources suggesting large cities such as Karakorum and Dadu (Beijing), provisioned from conquered agrarian areas (in this case North China), redistributed grain to nomads in regions of Mongolia hit by environmental disasters that had decimated their herds. The goal of the simulation is not to understand in full the multiple roles played by urban centres and the many motivations behind their creation. As in chapter 3, the focus is squarely on wealth inequality and hierarchical networks among non-urban nomadic pastoral herders. The goal is to test the effects of external disaster relief from urban areas on the degree of wealth inequality, and the size and resilience of patron-client networks developed between these herding households. This questions whether these centres played any strategic role (intended or not) in the management of historical polities and empires made up primarily of nomadic pastoral herders.

Chapter 5 presents a diachronic comparative analysis of the spatial organization of Mongolian nomadic pastoral livestock herding, with the goal of outlining the effects of ecological parameters fundamental to livestock production. This chapter characterizes nomadic pastoral livestock herding as a system of agriculture, whose focus on livestock over crops, and on extensive over intensive production methods, leads to unique production demands and requirements. The goal of this analysis is to uncover persistent features of social organization, if any, that are necessary to satisfy these demands and requirements. Data is drawn from the modern period (nineteenth century to the present), the Mongol period (twelfth to fourteenth centuries) and the Xiongnu period (second century BCE to first century CE). Results are useful because they indicate not only which features of social organization persist chronologically, but also which features exhibit significant variation over time. The main purpose of this chapter is to gather data to help form new hypotheses about the generation of spatial organization in nomadic socio-environmental systems that can be experimented with in future agent-based models.

The overarching concern of this dissertation is with exploring simulated generative mechanisms, internal to nomadic pastoral society, that can result in patterns of complex social organization and polity formation, rather than describing these patterns as found in the sources. These generative mechanisms are environmental variability, wealth inequality, and hierarchical network formation.

Chapter 2.1: Theories of Inner Asian nomadic pastoral complexity

Introduction

Two of the most persistent research problems in the literature on nomadic pastoral societies in Inner Asia are: 1) how they formed such large and powerful empires, and 2) understanding the relationship between nomadic and settled agrarian society. Both of these topics are fundamentally about questioning the internal capacity for nomadic pastoral social complexity. Early academics, influenced by theories of progressive linear cultural evolution prevalent at the time, initially placed nomadic pastoralism as an intermediary stage between hunting and gathering and agriculture (Smith, 1776; Huntington, 1907; Grousset, 1970). This was coupled with the relative material deprivation of extant nomadic societies compared to industrialized nations, and early ethnographic reports suggesting relatively egalitarian social relations (Dyson-Hudson, 1980). As a result, historical states and empires created by nomadic pastoralists were initially regarded as generated by surplus energy drawn from neighbouring settled agrarian societies. According to these theories, nomads would temporarily centralize for the purposes of trading, raiding, or conquest, and military elites would control and redistribute the products of sedentary society to maintain a complex hierarchical society. Catalysts for this process could be climatic downturns causing widespread deprivation among nomads (Huntington, 1907; Toynbee, 1934; Lattimore, 1938), an opportunistic or defensive response to neighbouring agrarian empires (Yü, 1967; Barfield, 2001; Di

Cosmo, 2002), or an inbuilt desire for conquest in a warlike society (Smith, 1776; Oppenheimer, 1907; *Muqqadimah*).

Since the dissolution of the USSR and increased international archaeological research in Mongolia, a new emphasis has been placed on the internal capacity for complexity in nomadic pastoral society, and theories of state and empire formation have consequently been revised. The balance of ethnographic reports now suggests significant wealth and social inequality frequently characterizes nomadic pastoral society. New climatic research has also pointed to an improving environment for herding during the initial formation and expansion of large nomadic polities.

This chapter will outline these developments in scholarship and suggest avenues for further research. The literature will be organized thematically rather than chronologically. While the two are roughly analogous, the development of new themes often cuts across several chronological eras. Avenues for future research consist mainly of researching generative mechanisms for the development of complex society among nomadic pastoralists. While recent research has problematized the generative mechanisms of past theories with new data, replacement mechanisms remain underdeveloped. The chapters of this dissertation aim to redress that balance.

1) Nomadic dependency theories

Egalitarianism

Debates over wealth inequality in nomadic society were especially prevalent in anthropology between the 1960s and 1980s (see Dyson-Hudson, 1980). Most anthropologists (summarized by Salzman, 1999) initially came down on the egalitarian side, arguing that specific elements of pastoral nomadic production (such as communal ownership of pastures) prevented substantial social inequality from developing. This perspective was possibly due to most Cold War-era ethnographic fieldwork by western academics being restricted to small-scale (by Inner Asian standards) nomadic societies in the Middle East, and East and North Africa. More importantly, early theories of progressive linear cultural evolution had placed nomadic pastoralism as an intermediary stage between hunting and gathering and agriculture (Smith, 1776; Huntington, 1907). While this chronology had been refuted by the 1920s (see Childe, 1926), the classification retained currency for some decades (for example Grousset, 1970). The notion of the egalitarian and/or backwards, underdeveloped nomad would have a much longer impact, arguably extending to the present day. As social complexity was seen as a feature of emerging agrarian states, the degree of egalitarianism observed was perhaps easy to overstate, given much fewer material correlates of inequality (namely, permanent settlements with dwellings of various sizes indicating social hierarchy) in comparison to settled society. In this light, Sneath (2007) argues that the egalitarian perspective on nomads arose because a fundamental issue in anthropology by the 1950s was the origins of socially complex agrarian states. As this was the main object of study, a foil was needed to compare it against, and thus Sneath argues the straw man of the egalitarian pastoral nomadic society was created. These ideas played an important role in laying the groundwork for nomadic dependency theories explaining observed historical instances of nomadic pastoralists creating complex states and empires.

Reactions to climatic downturns

At odds with nomadic pastoralism as an early evolutionary vestige, and a relatively egalitarian, subsistence-level production method, was the historical reality of the great Inner Asian nomadic empires. Such a paradox demanded explanation, and early theories tended to place nomads in a reactive position, dependent on the production of others for the generation of their polities. In this context, climate-centric theories of nomadic empire expansion in Inner Asia enjoyed great popularity (see Huntington, 1907; Toynbee, 1934; Lattimore, 1938; Jenkins, 1974). According to these models, detrimental drier and/or colder conditions lessened available biomass, forcing nomads to centralize for external conquest. Advocated in its most sophisticated form by Toynbee, these theories thus saw the famous invasions of nomads through time (including Xiongnu, Huns, and Mongols) as cyclical 'pulses' that could be calculated via environmental reconstruction. These theories retain some currency among non-specialists today (Holcombe, 2017, p. 136), and imply that resources from agrarian societies are a prerequisite for the development of social complexity among nomadic pastoralists.

Conquest culture

The idea that external conquest would be the nomadic reaction to climatic downturns arises from a longstanding perception of Inner Asian nomads as inherently warlike. This perception is understandable given that the nomadic peoples of Mongolia entered global consciousness via military expansion, whether in North China or Eastern Europe. Furthermore, the historical prevalence of livestock raiding within nomadic pastoral society (and pastoral societies generally, such as historical Britain and Ireland) is well documented (Irons, 2003; Patterson, 1994). Increasing yield without technology-dependent intensification in crop agriculture requires the permanent acquisition of new land. In contrast, pastoral groups can rapidly enhance immediate wealth and future production by appropriating the livestock of competitors. A natural consequence of these perceptions was theories assuming reactions to external factors by nomadic pastoralists would tend to be violent. Perceptions of the martial culture of Inner Asian and Eurasian nomads, as well as the pre-industrial military advantages of horse archery, are documented in primary sources written by external observers (for example, Herodotus Bk. 4, L. 10; *Shiji* 110) and are a common theme in popular scholarship (Gabriel, 2004; May, 2007). Influential in the western academic tradition was the theory of militarized-nomad and sedentary relations developed by Ibn Khaldun in his *Muqqadimah* in the thirteenth century. His cyclical view of history involved the rise and fall of polities conquered and ruled by nomads; the further away from the soft sedentary life nomads were, the higher their social cohesion. This greater sense of solidarity enhanced their military prowess, increasing the ease with which they could conquer their sedentary neighbours. Softened by years of sedentary rule, they would in turn be conquered by a new group of nomads from the periphery. Ibn Khaldun saw the relationship between nomadic and sedentary society as being one of the fundamental drivers of history. He argued that sedentary agrarian communities provided complex society, and pastoral nomads provided political rule over such societies.

Shadow empires

Inspired by the preliminary work of Yü (1967), Barfield (1989, 2001) developed the most influential modern theory of Inner Asian nomadic-sedentary interaction and nomadic empire formation. His 'shadow empire' theory placed nomads in a relatively egalitarian, subsistence-level mode, unable to sustain hierarchical political organization, surplus, and social inequality. Only by raiding or trading with neighbouring sedentary Chinese empires could they acquire enough surplus of what they could not produce (grain, weapons, precious metals and fabrics) to sustain complex political organization. Whenever China possessed a strong empire, a powerful nomadic 'shadow empire,' dependent on it in the manner of a parasite, would spring up on its border. A modified version of this theory argues nomadic empire formation was not a parasitic response to Chinese wealth, but a defensive response to inherently expansionary Chinese empires (Di Cosmo, 2002). The shadow empire theory was partially challenged by Drompp (2005), who showed that for Turkic and Uighur empire periods the chronology of strong Chinese empire followed by strong nomadic empire did not fit, and in fact was often the reverse (i.e. a strong nomadic empire could better exploit a fragmented China). However, this does not fundamentally challenge the assertion of dependency. Influential work by Khazanov (1994) also argued that the nomadic pastoral method of food production and prevailing Inner Asian environmental conditions resulted in volatile production levels and weak surplus in comparison to settled agriculture. He argued nomadic pastoralism is essentially a highly specialized economic niche dependent on the existence of sedentary agrarian trading partners.

2) Interim theories

Between nomadic dependency theories, and the development of new research stressing internal causes for the development of complex nomadic society, lies a body of interim research stretching across chronological eras that falls into neither of these categories. The bulk of this research consists of a) theories of global history seeing interactions between nomadic and sedentary civilizations as the main driver of complexity on both sides, and b) Soviet and post-Soviet scholarship, influenced by Marxist frameworks, aiming to uncover pseudo-feudalistic social inequalities in Inner Asian nomadic society.

Zones of interaction

The concept of interaction between nomadic steppes and agrarian China as the primary driver of internal developments predates shadow empire theories. Focusing on what he called the steppe-sown dichotomy, Lattimore (1940) developed a theory of Chinese and Mongolian history that changed the mixed agro-pastoral zone of interaction between the two civilizations from a mere periphery to the main center of gravity. He argued interactions in this zone would shape the socio-political organization and culture of both civilizations. While this theory provides the precursor to shadow empire models, it does not inherently imply dependency. Rather, it focuses on interdependency, as Chinese state and empire formation is also dependent on nomadic pastoral contacts. In this light it remains more sophisticated than its antecedents, and other modern scholars have continued in his vein, giving primacy to the zone of interaction concept. For example, Turchin (2009) argues that the competitive interaction of agrarian and pastoral nomadic civilization at the geographical frontier between steppe and sown led to a 'ratcheting up' of complexity, and the formation of states and empires, on both sides (see also Skaff, 2012). However, like nomadic dependency theories, the zone of interaction concept focuses on external interactions with non-nomadic society as the driver of nomadic social complexity.

Soviet nomadology

Like western academics, early Soviet researchers were also preoccupied with the placement of nomadic pastoralists in linear cultural evolution frameworks, albeit Marxist ones. According to Marx's modes of production, socialism is predated by capitalism and feudalism. As Russia at the time of revolution was considered to be in a feudal stage, Leninist theory involved skipping directly from feudalism to socialism. Uncovering feudalistic class-based relations among Inner Asian nomadic pastoral societies who were either incorporated into or (in the case of Mongolia) satellites of the Soviet Union became a matter of political importance. While the initial impetus may have been political, the result was some of the earliest research emphasizing wealth inequality, aristocratic class divisions, and complex social hierarchy in nomadic society.

Before considering this literature, it is worth noting that an uncommon strain of research did emphasize the nomadic pastoral capacity for inequality and centralized leadership, dating back at least to Adam Smith. In his *Wealth of Nations* and *Lectures on Jurisprudence*, Smith sketches out a four-tiered hierarchy of social evolution, somewhat different from Marx's. Smith focuses on mode of subsistence rather than mode of production, with nomadic pastoralism being the second stage in between hunting and gathering and sedentary agriculture. This type of classification system would long influence egalitarian and primitive perceptions of nomads in western academia, as previously discussed. Smith, however, also insisted that nomadic pastoral society was extremely unequal. Due to volatile environmental conditions, he argued elites would gather large herds and rule over their less fortunate brethren who owned few or no animals. This was the core of Smith's argument that nomads were inherently prone to centralization and despotic rule, facilitating their ability to conquer.

Nomadic feudalism

The most explicit early formulation of nomadic class relations in Soviet scholarship was 'nomadic feudalism' theory (Vladimirtsov, 1934). In its extreme formulations, Marxist-feudal categories (such as private land ownership) were overlaid on nomadic societies. As feudal, these societies, of which the early Soviet Union had many, could undergo revolution and class struggle along with Soviet peasants. Through the Stalinist era and beyond, scholars challenged this view. They were best represented by the work of Tolybekov (1959) who developed 'patriarchal-feudal' nomadic theory. Tolybekov recognized fundamental building blocks of nomadic organization, such as communal ownership of land, as inherently contradictory to medieval European feudalism, and thus that nomadism could not develop into full feudal relations. However, he switched the mode of production from land (in European feudalism), to private herd ownership, and thus allowed that 'weak feudal relations' could develop, although never fully. The main legacy of this theory was the idea that nomadic pastoralism was thus an evolutionary (in the Marxist sense) dead-end, incapable of progress without external intervention. This perspective influenced later Russian nomadic dependency theorists (represented by Khazanov, 1994), and communist-era attempts to alter the nomadic pastoral method of production (see Endicott, 2012). Other scholars like Potapov (in Gellner, 1994), argued strenuously against Tolybekov and his peers, insisting that beneath the veneer of egalitarian 'tribal' relations lay full hereditary aristocracy and class oppression, along the lines of arguments proposed more recently by Sneath (2007).

Even the more nuanced theories of weaker 'patriarchal-feudalism' presented a different focus on wealth inequality by herd size, and class relations such as hereditary aristocratic herd owners and their contract labourers. That these elements of Inner Asian nomadic pastoral society would be highlighted mainly in Soviet literature (not expressly discussed in western literature until Sneath, 2007) also has a geopolitical explanation. Inner Asia lay within the Soviet sphere of influence, out of reach of most western researchers during the formative years of modern western anthropology and archaeology (roughly 1950 to 1990). Most field work on nomadic pastoralists therefore took place in the Middle East and Africa, in which the scale of production is considerably smaller, and interactions with settled communities much more intense. Only in the Soviet sphere were vast uninterrupted tracts of land historically devoted largely to nomadic pastoralism, from which emerged some of the world's largest complex polities.

Post-Soviet era

Further Russian and Mongolian scholars have continued in similar veins, examining class divisions in nomadic pastoral society. Bold (2001) and Skrynnikova (2000) have made valuable compilations and analyses of terminology in primary textual sources related to class and social divisions during the Mongol period. While Bold argues Mongol nomadic society was not 'feudal' in the sense of European aristocratic land ownership, he highlights characteristic inequalities based on herd wealth and hereditary aristocracy. Skrynnikova follows Kradin (2008) in attempting to categorize various Inner Asian polities based on degrees of complexity. The most prolific current Russian scholar of nomadic complexity and polity formation, Kradin originally adopted the arguments of nomadic dependency, or a lack of internal prerequisites for complexity without settled agrarian inputs (Kradin, 1992). Since then, he has changed his position to allow for the internal generation of nomadic social complexity, up to the level of what he has variously termed the inchoate state, early state, or super-complex chiefdom (Kradin, 2003). While greatly influenced by somewhat out-dated linear cultural evolution schemes, Soviet and post-Soviet scholarship retains a long tradition of focus on inequality, hierarchy, and complexity in Inner Asian nomadic society. On the whole, English-language scholars have overly neglected this literature as a valuable resource.

3) Internal complexity

A new wave of nomadic scholarship arose in part out of a shift in western academic fashion, related to cultural and post-modern turns, and a focus on peripheries. This has been coupled with the opening of formerly Soviet-controlled Central Asia to western academics (mostly archaeologists and anthropologists). These developments have resulted in several shifts. Anthropologists have come to a broader consensus that high degrees of inequality can manifest in nomadic pastoral societies (Borgerhoff Mulder et al., 2010). Archaeologists pioneering extensive landscape survey in Mongolia point to a more flexible resource base than previously assumed, as well as internal complexity and economic surplus (Houle, 2010; Makarewicz, 2011; Wright, Honeychurch, & Amartuvshin, 2009). Waugh (2011) and Brosseder & Miller (2011) question the validity of received paradigms and categorizations such as 'steppe versus sown' and the nature of nomadic empires. As previously mentioned, Sneath (2007) has directly addressed the lack of emphasis in western academia on hereditary social inequality among Inner Asian nomads.

Perhaps the most prolific current researcher of Mongolian pastoral nomadic empires has been Honeychurch, who, along with his colleagues, has pioneered extensive landscape survey archaeology in Mongolia with the Egiin Gol valley survey in north central Mongolia, and the Baga Gazaryn Chuluu survey in the Gobi desert. From a combination of survey results and ethnography, Honeychurch (2014, 2015) argues that pastoral nomads in Inner Asia have since the late Bronze Age (second millennium BCE) created organizational forms of statehood permitting sophisticated long distance networking and rule, distinct from the structures created by agrarian sedentary civilizations. He argues the basic features of pastoral nomadic society (high mobility, resultant high levels of interaction, and organizational diversity) have made such regions particularly apt at the long distance rule characteristic of empires.

This problematization of previous parsimonious explanations for nomadic state formation by new particularistic field data for different regions and time periods reflects broader debates in anthropology. Struggles between generalist and particular emphases in understanding cultural change crystalized with the rise of post processualism/post modernism in anthropology and history, and the 'science wars' in academia at large (Hodder, 1985; Hegmon, 2003; Labinger and Collins, 2010; Snow, 2012). However, these follow much earlier debates between ecological and humanistic approaches to understanding the rise of early sedentary civilization in western anthropology (Flannery 1968, 1972), which were themselves predated by debates over general explanation versus detailed classification of cultural particulars (Buettner-Janusch, 1957). The agent-based modeling employed in this dissertation, while grounded in a generalist, scientific method, does offer a bridging mechanism between approaches, as unique, irreproducible behaviour with stochastic elements is the driving force behind the generation of emergent patterns. This methodology will be discussed in more detail in the following chapters.

Resurgence of climate theories

According to longstanding nomadic dependency climate models previously described, detrimental drier and/or colder conditions lessened available biomass, forcing nomads to band together for external conquest. In contrast, several recent climatological studies have linked favourable conditions, particularly an increase in available biomass, to the formation and spread of Inner Asian nomadic states and empires. Pederson et al. (2014) and Putnam et al. (2016) both present data indicating increased precipitation and thus biomass during the initial formation and expansion of the Mongol Empire. Houle (2017) has tested this correlation for the Xiongnu period (second century BCE). While he did not find uniform improvement in environmental conditions, results did indicate significantly ameliorating conditions in Central Mongolia (the heartland of the archaeological Xiongnu). Increased biomass in this region resulted in an estimated 300% increase in herd size and a doubling of the human population during the rise and expansion of the Xiongu Empire in the second century BCE. Meanwhile, diachronic surveys of environmental data and warfare indicate periods of increased conflict between Inner Asian nomads and sedentary China correlate with environmental upswings (Su, Liu, Fang, & Ma, 2016; Wu et al., 2009).

Conclusion and future directions

The bulk of literature has shifted from emphasizing external to internal factors in the development of complexity in nomadic pastoral societies. Some implications of new results include: 1) nomadic pastoral production could develop a surplus, 2) nomadic pastoralism was not so undifferentiated as previously assumed, 3) nomadic society could feature social class hierarchies, and 4) improved herding conditions characterize periods and regions of state and empire formation and expansion. Conversely, parsimony and proposals for generative processes of nomadic complexity have weakened. Increased nuance in empirical archaeological, climatic, and ethnographic data have problematized nomadic dependency assumptions without satisfactorily replacing the generative mechanisms they proposed. The explanatory power of, for example, a theory combining shadow empires and negative climate change is its parsimony and the clear generative mechanisms it proposes for nomadic complexity and state/empire formation. Crucially, another strength of these theories in advancing knowledge is that they are falsifiable. Assumptions behind such theories include a) nomadic pastoral production does not internally generate sufficient wealth and social inequality, and b) climatic downturns correlate with polity formation. Great advances have been made gathering data challenging these assumptions. Now what are needed are new parsimonious generative proposals for some of the following questions: how did nomadic pastoralists internally generate wealth and social inequality? What effect does environmental variability have on inequality and complexity? Why is increased biomass seemingly correlated with complexity? Why and how did Inner Asian nomadic states and empires form when they did? These are all questions that the subsequent chapters of this dissertation attempt to address.

Chapter 2.2: Simulation of inequality in archaeology and anthropology

Introduction

This chapter discusses how archaeologists and anthropologists have explored the development of wealth and social inequality through computer simulation, and in relevant non-simulation models. While inequality has been one of the fundamental anthropological questions, simulation continues to occupy a small niche within the overall methodological scheme of the discipline, and thus simulation of inequality has been rare in comparison with traditional research methods. The treatment of wealth and social inequality in simulation has reflected changing perceptions of simulation in the discipline over the last several decades. These changing perceptions have in turn reflected major trends in anthropological archaeology as a whole. This chapter focuses on simulations of inequality in two periods in which simulation is generally described as having flourished (Aldenderfer, 1991; McGlade, 2005; but see Lake, 2014, for a re-assessment of this chronology). First is 1970s, considered an age of optimism concerning the use of systems theory and the simulation of systems in archaeology, concurrent with the positivistic mood of the processual school. Second is the late 1990s till the present, which saw a resurgence in simulation after a period of decline. This era is especially characterized by the development and spread of agent-based modeling techniques that may address some post-processualist concerns with simulation. Concurrent with this has been the developing niche of evolutionary archaeology (Lake, 2014) and its connection with simulation-favourable fields like evolutionary biology. The major shift between these two periods saw a move away from top-down systems models analyzing the properties of patterns found in the archaeological record. These have increasingly been replaced with bottom-up agent-based models aiming to generate aggregate patterns by modeling individual agent behaviour.

The processual era

Classic systems theory dominated early ideas about simulation, as expressed by Doran (1970). In this perspective, society was thought to operate as a system that could be modeled as such, in line with the processual goal of moving archaeology to the systemic level (Binford, 1962). This meant analysis was on the group level; it was hoped that mathematical equations would accurately describe patterns of societies seen in the archaeological record, and the correct equations, or deviations from them, would then give clues as to the generation of those patterns. Classic examples of this type of analytical model include Renfrew (1977) and Hodder (1974), who use mathematical equations to describe the fall-off patterns of artifacts on the landscape. By defining the "law of monotonic decrement," by which commodities are found in fewer and fewer numbers the further one gets from their source, Renfrew and Hodder are able to explore differences in plot properties such as slope depending on the type of commodity in question, which brings their discussion to questions of social inequality. Hodder notes that prestige items, characteristic of stratified societies, have smaller slopes (i.e. the fall-off rate is slower as the items travel farther), and notes that down-the-line distribution patterns of this nature often indicate prestige items. While these are modifications to the properties of monotonic decrement, Renfrew notes that the law can be broken entirely in the patterns generated by a hierarchically structured (i.e. socially unequal) society. In this case major centres further from a source will receive more of a commodity than nodes closer to the source, as centres receive preferential trading. Furthermore, they may receive more per capita as well, given that they can function as a distribution hub, basically taking over the role of supply. This can be compounded by the presence of elites within the center, who will consume yet more per head of the valued commodities. What is important to note with these types of models is that the specific properties of the analytical equations describe certain types of societies rather than generate them. A certain type of divergence to a function replicating monotonic decrement, for example, indicates the presence of social inequality, but does not explain the generation of that inequality. This would be a major difference with the modern agent-based era. Previously, Doran (1970) had described the analytical equations of systems theory as inadequate for archaeology, and encouraged the use of simulation instead, which he termed systems theory's "practical equivalent" (p. 296). The premise was that it would be mathematically less complex to write simulation rules for a society and let patterns emerge than to write equations that described and predicted these patterns. In this context, Wobst (1974) provides a classic early simulation that preempts some elements of later agent-based techniques, while in important ways still falling short of them. Wobst simulates, at the level of individuals, the subsistence, mating and reproduction of minimum hunter-gatherer bands, with the goal of investigating the maximum estimated size (MES) of maximum hunter-gatherer bands (a society made up of minimum bands) under different environmental and cultural parameters. This is an example of whole-society modeling of the realist-generalist school (Costopoulos, 2015) prevalent in this era, in which whole societies were modeled in order to uncover generally applicable anthropological principles. As such, investigating social inequality is not the goal of Wobst's simulation, but being a perennial social element, it does receive oblique reference. Wobst concludes that the incest taboo in hunter-gatherer societies is adaptive, because while allowing incest in his simulation did not create an MES change, he argues it would create friction within minimum bands, as some members would have to travel quite far for mates, while others who were able to partake in the few incestuous matings available would not. In this case incest taboos could be an enforcement mechanism to prevent social inequality from developing. Furthermore, Wobst finds that increased cultural restrictions on marriage rules (besides first order incest) steadily increases the MES required so that all minimum band members can get mates. Wobst notes that the ritualization and regularization of contact between minimum bands encouraged as a result of restrictions may aid in maintaining order and coherence given a large MES. As cultural restrictions may come to require enforcement, large MES sizes, determined by unknown causes such as resource pressure, may favour the development of degrees of inequality. However, it is again important to note that Wobst's simulation, despite being proto-agent-based, is still descriptive when it comes to inequality. Whatever a model is to generate must be a dependent variable in that model. Wobst's interest is in the MES size, therefore that is his dependent variable. Cultural restrictions or types of inequalities are independent variables, input by the simulator beforehand.

With the rise of post-processual archaeology (see Hodder, 1985), in line with a cultural/postmodern turn sweeping the humanities and social sciences, simulation, and computational quantitative methods generally, came under attack in archaeology as removing human agency from history and the archaeological record. In this view, the society-as-system model, usually described at the stage of the entire group/society, deterministically saw faceless individuals members of said societies as blindly following systemic rules. In many ways early simulation efforts had failed even in regards to their own precepts, by failing to plausibly explain why given social patterns formed from the individual level up. The problems of equifinality that arise from describing a pattern with equations or systems models were considered so great by Hodder that he himself signed off of such methods.

Well prior to this era, however, Barth had laid the seeds of the modern agent-based approach in his *Models of Social Organization* (Barth, 1969). Here Barth lays out key differences between descriptive and generative models, and argues that anthropology must focus on developing generative models, whereby the same model can explain the emergence of many patterns of social organization in different socio-natural contexts. Barth argues that the way to do this lies in focusing on models of behavior at the individual level. He does this by developing his transactional model of human behavior, whereby the decisions of economically self-interested individuals in negotiating social roles and transaction contracts (broadly defined) can generate and explain any observed outcome based on knowledge of initial socionatural conditions. His case study explains the hierarchical (socially unequal) form of organization adopted by Norwegian fishermen in light of the specific laws governing fishing during a given period. He explains how transactional negotiation of social roles (from the captain at the top, to mates, net-casters, and lowly crewmen), when fishing laws are externally altered by government decree, results in the generation of an entirely new pattern of social organization. It is worthwhile to note here that Barth's models are still descriptive at the level of initial socio-natural conditions. All models must be descriptive at some level – again, the key to recognizing which phenomena in a model are generated and which are described is to ask which phenomena are dependent variables, and which independent variables. Barth thus shows a way forward in placing autonomous human individuals at the center of generating their own social patterns.

Resurgence and agent-based modeling

While cultural approaches related to post-processualism could still be said to dominate the anthropological scene as a whole (although Hegmon (2003) argues this is not the case in practice among archaeologists), the rise of a strain of archaeology Lake terms "evolutionary" (Lake, 2014, p. 267), and the development of agent-based modeling techniques in other fields, has allowed simulation in archaeology to see a resurgence in the last two decades. Rather than simulators inputting systemic rules with a top-down approach, agent-based modeling sees autonomous agents (representing individuals, groups, or other bodies) with a range of evolvable behavioral parameters generate systems and patterns from the ground-up. Coupled with the rise of abstract-generalist style simulation (Costopoulos, 2015), in which the focus of modeling narrows to very abstract processes with the intention of widest possible application, this has had powerful implications for simulating the evolution of social inequality. These developments have been greatly aided and inspired by activities in related social science disciplines, such as in the agent-based simulation platforms developed by Epstein & Axtell (1996), and NetLogo (Wilensky, 1999), the latter featuring model libraries with dozens of templates for experimenting with social inequality.

Nevertheless, simulation in archaeology remains a niche. Yet while Lake (2014) only records two archaeological simulation projects addressing social inequality since 2000, there have been a handful of notable efforts and significant progress. Pauketat (1996) simulates an ethnographically observed community of Shan farmers in Thailand who practice a domestic economy more-or-less at the subsistence level, in a mildly non-egalitarian society in which significant wealth inequality is culturally discouraged. His aim is to use a somewhat abstracted version of the Shan case to create a model with general applicability. In many ways his approach is then not unlike Wobst (1974). However, Pauketat's agent-based approach simulates at the individual level but with households as the main unit of analysis. Pauketat finds that with each household actively seeking to maximize their yield, normal annual stochastic vagaries in local environmental conditions and the labour conditions of households (such as the presence of young labor or an aging household, according to natural family processes) generate a constant source of inequality in wealth between village households, exacerbated further by changing cultural parameters such as the probability of single-heir inheritance. Pauketat thus concludes that these stochastic initial conditions coupled with normal individual behavior are key to the development of inequality, which may be encouraged or discouraged from sustaining itself by other cultural adaptations.

Bentley, Lake, & Shennan (2005) continue the theme of the evolution of social inequality in agricultural contexts. They find through agent-based simulation that in a trade network of autonomous agents, substantial wealth inequality develops when agents use best-price models to decide whom they wish to trade with, rather than subsistence models based on how much of a given quantity they need for their own survival. Bentley et al. thus conclude that notions of private property, argued to be related to best-price perspectives, may be inherent in an agricultural economy featuring private land ownership, and thus that inequality may have developed as expanding farmers interacted with and influenced hunter-gatherer bands to adopt a best-price outlook, which would then favour the evolution of wealth inequality.

Smith & Choi (2007) take a still different approach to agent-based simulation of inequality, experimenting with a "patron-client" model and a "managerial mutualism" model. In patron-client simulation, agents adopt a patron, client, or dove (pure cooperation) strategy, and their strategies can mutate and evolve on a sliding scale. They find that in homogeneous environments (equal resources on all patches of land), patron strategies, and thus inequality, do not develop and are selected against. In heterogeneous environments, however (unequal distribution of resources between patches), patron and client strategies are strongly favored, with those agents randomly on rich patches becoming patrons to poorer clients. They thus argue that resource pressure may be a major cause in the emergence of social inequality. The managerial mutualism simulation features group cooperation between agents to complete a task, with the potential strategies of agents being 1) managerial, 2) cooperation, or 3) defection. They found that under very specific combinations of parameters (managerial fee not too high or low, cost of enforcement not too high or low, etc.), a pattern quickly emerges whereby it is profitable for cooperative agents to pay a managerial agent to enforce cooperative rules against defectors. Smith and Choi thus conclude that managerial mutualism can result in the evolution of inequality, but is a less frequent route than patron-client dynamics.

Kelly has studied social inequality in complex hunter-gatherer groups for several decades, but his 2013 account provides a good synthesis, and while being non-simulation, incorporates many elements of Barth's generative transactional models and current agent-based approaches, for instance by citing the work of Smith and Choi (Kelly, 2013, p. 251). Kelly's model sees population increase and pressure as a driving initial condition for social inequality and thus complexity in hunter-gatherer society. He sees population pressure as necessitating the expansion of habitation to whatever locations remain unoccupied. This situation then results in the initial conditions of Smith and Choi's patron-client dynamic. Additionally, Kelly describes how cooperative resource extraction, namely whaling by canoe in the Pacific Northwest, leads to managerial mutualism dynamics in the context of population pressure: a whaling party may already have an optimal number of members, but more individuals still wish to join (a result of population pressure), even if offered a lower share of the resource than current members. Leaders have incentive to allow this as more followers lessen the effect of a defection. Key elements of Kelly's model are the generation of social inequality as an emergent phenomenon based on self-interested actions of individuals in a given context, and his canoe case study is very reminiscent of Barth's Norwegian fishermen.

An obvious question after the conclusions of the above three models is whether the 'rise' of social inequality around the world is really just a case of non-egalitarian societies out-competing egalitarian ones (even if the origination of egalitarian/non-egalitarian societies were purely stochastic). Rogers, Deshpande, & Feldman (2011) experiment with this type of agent-based simulation. Social inequality is not generated (it becomes an independent variable), while the group-selection-like spread of egalitarian and non-egalitarian societies becomes the dependent variable. Their finding is that in homogeneous constant environments egalitarian societies flourish and grow while non-egalitarian ones have smaller populations and suffer more extinction events. In heterogeneous environments with high risks of environmental fluctuation, however, the situation is reversed, as non-egalitarian societies absorb high-mortality disasters in the lower classes, while the upper classes survive and re-flourish.

The above examples (barring Kelly) are often modeled in agricultural/sedentary contexts, with resource extraction from fixed land patches. In recent years, simulation is slowly beginning to investigate the evolution of inequality in pastoral nomadic societies where the fundamental dynamics of wealth and resource production/extraction are somewhat different. So far, only one ongoing project has attempted computer simulation of nomadic pastoral state and empire formation (Cioffi-Revilla, Rogers, & Latek, 2010). This project is a classic example of the realist-particularist approach (Costopoulos, 2015) that emerged along with the rise of abstract-generalist agent-based models, and continues to have adherents in various disciplines. The goal of this school of simulation is extreme complexity and realism in whole-society modeling, in this case the accurate modeling of complete nomadic polities and their interactions. As such, it is not specifically seeking to model and understand inequality. By contrast, the present dissertation uses the abstract-generalist approach, modeling general processes that are assumed to be important for the generation of nomadic pastoral complexity, instead of attempting to recreate virtual nomadic empires. These processes include: 1) the generation of wealth inequality between nomadic pastoral households, 2) the effects of environmental variability on inequality, 3) the development of patron-client networks as a response to inequality, and

4) the effect of environmental variability on network size and resilience.

Conclusion

This chapter has shown how simulation and modeling of the evolution of wealth and social inequality in archaeology has changed over time in line with the theoretical and ideological landscape of the discipline, and the simulation techniques available. Major differences between the two main eras of simulation lie in the shift from studying the properties of patterns to studying the generation of patterns by aggregated individual actions. This type of agent-based modeling re-asserts the individual organism as the unit of selection. It can also generate variable, path-dependent outputs. Combined, these advantages offer a path to reconcile the conflict between the gathering of particulars and generalized pattern seeking that has long been a fixture of the anthropological discipline (Buettner-Janusch, 1957). In terms of social complexity in nomadic pastoral societies, the current need is for new generative mechanisms to reconcile recent archaeological and climatic data. The present era of abstract-generalist agent-based modeling provides an ideal tool to develop the necessary generative models. This kind of modeling is presented in chapters 3 and 4, and forms the core of this dissertation.

Chapter 3: Modeling environmental variability and network formation among pastoral nomadic households: implications for the rise of the Mongol Empire

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Abstract

We use agent-based computer simulation to test the effect of environmental conditions (available biomass/carrying capacity and environmental risk) on the development of wealth inequality and patron-client herding networks in nomadic pastoral economies. Our results show that 1) wealth inequality reaches very high levels when carrying capacity is high and risk is low, and 2) patron-client contract herding networks increase in size and duration when carrying capacity is high and risk is low. We compare empirical data from the Mongol (1206 – 1368 CE) and Xiongnu (209 BCE – 48 CE) empires with simulation results to develop an explanatory mechanism for the apparent correlation between nomadic empire creation and positive environmental conditions. We argue that the internal dynamics of nomadic pastoral societies are sufficient to produce high degrees of inequality and hierarchical herding networks. Nomadic empires are more likely to form during key periods of increased biomass and decreased environmental risk.

Introduction

Climate-centric theories of nomadic empire expansion in Central Asia have been prevalent for over a century (Huntington, 1907; Toynbee, 1934; Lattimore, 1938; Jenkins, 1974). According to these longstanding models, detrimental drier and/or colder conditions lessened available biomass, forcing nomads to band together for external conquest. In contrast, several recent climatological studies have linked favourable conditions, particularly an increase in available biomass, to the spread of the Mongol Empire (1206 – 1368 CE) (Pederson et al., 2014; Putnam et al., 2016; Su et al., 2016; Wu et al., 2009).

We use agent-based simulation to test the effects of positive and negative environmental conditions on wealth inequality and patron-client networks between herding households, two variables related to nomadic empire formation. We find that in simulated pastoral populations, wealth inequality is high under most environmental conditions, and the size and duration of patron-client networks increases with available biomass.

Ethnographic and historical research indicates that patron-client herding networks resulting from an unequal distribution of wealth may be characteristic of the organization of historical nomadic societies in Central Asia (Cribb, 1991, p. 42; Lattimore, 1940, p. 96; Shahrani, 1979, p. 179; Vainshtein, 1980, p. 104; Murphy, 2015; Sneath, 2007). We hypothesize that increases in carrying capacity/biomass during periods of favourable climate would increase network size and duration, making large and successful empires or polities more likely to form and expand during these periods. Our paper thus proposes an explanatory mechanism for the relationship between a favourable environment and the initial formation of successful nomadic polities, via networks formed in response to wealth inequality.

Other models of nomadic empire formation have focused on the dependency of nomads on neighbouring sedentary civilizations, from whom nomads acquire surplus energy via trading, or raiding and conquest, allowing them to sustain unequal the hierarchies of complex polities (Barfield, 2001; Khazanov, 1994). Our results add to recent research challenging these theories (Houle, 2009; Makarewicz, 2011), as we suggest that internal dynamics of pastoral nomadic economies allow the rapid emergence of wealth inequality, in line with many ethnographic reports (Borgerhoff Mulder et al., 2010; Murphy, 2011), as well as social inequality and complexity via hierarchical networks.

Computer simulation remains an uncommon method for the study of pastoral nomadic societies in Central Asia (but see Cioffi-Revilla, Honeychurch, & Rogers, 2015; Cioffi-Revilla, Rogers, & Latek, 2010; Rogers, Cioffi-Revilla, & Linford, 2015). This team has been developing a whole-society model of Central Asian pastoral nomads with the aim of understanding political processes, strategies, and dynamics related to inter-group conflict and the rise and fall of tribal confederations and empires. Our simulation is narrower in scope, focusing specifically on the relationship between environmental conditions and network formation in response to wealth inequality. In this regard, it engages directly with longstanding and recent debates and research concerning climate and the creation of nomadic empires.

Agent-based simulation

Agent-based modeling (ABM) is a type of simulation that models the behaviour of individual agents, in this case herding households. In ABM, agents exist on a landscape, and interact with each other and their environment (see Lake, 2014 for the history of ABM use in archaeology). The macro-level patterns their behaviour produces manifest as emergent phenomena that can be analysed statistically. The relationship between individual human agency and the structures of social organization is an ongoing debate in many academic fields. In sociology and literary criticism, structuralists and post-structuralists have proposed various theories explaining how individual agency is constrained by, gives rise to, or is indistinguishable from societal constructs and structures (Giddens, 1979; Lévi-Strauss, 1963; Foucault, 1969). In behavioural economics and behavioural ecology, macroeconomic or socionatural patterns are aggregations of individual decision-making, in reaction to an external environment, based on self-interested bounded rationality models, such as Expected Utility Theory (Kahneman and Tversky, 1979; Schoemaker, 1982; Matsumori, Iijima, Koike, and Matsumoto, 2019). Agent-based modeling offers another perspective on agency and the agency-structure feedback loop. Agents are the autonomous units in a simulation that act upon their environment according to programmed rules. Any quantifiable dynamics, phenomena, or patterns (all perhaps the equivalent of 'structures') resulting from agent actions are termed emergent phenomena. In social science simulations, these are the emergent structures of social organization. Emergent phenomena can then alter the environment, and subsequent agent behaviour. In simulations with an evolutionary component, agent rule sets governing behaviour can mutate and undergo selection pressure, both as a result of environmental shifts and emergent phenomena they create.

Rules governing agent behaviour are typically heuristics based on rationality models. While purely rational choice models of decision-making have long been problematized, current scholarship on decision-making has mostly settled on the concept of bounded rationality. Behaviour is not random or irrational, but rather aims to achieve various goals in a limited rational manner in accordance with cognitive power and cultural apparatus (Nobandegani et al., 2019a, 2019b). In a biological sense, it would be very difficult to understand how rationality in organism behaviour would not be strongly selected for. Agent behaviour in ABM generally follows the bounded rationality concept, unless studying the outcomes of random behaviour is the goal. To use our model as an example, agents seek to maximize their own wealth and seek protection against loss, but they do not have an omniscient, absolute rationality allowing ideal strategies and organizational forms. Rather, the aggregate of bounded rational acts creates unintended emergent social phenomena and forms that can then be studied. Simulations can be run many times at each combination of initial conditions, and the surprising variety of results have the potential to bridge the gap between particularistic and pattern-based explanations of human behaviour.

The approach to ABM we follow here is about understanding abstract baseline dynamics, rather than describing the historical realities of particular regions or time periods. Instead of attempting to pinpoint temporally or spatially realistic values for parameters, we test through a wide enough range of parameter values to discover under what conditions interesting dynamics occur. The usefulness of the results for understanding specific historical situations can be determined later. Simulation can then function as a thought exercise to aid in developing interpretive ideas about actual historical, archaeological, and environmental data. The simulations in this paper are written in NetLogo, an open-source ABM package developed primarily for social science research (Wilensky, 1999).

Simulation overview

We explore the relationship between environmental conditions (available biomass and environmental risk), wealth inequality (herd size differences between households), and network formation and duration. Our simulation features independent herding households on a communal landscape, growing their herds and undergoing losses due to environmental disasters. ABMs proceed according to a turn-based system of time steps. Our simulation uses 2,000 time steps per run. Hundreds of simulation runs at each parameter combination revealed this to be a more than sufficient length of time for stable system dynamics to emerge, as running more time steps did not change trends in the results. Since the 'spool-up' time (time steps till stable dynamics commence) was extremely short at each parameter combination, we include this period of simulation runs in our final results. Households grow their herds by 10% every time step, while system carrying capacity has not been reached. Each time step they have a probability of suffering an individual environmental disaster, reducing their herd size by 50%. There is also an equal probability of a system-wide disaster that reduces all herds by 50%. If carrying capacity is reached, herds stop growing until disasters lower the population below capacity. If a household's herd descends below 60 animals, they look for a patron household whose herd size is above 800 animals. This patron transfers 60 animals to the client household, and forms a link with it. If there are no patrons, and the poor household's herd drops below 2 animals, the household dies, and is removed from the simulation. We vary carrying capacity from 5,000 to 50,000 animals, in intervals of 5,000. The environmental disaster frequencies tested are 5, 10, 15, and 20%. For the empirical basis behind these chosen parameter values, see the below sections on simulation entities and independent variables. The simulation is run 20 times at each combination of carrying capacities and disaster frequencies (thus totalling 1,000 runs). Given the stochastic element of environmental disasters, results vary between simulation runs. Only average results from 20 runs at each combination are used for analysis, to ensure statistical robustness. Repeating 20 run experiments at the same parameter values dozens of times confirmed that 20 runs was sufficient for average results to be nearly identical in each experiment. This ensures that the full range of possible outcomes at each parameter combination is included in our results. Every time step, each household performs the following procedures:

1) Checks whether total animals in system is below capacity

    a) If yes, grows herd by herd growth rate; proceeds to step 2

    b) If no, proceeds to step 2

2) Draws a random number to check if they will suffer an environmental disaster

    a) If yes, reduces herd size by 50%; proceeds to step 3

    b) If no, proceeds to step 3

3) Checks if own herd size is < 60

    a) If yes, and household already has a patron, patron transfers them 60 animals

    a) If yes, and household has no patron, household searches for a patron

    b) If patron is found, receives 60 animals from patron and a link is formed between households

    e) If no patron is available, and household's herd is < 2, household dies

4) If herd size is > 800, and another household requests to be a client, household becomes a patron

    a) Transfers 60 animals to client

b) Forms link with client

5) If herd size drops < 500

a) Household loses patron status

b) Links with clients in its network are dissolved

The goal of this type of abstract ABM is to use as little real-world input data as necessary, avoiding making too many unjustifiable or inaccurate assumptions about the past. This is especially relevant when archaeological and historical data are sparse, as is the case with historical pastoral nomadic societies in Central Asia. Assumptions are derived mainly from ethnographic analogy. If available historical and archaeological data matches well with a portion of simulation output, this adds validity to assumptions made. The dangers of equifinality remain, as with most theory-driven archaeology, but if assumptions have an ethnographic and/or historical basis, and simulation output helps fill in in the sparse historical and archaeological record, then the results are as useful as theories derived by more traditional methodologies. Assumptions consist of the entities and independent variables that make up our simulation. They are described here, along with justifications for their inclusion:

Entities

1) Herding households, animal herds, and communal pastureland (i.e. the private ownership of herds, communal ownership of land, and the individual family household as the basic unit of the nomadic pastoral economy):

These are well established in the ethnographic literature (Cribb, 1991; Khazanov, 1994), and remain characteristic of herding in Mongolia today (Goodland, Sheehy, & Shine, 2009; Murphy, 2011). The disastrous effects associated with forced attempts at communal herd ownership in Central Asia during the Soviet period have been well documented (Endicott, 2012, p. 65-83). Given that an extensive pastoral nomadic system requires wide dispersal of the total number of animals to ensure adequate pasture, and to prevent overgrazing, dispersed households with private herd ownership/management is a practical adaptive strategy. This provides maximum flexibility for each household to adapt to fluctuating environmental conditions in their given locality.

2) Patron-client networks:

Given private ownership of herds by households, the effects of environmental disasters are felt differentially, depending on location, as well as luck and management skill, leading to the rapid development of wealth inequality. In this regard, Cribb (1991, p. 39) has noted that resultant forms of social organization in nomadic pastoral societies play the role of solving discrepancies between labour and capital, or the differential herding success of households, as some have surplus animals, while others are willing labourers but have lost their herds. These latter become contract herder clients to wealthy patrons, shifting from individual household herd ownership to individual household herd management, as wealthy absentee herd owners come to own a large percentage of the total animals in the system (Cribb, 1991, p. 42). Other social relations beyond a simple patron-client structure have been empirically observed in nomadic society, including institutionalized aristocracy (Sneath, 2007) and communist state ownership and herd redistribution (Endicott, 2012). However, we are interested here in theoretical mechanisms for the initial emergence of hierarchical structures, and patron-client networks represent a simple starting point, from which more complicated social relations and political forms could emerge.

Independent variables

1) Carrying capacities/available biomass:

We use carrying capacity as our main environmental variable, despite the traditional non-equilibrium theory of pastoral land use. According to non-equilibrium theory, carrying capacity of pastures is never reached because natural disasters such as droughts are so frequent that herd sizes are kept low. We use carrying capacity because 1) much of modern Mongolia is not a non-equilibrium zone (Fernandez-Gimenez & Allen-Diaz, 1999), particularly the productive central and eastern portions that formed the heartland of the Mongol and Xiongnu empires; and 2) much recent ecological research indicates that traditional non-equilibrium zones, as well as lusher equilibrium areas, suffer measurable and severe pasture degradation due to overgrazing, calling into question the main tenet of non-equilibrium theory (Werger & Van Staalduinen, 2012). In our simulation carrying capacity (the maximum number of animals in the system) is varied between 5,000 and 50,000, increasing in intervals of 5,000. Since our ABM simulates 100 households, this equates to an average of between 50 (very low for a herding society) and 500 animals per household, if no inequality were to develop. Our choice to simulate 100 households is arbitrary, except in its relative proportion to carrying capacity, grounded in the empirical evidence on common herd size ranges cited here. If we were to simulate more or less households, we would adjust the range of carrying capacities we test to maintain these proportions. For comparison, in 2014 the herding economy in Mongolia consisted of 213,400 households managing a total of

51,982,600 head of livestock, or an average of 243 animals per household (Erdenesan, 2016, p. 19, 23.). This equates to a capacity of slightly fewer than 25,000 in our simulation. A range of 5,000 to 50,000 was thus considered broad enough to ascertain the effect of increasing carrying capacity on wealth inequality and network size. Furthermore, the range of disaster frequencies we test (discussed below) is sufficient to allow the emergence of non-equilibrium dynamics at some settings.

2) Herd growth rate:

We use a fixed growth rate of 10% per time step. In real life the growth rate of herds is modulated by the gestation period of animals, and the specific herd management/husbandry strategy adopted. It has been well established that herd size maximization is a common strategy in extensive pastoral nomadic systems, as a buffer against losses due to environmental disasters (Endicott, 2012; Naess & Baardsen, 2013). A rate of 10% seems high, but this is herd growth before reductions due to environmental disasters, and has an ethnographic basis. From 2013 to 2014, total livestock in Mongolia increased by 15%, and from 2014 to 2015 by 7.6% (Erdenesan, 2016, p. 23). Therefore, in good years without widespread disasters, growth of around 10% is not unreasonable. In any case, experimentation showed that varying the growth rate did not produce new system dynamics. This is because what governs system dynamics related to growth rate is the ratio of average growth (the growth rate) and average loss (disaster frequency * disaster effect) that households face each time step. One set of dynamics held when average growth was greater than average loss, and another set held when average loss was equal to or greater than average growth. In this sense, varying the growth rate only varied the specific combination that would produce this threshold, providing no new information about system behaviour. This will be discussed further in the results section.

3) Disaster frequencies:

Households have between a 5% and 20% chance of suffering an individual environmental disaster per time step (and an equal chance of a system-wide disaster affecting all households simultaneously). Again, this broad range proved large enough to understand changes in system dynamics from low risk environments (5% frequency) to more high risk environments, and increasing disaster frequency beyond 20% did not result in any new noteworthy system behaviours. As extensive pastoral nomadic environments are characterized by risk, even under good conditions, the lowest risk frequency of 5%, or one disaster every twenty years, seems reasonable given available modern data (see Mahul & Skees, 2006; Rao et al., 2015). Real world correlates to simulated environmental disasters include everything from droughts, snowstorms, freezing rain, disease, and human error or mismanagement.

4) Disaster intensity:

We use a fixed 50% reduction in herd size if a household suffers an environmental disaster. This may seem unrealistic, but as mentioned, the important dynamic between growth rates, disaster frequencies, and disaster effects was discovered to be average growth per time step (the growth rate), and average loss per time step (disaster frequency * disaster intensity). Therefore, the average losses per time step we test range from 2.5% (5% * 50%) to 10% (20% * 50%). Again, this range of average losses was sufficient to observe all noteworthy changes in system dynamics as the level of risk in the environment increases. To confirm this we also tested uniform random disaster intensities (0 to 100% reduction in herd size). Trends were identical but values were slightly fuzzier, as it became impossible to precisely calculate average loss per time step (now disaster frequency * a random number between 0 and 100).

5) Poverty threshold and patron threshold:

When a household's herd size drops below 60 animals, they begin to look for a patron. Only households with herds larger than 800 animals can serve as patrons. Patrons transfer 60 of their own animals to a new client. If a patron's own herd drops below 500, they lose their patron status and their clients. While real-world values will naturally vary depending on time, place, and context, these numbers have an ethnographic basis: Barth (1961, p. 109) locates 60 animals as the approximate poverty threshold among Basseri herders in present-day Iran, and similar values are located by researchers in Mongolia (Goodland et al., 2009, p. 8). Likewise, in present-day Mongolia households with over 500 animals are comparatively rare, and regarded as wealthy. While the majority of Mongolian households currently own between 100 and 400 animals (Goodland et al., 2009, p. 7), more than half the population has left the herding economy (often through poverty) and urbanized. In previous lean times before mass urbanization, such as following the de-collectivization of herding in Mongolia after 1990, average herd size was under 60 animals per household (Goodland et al., 2009, p. 22). It is important to note that in some sense our choices for these thresholds are unimportant; so long as they are held constant, the relative effect of independent variables such as carrying capacity and disaster frequency on network development can be measured.

Dependent variables

1) Wealth inequality:

In our simulation, wealth is measured by household herd size. While additional forms of wealth may have been employed in historical societies, our simulation aims only to understand baseline dynamics related to the herding economy. To measure wealth inequality we employ the gini index, a standard measurement of wealth inequality that varies from 0 to 1, with 1 representing perfect inequality. When the index value is 1 all animals in the system belong to only one household. A gini index of 0.8 roughly equates to 80% of total wealth in the hands of 20% of the households. The gini index is re-calculated at every time step, and its final value after 2,000 time steps is recorded. We measure wealth inequality using a more basic version of the simulation, in which households grow their herds and suffer environmental disasters, but do not interact with each other and form networks. This is because during interaction patrons redistribute wealth to their clients, masking total inequality.

2) Network size:

Every household who becomes a patron keeps a record of the clients that form its network. We record the largest number of clients (or nodes in a network) a single patron managed to maintain simultaneously each simulation run. The larger this number, the larger the network size that was able to form under the given parameter settings.

3) Network duration:

Besides recording the size of the largest network that developed during each run, we also record the number of time steps (out of 2,000) that it lasted as the largest within that run. This measures network duration or stability, and the average number of time steps the largest networks lasted over 20 runs at each set of environmental conditions is calculated and used for analysis.

Results

Figure 1 (average values over 20 runs):

wealth inequality (gini index)

capacity	5	10	15	20
50000	0.95	0.95	0.93	0.5
40000	0.94	0.95	0.94	0.5
30000	0.95	0.94	0.91	0.5
20000	0.94	0.94	0.9	0.43
10000	0.93	0.92	0.87	0.51
pearson r:	0.76	0.9	0.92	0.24

disaster frequency (%)

Figure 1 shows results for a version of the simulation that does not allow interaction between households and formation of patron-client networks. Households grow their herds every time step, which are then reduced whenever they suffer environmental disasters. It corresponds with steps 1 and 2 of the scheduling overview described above. Running only this portion of the simulation allows for a baseline analysis of the degree of wealth inequality that can develop, before households start to redistribute wealth through network formation. These results are average gini values from 20 simulation runs at each combination of carrying capacity and disaster frequency (totalling 500 runs). Up to a 15% disaster frequency, wealth inequality is very high at all carrying capacities. At disaster frequencies of 20% and above, wealth inequality drops significantly. At a disaster frequency of 20%, average losses per time step are 10% (20% * 50%), equalling the growth rate. When average losses are equal to or greater than average gains, all households continually descend into poverty and are unable to distinguish themselves via wealth. Long term, these situations may be described as unsustainable. As discussed, examination of current empirical data indicates that disaster frequencies of between 5 and 15% are probably reasonable approximations of the extensive pastoral nomadic environment in the region. Within this range, our findings show that environmental heterogeneity engenders significant wealth inequality in the absence of social adaptations to mitigate it.

Figure 2 (average values over 20 runs):

network size (number of clients/100 households)

capacity	5	10	15	20
50000	80	89	82	11
40000	77	89	82	8
30000	67	79	75	9
20000	38	43	47	9
10000	33	33	32	9
	disaster frequency (%)			
pearson r:	0.95	0.94	0.94	0.43

Figure 2 shows results for the full simulation. Between disaster frequencies of 5 and 15%, there is a strong correlation between carrying capacity and network size increase, with R-values of .95 and .94. The biggest jump is from a capacity of 20,000 to 30,000. Further testing showed that increases in network size taper off at around a 50,000 capacity. As our ABM simulates 100 households, the largest possible network would feature 99 clients. The networks developing at the highest carrying capacities thus incorporate 80 to 90% of the households on the landscape. As with wealth inequality, network sizes plummet at disaster frequencies of 20% and beyond, where average losses equal or exceed average growth. Under these conditions, households rarely gain enough wealth to afford or maintain patron status.

Figure 3 (average values over 20 runs):

network duration (number of time steps)

capacity		disaster frequency (%) 5	10	15
	50000	392	281	170
	40000	308	195	131
	30000	254	135	106
	20000	115	53	41
	10000	86	46	32
pearson r:		0.98	0.98	0.98

Figure 3 shows network duration in relation to carrying capacity, within the disaster frequency 'sweet spot' of 5 to 15%. Duration increases significantly with carrying capacity, and is highest at lower disaster frequencies. Therefore, as environmental conditions ameliorate, not only are networks getting significantly larger, but they are increasingly long lasting as well.

Figure 4 (average values over 20 runs):

network size and duration (disaster rate 10%)

capacity	network size	duration	population (out of 100)
50000	89	281	100
45000	89	236	100
40000	89	195	100
35000	87	177	100
30000	79	135	100
25000	67	106	100
20000	43	53	100
15000	33	44	95
10000	33	46	75
5000	29	44	51
pearson r:	0.95	0.97	

Figure 4 shows complete results at a disaster frequency of 10%. The right-hand column shows the remaining population at the end of a run, averaged from the results of 20 simulation runs at each carrying capacity. Households only died off at capacities of 15,000 and below. These results show that more household deaths at lower carrying capacities are not confounding the relationship between increasing carrying capacity and network size. At a capacity of 10,000, the largest network incorporated less than half of the surviving households, compared to the incorporation of 90% of surviving potential clients at capacities above 40,000.

Figure 5 (average values over 20 runs):

varying capacity

capacity	network size	duration	population
10000 to 50000	81	271	92
10000	33	46	75

Figure 5 shows an experiment where whenever a network of 20 or more clients formed during runs at a capacity of 10,000, carrying capacity would be raised to 50,000 while that network remained in existence. We show average results from 20 runs of that experiment, again using a disaster frequency of 10%. Now a much larger and longer-lasting network formed in every run, and in 13 out of 20 runs this network incorporated more than 80 households. This experiment indicates that if available biomass increases during key moments when burgeoning networks are still small but beginning to form, the likelihood that a large network will develop is much increased.

Discussion

We compare model results with the Mongol (1206 – 1368 CE) and Xiongnu (209 BCE – 48 CE) empires. We also discuss common confounding variables that may act upon our simulation dynamics in empirical cases, and how our type of simulation can be applied to empirical analysis. We stress that by examining multiple case studies we are not implying a necessary or exclusive correlation between positive climatic change and nomadic empire creation. This latter is a multivariate process, and the effects of climate may be confounded or outweighed by any number of political, social, and cultural variables emerging from a long causal chain of historical particulars. Nonetheless, our approach is to use simple, abstract simulations involving as few variables as possible. This builds up an understanding of relationships that allows for a better appreciation of the ultimate effect of additional variables. Additionally, the more abstracted a model, the more potential it has to be applied and analyzed in a variety of particularistic scenarios.

In applying our model, we are primarily interested in cases where empirical evidence has already suggested enhanced environmental productivity did correlate with documented moments of nomadic empire creation, hierarchy, and centralization. Comparing model processes with empirical data is a great challenge, since the archaeological and historical record on the particulars of the emergence of these empires is so scarce. In the case of the creation of the Mongol Empire, Di Cosmo (2014, p. 15) notes that the only early historical source, the *Secret History of the Mongols*, is of unknown reliability. This is compounded by its overwhelming focus on lauding the military exploits of Genghis Khan and his allies, at the expense of elucidating critical background factors involved in the economics and logistics of network creation and maintenance. In cases such as these, we feel simulation is an ideal tool to experiment with mechanisms that can connect the dots between a) an empirically observed environmental context, and b) an empirically observed socio-political phenomenon. Two of these correlations between climate and empire (the Mongol and Xiongnu periods) happen to be the two largest and longest lasting nomadic empires in the historical record. As such, they are our primary case studies. We are also interested in evidence for the adoption of strategies designed to mitigate the effect of climatic downturns on hierarchical networks and polities among nomads, and cases where the effects of climate have been confounded by other political, social, or cultural variables.

Mongol Empire (1206 – 1368 CE)

According to recent dendroclimatology research, Mongolia experienced drought from 1180 to 1190 CE, and an unprecedented pluvial from 1211 to 1225 CE, along with above-average temperatures (Pederson et al., 2014). The drought corresponds with historical evidence for violent tribal warfare within Mongol society, and the warmer and wetter period corresponds with Genghis Khan's early expansion and consolidation of the

Mongol Empire. Pederson et al. (2014) hypothesize the pluvial would have aided expansion due to lusher pastures easing the logistics of military conquest. They also propose that the breakdown of social order prior to Genghis Khan's rise to power would have been exacerbated by drought, clearing the way for a new polity to emerge. Putnam et al. (2016) adopt a more macro perspective on climate reconstruction, suggesting that little ice age cooling led to glacier expansion across the Eurasian continent from, at the latest, 1180 CE through to nineteenth century. In Mongolia, they argue this led to a southward push of snow lines, grasslands, and concomitant wetting of Inner Asian deserts, substantially increasing available biomass.

Climate data suggesting a warmer and wetter period in the early years of the Mongol Empire fits well with our model predictions, as these are the conditions characterized by increased rangeland productivity that increase the probability of large stable network formation (Fig 4). Furthermore, the heartland of the early Mongol Empire was between the Kherulen and Onon rivers in Mongolia's present-day Khentii province, home territory to Genghis Khan's Khamag Mongol confederation. In the present, Khentii is known as one of the most productive regions in Mongolia; in 2016 it had 789 households with over 1,000 head of livestock, placing it second in Mongolia, at double the national average (Erdenesan, 2016). The relatively high carrying capacity of Khentii pastures is borne out by NDVI satellite imagery, reflecting photosynthesis capacity per unit land (Fig 6).

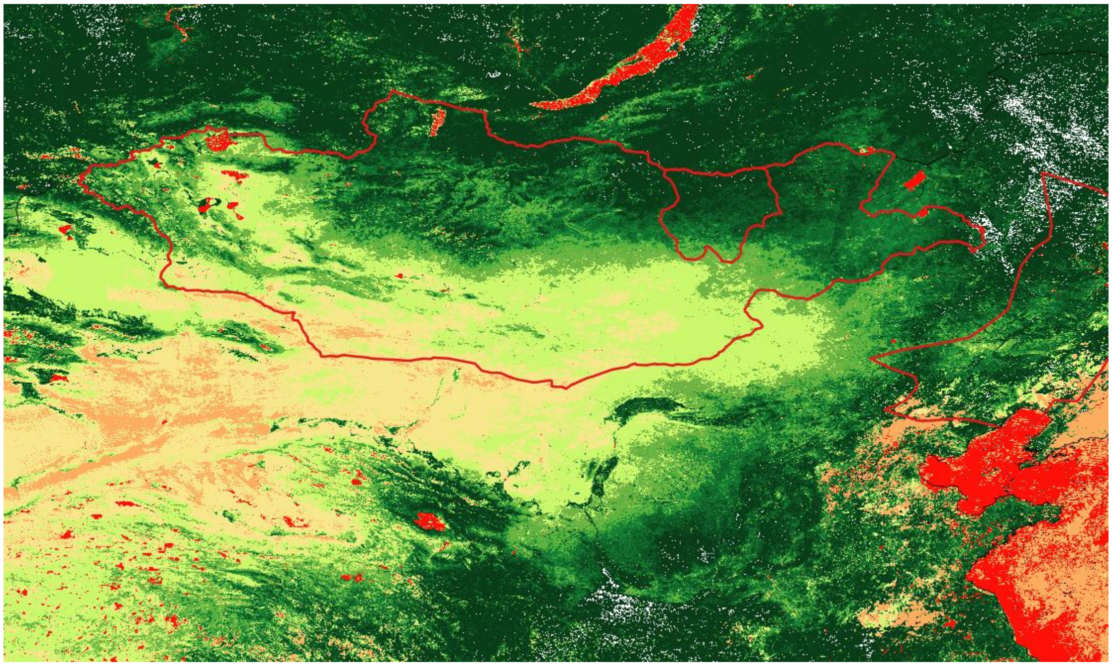

Figure 6 shows sample NDVI satellite imagery for July 2014, with Mongolia and Khentii province outlined in red. Darker green indicates higher biomass. Our analysis of imagery suggests Khentii generally features NDVI values 75% higher than the Mongolian national average.

While we experiment with poor climatic conditions followed by positive climate change and enhanced productivity (Fig 5), the preceding period of negative productivity (drought) observed by Pederson et al. (2014) is not a necessary component of large network formation in our model. Even in simulations run exclusively in high productivity, low risk environments, network duration shows regular turnover in patrons, such that roughly ten different large networks could be expected per 2,000 time cycles under these parameters (Fig 3). In the specific case of the Mongol Empire, however, a chaotic breakdown and civil violence (which we do not model), potentially exacerbated by drought, could undoubtedly have played a role in Genghis Khan's emergence as a new leader.

The actual process simulated in our model, of differential success of herding agents followed by redistribution of animals from rich to poor households, is extremely difficult to identify in historical sources, and particularly in archaeological data. The aforementioned *Secret History of the Mongols* (SHM) may be an embellishment of military valour, but social and cultural references would probably have been recognizable to contemporary readers, and provide indirect evidence for processes seen in simulation. Chapters covering the reign of Ogedei Khan (1229 – 1241 CE) make passing reference to Ogedei mandating the collection and redistribution of sheep from aristocratic and military leaders to poorer households (SHM 279 – 280). Aristocratic characters in the *Secret History* also make occasional references to the camp locations and movements of specialist herders of horse, sheep, and other animals working for them, implying contractual herding agreements (e.g. SHM 118, 152, 169). Wright (2015) has recently argued that the characteristic empty walled enclosures of the Mongol Empire period functioned as animal collection centres, in an early example of nomadic pastoral taxation and surplus. Regular taxation of livestock at these enclosures during seasonal migratory movements indicates one way a centralized power, or patron, could redistribute wealth where it was needed to maintain followers and authority. While the *Secret History of the Mongols* is equivocal regarding exactly how Genghis Khan provisioned and maintained his growing network of followers (Di Cosmo, 2014), Pederson et al. (2014) note that increased carrying capacity in central valleys would have permitted larger, more permanent habitation sites. This matches with historical and archaeological evidence for *ordos* (large camps/territories) of elite leaders, along with other permanent structures, during the Mongol Empire period (SHM 96, 104; Rubruck XII; Allsen, 1994; Wright, 2015). Taken in isolation, this sparse data would be difficult to form into a coherent theory of empire creation, but coupled with simulation experiments, a pattern of network formation based on redistribution of unequal herding surplus seems plausible. This is further supported by data from the ethnographic era on the development of patron-client contract herding relations in a variety of nomadic pastoral societies (Barth, 1961; Cribb, 1991).

Other elements of the Mongol Empire and its rise provide an opportunity to understand the complex interplay between the simple relationship our model demonstrates, and its interaction with socio-political variables. While a climatic upturn at the end of the twelfth century increased the probability of a nomadic polity, political occurrences external to the Mongolian herding landscape were also critical. From the tenth to twelfth centuries, Mongolia was a territory within the Khitan Liao Empire, a status severely curtailing any indigenous polity creation. The collapse of the Liao after military defeat at the hands of the Jurchen Jin Empire subsequently created a relative power vacuum on the Mongolian steppe, which grew larger following Jin withdrawal in the mid twelfth century (Barfield, 1989). External political and military events played a critical role in creating an environment of relative freedom from confounding external variables, in which network dynamics among herders could play out against the backdrop of an enhanced climate.

Likewise, socio-political structures, whether by design or by accident, may sometimes function to mitigate effects that emerge in our model, such as the rapid breakdown of large networks during climatic downturns. A noteworthy feature of the later Mongol Empire, in comparison to earlier nomadic polities, was its adaption of sedentary features such as fixed urban centres. These included the capital city of Karakorum, and the later capital of Dadu (present-day Beijing). These cities could be supplied with and store grain from conquered Chinese agricultural areas (Pohl et al., 2012). Official documentation from the Mongol Yuan Dynasty makes repeated mention of large numbers of Mongolian herders, made destitute by environmental disasters such as winter snow storms, entering these centres and being granted grain or cash (Endicott, 2004; Munkuev, 1977). An adaptation of our present simulation model includes externally provisioned urban centres that poor agents can migrate to instead of seeking herding patrons (see chapter 4). Results indicate these centres substantially increase the resilience and duration of remaining herding networks during short-term climatic downturns, by providing a runoff zone for agents that would otherwise drain the energy resources of their patrons. Mongol Empire urban centres are a useful example of how an additional variable may confound the relationship between climate and networks expressed in our model. However, understanding of the effect of this new variable is substantially enhanced by prior knowledge of the simple relationship between climate and networks we report here.

Given that our results indicate relative probabilities of large network creation, it does not surprise us to find that the largest of all nomadic empires 1) originated in a part of the pastoral world that is relatively lush (Fernandez-Gimenez & Allen-Diaz, 1999), 2) centered on a sub region of Mongolia that is arguably its most productive, and 3) arose during a time period with an uncharacteristically favourable climate for herding. While these correlations may seem fairly obvious in hindsight, this is not the case, given longstanding negative climate theories of nomadic empire creation. The history of this intellectual tradition stretches back at least to thirteenth century historian Ibn-Khaldun's *Muqadimmah*, where he identified the relative privation of nomads as the driving force behind nomadic conquest and state formation. This has been coupled with the longstanding viewpoint of sedentary societies concerning the relatively primitive character of nomadic social organization and its dependency on sedentary neighbours for surplus energy.

Xiongnu Empire (209 BCE – 48 CE)

The Xiongnu Empire is the first historically documented empire created by nomads in present-day Mongolian territory, and the longest lasting, presenting a useful comparison with the later Mongol period. Ge, Hao, Zheng, & Shao (2013) use proxies including sediment, tree rings, ice cores, and historical documents to reconstruct regional temperatures on a decadal timescale over a 2000-year period. Similar to the initial years of the Mongol Empire, they find that there was a significant warm period from roughly 200 BCE to 180 CE. Likewise, precipitation research indicates this warm period was also wet (Shao et al., 2010; Zheng, Wang, Ge, Man, & Zhang, 2006). More specific to the Xiongnu, Houle (2017) has collected relevant environmental, archaeological, and faunal data from multiple regions of Mongolia to test the Mongol Empire model of climate and empire creation developed by Pederson et al. (2014) on the Xiongnu period. He finds that lake core data from the central Mongolia/Khanuy Valley area indicate warmer and wetter conditions during initial creation and expansion of the Xiongnu polity. Faunal analysis in the Khanuy Valley indicates this led to expanded rangeland productivity, with an estimated threefold increase in the large domestic mammal population, and a doubling of the human population during the initial Xiongnu period. This region is associated archaeologically with elite Xiongnu burials and is generally taken as the heartland of the Xiongnu polity. In contrast to the Mongol Empire climate model developed by Pederson et al. (2014), Houle finds a) no evidence of poor environmental conditions prior to the initial Xiongnu period, b) no evidence of violence preceding Xiongnu polity formation, and c) no evidence for clear centralization of power in a manner comparable to the Mongol Empire.

We agree with Houle's conclusion that climate cannot be thought of as the sole driver of empire creation in the Xiongnu case (Houle, 2017). Each empire is a multivariate phenomenon with different particulars governing emergence. Even in our model, which tests the effect of environmental productivity on network formation, climate change is not the sole driver, as we observe the formation of large networks (albeit at differing rates of probability) under a wide variety of environmental parameters. Rather, wealth inequality, or more precisely the ability of some agents to gather, store, and redistribute surplus energy, is ultimately the driver of hierarchical network formation in our model. What our simulation shows is that a rise in environmental productivity increases the probability of large network formation. In this context, our findings provide interesting insights into the Xiongnu, who were able to maintain an uncharacteristically large and long lasting nomadic polity during a period of documented warmth, wetness, and increased rangeland productivity.

As Houle (2017) notes, archaeological evidence on the degree of centralization in the Xiongnu polity is unclear in comparison to the Mongols, whose politics have greater historical documentation, and whose material remains include capital cities. However, nomadic empires before the adaption of sedentary features such as fixed capitals may present little to no material evidence of centralization or hierarchy for future archaeologists. For example, our virtual simulation space features redistribution of herds from wealthy patrons to poorer clients, forming hierarchical networks. If this simple space with no other additions were an archaeological landscape, it would present the appearance of a dispersed homogeneous population of fairly egalitarian herding households. Archaeological evidence aside, historical primary sources, while providing no information on the initial formation process of the Xiongnu Empire, certainly document its hierarchical, centralized network of power. This is represented by the military decimal system, consisting of leaders and groups of 10, 100, 1,000, and 10,000, with the *Shanyu*, or emperor, at the top (*Shiji* 110). There is longstanding debate concerning the reliability of primary sources discussing Xiongnu society, due to the ethnic Chinese origins of these texts (Chin, 2010). In this case however, the description of the Xiongnu decimal system is identical to the Mongol Empire decimal system over a thousand years later, which is more reliably documented in indigenous Mongol, European, and Persian primary sources (SHM 224; Juvayni I 23; Carpini V 22, VI 2; Rubruck IV, XII). The decimal system thus appears to be a long lasting steppe tradition and a reliable observation from Xiongnu primary sources. As the non-military, administrative role of the decimal system for the Mongol period has been well argued (Allsen, 1994; Bold, 1996), it is likely an elegant mathematical representation of a hierarchical system of livestock herding in use during the Xiongnu period.

However, we are agnostic regarding degrees of centralization amongst the Xiongnu elite relative to the Mongol Khans and Emperors, so long as there were elites with networks. Historical documentation and tomb burials strongly suggest this to be the case. Our abstracted simulation could be considered analogous to the development of a single regional network. We do not simulate horizontal interactions between multiple pre-existing hierarchical networks, which may operate under a variety of different dynamics, and represents an area for future research. Houle's (2017) conclusion based on archaeological findings that the emergence of the Xiongnu polity, unlike the Mongols, was not characterized by violence, fits well with our model, which simulates only non-violent economic exchanges between agents. Honeychurch (2014, 2015) characterizes the lack of violence preceding the emergence of the Xiongnu polity as indicative of the long-term peaceful agglomeration of networks. Makarewicz' (2011) pioneering zooarchaeology research in Mongolia also finds strong evidence in favour of nomads being able to develop highly mobile surplus energy (in the form of herd animals) during the Xiongnu period. This ability to accumulate and redistribute energy is of course critical to the functioning of our network creation model, and supports arguments for the intrinsic capability of nomadic pastoralists to develop social complexity.

Beyond the Xiongnu and Mongol Empires, numerous pastoral ethnic groups in the region have coalesced into polities of varying sizes and are documented with varying degrees of reliability in Chinese written sources. Particular area and chronological specialists will be needed for future research to weigh different causal factors, including climate, in the emergence of these groups. Thus far, a small number of large-scale quantitative projects have attempted to correlate environmental data with nomadic political activity over long time spans. Su et al. (2016), make use of multiple climate reconstructions (namely Ge et al., 2010; Ge et al., 2013; Ge et al., 2003; Shao et al., 2010; Zheng et al., 2006), and find that periods of warfare between East Asian nomads and neighbouring sedentary societies occurred most frequently during climatic upturns, in contrast to previous models proposing nomadic warfare as a reaction to resource scarcity (Zhang et al., 2006). According to Su et al. (2016), this divergence is due to their focus on warfare between nomadic and sedentary groups, and not violence within groups. In other words, a unified nomadic society warring against a foreign power occurs more frequently in climatic periods of enhanced productivity. The primary explanatory mechanism proposed is that improved pastoral productivity in a favourable climate provided a foundation of strength and population growth to nomadic polities (Wu et al., 2009). While we do not simulate warfare, our results support this proposal for the enhanced backdrop to successful warfare and social cohesion that increased environmental productivity could provide. As in our simulation model, this study is expressed in terms of probabilities. A climatic upturn makes warfare between a unified nomadic group and sedentary neighbours more likely, with statistical significance, but warfare between groups can and does occur across the full climate spectrum.

As previously stated, we do not expect that the examination of further case studies will continuously result in findings supporting our model predictions. Not only do our results include the formation of large networks under a wide variety of conditions, but multiple additional variables we do not simulate are also involved in real world polity creation. In this regard, traditional theories predicting climatic downturns would correlate with the creation of nomadic empires have theoretical merit (and probably some empirical validity, given a large enough sample of cases). In our model, very poor environmental conditions (where average losses per time step are equal to or greater than average herd growth) do not result in large network formation because no agents are wealthy enough to maintain networks, which quickly collapse. In this environment, additional variables such as military and political organization and charismatic leadership could potentially counterbalance this outcome. Subsequently, extraction of surplus energy by force from neighbouring societies could be used to maintain a social hierarchy (Barfield, 2001).

Since our model supports network creation mechanisms under a variety of conditions, increased rangeland productivity is not the actual mechanism of network creation; rather, it increases the probability of creation. The actual mechanism is environmental heterogeneity and the subsequent unequal accumulation of surplus energy, coupled with its storage and redistribution in a highly mobile form (herd animals). As such, our model provides a mechanism for nomadic social complexity and polity formation even in the absence of positive climate events. This finding is supported by recent research recognizing the critical influence of animal domestication and the development of pastoralism in the rise of wealth inequality in Eurasia (Kohler et al., 2017).

Conclusion

Many different paths to nomadic empire or polity formation have undoubtedly occurred, and this paper makes no claims that ameliorating environmental conditions are a prerequisite. In our simulation, substantial networks (incorporating more than 40% of surviving households) formed even under relatively poor environmental conditions. Inter-group violence and other political tactics are not simulated, and could lead to polities or empires under varying sets of preconditions. Our results are particularly pertinent to situations where empirical evidence indicates substantial expansion of available biomass during or prior to nomadic polity expansion, or to polities that originated out of relatively favourable sub-regions. Under these conditions, we propose an explanatory mechanism for this correlation, whereby an increase in available biomass and heightened wealth inequality increase the probability of larger and longer lasting hierarchical livestock herding networks. This can occur regardless of whether preceding conditions were poor or favourable, and in the absence of large-scale violence or social upheaval. More generally, we show how a variety of heterogeneous environments can result in the unequal accumulation of surplus energy and the subsequent emergence of social hierarchy. These dynamics are relevant for the initial creation of polities and empires in livestock herding societies. They add to recent research on the internal capacity of nomadic society for social complexity, and on the effects of increased biomass on the expansion of nomadic empires.

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Chapter 4: The role of cities in nomadic steppe empires: modeling urbanization of herders during environmental downturns

Abstract

The role and nature of urban centres in Central Asian nomadic empires and polities has been a subject of recent scholarly debate. This paper investigates whether the creation of new cities during the Mongol Empire period had a strategic impetus. It uses agent-based computer simulation to examine the relationship between urbanization by pastoral nomadic herding households and the maintenance of size and stability among networks of active herding households during periods of poor environmental conditions. Results show that hierarchical networks among herding households are more resilient to climatic downturns when they are supported by externally provisioned urban centres. Historical and archaeological evidence from the Mongol Empire period is discussed, along with ethnographic data, to develop a framework for one role of urban centres within the Mongol Empire. It is argued that part of their function was to stabilize key herding networks, forming the basis of Mongol power, during climatic downturns, by providing a 'run-off zone' for destitute herding households, reducing internal social conflict.

Introduction

Recent academic discussion on the phenomenon of 'steppe urbanism' has sought to uncover how urban areas were integrated into a nomadic livestock herding context, how to classify or differentiate between different types of urban sites, what role these areas played within nomadic polities, and whether they were even 'cities,' according to standard nomenclature.[1] This paper uses agent-based computer simulation to model the effect of urbanization by herding households on the size and duration of livestock herding patron-client networks, under a variety of environmental conditions. Results indicate that 1) most urbanization of livestock herders occurs during poor environmental conditions (low available biomass), and 2) under poor environmental conditions, urbanization of destitute herding households increases the size and duration of patron-client networks between remaining herding households, compared to a system without urban centres. Therefore, it is argued that one strategic function, or unintended strategic consequence, of the creation of new planned cities during the Mongol Empire period was to maintain social stability among livestock herders during environmental downturns. This may have allowed Mongol rulers to prolong the maintenance, and allegiance, of large, far-flung nomadic pastoral networks that were the basis of their military power. During this period, large planned urban areas were founded, built, and populated, including Karakorum in the Orkhon River Valley, Dadu on the site of present-day Beijing, and Shangdu, or Xanadu, in present-day Inner Mongolia. Historical, ethnographic, and archaeological evidence is used to support the argument that these cities, provisioned mainly from sedentary agricultural regions of China conquered by the Mongols (Pohl et al., 2012), functioned as a security net for livestock herding households during environmental downturns. This served to enhance the stability of hierarchical networks among herding households that were the foundation of Mongol power.

While computer simulation remains an uncommon method for the study of pastoral nomadic societies in Central Asia, Cioffi-Revilla et al. (2010, 2015; also Rogers

[1] Two recent conferences with panels devoted to the issue of steppe urbanism include the Society for East Asian Archaeology (2014) in Ulaanbaatar, Mongolia, and the Society for American Archaeology (2017), in Vancouver, Canada.

et al. 2015) have been developing a whole-society model of Central Asian pastoral nomads with the aim of understanding political processes and strategies, and dynamics related to the rise and fall of empires. The present simulation is much narrower in scope. While urban centres in the Mongol and other empires served a wide variety of functions and motivations (Khazanov, 2005; Pohl et al., 2012; Rogers, Ulambayar, & Gallon, 2005), this simulation project focuses specifically on the effects of urban grain distribution and urbanization on network size and strength among non-urban pastoral nomadic households. In this sense, this paper is not concerned with cities themselves, but rather with nomadic herding networks outside them. The author is unaware of another simulation model specifically investigating this aspect of the relationship between pastoral nomads and urban centres. While archaeological investigation of the role of walled permanent sites during the Xiongnu and other periods are ongoing (Davydova, 1968; Ramseyer & Volkan, 2011), much more empirical data, particularly historical, is available for the Mongol period. As such, this paper focuses on a comparison of model results with Mongol period urban centres. While the dynamics described here could be equally applicable to nomadic empires that adopted urban centres in earlier periods, this awaits further clarification of the empirical record.

Agent-based simulation

Agent-based modeling (ABM) is a type of simulation that models the behaviour of individual agents, in this case herding households. In ABM, agents exist on a landscape, and interact with each other and their environment. The macro-level results and patterns produced by their behaviour then manifest as emergent phenomena that can be analysed statistically. This is in contrast to modeling a system where the structure and rules are inputted from the top-down. Simulations can be run many times at each combination of initial conditions, and the surprising variety of results have the potential to bridge the gap between particularistic and pattern-based explanations of human behaviour. The simulations in this paper are written in NetLogo, an open-source ABM language and software package developed primarily for social science research.[2]

The approach to ABM followed here is about understanding abstract baseline dynamics, rather than describing the historical realities of particular regions or time periods. This is in contrast to complex computer simulations that try to gather as much real-world data as possible in order to develop a hyper-realistic model. Examining archaeological, historical, or ethnographic data in one's particular area of interest then reveals whether insights gleaned from simulation results help augment understanding of this data. It is sometimes helpful to consider this kind of abstract simulation as a thought exercise to aid in developing interpretive ideas about actual historical, archaeological, environmental, and ethnographic data.

Simulation overview

This simulation adds urban centres and urbanization to a previous agent-based model investigating the effects of environmental variability on wealth inequality and patron-client network formation among pastoral nomadic households. A full description of that model, along with justifications for all assumptions and parameter values, can be found in chapter three of this dissertation, so only a brief overview will be repeated here:

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[2] For more information concerning Netlogo and ABM, see Wilensky & Rand (2015). Concerning the history of ABM use in archaeology, see Lake (2014), and Costopoulos (2015).

Households grow their herds by a herd growth rate every time step (a turn-based system used in ABMs), so long as the carrying capacity of the system has not been reached. Each time step they have a probability of suffering an environmental disaster, according to a set disaster frequency. These disasters reduce a household's herd size by 50%. If carrying capacity is reached, herds stop growing until disasters lower the population below capacity. Poor households are those whose herd is < 60, and wealthy households have herds > 800. Poor households attempt to become client to a wealthy household who can act as patron, transferring animals to them. The number of clients that patrons are linked to measures their network size. Patrons lose their status and network links if their own herd drops < 500. In the original simulation, if a household's herd dropped below 2 animals (and no households were wealthy enough to act as patron), they died off. In this version, an urban centre is included on the landscape, and if poor households herds drop < 40, they move to this centre and play no further part in the simulation. Each simulation records the urban population, the herding population, the largest network that developed, and how long this network lasted. These results are compared to their values when running the simulation without the urban feature.

Each simulation starts with 100 households. Carrying capacity of pastureland (to simulate poor or favourable environmental conditions) is varied from 5,000 to 50,000 animals. In the original simulation, a broad range of herd growth rates, disaster frequencies, and disaster effects were experimented with, but here fixed growth and disaster rates of 10%, and a disaster effect of 50%, are used for simplicity's sake, as this model aims only to uncover the effect of urbanization on network size and duration. For example, experimentation revealed urbanization is higher, and network size and duration are lower, if the disaster frequency is raised (and the opposite if it is lowered), but the relative difference between network size/duration with and without urbanization remains stable. Each simulation run lasts for 2,000 time steps. The simulation is run 20 times at each carrying capacity, with and without urbanization (thus totalling 400 runs). Only average results from 20 runs at each carrying capacity are used for analysis, ensuring statistical robustness.

Results

Figure 1 and 2:

urban population

	urban population (out of 100)
50000	10
45000	9
40000	11
35000	11
30000	10
25000	12
20000	12
15000	31
10000	53
5000	72

herding population with and without urbanization

	without urbanization	with urbanization
50000	100	90
45000	100	91
40000	100	89
35000	100	89
30000	100	90
25000	100	88
20000	100	88
15000	95	69
10000	75	47
5000	51	28

Figure 1 shows the urban population at each carrying capacity. Figure 2 shows the remaining herding population by carrying capacity, with and without urbanization. Most urbanization occurs at low carrying capacities (15,000 and under). As a result the active herding population is substantially lower at these carrying capacities. At these carrying capacities, is also substantially lower than the surviving herding population in runs without urbanization.

Figures 3 and 4:

network size as % of active herding households

	without urbanization	with urbanization
50000	89	91
45000	89	87
40000	89	84
35000	87	85
30000	79	83
25000	67	80
20000	43	60
15000	35	67
10000	44	79
5000	57	93

network size with and without urbanization

	without urbanization	with urbanization
50000	89	82
45000	89	79
40000	89	75
35000	87	76
30000	79	75
25000	67	70
20000	43	52
15000	33	46
10000	33	37
5000	29	26

Figure 4 shows the average size (over 20 runs) of the largest network (measured by number of clients) at each carrying capacity. Total network size is similar with and without urbanization. However, as seen in figure 3, network size, as a percentage of surviving herding households, is much higher with urbanization at low carrying capacities (15,000 and under). As carrying capacity rises (and urban population decreases) these values equalize by a capacity of around 30,000.

Figure 5:

network duration with and without urbanization

	without urbanization	with urbanization
50000	281	277
45000	236	232
40000	195	216
35000	177	201
30000	135	164
25000	106	155
20000	53	78
15000	44	82
10000	46	95
5000	44	117

Figure 5 shows the average duration of the biggest network at each carrying capacity, measured in time steps (out of 2,000). Urbanization substantially increases network duration at carrying capacities of 15,000 and under. As carrying capacity rises, these values increasingly equalize.

The mechanism at work here is that a greater reduction in active herding households under poor conditions than would have occurred had there been no urbanization option (as households urbanize at herd < 40, but only die at herd < 2) means patrons expend less total wealth, allowing them to maintain their networks for longer. Networks without the urbanization option were collapsing sooner as patrons were exhausting their wealth more rapidly by having to support more households. With an urbanization option, this lessened strain on their resources means their wealth is now sufficient for patronage of a larger relative percentage of active households as compared to the situation without this option.

Alternatively, reducing the number of households in the system via urbanization raises the relative carrying capacity (average herd size per household), giving equivalent results to a higher level of absolute capacity with no urbanization and more households in the system. When 53 of 100 households urbanize at a carrying capacity of 10,000, relative capacity changes from an average of 100 animals per household to 213 animals per household. This is roughly equivalent to a situation without urbanization and a capacity of 21,300.

It is important to note that the simulation system functions as it does because no energy input from the livestock economy is used to sustain households that move to urban centres. In other words, the urban centres are essentially external to the livestock herding economy. These results then pertain to situations where urban centres are provisioned by means external to the herding economy; when available biomass declines, the remaining non-urbanized herding society features relatively larger, and much more stable (longer lasting) networks.

Discussion

These results indicate one function of urban centres in a nomadic livestock herding context can be to help maintain social stability among hierarchically organized herding households when environmental conditions deteriorate. Do we have evidence for steppe urban centres being used in this way? Khazanov (2005) has provided the main overview of the historical relationship between pastoral nomads and urban centres in Central Asia. He argues that in all cases, the evidence is that nomads made extensive use of cities within their polities (whether conquered or newly created), but rarely urbanized themselves. He outlines three types of relationships between nomads and urban centres: 1) the relationship between nomads and cities controlled by neighbouring powers, usually in the realm of mutually beneficial trade; 2) when nomads appropriate pre-existing cities in conquered areas for their own benefit, and 3) the founding of cities by nomads. This last relationship is the main concern of this paper. In these cases, Khazanov's model is as follows: nomads found a city, often in an unsustainable location (from a local agricultural perspective), which therefore doesn't feed itself and must be provisioned through extensive food transport from conquered agricultural areas. Furthermore, it is generally designed, built, and largely inhabited by conquered or incorporated sedentary non-nomad populations of different ethnic groups. For the Mongol period, he notes that the design, building and population of the urban centres of Karakorum, Shangdu (briefly the capital and then summer capital of the empire), and Dadu (the final capital, and modern-day Beijing) were all the responsibilities of foreigners tasked by the Mongols. He notes that despite no evidence of mass movements towards urbanization, "archaeological data apparently indicate that some rank-and-file and/or impoverished nomads might visit the cities, live in them for a while, or even settle in them permanently." What value did Mongol rulers then see in creating and externally populating and provisioning new cities on their territories? It is useful to examine a broader review of anthropological theories on the relationship between pastoral nomads and urban centres.

Barth, in his study of the Basseri tribe in *Nomads of South Persia* (1961, p. 111), remarks that generally only two strata of nomadic society partially or fully sedentarize: the very rich, and the very poor. Wealthy herders eventually see diminishing returns from continuous herd growth; with their animals spread over a large area with multiple contract shepherd households, they are increasingly susceptible to being cheated. Diminishing returns increase the probability they will want to invest a growing portion of their wealth in sedentary assets (farming land or urban business interests). As for poor households, Barth notes they sedentarize when 1) they lose most of their own animals due to environmental disasters or mismanagement, and 2) fail to acquire herding contracts from wealthier households (environmental disasters also make available contracts fewer in number). They turn to seasonal work in villages or urban centres, which can quickly become permanent as it affects their ability to successfully participate in annual pastoralism cycles. Barth argues that the continuous sedentarization of poor herding households enhanced Basseri social stability.

Extensive pastoral nomadic livestock herding in Mongolia occurs on a much larger scale than in Western Asia, where territories are comparatively small, and pastoral nomadic lifeways are more deeply integrated with sedentary agriculture. Consequently, we can argue that the above patterns are amplified in the Mongol Empire. Rather than wealthy households simply investing in sedentary assets, we see Mongol Empire period elites creating an empire and founding or conquering their own cities to diversify their portfolios.

Cribb (1991) makes extensive comparisons between pastoral and agricultural modes of production. His arguments most pertinent to this discussion are:

1) There is no reason to assume that pastoralism and agriculture are complementary systems; in the abstract they are each complete and function separately.

2) Pastoralism and agriculture can be combined at different scales; the lowest scale is when the same person or household does both; at the highest level of integration they are pursued separately, either by two distinct sections of a group or polity, or by different polities. The fullest expression of this high-level integration is found in Rowton's (1973) concept of the dimorphic state, in which the ruler in a sedentary capital controls two groups: nomads (who form the ruler's power base) and agriculturalists (forming the productive base). The integration of pastoralism and agriculture occurs on a sliding scale between nomadization and sedentarization. Only when integrated at the highest level does pastoralism become fully 'nomadic,' as the entire social community is tied to the transhumant herd, rather than a place. Mongolian society during the Mongol Empire period would thus represent the fullest form of 'nomadic' pastoralism, while the conquest of sedentary areas and the founding of cities by Mongol rulers represents an amplified

version of the dimorphic state.

Turning to historical sources from the Mongol Empire and Yuan Dynasty periods, we do find discussion of the relationship between herders and cities, in the form of several imperial memoranda in the *Yuanshi*, the official history of the Mongol Yuan Dynasty compiled during the Ming period. These passages were compiled by Munkuev (1977) in a Russian-language publication, and have been translated to English by Endicott (2004, p. 467-471) as follows:

On August 1, 1330: "As for the Mongolian commoners who because of hunger and privation came to Shangdu (the summer capital in Inner Mongolia), [the Emperor] bestowed upon each of them grain for travel so that each might return to his tribe."

On June 28, 1265, "… through investigation it was ascertained that among the people in imperial prince Urughdai's appanage, those who were impoverished and without livestock numbered 30,724. [An imperial decree ordered that] every month each person should be provided with two *dou* and five *sheng* of grain; this should be discontinued after four months."

On March 17, 1308: "A great number of destitute people from Qara Qorum (Karakorum) arrived [presumably in Dadu, the Yuan capital]. One hundred thousand *ding* in paper currency was given to them in aid…"

On December 5, 1331: "Great snowstorms caused the herds of more than 11,100 households of falconers and Mongols in Xinghe Route to freeze to death. [The Emperor] ordered aid [in the form of] 5,000 *shi* of grain."

On February 15, 1287, "the people of the Yong-gu (Onggud) tribe were starving. [The Emperor] ordered the distribution of 4,000 *shi* of grain to aid them; if this was insufficient, a further grant [in currency] valued at 6,000 *shi* of grain would be made."

On February 23, 1291, "[an imperial decree ordered] Datong Route to distribute grain to aid the starving people of the Weng-gu [Onggud]."

On April 12, 1288, "because there had been great wind and snow storms in the northern border regions the previous year, many of the cattle and horses belonging to Batu Gulun (Batu Gurun?) died. [The Emperor] bestowed [upon him] 1,000 *shi* of grain."

On October 12, 1323, "During this year, wind and snow storms killed herds belonging to the Mongols of the Great Chiliarchs in Daning. [The Emperor] bestowed [upon them] 150,000 *shi* of grain."

These passages can be divided into two types: one where people are directly traveling to cities for relief, and another where grain handouts appear to be shipped from cities to nomads. For the both types, clearly the founding of cities by nomads was instrumental in allowing authorities to gather and store large amounts of grain in one place that could then be used for centralized disaster relief. Based on the quoted numbers, grain was being stored in large quantities. This created a new dynamic for nomadic adaptation to environmental disasters. In the simulation model presented here, only the first type (urbanization of herders) is experimented with. The provision of disaster relief directly to herders who continue as nomadic pastoralists would be akin to aid in the form of livestock already included in the simulation of network formation. Adding external grain relief into this dynamic during environmental downturns would simply lessen the strain on a network's leader (particularly if the latter also controlled grain distribution, as would be the case in a nomadic empire), resulting in increased stability.

Conclusion

Hierarchical pastoral nomadic networks based on wealth inequality are easy to form, but difficult to maintain. This is because wealth in extensive pastoral nomadism can be gathered and lost with equal rapidity. Boom and bust cycles are arguably more extreme than in an agricultural system (Cribb, 1991, p. 29-34). By founding cities (Karakorum, Shangdu, Dadu) that were provisioned from incorporated sedentary agricultural territories, Mongol rulers were able to store up a significant surplus of grain at these locations. A combination of sedentarization, temporary or permanent, and grain distribution, could then be used to sustain herding households rendered destitute by environmental disasters. This afforded greater stability to existing herding household networks, as demonstrated by the simulation described in this paper. This is not to say that nomadic society is dependent on a surplus from sedentary civilization to sustain its unequal social hierarchies. High wealth inequality, redistribution of surplus animals, and consequent social inequality (in the form of patron-client herding networks) emerge with rapidity in a nomadic pastoral economy. However, having the capacity to manage extensive resources from conquered territories, Mongol rulers leveraged this advantage to provide even more of a buffer to stabilize herding networks during environmental downturns – networks that undoubtedly formed a key component of the power base of any nomadic empire or polity.

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Chapter 5: Pastoral production and the organizational structures of Mongolian nomadic society

Abstract

This paper presents a comparative analysis of the spatial organization of Mongolian nomadic pastoralist society, using archaeological, historical, ethnographic, and environmental data. The goal is to identify diachronic patterns and variance in social organization generated by food production. Empirical data is drawn from three periods over two millennia: 1) the Xiongnu Empire (209 BCE – 48 CE), 2) the Mongol Empire (1206-1368 CE), and 3) the modern period (nineteenth century to the present). Results indicate extensive Mongolian pastoralism and facilitative social structures exhibit surprising continuity, particularly in spatial organization. These results emphasize the value of comparative and ethno-historical approaches.

Introduction

Reconstructing the social organization of livestock herders in historical Mongolian nomadic states and empires faces several challenges. For archaeologists, nomads leave comparatively little in the way of material remains at their seasonal campsites, presenting difficulties for extensive survey. Fixed settlements and monumental architecture are also fewer in number compared to sedentary societies. Furthermore, the (potentially marginal) role of these sites in overall social organization and economic production is not well understood. Standard survey methods designed to uncover spatial organization and social inequalities via the designation of site hierarchies become mostly inapplicable, and opportunities for intensive excavation are limited mainly to mortuary sites. For periods in which large empires incorporated sedentary areas, features, and peoples, excavating capital cities does not directly address the question of organization in nomadic pastoral society. Many important social features, such as the extent and causes of wealth and social inequalities, may not manifest in material terms visible to archaeologists (outside of elite tomb burials), unless societies begin to incorporate sedentary features.

For historians, primary textual sources present their own array of problems. Writing was not a feature of Mongolian nomadic society until the thirteenth century Mongol Empire, and even after this period primary nomadic texts are few in number. Foreign observers from neighbouring sedentary civilizations thus produced the majority of primary texts describing nomadic society. Consequently, the veracity of these sources and associated problems of text-driven historical archaeology (archaeological research designed to corroborate information in texts that themselves may be inaccurate) have become subjects of debate (Brosseder & Miller, 2011; Chin, 2010; Honeychurch & Amartuvshin, 2008). This is particularly the case for the Xiongnu (the first Mongolian empire, 209 BCE – 48 CE) all the way to the Mongol Empire (1206 – 1368 CE), when the first indigenous nomadic text was produced. This text, the *Secret History of the Mongols*, being an account of the personal political and military career of Genghis Khan, is not ethnography, and glosses over any deep discussion of social organization and land use (Endicott, 2012, p. 43). The situation for historical evidence is thus analogous to the archaeological landscape. While there are texts from a variety of contexts, they are few in number and must be carefully evaluated.

Researchers interested in historical Mongolian nomadic society must therefore make use of alternative sources, namely ethnographic analogy or ethnoarchaeology, and abstracted quantitative models. The latter has seen little use among Mongolian archaeologists (but see Cioffi-Revilla, Rogers, & Latek, 2010 for one example). By contrast, ethnographic analogy is widely employed, whether consciously or unconsciously, but faces the usual problems. These include equifinality and uncertainty about the degree of dynamism and change in nomadic social systems over time. Limited archaeological remains compound this, making verification of ethnographic analogies difficult. Many important ethnographically observed features of modern nomadic pastoralists, such as substantial wealth inequality as measured by herd size, unequal social relations, patron-client relationships between herders, and absentee herd ownership, may not manifest in material terms, thus remaining absent from the archaeological record. While such features may appear in textual sources, the dearth of indigenous primary texts becomes a problem. This creates major difficulties in ascertaining the degree to which relying on ethnographic information in the study of historical Mongolian nomadic societies is acceptable. By the same token, this also makes interdisciplinary approaches especially critical, pooling diachronic archaeological, historical, and ethnographic material to create richer datasets.

On the surface, Mongolian nomadism seems to feature striking degrees of continuity. The military/administrative decimal system is described in identical terms in Chinese texts on the Xiongnu Empire, and in Mongol, European, and Persian sources for the Mongol Empire, despite these two polities being separated by some 1,200 years (*Shiji* 110; SHM 224; Juwayni I 23; Carpini V 22, VI 2; Rubruck; Marco Polo (tr. Ricci, pp.

86-87)). Aspects of accounts in European travelogues on dwelling places and diet during the Mongol Empire (Rubruck IV, V, VI) would be immediately recognizable to modern-day Mongolians or tourists who have spent time in the Mongolian countryside. The few extensive archaeological surveys done in Mongolia have often noted present-day herders camping on the same seasonal sites identified as camps during historical and prehistoric periods (Houle, 2010; Wright et al., 2009). Popular culture arguably portrays present-day Mongolian nomads as a unique vestige, continuing an ancient tradition, more so than modern commercial mono-crop farmers are linked with their Neolithic ancestors. Current Mongolian agricultural livestock sector studies tend to view all periods before the communist collectivization era (1960-1990) as 'traditional' and undifferentiated in matters of social organization among herders (Barzagur, 2002; Goodland et al., 2009). Many of these apparent continuities are quite striking, and require careful evaluation and explanation.

This paper engages in a comparative analysis of social organization among Mongolian nomadic herders over the full chronology of historically documented nomadic pastoralism in the region.[3] It is hoped that pooling diachronic historical, archaeological, and ethnographic data will help overcome the data scarcity of particular historical time periods. Empirical data is drawn from three periods over more than two millennia: 1) the Xiongnu Empire (209 BCE – 48 CE), 2) the Mongol Empire (1206-1368 CE), and 3) the modern period (nineteenth century to the present). The goal is to determine what, if any, essential aspects of social organization are tied to the Mongolian nomadic pastoral mode of food production. These essential elements, if they exist, should manifest themselves

[3] For the purposes of this paper, the region under discussion consists of those historical states, empires, and societies centered on and around the territory of the present-day state of Mongolia.

diachronically in available empirical data. Emphasizing similar patterns, rather than the unique aspects of particular time periods and regions, is a useful thought exercise that provides insights into the generation of particular forms of social organization. It follows Healy's (2017, p. 118) argument that emphasizing nuance (in this case an increased interest in unique and particular features of time periods and regions) "typically obstructs the development of theory that is intellectually interesting, empirically generative, or practically successful." To this I add that explicit attempts at studies and methods to draw out generalized patterns are required; it is not self-evident that they will organically emerge after sufficient time has been spent in a Boasian gathering of particulars (see Buettner-Janusch, 1957). As a side effect, the process of drawing out common features makes it easier to identify those areas of social organization that have changed over time.

Figure 1: Modern Mongolia and surrounding regions

Food production and social organization

Connecting food production with social organization is of course not a new idea in anthropology. The early twentieth century saw the heyday of environmental determinism - that cultural features of groups, and even individual psychology, were determined by local environmental conditions. This gave way to the less parsimonious (and truistic) environmental possibilism, in which environment dictates only the absence of cultural features (such as grain agriculture in the arctic). From the 1960s till the present, variations of cultural ecology approaches that analyze the relationship between environment, subsistence methods, and associated behaviours have been commonplace (see Weinstock, 1986 for a useful summary of developments from determinism to cultural ecology). Predating all this is the mode of production theory of progressive linear cultural evolution developed by Karl Marx, although rather than food production, Marx's modes are a mix of economic systems (e.g. capitalism) and political systems (e.g. feudalism). Adam Smith's mode of subsistence theory is more coherent in its focus only on subsistence methods (hunting and gathering, pastoralism, farming, and commerce), of which the first three are food production or extraction methods. Smith's theory connects the method of food production with aspects of social organization (such as spatial organization, military structure, and views on property), divorced from particular political or economic systems.

The term nomadic pastoralism itself refers to a method of food production, and research on nomads has of course also been preoccupied with understanding the relationship between their method of food production and social organization. However, most of this research has centred on the relationship between mode of subsistence and political systems in nomadic society, rather than the organization of society for the purposes of pastoral production. For example, commonly debated topics include whether historical Mongolian nomadic societies were able to generate states and empires indigenously, or only via the contributions of external societies (Barfield, 1989; Honeychurch & Amartuvshin, 2008). Others include whether historical nomadic society was structured along tribal/kinship lines (Sneath, 2007; Barfield, 2009; Golden, 2010; Kradin, 2012). Soviet and soviet-influenced scholarship has traditionally been concerned with determining the feudal character of Mongolian society (Vladimirtsov, 1934; Bold, 2001; Kradin, 2003; Skrynnikova, 2000). Endicott's (2012) valuable survey of land use in Mongolia from the thirteenth century to the present is fundamentally about the demands placed on the herding system by various political structures and external institutions (tribal khans, empires, Buddhist monasteries, communists, present-day government and multi-national corporations), rather than an attempt to articulate the herding system itself. In addition to politics, another longstanding debate concerns the degree of inequality present in nomadic pastoral societies, which remains contentious because ethnographic results vary widely depending on group, region, and time period (see Dyson-Hudson, 1980 for an old but superior review of this issue).

In keeping with Adam Smith, I distinguish mode of subsistence, or food production, from political system. All best evidence indicates nomadic pastoral livestock herding has been the primary system of food production in Mongolia over the last two or three millennia. During this time Mongolia has cycled through the spectrum of political systems, including tribalism, aristocratic states and empires, communism, and liberal democracy. Clearly the mode of food production does not rigidly determine political organization. Social organization is a broader category, however. This paper contributes to the existing literature by skirting debates over political organization, and deliberately seeking out aspects of social organization that emerge consistently over time as a consequence of food production.

Mongolian extensive nomadic pastoralism

Agriculture can generally be divided in two ways: 1) a focus on either livestock or growing crops, and 2) the use of intensive or extensive production methods. With factors of production being capital, labour, and land, intensive methods use more labour and capital input to produce higher yields per unit of land. For livestock production, this generally refers to modern confinement operations with externally sourced feed. For crop production, intensive methods include industrial mono-crop farms with high inputs of equipment and synthetic fertilizers. Extensive livestock production involves letting animals graze on natural pastures. This means that capital inputs are significantly lower, but the amount of land required per unit of yield is higher. Precisely how much land is required depends on ecological considerations governing the amount of biomass for grazing, such as soil quality, precipitation levels, and the length of growing seasons. Due to short growing seasons, poor soil, and low precipitation, most of Mongolia has been unsuitable for intensive crop production (and by extension, confinement/feed livestock operations) over the last few millennia (Barzagur, 2002; Endicott, 2012; Goodland et al., 2009; Honeychurch & Amartuvshin, 2008). However, vast grasslands are predominant in the region, ideal for extensive livestock production. Low precipitation levels, short growing seasons, and thus relatively low biomass means that land required per unit of output is much higher than in extensive livestock grazing practiced elsewhere, such as the British Isles. So much land is required to secure adequate biomass that rotational grazing on a household farm is insufficient; Mongolian herders must nomadize – moving camp a number of times per year to ensure adequate pasture and allow for regrowth and the prevention of overgrazing.

Since the adoption of animal domestication and horse riding by the late Bronze Age, the predominant food production method in Mongolia has been extensive nomadic pastoralism (Honeychurch & Amartuvshin, 2008). Primary sources include countless references to nomadic pastoralism, meat, and dairy, with next to no mention of grain agriculture (SHM; Rubruck; Carpini). This is despite the fact that varying degrees of crop production have continuously occurred historically, and in the present day, in regions of Mongolia and the surrounding areas (Lattimore, 1935, 1938; Honeychurch & Amartuvshin, 2008. See Davydova, 1968 and Ramseyer & Volkan, 2011, for archaeological examples). Looking at Mongolia as a whole, archaeological theories of multi-resource nomadism, whereby nomadic subsistence is characterized as a flexible mix of pastoralism, crop agriculture, hunting, fishing, and gathering, are somewhat overstated. During the communist era, wheat production on Mongolian state farms was heavily encouraged and subsidized by the Soviet Union, in large part to satisfy Russian grain demands (Cassidy, 1971; Hibbert & Hibbert, 2005). Nevertheless, even during this period total agricultural production remained 70% livestock (Bayarsaihan & Coelli, 2003, p. 123). In the present day, the Mongolian government has dedicated perhaps unprecedented investment to crop growing and self-sufficiency in wheat and potato production (Endicott 2012, p. 129-157), coupled with industrial machinery and advanced irrigation technology, yet 90% of total agricultural sector production remains nomadic pastoral livestock production (Erdenesan, 2016, p. 18). In this paper I argue that any widespread diachronic elements of Mongolian social organization related to food production should emerge from the factors of livestock production rather than limited crop growing or other types of agricultural production. This is especially the case for pre-modern periods, as the historically documented method of occasional limited extensive crop cultivation practiced by Mongolian nomads consisted of light ploughing and hand sowing at seasonal pasture campsites that would be returned to during annual migration (Lattimore, 1935, 1938). Thus, even the spatial organization of limited crop production was largely determined by nomadic pastoral patterns.

Extensive nomadic pastoralism represents possibly the most extensive type of production within the global agricultural sector, meaning the lowest inputs of capital and labour, and the highest amount of land required per unit of output. Changes in crop agriculture from the Neolithic to the present have largely been based on intensification, namely through increased capital investments via technological innovation. Given the maximally extensive nature of Mongolian livestock production, the potential for intensification of production is by definition relatively low, as neither increased capital nor labour will change low precipitation, short growing seasons, and other predominant environmental conditions. Crossbreeding and genetic modification of animals has been attempted in the modern era, but for an extensive system of natural pasturing, breeds emerging over centuries have generally developed the best suite of adaptations to local conditions. Possibilities for intensification are largely limited to 1) intelligent migrations and use of pastures to prevent overgrazing and secure adequate biomass, 2) intelligent herd composition and management strategy to ensure maximal use of available biomass while limiting its degradation, 3) labour cooperation to ensure adequate personnel are available, economies of scale are actualized, and the alleviation of poverty by solving discrepancies between labour and capital, and 4) a system of social organization that facilitates the above three inputs. Suffice to say that with three millennia of experience, Mongolian herders carry a wealth of knowledge on how to manage extensive herding. Systemic changes would have to fall within the boundaries of the number of possible strategies that can efficiently accomplish the above four points. These limited routes to intensification imply that historically, fundamental shifts in livestock production techniques in Mongolia were unlikely.

Empirical data

Since data becomes increasingly sparse the further back one reaches, this paper will treat the Xiongnu, Mongol, and modern periods in reverse chronological order. This is done in the hopes that patterns uncovered in the empirical record of later periods will help make sense of more scarce data in earlier periods.

The modern period

The nineteenth to the twenty-first century is the period with the most robust ethnographic and quantitative data on food production in Mongolia. Given the above discussion on the relatively constant nature of the demands of extensive production (in comparison to intensification), ethnographic analogy is arguably more useful in the case of Mongolian herding than in a society in which intensive crop production predominates. In extensive production, by definition labour and capital inputs change little, and land and environmental conditions have, according to the best available data, remained stable over the last three millennia. In light of this, data from the nineteenth to twenty-first centuries provides a useful source of information on the range of possible organizational structures in Mongolian herding.

Manchu banner system

During the nineteenth and early twentieth centuries Mongolia was a part of the Manchu empire known in China as the Qing Dynasty. Under Manchu rule, Mongolia was officially divided into roughly 83 ‘banners,’ or *khoshuu*, in reference to the Manchu military and administrative structure known as the banner system. Each banner was ruled by a Mongol aristocrat, and was subdivided into a number of *soum*, or counties. The herding households in each *soum* were further subdivided into groupings known as *bog*. Boundaries between *khoshuu* were strictly controlled, as the Manchu were wary of large networks or confederacies of herders once again rising on the Mongol steppes (Endicott, 2012, p. 57). Therefore, seasonal pastures within each *khoshuu* were subdivided between *soums* and *bogs*, providing land use rights for herding households.

Despite relatively strict control on mobility, scholarly consensus is that the Manchus did not fundamentally alter the herding system, and that this was a conscious decision, based on the need for Mongolia as a military resource, and on the Manchus' own herding heritage (Endicott, 2012, p. 57, 61). Most present-day Mongolian livestock sector research identifies herding organizational structures prevalent during this period as the 'traditional' system of Mongolian herding. These structures are usually identified as the *khot ail*, *neg usniihan*, and *neg nutgiinhan* (Barzagur, 2002; Bold, 1996; Bruun & Odgaard, 1996; Mearns, 1993; Undargaa, 2016), and are roughly equivalent to *bog*, *soum*, and *khoshuu*. While the latter are Manchu top down administrative zones with geographic boundaries, the former can be thought of as the equivalent mobile livestock herding groups. Since these groupings are not officially tied to geographic location, their subjugation under the strict *khoshuu* system could create conflict. The *khot ail* consisted of a small group of two to ten households who would camp together at seasonal sites and cooperate in daily herding tasks. The *neg usniihan* ("people of the same water source") and *neg nutgiinhan* ("people of the same region") were groupings made up of multiple *khot ail*, and functioned to organize land usage among their constituents. Other terms for these groups are *neg gol* and *neg jalnyhan* (both roughly "people of the same valley";

Mearns, 1993). By most accounts, this organizational structure continued through the fall of the Qing in 1911, through the early decades of the communist Mongolian People's Republic (1924-1992), up until communist herd collectivization policy took hold in the late 1950s (Barzagur, 2002; Bold, 1996).

Herding organization during the Manchu period is by far the best documented in terms of pre-twentieth century history, and as such has formed the basis for modern attempts at reconstructing the 'traditional' herding system (for examples see Barzagur, 2002; Bold, 1996; Bruun & Odgaard, 1996; Mearns, 1993; Undargaa, 2016). Three tiers of organization with an ecological basis are clearly seen. However, due to external Manchu political needs, the emphasis is on the highest level of organization, the *khoshuu*, which were in turn tied to Manchu overlords in Beijing. This emphasis then hardened administrative boundaries, and while land always remained common property, mobility choices and ecologically sound longer migration strategies were sometimes disrupted (Bold, 2001; Jagchid & Hyer, 1979).

Communist collectivization era (1960-1990)

Discussions of 'traditional' herding in Mongolia often gloss over the communist herd collectivization era (1960-1990) as a failed experiment that resulted in great disruption (Barzagur, 2002; Bold, 1996). However, livestock numbers increased during this era, and the break with past traditions was arguably not as strong as in popular conception (Endicott, 2012; Sneath, 2007). Herders were organized by the state from the top down into collectives known as *negdel*, numbering 289 in 1965. Each *negdel* was further subdivided into *brigad*s, and each *brigad* into *suuri*. The *suuri*, consisting of on average two to five households, was the basic labour unit, and each *negdel* averaged 500 households (Endicott, 2012, p. 74). This tiered system is a functional equivalent of the *khoshuu* > *soum* > *bog* or *khot ail* < *neg usniihan* < *neg nutgiinhan* system of the Manchu and early twentieth century eras. The major distinction was that most animals were owned by the state via the *negdel*, which assigned herds to its constituent *suuri*. Each household was also allowed a small private herd. Even state ownership was not such a conceptual leap, since due to wealth inequality and institutionalized social inequality, many herders during the Manchu era would have been under contract, herding animals owned by wealthy Mongol aristocrats (Sneath, 2007).

Additionally, the state mandated specialization in herd composition as a Soviet strategy to modernize and increase production, such that each *suuri* would typically be assigned only one type of animal to herd (Endicott, 2012, p. 73). From an ecological and risk management perspective, herd diversification is strongly advantageous and has largely been standard practice in Mongolia. It is well known in livestock grazing industries around the world how multiple animal types can use pasture and survive in a complementary fashion. Examples include combining sheep, who prefer taller grass, with cattle, who can graze shorter stalks (Undersander, Albert, Cosgrove, & Johnson, 2002), using horses to break through ice and snow for other animals, or using the mobile tendencies of goats to encourage sheep not to overgraze pasture (Endicott, 2012). In terms of risk management, diversification avoids breed-specific diseases wiping out the entirety of a household's wealth. The degree of specialization during the collectivization era, in which the highest tier *negdel* was the emphasized organizational structure, was undoubtedly unprecedented. Nevertheless, the concept has historical precedent during other eras emphasizing higher tiers of organization, such as the well-documented demand for production of warhorses during the Mongol Empire (Allsen, 1994, p. 326; Jagchid & Bawden, 1965).

The documented problems of herding in this era arguably have more to do with group-level emphasis than a strong break with traditional structures. State emphasis on communist party dictates and the *negdel* results in a top-down micromanagement of the entire system, drowning out the voice of herding households. This could lead to inefficient allocation of labour, failure to respect ecological and grazing demands when allocating pastures and institutionalizing migration routes, and a sense of alienation among herders caring for animals they did not own, and without seeing recompense commensurate with their inputs (Barzagur, 2002; Namkhaĭniambuu & Rossabi, 2000). At the same time, institutionalized emphasis on the *negdel* and the state led to major advances in centralized hay cultivation, harvesting, and distribution as crucial winter fodder buffering against *dzud* (winter storms), and access to subsidized social services such as veterinary medicine at *negdel* centres (Endicott, 2012, p. 76). These higher levels of institutionalized organization would be sorely missed in the early stages of privatization after the collapse of the USSR (Barzagur, 2002; Bold, 1996).

Post-1991

The period from the collapse of the USSR and the Mongolian People's Republic in the early 1990s till the present is an interesting test case for studying nomadic pastoral organization. Herds were privatized, land was kept common, the economy became market-based, and the institutionalized herding structures of the collectivization period disintegrated, without being officially replaced. While this relative free-for-all led to much chaos and disruption (Bold, 1996; Endicott, 2012; Sneath, 2007), it also provides a unique opportunity to observe the emergence of organizational structures based on practical necessity. Two main trends are characteristic of the first two decades after de-collectivization: first, the re-emergence of the *khot ail*, or small grouping of cooperative herding households, and second, increasing calls for the institutionalization of higher levels of herding organization beyond the *khot ail*, to manage mounting environmental, social, and economic problems caused by the absence of higher levels of organization (such as the *negdel*) prevalent in the communist period.

The most immediate demand of extensive Mongolian pastoralism is the spatial dispersal of herds to ensure adequate seasonal grazing. Therefore it is predictable that post-1991 the family household with its newly privatized herd would remain the basic unit of labour. Despite the relatively arid, low biomass conditions prevalent in Mongolia, small numbers of households can still camp together, as long as surrounding pastures provide sufficient biomass for their total herds, and the advantages of labour cooperation provides a strong incentive to do so. The number of households and size of herds that can be sustained at the same camp increases with available biomass, presenting regional differences (Simukov, 1935). Bold (1996) and Bruun & Odgaard (1996) have also noted the *khot ail*'s capacity to manage a certain degree of inequality. Successful herders have a strong incentive to cooperate with other households who can provide the surplus labour their large herds require. Likewise, poor herders are sustained by herding for the wealthier leader of their *khot ail*. In light of these advantages, it is not surprising that the pre-collectivization *khot ail* made a strong comeback amid mounting inequality post-1991, as noted in many livestock sector studies from that period (Barzagur, 2002; Bold, 1996; Bruun & Odgaard, 1996; Dorligsuren, 2010; Mearns, 1993; Undargaa, 2016).

However, larger tiers of organization are not so quick to emerge organically, as they require consensus between large numbers of households and regional administrative bodies. Consequently, some researchers have suggested an official institutionalization of the ‘traditional’ categories of *neg usniihan* and *neg nutgiinhan* (Barzagur, 2002; Mearns, 1993). Without institutionalized collective organization beyond the *khot ail*, ecological problems arose from a tragedy of the commons dynamic characterized by unregulated growth of individual herds as a buffer against losses during natural disasters, and a lack of personal incentive to manage collective pasture degradation (Barzagur, 2002; Endicott, 2012; Ykhanbai, Bulgan, Beket, Vernooy, & Graham, 2004). Likewise, individual households responding to market demands increased overgrazing around market centres and led to a well-documented, disproportionate rise in cashmere-producing goats, exacerbating ecological problems. Foreign agencies focused on pasture privatization as the necessary incentivizing solution to a tragedy of the commons-type situation (Endicott, 2012, p. 91-93), although such policies were never implemented. Mongolian herders and researchers felt, probably correctly, that pasture privatization was inapplicable and inefficient in an extensive grazing system demanding flexible movement to maximize environmental capacity.

In recent years, many initiatives developed through collaboration between government, local herders, and academic researchers, designed to answer these challenges without privatizing pastureland, have been successfully experimented with. Notably these include pasture co-management schemes (Ykhanbai, 2004; Ykhanbai et al., 2004) and a resurgence of *neg nutgiinhan* (Undargaa, 2016). What unifies these schemes is that they bring together multiple *khot ail* in the same region in order to collectively manage, among other things, pasture allocation, environmental sustainability, and negotiations with other government and corporate interest parties. They thus fulfill the role of higher tiers of organization above the small household cooperative level.

Another example of a three-tiered structure that is overlapping, but not identical, with *khot ail* > *neg usnihaan* > *neg nutgiinhan* is the current Mongolian system of political administration. The country is divided into 21 *aimag*, or provinces (in the Mongol period, *aimag* referred to a tribal federation). Each *aimag* is subdivided into *soum*, or counties, totalling 331 for the whole country. Given that the capital city Ulaanbaatar is administered separately, the majority of *aimag* populations are nomadic herders. Each *soum* has a population averaging 5,000, or roughly 1,000 households, and is further subdivided into *bog*. The *bog* is a virtual category used to classify nomadic herding households in the *soum*, rather than referring to a geographical location. Within each *soum* is also a *khoshuu*, or fixed municipal center, serving as a focal point for organization and access to services among herders. Studies on successful modern examples of *neg nutgiinhan* indicate these groupings need to function roughly parallel to and in concert with the top down *soum* and *khoshuu* administrative structures, given that the former are not currently formally institutionalised entities (Undargaa, 2016).

Mongol Empire (1206 – 1368 CE)

Of the two pre-modern periods analyzed in this paper, the Mongol period is by far the best documented in Mongolian, Persian, and European primary sources. Knowledge of the Mongol primary sources gives a significant advantage in evaluating primary Xiongnu texts.

A particularly famous and well-known feature of the Mongol Empire was its system of military organization, referred to as the decimal system. It is well-attested in contemporaneous Mongol (SHM 224), Persian (Rashid al-Din, Juvayni I 23), and European (Carpini V 22 and VI 2; Rubruck IV, XII; Marco Polo (tr. Ricci, pp. 86-87) primary sources. The Mongol decimal system consisted, from the bottom up, of groups of 10, 100, 1,000, and 10,000 mounted horsemen. The basic unit of Mongol forces consisted of groups of 1,000, with Genghis Khan personally appointing 95 leaders of 1,000 in 1206 CE, and delegating to them the responsibility for naming their leaders of 100 and 10 (SHM 224). While small number of permanent groups of 10,000 were maintained (such as Genghis Khan's personal bodyguards), most groups of 10,000 or more were constituted from groups of 1,000 only when the need arose during campaigns, and were led by temporary appointees (Allsen, 1994, p. 345). Therefore, the permanently constituted Mongol decimal system consisted of three tiers – 1,000, 100, and 10. Numerous scholars have concurred that the decimal system groups actually referred to the number of family households required to supply 10, 100, or 1,000 military men, and that actual group numbers could vary substantially from their nominal decimal values (Allsen, 1994, p. 345; Bold, 2001, p. 84-85; Skrynnikova, 2000, p. 461).

It goes without saying that the structure of the groups of 10, 100, and 1,000 of the decimal system is reminiscent of the *khot ail* > *neg usniihan* > *neg nutgiinhan*. If the decimal system served an administrative as well as a military purpose (Allsen, 1994, p. 346; Honeychurch & Amartuvshin, 2008, p. 263; Bold, 2001, p. 85) then it is easy to see the advantage accrued by organizing herding households according to this tiered layout. However, while the *khot ail* is currently the most emphasized structure in the context of a peaceful modern state, in the context of tribal and eventually state level warfare in the Mongol and Xiongnu periods, greater emphasis on larger groupings might be expected. Despite being subdivided into groups of 100 and 10, the group of 1,000 formed the core operational unit of the military of the early Mongol state (SHM 224; Allsen, 1994, p. 345). To maintain military readiness, groups of 1,000 would have to be geographically constituted, which would also require break-up into *khot ail* level groupings to effectively manage the dispersal of herds attached to the group and prevent overgrazing. William of Rubruck's observations on the decimal system during his travels in the Mongol Empire on behalf of Louis IX of France describe this: "Every captain, according to whether he has more or fewer men under him, knows the limit of his pastorage and where to feed his flocks in winter, summer, spring and autumn." (Rubruck IV)

Some larger camps, centred on elite tribal, state, or empire figures, may have subsisted with relative permanency, supplied by the daily surplus (particularly dairy) from the surrounding *khot ail*-level groups. The *Secret History* mentions such camps belonging to major figures, including Toghrul, Ong Khan of the Khereid tribe, Genghis Khan, and the latter's ally-turned-rival Jamukha (SHM 96, 104). Rubruck describes the camp (*ordos*) of Batu Khan, Genghis Khan's grandson and leader of the Golden Horde, on the steppes of Eastern Europe, which may have coincided roughly with a group of 1,000 or 10,000:

"When I saw the *ordu* of Baatu, I was astonished, for it seemed like a great city stretched out about his dwelling, with people scattered all about for three or four leagues… Baatu has thirty men around his camp at a day's distance, each of whom sends him every day such milk of a hundred mares, that is to say every day the milk of three thousand mares, exclusive of the other white milk which they carry to others. As in Syria the peasants give a third of their produce, so it is these (Tartars) must bring to the *ordu* of their lords the milk of every third day." (Rubruck XII)

This example is one way in which *neg usniihan* and *neg nutgiinhan*-type levels of organization could have been institutionalized. During state and empire periods, these structures present a natural fit for groups of 100, 1,000, and indeed 10,000, on the rare occasions these latter were permanently constituted. This highlights the ways in which a tiered or decimal herding structure can alter its emphasis over time. In the present day the *khot ail* predominates, but in tribal periods or times of ancient warfare the larger groupings of 100 and 1,000, having increased their administrative portfolios by virtue of warfare and the needs of organizing military campaigns, likely became the emphasized categories.

The decimal system could, and did, disrupt the traditional order of pre-state society. There is much evidence throughout the *Secret History* of Genghis Khan breaking up conquered tribes and placing survivors across multiple decimal groups, or allowing close allies to reconstitute their own groups of 1,000 from followers currently dispersed among different tribes, and founding entirely new groups of 1,000 or 10,000 not based on pre-state tribes (see SHM 224-226). However, there is obvious similarity between the decimal system and tiered structures of herding organization in different periods, as they both answer the demands of wide dispersal coupled with cooperation that characterizes extensive nomadic herding. More precisely, the group of 10/*khot ail* represents the largest grouping of herders that can camp and pasture together without overgrazing relatively arid grasslands. Multiple such groups sharing water sources and seasonal pastures (forming the group of 100/*neg usniihan* level) must coordinate their seasonal migratory movements to avoid land disputes and overgrazing. At the regional level (group of 1,000/*neg nutgiinhan*), households are connected by proximity and the specific demands of their shared ecological zone. Tribal or family structures are not necessary elements in terms of function – they are best seen as elements that emerge organically over a long time span, as neighbours within ecological zones are more likely to be working together and marrying, and bonds of descent will gradually develop. The lack of functional necessity of these bonds is evidenced by their frequent dissolution and reconstitution under Genghis Khan, and later during the communist *negdel* period.

In the pre-empire period, the focus of the *Secret History* is also on larger organizational tiers, namely the o*bog* (tribe) and *aimag* (tribal federation). For instance, Genghis Khan's father Yesugei is described as Khan of the Khiyat Mongol tribe within the larger Khamag Mongol federation, or *aimag*. Given that the *Secret History* is about power struggles and war amongst steppe aristocrats, this focus is understandable. Bold (1996) also notes mentions of pre-empire defensive camps known as *khoshuu*, which may have included *khot ail*-level groups (see SHM 90 for an example). Nevertheless, smaller *khot ail*-like structures are hinted at indirectly. When a young Genghis Khan is captured by Targutai, now leader of the tribe after Yesugei's death, Targutai "ordered his people to allow Temujin to stay one night in each of their camps in turn." (SHM 81) Likewise, when Jamukha and a young Genghis Khan are moving their large camps together, they discuss where to send the various shepherding households under them (SHM 118).

While conditions of tribal warfare may have increased the emphasis on larger groupings as the primary administrative level, it is difficult to see how so many households and animals could camp together regularly without overgrazing. It seems more likely that dispersal into *khot ail* within the same general region was how daily herding would have proceeded. It also seems unlikely that a dual military/administrative structure including household groups as small as a group of 10 would have been instituted if it did not bear some relation to the extensive nomadic pastoral herding system (in this case, facilitating ecologically appropriate dispersal of herds attached to the core groups of 1,000). Problems related to an over-emphasis on higher tiers of organization are in fact referenced in the Mongol sources, as a Yuan Dynasty memorandum reports that the herds of the leaders of the four great *ordos* were declining, as these were ordered by the khan to stop nomadizing and maintain their geographic position, leading to overgrazing (Munkuev, 1977).

Xiongnu Empire (209 BCE – 48 CE)

The Han Dynasty court historian Sima Qian describes the same decimal system in his discussion of Xiongnu society in the *Shiji* (110). The *Shiji* is the main textual source for the Xiongnu, but since the latter did not write, there has been debate over the validity of Sima Qian's information (Brosseder & Miller, 2011; Chin, 2010; Honeychurch & Amartuvshin, 2008). Di Cosmo (2002, p. 267) argues that the Xiongnu represented the major foreign policy challenge for the Han Dynasty, and that accurate intelligence would have been critical. As such, court historians such as Sima Qian would have had access to sources including returned Han hostages, Xiongnu hostages, prisoners, slaves, defectors, firsthand accounts of military officers engaged in fighting the Xiongnu, personal visits to the frontier, and access to court documents relating to negotiations with the Xiongnu (Di Cosmo, 2002, p. 268-270). Using a comparative diachronic approach, we can evaluate Sima Qian's description of Xiongnu social organization by comparing it with the Mongol period decimal system, as the latter is well documented in multiple reliable primary sources. Sima Qian's description of the decimal system is as follows:

> "Among the other leaders, from the wise kings on down to the household administrators, the more important ones command 10,000 horsemen and the lesser ones several thousand, numbering twenty-four leaders in all, though all are known by the title of "Ten Thousand Horsemen." … The *Shanyu* has his court in the region north of Dai and Yunzhong. Each group has its own area, within which it moves about from place to place looking for water and pasture… Each of the twenty-four leaders in turn appoints his own "chiefs of a thousand", "chiefs of a hundred", and "chiefs of ten" …" (*Shiji* 110)

Sima Qian's description of the Xiongnu Empire decimal system features twenty four leaders of 10,000, whose forces are subdivided into groups of 1,000, 100, and 10. Despite predating the Mongol Empire by more than a millennium, the decimal system is described in strikingly similar terms. The decimal system is also described in primary sources for interim nomadic empires in Mongolia, including the Turkic empires and the Khitan Liao (Allsen, 1994). This all serves to increase the credibility of the *Shiji*'s discussion of Xiongnu social organization.

Meanwhile, archaeological evidence from a survey of the Eigiin Gol valley in North Central Mongolia during the Xiongnu Empire period indicate 1) a major increase in the size of seasonal habitation sites, and 2) a re-positioning of these sites along major mobility corridors in the main valley, suggesting a stronger hierarchy of sites and centralization of power (Honeychurch & Amartuvshin, 2008). This could be a material reflection of a stronger emphasis on the higher levels of organization during the Xiongnu Empire, similar to the large aristocratic campsites described by Rubruck for the Mongol Empire, around which were arrayed groups of 100 and 10. Higher level group emphasis would offer stronger controls on the mobility of smaller tiers of herders, access to their surplus produce, and the obvious military benefits of having geographically organized and ready fighting units.

Nonetheless, differences in group-level emphasis occur chronologically but also on a regional basis, with higher biomass zones tolerating a more intense focus on higher tiers of organization. Recent environmental research suggests high biomass zones were at the center of the Xiongnu polity (Houle, 2017). Reinforcing regional ecological differences in nomadic pastoral social organization, survey results of the Baga Gazaryn Chuluu area in the more arid Gobi desert during the Xiongnu period find much smaller, more ephemeral, and dispersed habitation sites over a wider region (Honeychurch, 2014, 2015). Simultaneously, comparison of mortuary evidence indicates similar cultural practices in Baga Gazaryn Chuluu and Eigiin Gol during the Xiongnu period (Honeychurch, 2015; Wright et al., 2009).

Discussion

Comparative data drawn from over two millennia identify clear patterns of similarity and variance in the social organization of Mongolian nomadic pastoralists. In particular, the spatial organization of herders into tiers of increasing size exhibits significant diachronic stability. These tiers follow an ecological logic and provide the framework for effective extensive pastoral production. Variations in organization through the time periods examined also exhibit similar patterns. Tier emphasis changes frequently in response to external or internal political demands, along with political systems themselves. Likewise, production emphasis, social inequality, and the constituency of labour groupings appear to be flexible elements.

Similar patterns: tiered spatial organization

Ecologically efficient tiered groupings of herders are elegantly illustrated by the decimal system. Its groups of 10, 100, and 1,000 are strikingly similar to the *khot-ail* > *neg usniihan* > *neg nutgiinhan* and *suuri* > *brigad* > *negdel* frameworks. It is likely that the persistence of these spatial groupings lies in the effective solution they provide to the fundamental ecological demands of extensive pastoralism. Wide dispersal of individual herds and flexible mobility is critical to prevent overgrazing and maximize use of available biomass. Caring for these herds also requires equal dispersal of labour, and the group of 10 level of organization consisting of a few family households efficiently answers this demand, along with permitting some degree of resource and labour pooling. The specific size of these groups generally has a positive relationship with quantity of biomass available in a region - lower biomass zones sustain smaller group sizes and longer, more frequent migrations (Simukov, 1935).

Table 1: Tiered organizational structures over time

Xiongnu	**Mongol pre-empire**	**Mongol Empire**	**Communist**	**Modern**
Group of 10	?	Group of 10	*Suuri*	*Khot Ail*
Group of 100	*Khoshuu*	Group of 100	*Brigad*	*Neg Usniihan*
Group of 1,000	*Obog*	Group of 1,000	*Negdel*	*Neg Nutgiinhan*
Group of 10,000	*Aimag*	Group of 10,000	N/A	N/A

Table 1 shows examples of tiered organizational structures in Mongolian herding society over time. I suggest that the lower tiers of organization respond to the dual requirement of herd dispersal and labour cooperation in an extensive pastoral system operating in a relatively arid environment. The higher tiers respond to problems requiring collective action, such as coordinating seasonal pasture movements or military campaigns.

As we have seen, collective action problems such as overgrazing tend to select for the emergence of organizational structures above the group of 10. Since environmental heterogeneity means household groupings are not distributed equally, larger tiers with more frequent contact and similar lifeways and production strategies according to local ecological variation emerge. In this way, tiers roughly equivalent to the groups of 100 and 1,000 have tended to be persistent features of herding structure in Mongolia.

Variations in the herding system: tier emphasis, group constituency, political system, and production emphasis

Historically, the family household or grouping of households appears to have been the most efficient basic labour unit. It is easy to envision how, coupled with regional marriage patterns and a degree of geographic separation between regional ecological zones, a tribal/kinship-based socio-political organization could emerge. Nevertheless, historical evidence indicates this kin-group constituency of herding organizational tiers is a byproduct of geographical proximity, unlike the ecological necessity of the organizational tiers themselves. As noted, Genghis Khan re-ordered groupings of 1,000 and 100 and their leaders, sometimes along previous tribal lines, and sometimes not. Likewise, during the communist period centrally organized labour groups meant members were not always kin relatives.

While extensive pastoralism and its tiered spatial organization has been the main Mongolian food production method for the last two-and-a-half millennia, political systems have changed drastically. Kin-based, aristocratic-feudal, centralized empires, and communist and democratic states have all been experimented with, suggesting food production in Mongolia is not a direct determinant of political system. In terms of their impact on herding, political systems primarily alter ownership conditions and degrees of institutionalized social inequality. For example, ethnographic data and simulations have outlined how high variation in a heterogeneous environment, coupled with geographic dispersal of agents, can result in high stochastic inequality in production outcomes (Barth, 1961; Cribb, 1991; see also chapter 3). Whether and how this translates into social inequalities is largely a function of political adaptations. A small aristocratic class of absentee herd owners and a large underclass of contract herders could easily emerge as a solution to the above stochastic dynamics, as is suggested in the Manchu, Mongol, and Xiongnu data discussed in this paper. By contrast, the communist era solution was centralized collective herd ownership and redistribution. In contemporary market-oriented democratic Mongolia, inequality amongst herd owners is very significant (see Murphy, 2011), but a central government with diversified revenue streams is increasingly able to support livestock insurance schemes (Mahul & Skees, 2006) and opportunities for diversifying investments.

Another source of variation related to political systems is the emphasis placed on each tier of herding organization. This often seems to be a function of external or internal political demands. We have seen how in historical empire and pre-empire periods, defense and military requirements meant a focus on group of 1,000 and 100 equivalents. Furthermore, times or regions of relatively high biomass could better sustain a focus on larger groups, and were thus often at the centre of Mongolian empires (Houle, 2017; Pederson et al., 2014). The communist period was similarly focused on the higher tier *negdel* collectives, to satisfy political doctrines of progressive modernization. In both cases, this focus on higher tiers for reasons external to the ecological logic of herding was sometimes detrimental to production efficiency. By contrast, in the post-Soviet period, herders in an unregulated free market environment immediately revived the group of 10 level *khot ail*, as the most fundamental structure for short term herding success. Higher tiers of organization are less likely to emerge as quickly or organically, as they require widespread collective agreement. In this light, an over-emphasis on the lowest level of production (the individual household group) has increasingly resulted in collective action problems of environmental degradation, leading to calls and experimentation with institutionalizing higher levels of organization.

In addition to group emphasis, production emphasis in herding can vary depending on priorities: maximizing efficiency in the production of meat, milk, wool, specific animal types, large herd size (as a buffer against risk), maximal environmental sustainability, or a combination of any of these. Comparative historical analysis indicates warhorses were prioritized in the Mongol period, while specialization in animal types between collectives and overall numbers were the focus of the communist period. In the modern era, an increase in cashmere-producing goats to meet international market demands is well documented (Waldron, Brown, & Komarek, 2011).

Because of changing tier and production emphasis, Endicott (2012, p. 43, 63-64) is correct in pointing out that there has never been a golden age of Mongolian herding; it is in flux, depending on goals and priorities of different time periods. The lag before systemic collapse due to problems caused by an over-emphasis on different tiers of organization or animal types is clearly quite long. Despite documented problems due to a focus on higher tiers in the empire and communist period, and collective action problems due to a lack of these tiers in the present, extensive herding has persisted as the main Mongolian agricultural sector and largest single employment sector. Nevertheless, outlining theoretical golden age parameters of ecologically sound, efficient extensive herding organization permits a finer appreciation of the sources of variation in social organization over time.

Conclusion

This paper has addressed the dearth of historical and archaeological data on the social organization of Mongolian herders by a comparative diachronic analysis over two-and-a-half millennia. This long time span approach creates a richer data set, and clarifies important patterns in spatial social organization that are remarkably persistent. I have outlined some arguments explaining this persistence, namely related to the ecological demands of an extensive livestock herding system of food production in Mongolia's environmental context. Given that extensive production methods remain the most efficient in this environment, more continuity in method and organization is expected in comparison with societies using intensive production strategies. This implies that long time span comparative analyses, and ethnographic analogy, may be especially useful in studying historical Mongolian society. However, great care must be taken when drawing analogies across time, and the goal of this paper is not to support a rigid environmental determinism or present Mongolian nomadism as an unchanging evolutionary dead end. In this light, drawing out persistent diachronic patterns has also clarified degrees and sources of variation within Mongolian nomadic herding society, including political systems, social inequality, ownership, production emphasis, and group constituency. As a whole then, extensive nomadic pastoralism in Mongolia presents striking spatial continuities, as well as a large scope for flexibility in other aspects of social organization, so long as critical ecological demands are satisfied.

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Chapter 6: Conclusion

Past theories of Inner Asian nomadic pastoral social complexity have emphasized external causal mechanisms. Recent archaeological and ethnographic data has increasingly challenged these models, implying an internal capacity for complexity in nomadic pastoral society. This dissertation has proposed some internal causal mechanisms for nomadic complexity that complement this new data. This was done by simulating general processes relevant to the development of complex society, particularly the development of wealth inequality and patron-client networks.

Chapter 2 gave an overview of the literature on nomadic pastoral complexity in Inner Asia, and of the simulation of inequality in archaeology and anthropology. For the former, major developments include substantial new data problematizing past theories based on nomadic dependency on sedentary civilization. For the latter, some computational modeling approaches have shifted from analyzing the properties of patterns to modeling micro behaviour that can generate patterns matching the archaeological and historical records.

Chapter 3 presented a simulation of the development of wealth inequality and patron-client networks among herding households. Households on a heterogeneous landscape grow their herds and suffer environmental disasters differentially. Environmental conditions were varied to experiment with the effects of lower or higher carrying capacity and disaster frequencies. If sufficient wealth inequality develops, patron-client networks are formed between rich and poor households. Results show that high wealth inequality develops consistently under a broad range of environmental conditions, and that patron-client networks are larger and more stable as carrying capacity increases. These findings have two implications. First is an explanation for the internal development of nomadic pastoral complexity. Heterogeneous environmental conditions result in high wealth inequality, and mobile capital (herd animals) can be redistributed to form hierarchical networks. Second is an explanation for the apparent correlation between increased biomass and nomadic empire formation. Conditions of increased biomass consistently resulted in larger and more resilient patron-client networks, increasing the probability of large-scale centralization and hierarchy. This prediction fits well with empirical data for the Mongol and Xiongnu empires.

Chapter 4 presented an extension of the simulation in chapter 3. Poor households gained the option of moving to urban centres if they could not find a patron household. With this option, results in high biomass conditions were identical to those in chapter 3. However, in conditions of severely decreased biomass, the presence of urban sites substantially increased the size and resilience of patron-client networks among the remaining herding households. These results indicate that urban centres provisioned by means external to the livestock production sector could perform a strategic role in maintaining the stability of hierarchical networks among herding households during environmental downturns. Under the conditions simulated in chapter 3, strong environmental downturns placed hierarchical networks at greatest risk of collapse. These results are consistent with primary historical sources from the Mongol Empire, indicating occasional urbanization and Chinese-sourced grain redistribution to herding regions affected by disasters, from the large urban centres of Karakorum and Dadu (Beijing).

Chapter 5 presented a diachronic comparative analysis of spatial organization in Mongolian nomadic society, using archaeological, historical, and ethnographic data.

Given the relative data scarcity of particular historical periods, the goal of this comparative analysis was to develop a richer diachronic dataset that will be useful for the development of future modeling efforts. Findings indicate significant continuity in spatial organization and land usage (illustrated by the three tiers of the decimal system), resulting from the ecological pressures of extensive nomadic pastoral herding. At the same time, other aspects of social organization such as political system and social relations between herders have been fluid over time. Understanding the demands extensive nomadic herding exerts on social organization will aid in developing new computational models incorporating spatial components.

While new data has problematized past theories of Inner Asian nomadic pastoral complexity, parsimonious theories proposing causal mechanisms have comparatively weakened. This dissertation attempts to redress that balance by simulating processes internal to nomadic pastoral society that can generate and sustain complex hierarchy. These processes show how prevailing environmental conditions and the pressures they exert on nomadic pastoral food production can generate high wealth inequality and hierarchical networks based on the redistribution of capital. In relation to recent climatic reconstruction data, these simulations show how increased biomass can create and sustain even higher levels of internal centralization and hierarchy. In terms of theoretical and methodological approach, the simulations in this dissertation do not attempt to simulate nomadic pastoral empires. Instead, the abstracted agent-based approach used here simulates general processes and generates virtual datasets to help fill the gaps in contexts of empirical data scarcity. Additionally, chapter 5 of this dissertation has compiled a diachronic inter-disciplinary dataset aimed at the creation of future computational models, with particular emphasis on the spatial components of social organization.

Future Directions

This dissertation uses computer simulation to explore the relation between environment, inequality, and the formation of historical nomadic polities and empires. A promising avenue for future research is the application of the simulation methodology developed here to the initial innovation of mounted nomadic pastoralism in the Mongolian Bronze Age (3000 to 1000 BCE). Archaeological evidence indicates animal domestication and specialized pastoral adaptations predominated in Eurasia since the third millennium BCE (Taylor et al., 2017), and these developments have been linked to rising wealth inequality and social complexity (Kohler et al., 2017). Computer modeling and a more fine-grained reading of archaeological chronology suggests that the increased mobility afforded by the technological development of mounted horseback riding (adopted in Mongolia around 1200 BCE) led to a substantial population increase and a shift in landscape exploitation strategies (Shultz & Taylor, 2018). Furthermore, this period of mounted pastoralism during the Late Bronze Age correlates with the clearest archaeological evidence for the beginnings of complex hierarchical society in the region (Houle, 2016).

Therefore, in future projects I will explore how an increase in personal mobility and transport afforded by horse riding and traction altered the parameters of pastoral livestock production, and subsequently social organization and the evolution of social complexity in the region. More broadly, understanding the role of mobility in the ability to acquire, store, and distribute surplus energy is critical to understanding the cultural evolution of complex society in a variety of environmental and chronological contexts. Questions I aim to address with simulation experiments include: 1) the relationship between mobility of agents and spatial land use patterns in varying environmental contexts; 2) how environmental change relates to the development and spread of mobility innovations; 3) how a mobility innovation spreads through a population, and the fitness advantages and disadvantages accrued by early and late adopters; and 4) the relationship between personal mobility, population growth, wealth inequality, and social hierarchy. A dearth of archaeological evidence for Bronze Age social organization, in comparison to sedentary societies and later periods of Eurasian history, creates challenges in addressing these questions through empirical data alone. This presents an ideal opportunity for the application of the computational and interdisciplinary approaches developed throughout this dissertation.

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Appendix A: Agent-based model code for chapters 3 and 4

This appendix contains the code for the simulations presented in chapters 3 and 4, written in the NetLogo programming language. See chapters 3 and 4 for further details on the functioning of the simulations and parameter values used in each experiment.

```
globals [
  capacity
  gini-index-reserve
  lorenz-points
  gini
  leaderboard
  longest-leader
  urban-population
  most-total-clients
  most-clients
  p-list
  biggest-network
  max-patron-counter
  network-list
  turtle-id-list
  duration
]

turtles-own [
  herd
  new-herd
  herd-list
  time-at-top
  total-herd
  patron
  partner
  patron?
  clients
  total-clients
  p
  patron-counter
]

;; setup procedures:
```

```
to setup  ;; using setup button
  clear-all
  setup-patches
  setup-turtles
  set capacity 200 ;; starting total herd size (not total carrying capacity): 100 households x
2 animals each
  ;;update-lorenz-and-gini
  list-herds
  set network-list (list)
  set turtle-id-list (list)
  reset-ticks
end

to setup-patches
  ask patches [ set pcolor green ]
  ask n-of num-cities patches [ set pcolor white ] ;; num-cities slider, set to 0 for chapter 3
model; set to 1 for chapter 4 model
end

to setup-turtles
  create-turtles number ;; slider on interface for starting population size
  ask turtles [ setxy random-xcor random-ycor ]
  ask turtles [ set herd 60 ] ;; starting herd size
  ask turtles [ set herd-list (list)]
  ask turtles [ set time-at-top 0 ]
  ask turtles [ set color blue]
end

;; runtime procedures:

to go
  if ticks >= 2000 [ stop ]
  grow-herd
  check-disaster
  check-death
  stop-being-patron
  stop-having-patron
  find-patron
  calculate-largest-network
  update-lorenz-and-gini
  list-herds
  show-wealth
  count-leadership
  count-turtles
  tick
end
```

```
to grow-herd
  ask turtles [
    if capacity <= capacity-level [ ;; capacity-level = interface slider representing carrying
capacity
      set new-herd (herd * growth-rate) ;; growth-rate = interface slider
      set capacity (capacity + (new-herd - herd))
      set herd (herd + (new-herd - herd))
    ]
  ifelse show-herd?
    [ set label herd ]
    [ set label "" ]
  ]
end

to check-disaster
  ask turtles [
    if random 100 < disaster-rate and herd >= 2 [ ;; disaster-rate = interface slider
      set new-herd (herd * disaster-effect) ;; disaster-effect = interface slider
      set capacity (capacity - (herd - new-herd))
      set herd (herd * disaster-effect)
    ]
  ]
end

to stop-being-patron
  ask turtles with [color = red] [
    if herd < 500 [
      ask my-in-links [die]
      set clients 0
      set color blue
    ]
  ]
  ask turtles with [color = blue] [
    set clients 0
  ]
end

to stop-having-patron
  ask turtles [
    if patron? = 1 and patron != nobody and [color] of patron = blue [
      set patron nobody
      set patron? 0
    ]
  ]
end
```

```
to check-death
  ask turtles [
  if [herd] of self < 2 [die]
  ]
end

to find-patron
  if any? turtles with [herd >= 800] [
  ask turtles with [herd < 60] [

    ifelse patron? = 1 and patron != nobody and [herd] of patron >= 800

       [borrow-from-patron]

       [ifelse any? other turtles in-radius radius with [herd >= 800] ;; radius = interface
slider, always set high enough to cover whole grid. This slider is for future
experimentation and was not a variable used in these simulations.

            [select-patron]

            [ifelse any? patches in-radius radius with [pcolor = white]

                [urbanize]

                [turtles-check-death]
                ]
            ]
       ]
    ]
end

to borrow-from-patron
  set herd (herd + 60)
  ask patron [set herd (herd - 60)]
end

to select-patron
  ask my-out-links [die]
  set patron? 0
  choose-patron
  set patron one-of other turtles in-radius radius with [color = white]
  create-link-to patron
  set patron? 1
  set herd (herd + 60)
  ask patron [set herd (herd - 60)]
```

```
  ask patron [set color red]
  ask patron [set clients (clients + 1)]
  ask patron [set total-clients (total-clients + 1)]
end

to calculate-p
  let wealth-list sort-by > [herd] of turtles in-radius radius with [herd >= 800]
  let total-wealth sum [herd] of turtles in-radius radius with [herd >= 800]
  ask turtles in-radius radius with [herd >= 800] [
    set p precision (herd / total-wealth) 2
  ]
  set p-list sort-by > [p] of turtles in-radius radius with [herd >= 800]
end

to choose-patron
  calculate-p
  while [all? turtles in-radius radius with [herd >= 800] [color != white]] [
    ask other turtles in-radius radius with [herd >= 800] [
      if random-float 1 <= [p] of self [
        if all? other turtles in-radius radius with [herd >= 800] [color != white] [
        set color white
        stop
        ]
      ]
    ]
  ]
end

to urbanize
  if herd < 40 [
  move-to one-of patches in-radius radius with [pcolor = white]
  set patron? 0
  set urban-population (urban-population + 1)
  ask my-out-links [die]
  ask my-in-links [die]
  die
  ]
end

to turtles-check-death
 if herd < 2 [die]
end

to make-partner
  set partner one-of other turtles in-radius radius with [herd >= 4]
  set herd (herd + 2)
```

```
  ask partner [set herd (herd - 2)]
end

to calculate-largest-network
  if count turtles >= 1 [
  let count-clients sort [clients] of turtles
  set network-list lput max (count-clients) network-list
  if max (count-clients) > biggest-network [
    set biggest-network (max count-clients)
  ]
   ask one-of turtles with [clients = max (count-clients)][
      set turtle-id-list lput self turtle-id-list
    ]
  ]
end

to calculate-patron-counter
  ask turtles with [color = red] [
    set patron-counter (patron-counter + 1)
  ]
end

to update-lorenz-and-gini ;; to produce the lorenz points and gini index calculation
necessary for graphing results
  let num-people count turtles
  let sorted-wealths sort [herd] of turtles  ;;
  let total-wealth sum sorted-wealths
  let wealth-sum-so-far 0
  let index 0
  set gini-index-reserve 0
  set lorenz-points []
  repeat num-people [
    set wealth-sum-so-far (wealth-sum-so-far + item index sorted-wealths)
    set lorenz-points lput ((wealth-sum-so-far / total-wealth) * 100) lorenz-points
    set index (index + 1)
    set gini-index-reserve
      gini-index-reserve +
      (index / num-people) -
      (wealth-sum-so-far / total-wealth)
    set gini ((gini-index-reserve / count turtles) * 2)
  ]
end

to list-herds
  ask turtles [
    set herd-list lput herd herd-list
```

```
    ;;show (herd-list)
  ]
end

to show-wealth
  ask turtles [
    if ticks >= 1999 [
      set total-herd sum herd-list
      ;;show total-herd
      ]
  ]
end

to count-leadership
  if count turtles >= 1 [
  ask turtles [
    if ticks >= 0 [
    set leaderboard sort [herd] of turtles
    if [herd] of self = max (leaderboard) [
      set time-at-top (time-at-top + 1)
    ]
  ]
  ]
  if ticks >= 1999 [
   let total-time sum [time-at-top] of turtles
     ;;show total-time
  ]
  if ticks >= 1999 [
    set longest-leader sort [time-at-top] of turtles
    ;;show max (longest-leader)
    ;;show max-one-of turtles [time-at-top]
  ]
  ]
end

to count-turtles
  if count turtles >= 1 [
  if ticks >= 1999 [
  let turtle-count count turtles
  let patron-count count turtles with [color = red]
  set most-total-clients sort [total-clients] of turtles
  ;;show max (most-total-clients)
  set most-clients sort [clients] of turtles
  ;;show max (most-clients)
  ;;show biggest-network
  set max-patron-counter sort [patron-counter] of turtles
```

```
  set duration 0
  let index position max (network-list) network-list
  let n length turtle-id-list - index
  let i 1
  while [(i < n) and (item (index + i) turtle-id-list = item index turtle-id-list)] [
     set duration duration + 1
   ;;]
   set i i + 1
  ]
  set i 1
  while [(i < index) and (item (index - i) turtle-id-list = item index turtle-id-list)] [
     set duration duration + 1
  ;; ]
   set i i + 1
  ]
  ;;show duration
  ]
  ]
end
```

Appendix B: Xiongnu and Mongol Empires

The following short paragraphs will provide a brief description and chronology of the Mongol and Xiongnu empires, along with an overview of empirical sources. Further, more detailed information and analysis is included throughout the chapters of this dissertation.

The Xiongnu Empire is the earliest nomadic polity recorded historically, and was centred on present-day Mongolia. The Xiongnu were some manner of nomadic tribal confederation that came to dominate other groups on the Mongolian and Northern Chinese steppes by the third century BCE. The founding of the Empire is traditionally given as 209 BCE, when Chinese sources assert that the *Chanyu* (or leader) known as Modu unified the steppe tribes into a centralized polity. The traditional end of the Xiongnu Empire is 48 CE, when Chinese sources recount a split within the Xiongnu polity into Northern and Southern branches. Both start and end dates are therefore somewhat arbitrary, and the Xiongnu feature heavily in contemporary Chinese written sources from the third century BCE to the mid second century CE. During this time they are recorded to have engaged in numerous wars with Chinese dynasties, particularly the Han (202 BCE – 9 CE). Written sources describe the military and social organization of the Xiongnu as based on a centralized, stratified decimal system, similar to the later Mongols and other Eurasian nomadic polities and militaries (*Shiji* 110). Their reliance on horse archery, nomadic animal husbandry, and diet are also in keeping with later descriptions of Eurasian nomads. The ethnic, genetic, and linguistic makeup of the ruling strata of the Xiongnu is a longstanding research topic, with most evidence indicating a diverse genetic and linguistic makeup featuring commonalities with both Turkic and Mongolian populations in the present day (Tumen, 2008).

Contemporary historical sources for the Xiongnu Empire consist entirely of Chinese texts, namely Sima Qian's *Shiji*, compiled in the early first century BCE. As a result, the accuracy of these texts has been the subject of much debate (Di Cosmo, 2014; Chin, 2010). Archaeologically, the Xiongnu are known from numerous elite tomb burials (Allard, Erdenebaatar, Batbold, and Miller, 2002), and a distinctive pottery style roughly overlapping with their historical chronology (Wright and Honeychurch, 2009). Additionally, Xiongnu campsites and permanent walled sites have increasingly been subject to archaeological surveys and limited excavation (Ramseyer and Volkan 2011; Davydova, 1968; Wright and Honeychurch, 2009), although a dearth of material evidence for Xiongnu nomadic social organization remains. While archaeological evidence concerning the social organization of nomadic herders during periods of empire is currently scarce, some avenues for future empirical research may be promising. In particular, the continued development of zooarchaeological research in Mongolia may make possible the tracing of herd animal life histories through isotopic analysis of teeth and bones (Makarewicz, 2017). Knowing which region an animal was born in and where it ended up may help elucidate patterns of network organization, when compared with modern empirical databases.

The Mongol Empire was founded by Genghis Khan (born as Temujin) in 1206 CE. Temujin, son of a Khamag Mongol tribal chieftain, successfully united the ethno-linguistic Mongol tribes active in present-day Mongolia, and subsequently conquered neighbouring nomadic groups. The Mongol polity would continue these conquests, eventually incorporating China and the Eurasian steppes all the way into Eastern Europe, forming the largest contiguous land empire in history by the late thirteenth century. Famed for their horseback archery, light cavalry tactics, siege engines, and mass slaughter of conquered populations, the Mongol Empire also facilitated trade and contact between disparate ethnic and religious groups between Europe and Asia. By 1294 CE the empire had fractured into multiple *Khanates*, and by 1368 CE, the Mongol Yuan Dynasty in China was overthrown by the Chinese Ming Dynasty (1368 – 1644 CE). While this marks the traditional end point of the Mongol Empire, various Mongol polities in Eurasia persisted into the seventeenth century.

Historical sources for the Mongol Empire consist of numerous primary texts produced by conquered or contemporary civilizations in the Middle East, Persia, China, and Europe. Additionally, the indigenous Mongol text known as the *Secret History of the Mongols*, produced shortly after Genghis Khan's death in 1227 CE, gives an account of his initial rise to power. Archaeological surveys of Mongol-era nomads in Mongolia are as sparse as for earlier periods, but more urban and walled sites have been studied and excavated, including the one-time Mongol capital city of Kharakhorum (Pohl et al. 2012).