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☐ SMALL BUSINESS ☐ MINORITY BUSINESS
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☐ IF THIS IS A PRELIMINARY PROPOSAL THEN CHECK HERE

TITLE OF PROPOSED PROJECT **EAGER: Modeling Coupled Herd and Household Dynamics in Pastoral Systems**

REQUESTED AMOUNT	PROPOSED DURATION (1-60 MONTHS)	REQUESTED STARTING DATE	SHOW RELATED PRELIMINARY PROPOSAL NO. IF APPLICABLE
$ 48,867	12 months	08/15/15	

THIS PROPOSAL INCLUDES ANY OF THE ITEMS LISTED BELOW
- ☐ BEGINNING INVESTIGATOR (GPG I.G.2)
- ☐ DISCLOSURE OF LOBBYING ACTIVITIES (GPG II.C.1.e)
- ☐ PROPRIETARY & PRIVILEGED INFORMATION (GPG I.D, II.C.1.d)
- ☐ HISTORIC PLACES (GPG II.C.2.j)
- ☐ VERTEBRATE ANIMALS (GPG II.D.6) IACUC App. Date ________ PHS Animal Welfare Assurance Number ________
- ☒ FUNDING MECHANISM EAGER
- ☒ HUMAN SUBJECTS (GPG II.D.7) Human Subjects Assurance Number 00006378 Exemption Subsection ________ or IRB App. Date 11/11/14
- ☐ INTERNATIONAL ACTIVITIES: COUNTRY/COUNTRIES INVOLVED (GPG II.C.2.j)
- ☒ COLLABORATIVE STATUS A collaborative proposal from one organization (GPG II.D.4.a)

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PROJECT SUMMARY

Overview:

This proposal for an Early-concept Grant for Exploratory Research (EAGER) offers an innovative hypothesis and method to examine a well-known phenomenon. Population models show that livestock populations have the potential to grow exponentially in pastoral societies, but the empirical evidence shows that population sizes are relatively stable. Until now the explanation has been that droughts, diseases and other disasters keep livestock populations in check. This project proposes an alternative explanation. It will examine whether and how demographic dynamics at the herd and household level constrain the growth of livestock populations in pastoral societies. The researchers will use multi-agent simulations to examine the impact of the domestic cycle of households on the demography of family herds and ultimately on regional livestock populations. The research will be conducted by an interdisciplinary team consisting of an anthropologist, ecologist, and a veterinary epidemiologist.

Intellectual Merit :

This project uses the conceptual framework of coupled systems to examine how the domestic cycle of households affects the demography of family herds, and ultimately the growth of livestock populations in pastoral societies. The hypothesis - herd and household dynamics keep livestock populations in check - is innovative, and so is the proposed methodology of using agent-based modeling to examine the non-linear dynamics of coupled demographic systems. This is a high-risk project because the simulations may show that herd and household dynamics have no significant impact on livestock population growth. However, there is also a high pay-off. If the simulations support the hypothesis that herd and household dynamics keep livestock populations in check, it will fundamentally change our understanding of pastoral systems. It will likely generate a number of large-scale projects that integrate empirical research and modeling studies to examine how herd and household dynamics shape and are shaped by economic development, management of natural resources, and the ecology of infectious diseases.

Broader Impacts :

This project makes two educational contributions by training undergraduate and graduate students in agent-based modeling and systems thinking. First, a graduate student will be trained in the use of agent-based models to study coupled demographic systems. The training involves building a conceptual model, coding in NetLogo, conducting sensitivity analyses, conducting simulations, analyzing data, and preparing the model and paper for publication using the standard ODD protocol. Second, educational materials for the classroom will be developed that can be used in courses on complex systems and agent-based modeling. The educational materials will be a representation of the agent-based model in the form of a board game in which students play the role of households that seek to maximize their herd size. An important component of the game is that students will modify its rules and chance elements to explore the system dynamics. Students will be able to systematically evaluate rule changes in the game using the agent-based model. The learning goal of the materials is that students start to think of research problems as systems that can be modeled.

RESEARCH PROBLEM

This proposal for an Early-concept Grant for Exploratory Research (EAGER) offers an innovative hypothesis and method to examine a well-known phenomenon. One of the dominant narratives about pastoral systems is that livestock populations have the potential to grow exponentially and destroy common-pool grazing resources. However, longitudinal and interdisciplinary research has shown that pastoralists are able to sustainably manage common-pool resources and that livestock populations are not growing exponentially (Coughenour et al. 1985; Little and Leslie 1999). The current explanation for limits on livestock population growth is that reoccurring droughts, diseases and other disasters keep populations in check (Ellis and Swift 1988). However, we hypothesize that demographic processes at the level of the herd and household may be other important mechanisms that keep livestock population growth in check. Our hypothesis is that there are two mechanisms at the herd and household level that explain why livestock populations grow much slower in pastoral systems than predicted by conventional models. The two mechanisms are: 1) the domestic cycle of the household, and 2) the herd-size threshold effect. To give a quick example, when a patriarch dies young and leaves his three sons with herds that are too small to support their respective families, there is a great chance that all three herds will disappear over time because the herds do not provide enough milk and the sons have to sell reproductive animals to feed their families. We propose to use multi-agent simulations to evaluate our hypothesis and examine whether and how these two mechanisms keep livestock population growth in check.

Pastoralists keep herd animals and this shape their lives – socially, culturally, economically, and ideologically. Herding animals is a commitment to a way of life in which the interdependence with their animals structures pastoralists' lives (Chang and Koster 1994). This interdependence is also evident in the relationship between human and animal demographic processes. Stenning (1958) explained how pastoralists seek an equilibrium between herd and household, which is a situation in which the herd provides enough milk to feed the household and the household provides enough labor to manage the herd. This equilibrium is dependent on the fertility of herd and household. In pastoral households there is often a strict division of labor in which men are responsible for the fertility of the herd and women are responsible for the fertility of the household. If there are fertility problems in either one, there is a potential imbalance or disequilibrium between herd and household, and this may lead to the dissolution of the household.

Pastoral households regularly go through periods of disequilibrium because of the domestic cycle in which households expand and dissolve. In the domestic cycle, households start with a husband and wife, expand with the addition of children (and sometimes additional wives), and dissolve as children marry and set up their own independent households. Because of the domestic cycle, households regularly experience times of labor shortage and/or shortage of food. Pastoral societies across the world have developed practices and institutions to resolve these imbalance between herd and household, for example through labor contracts and livestock exchanges. However, there are also imbalances between herd and household due to misfortunes, e.g., infertility problems may limit growth of the herd or an early death of a patriarch may lead to an untimely division of the family herd among heirs. One of the main risks of these unfortunate events is that the size of the family herd falls below a critical threshold.

Studies on pastoral wealth have shown that the dynamics of herd growth are to the advantage of pastoralists with larger herds and that those same dynamics work against pastoralists whose herd size is below a certain threshold (Bradburd 1982; Fratkin and Roth 1990; Lybbert et al. 2005). In other words, pastoralists with herd size above the threshold likely see their herds increase over time and pastoralists with herds below the threshold see their herd decrease in size (Grandin 1989; Fratkin and Roth 1990; Sieff 1999; Borgerhoff Mulder and Sellen 1994) and that this inequality persists over generations (Borgerhoff Mulder et al. 2010). This is due to two processes. First, if herd size is above a certain threshold, households are buffered against risks of droughts, diseases and other disasters (Bradburd 1982; Fratkin and Roth 1990). Second, if herd size is below that threshold, households have to sell reproductive animals to support their families and this limits the natural growth potential of their herds. Eventually, when herd size becomes too small, poor households have to leave the pastoral system and pursue other livelihood strategies like agriculture. This process has been called "sloughing off" (Barth 1961) and has been described for pastoral societies across the world (Fratkin and Roth 1996; Loftsdóttir 2008; Bradburd 1989). One of the consequences of the sloughing off of households is that animals are also removed from the pastoral system as impoverished households are selling more animals at local and regional livestock markets than other households. The great majority of livestock sold at these markets is either consumed locally or exported for consumption elsewhere.

Our hypothesis is that the herd and household demographic processes limit livestock population growth at the regional level. It explains how human populations grow but livestock numbers do not grow in pastoral areas across the world. Sandford (2006) has argued that there are too many people and too few livestock in the Horn of Africa and that this is a recent problem. We would argue instead that it is not a recent problem, but the result of a dynamic inherent in pastoral systems across the world.

Our project builds on the literature on population ecology where models of non-linear dynamics of coupled populations haven been developed, like the Lotka Volterra model that explains the dynamics of prey and predator populations (Turchin and Taylor 1992; Volterra 1931). However, our herd-household model is more complex than the prey-predator model as it considers how the structure and function of smaller social units shape the demographic processes of each other. Similarly, we expected to find some Allee effects, in which there is a positive relationship between individual fitness and population densities (Courchamp, Clutton-Brock, and Grenfell 1999; Stephens and Sutherland 1999; Allee 1931), which may be caused by different factors (Berec, Angulo, and Courchamp 2007). The Allee effect is similar to the herd size threshold effects described above. For example, Courchamp et al. (1999) show that populations can be at unstable states at low densities and stable states at high densities, which describes similar phenomena in family herds: small herds decrease in size because animals have to be sold to feed the household, while large herds do not grow as much in size because there is not enough labor in the household to manage the herds well.

RESEARCH PLAN

The goal of this research project is to build an agent-based model that will allow us to examine how the domestic cycle of the household affect the demographic processes of the family herd (and vice versa), and ultimately how this shapes livestock populations at regional and national levels. We will use empirical data from 25 individual family herds and households in the Far North Region of Cameroon (Moritz 2012; 2013) and a cross-cultural data set of herd demography (Dahl and Hjort 1976) to parameterize the agent-based model. The model will simulate the domestic cycle of an initial population of 100 households and the demographic processes of their family herds for 250 years (or 10 generations). We will run several experiments in which we investigate how the domestic cycle affects herd demography, for example by examining the effect of changes in age of first marriage, increase in the number of sons, increase in polygyny rates. We will also examine the sensitivity of the herd-size threshold for household viability on the growth of regional livestock populations, i.e., whether a lower threshold leads to stronger growth of livestock populations at the regional level.

We will build the model using NetLogo (Wilensky 1999) and will provide a description of the agent-based model following the Overview, Design concepts, Details (ODD) protocol that has been developed by Grimm et al. (2006, 2010), which is considered the golden standard in ABM protocol description. We will make the agent-based model publicly available via the OpenABM website (www.openabm.org) and will seek certification of the model by the Network for Computational Modeling in the Social and Ecological Sciences (CoMSES Net). The results from the sensitivity analysis will be published together with the model on the OpenABM website. By making the model publicly available and describing it clearly and accessibly using the ODD protocol, other researchers will be able to replicate our simulations and build on our research project.

We have used agent-based modeling successfully in other projects to examine other research questions about the dynamics of pastoral systems in the Far North Region of Cameroon, including how pastoralists manage common-pool grazing resources in a situation of open access (Moritz et al. 2015) and how pastoral mobility shapes foot and mouth disease epidemics (Kim et al. 2012), but we have also used these models to examine how to control the spread of infectious diseases by street dogs in India (Yoak and Hamilton 2014).

While agent-based models have been used to study the dynamics of pastoral systems before, including risk management through social strategies (Clark and Crabtree 2015; Aktipis, Cronk, and Aguiar 2011), management of grazing resources (Moritz et al. 2015; Rouchier et al. 2001), climate change and conflict (Kuznar and Sedlmeyer 2005; Hailegiorgis et al. 2010), however, the method has not yet been used to examine the demographic dynamics of two coupled systems of herd and household.

RESULTS FROM PRIOR NSF SUPPORT AND PREVIOUS RESEARCH

The project features a small team of experienced researchers who use a transdisciplinary approach to study complex social-ecological systems using a combination of ethnographic research, spatial analysis, and different modeling approaches. The researchers collaborate in two interdisciplinary labs at the Ohio State University together that have active research programs in Cameroon and are funded by the National Science Foundation. The Modeling Regime Shifts in the Logone Floodplain (MORSL) lab focuses on coupled systems in the Logone Floodplain. The Disease Ecology and Computer Modeling Laboratory (DECML) lab focuses on the ecology of infectious diseases, in particular the transmission of foot-and-mouth disease in pastoral systems. The team members come from different departments, including Anthropology, Preventive Veterinary Medicine, Evolution, Ecology and Organismal Biology, and Mathematics and have demonstrated a strong commitment to transdisciplinary research and training of graduate and undergraduate students by collaborating in innovative projects, including ones that have received prior funding from the National Science Foundation.

CAREER Pastoral Management of Open Access: The Emergence of a Complex Adaptive System, (BCS-0748594, 2008-2013), **Mark Moritz** (PI). This project examined how mobile pastoralists in the Logone Floodplain, Cameroon, sustainably manage common-pool grazing resources in a situation of open access. This interdisciplinary study integrated spatial and ethnographic analyses as well as multi-agent simulations and resulted in 12 publications and one agent-based model.

EEID: Livestock Movements and Disease Epidemiology in the Chad Basin: Modeling Risks for Animals and Humans, (DEB-1015908, 2010-2015), **Rebecca Garabed** (PI), Song Liang, **Mark Moritz**, and Ningchuan Xiao. This project seeks to understand the epidemiology of infectious diseases in the ecological context of networks of host movements. A specific goal is to understand transmission and maintenance of Foot and Mouth Disease Viruses (FMDV) in networks of livestock movements in the Far North Region of Cameroon. Graduate and undergraduate students from OSU and Universities of Maroua and Ngaoundére in Cameroon are being trained in the interdisciplinary study and modeling of the ecology of infectious diseases.

CNH: Exploring social, ecological, and hydrological regime shifts in the Logone Floodplain, Cameroon, (BCS-1211986, 2012-2016) **Mark Moritz** (PI), Michael Durand, **Ian Hamilton**, Bryan Mark, and Ningchuan Xiao. This interdisciplinary research project will focus on the impact of human activities and climate change on African floodplains. The goal is to develop an integrated computer model that simulates the dynamic couplings among social, ecological and hydrological systems of the Logone floodplain in Cameroon.

UBM – Institutional - BioMathletic Training: Creating the Next Generation of BioMath Stars at Ohio State University. (DBI-0827256, 2008–2013). **Ian Hamilton** (PI), Laura Kubatko, Yuan Lou, Elizabeth Marschall, Tony Nance, and David Terman. This grant funded an interdisciplinary undergraduate research program in mathematical and statistical biology at Ohio State University through a collaborative effort between the Departments of Mathematics, Statistics, and Evolution, Ecology and Organismal Biology. Three key components of the program include: (1) the exposure of a broad group of students to research problems in the mathematical biosciences; (2) curricular development to prepare students for advanced study in interdisciplinary fields; and (3) participation of undergraduates in an intensive and integrated research experience. The program also resulted in a number of papers co-authored by students and faculty mentors (e.g., Gerard, Gibbs, and Kubatko 2011; Wolfe et al. 2014; Moritz et al. 2015).

CONTRIBUTIONS

The project will yield several deliverables. First, we will write research articles that synthesize the literature on the problem of livestock population growth and discuss the results of our multi-agent simulations that examine how the domestic cycle affects family herd demography and livestock populations in pastoral societies. Second, we will publish the agent-based model at the OpenABM website (www.openabm.org) and seek model certification from the Network for Computational Modeling in the Social and Ecological Sciences (CoMSES Net). Third, if the simulation results support our hypothesis, we will develop a number of large-scale projects that integrate empirical research and modeling approaches to examine how herd and household dynamics shape and are shaped by economic development, management of natural resources, and the ecology of infectious diseases.

Intellectual Merit

The literature on pastoral systems is dominated by concerns about the Malthusian specter of livestock populations growing exponentially in a situation of limited natural resources (Malthus 1798; Ehrlich and Holdren 1971; Hardin 1968). However, we hypothesize that there is a build-in dynamic in the domestic cycle of pastoral households that limits the growth of livestock populations. This project uses the conceptual framework of coupled systems to examine how the domestic cycle of households affects the demography of family herds, and ultimately the growth of livestock populations in pastoral societies. The hypothesis - herd and household dynamics keep livestock populations in check - is innovative, and so is the proposed methodology of using agent-based modeling to examine the non-linear dynamics of coupled demographic systems. This is a high-risk project because the simulations may show that herd and household dynamics have no significant impact on livestock population growth. However, there is also a potential high pay-off. If the simulations support the hypothesis that herd and household dynamics keep livestock populations in check, it will fundamentally change our understanding of pastoral systems. It will likely generate a number of large-scale projects that integrate empirical research and modeling studies to examine how herd and household dynamics shape and are shaped by other economic, ecological, and political drivers. Understanding how demographic dynamics at the level of the household and family herd play out at the population level is thus only advancing our theoretical understanding of the ecology of pastoral societies, but also advance our understanding of the collapse of societies in history and prehistory (Turchin 2009; Axtell et al. 2002).

Broader Impacts

This project makes two educational contributions by training undergraduate and graduate students in agent-based modeling and systems thinking. First, we will train a graduate student in the use of agent-based models to study research problems in coupled demographic systems. The training involves building a conceptual model, coding in NetLogo, conducting sensitivity analyses, conducting simulations, analyzing data, and preparing the model and paper for publication using the (ODD) protocol (Grimm et al. 2006; 2010).

Second, educational materials for the classroom will be developed that can be used in courses on complex systems and agent-based modeling. The educational materials will be a representation of the agent-based model in the form of a board game in which students play the role of households that seek to maximize their herd size. An important component of the game is that students will modify its rules and chance elements to explore the system dynamics. Students will be able to systematically evaluate changes in the game using the behavior-space function of NetLogo, which allows students to run experiments with multiple simulations. The goal of the materials is that students learn to think of research problems as systems that can be modeled.

The use of games in education is gaining ground (Evensen 2009; Salter 2013), in what has been called the 'gamification of learning' (Kapp 2012). Agent-based models are in many ways like board games and lend themselves well for innovative learning strategies in the classroom. Agent-based models of social-ecological systems have already been translated into participatory multi-agent simulations in which stakeholders play the roles of the different agents in the model, particularly in the context of natural resource management (Bousquet et al. 2002; D'Aquino et al. 2003; Bah et al. 2006). However, their use in the classroom has not been well developed, even though they offer great opportunities for students to learn about complex systems, system dynamics, and agent-based modeling. A good example that we seek to emulate is the ERAMAT board game about Maasai pastoralists that researchers at James Madison University have developed to encourage system thinking among their students (Mayiani 2013).

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