Model Description

The Agent-Based Model (ABM) that we developed to examine the dynamics of herd growth is part of a larger study that examines the coupled dynamics of herds and household demography in African pastoral systems. ABMs are commonly used tools to examine the dynamics of complex systems, but they can also be used to simulate demographic dynamics in which stochasticity plays an important role. We used the model to examine the role of scale (herd size) stochasticity (in mortality and fertility) on herd growth in African pastoral systems.

We built the model in NetLogo (version 5.05) (Wilensky 1999) and will publish the model at OpenABM (www.openabm.org) (Janssen et al. 2008). We have requested that our model be certified by the Network for Computational Modeling in the Social and Ecological Sciences (CoMSES Net)(Rollins et al. 2014). The model description follows the ODD (Overview, Design concepts, Details) protocol (Grimm et al. 2006; Grimm et al. 2010) to provide a clear and comprehensive description of our model below.

In designing our ABM we used a strategy called pattern-oriented modeling (POM) in which the goal is to use multiple patterns observed in pastoral systems to guide the design of the model (Grimm et al. 2005). We derived the mortality, fertility, and offtake rates from a review of the literature (notably, Dahl and Hjort 1976; Wagenaar, Diallo, and Sayers 1986; Sutter 1987). Our model is relatively simple but captures the key dynamics of the family herds in African pastoral systems in which herds consists of animals in different age and sex classes (e.g., calves, heifers, bullocks, cows, bulls) that each have different mortality and offtake rates. The model is non-spatial – we model only the herd and not the environment – and there are thus no density-dependent feedbacks.

Purpose: This model was designed to examine the dynamics of cattle herds in African pastoral systems, in particular to examine the role of scale (number of animals in a herd) and stochasticity (in mortality and fertility rates) on herd growth in African pastoral systems. The hypothesis is that herd size may increase and decrease due stochasticity in mortality and fertility rates and that when herd size is below a certain threshold there is a higher risk that the herd will "die" or cease to exists. The effect of stochasticity does not threaten herds that are above the herd-size threshold.

Entities, state variables and scales: The model has only one entity: a family herd of cattle. The herd consists of animals in different age and sex classes (e.g., calves, heifers, bullocks, cows, bulls) that have different mortality and offtake rates. The model is non-spatial – we model only the herd and not the environment – and there are thus no density-dependent feedbacks. The time steps in the model are six-month seasons – rainy and dry – that make up one year.

Process overview and scheduling: The simulation starts in the rainy season. In the rainy season animals increase one-year in age and cows have a chance to reproduce. In the dry season animals have chance to die or be sold. Animals in different age and sex classes (e.g., calves, heifers, bullocks, cows, bulls) have different probabilities of dying and being sold. These probabilities have been derived from our literature review.

Design Concepts: The basic principle or question of this model is that stochasticity in fertility, mortality, and offtake rates and economies of scale (herd size threshold) can lead to different outcomes in terms of herd size and composition. The emergent property is herd size and composition. The objective of herds is to grow in size. Stochasticity and scale (herd size) are critical components of the model as they shape the emergent properties of herd size and composition. There is no adaptation, learning, prediction, collectives or interaction in the model. In the simulations we can conduct observations of the following data: herd size, herd composition, and growth rate.

Initialization: The size of the herd can be set at the start of each simulation. The composition of the herd – number of animals in each of the age and sex classes – is randomized but follows a distribution that de derived from our literature review. The mortality, fertility, and offtake rates are probabilistic and also derived from our review.

Parameters		**Initial values**	
Fertility rates			
	Cows	0.7	Cows have a 70% chance of calving
Mortality rates			
	Calves	0.2196 (0.0930)	Calves have about 22% chance of dying
	Heifers	0.0606 (0.0146)	Heifers have about 6% chance of dying
	Bullocks	0.0606 (0.0146)	Bullocks have about 6% chance of dying
	Cows	0.0572 (0.0346)	Cows have about 6% chance of dying
	Bulls	0.0572 (0.0346)	Bulls have about 6% chance of dying
	Older cows	0.6950 (0)	Older cow have about 70% chance of dying
Offtake rates			
	Calves (f)	0.0008 (0.0007)	Calves have a very small change of being sold
	Calves (m)	0.0026 (0.0020)	Calves have a very small change of being sold
	Heifers	0.0210 (0.0190)	Heifers have about 2% change of being sold
	Bullocks	0.0280 (0.0120)	Bullock have about 3% change of being sold
	Cows	0.0085 (0.0080)	Cows have less than 1% change of being sold
	Bulls	0.0110 (0.0040)	Bull have about 1% change of being sold
	Older cows	0.0049 (0.0020)	Old cows have a very small change of being sold
Herd composition at initiation			
	Calves (f)	10.06 (2.54)	Female calves are about 10% of the herd
	Calves (m)	8.95 (2.76)	Male calves are about 9% of the herd
	Heifers	20.60 (6.18)	Heifers are about 21% of the herd
	Bullocks	14.73 (5.64)	Bullocks are about 15% of the herd
	Cows	34.49 (8.45)	Cows are about 34% of the herd
	Bulls	4.04 (3.11)	Bulls are about 4% of the herd
	Older cows	2.61 (0.46)	Older cows are about 3% of the herd

Input data: We used data derived from an extensive literature review to derive parameters for herd composition, mortality rates, fertility rates, and offtake rates (notably, Dahl and Hjort 1976; Wagenaar, Diallo, and Sayers 1986; Sutter 1987).

Submodels: There are four submodels. The first one increases the age of all the animals in the rainy season. The second one gives cows a chance to reproduce in the rainy season. In the third one animals have a chance to be sold and in the fourth one animals have chance to die. After each submodel, the herd composition – the number of animals in the different age and sex classes – is updated.

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