Ecological Modelling 352 (2017) 113–127

Contents lists available at ScienceDirect

Ecological Modelling

journal homepage: www.elsevier.com/locate/ecolmodel

Modeling Boran cattle populations under climate change and varying carrying capacity

Samuel Tuffa[a,b,*], Anna C. Treydte[b,c]

[a] Yabello Pastoral and Dryland Agriculture Research Centre, P.O. Box 85, Yabello, Ethiopia
[b] University of Hohenheim, Department of Agroecology in the Tropics and Subtropics, Garbenstr. 13, 70599 Stuttgart, Germany
[c] Nelson Mandela African Institution of Science and Technology, Arusha, Tanzania

ARTICLE INFO

Article history:
Received 10 March 2017
Accepted 10 March 2017

Keywords:
Drought scenario
Demographic stochasticity
Population trajectory
Ethiopia
Livestock
Rangeland

ABSTRACT

Cattle populations in semiarid rangelands are currently facing severe threats due to erratic rainfall and increasing drought frequencies, leading to poor vegetation quality and a consecutive cattle population decline. However, little is known about how particular sex- and age-cohorts of cattle respond to these environmental threats and on how sales influence population trajectories. In the Borana rangelands, southern Ethiopia, much detailed information is available on the Boran cattle (*Bos indicus*) population demographics, a special breed, which is highly adapted to semiarid environmental conditions. We collected data on Boran cattle demographic and environmental factors such as carrying capacity, market values, and herdersí management decisions. We generated stochastic models and assessed the future development of cattle population trajectories under four different drought scenarios. We analyzed changes in age- and sex-cohorts of cattle populations by introducing different drought frequencies and their effect on vital rates, carrying capacity, and sales. We calibrated the model on the basis of a 12-year data set of a neighboring Boran cattle group. In our population model, the cattle numbers significantly declined after 18 years under the higher drought frequency scenarios (scenarios 3 and 4) while numbers remained high over 100 years for the lower drought frequency scenarios 1 and 2. The sale of senescent and adult females most strongly (77%) affected population trajectories, and model outcomes were most sensitive to sale rates of senescent, adult, and juvenile females compared to vital rates and male sale rates of the population. Management should focus on lowering herd crashes through increasing sale of mature males, which increases feed availability to females during drought years in the Ethiopian Rangelands. Drought early-warning systems and market information must be strengthened so that pre-planned selling of cattle can be realized for a sustainable use of the animal resource.

1. Introduction

1.1. The Boran cattle and their habitat

About 58% of sub-Saharan Africa's cattle population is found in eastern Africa, the largest number of which is within Ethiopia, with 56.7 million head of cattle (CSA, 2015; Otte and Chilonda, 2002). Cattle production plays a significant role in Ethiopia's economy, contributing to about 40% of the annual agricultural output and 15% of the gross domestic product (Haile et al., 2011). The Boran cattle, which are grouped under the East African shorthorn cattle known as zebu (*Bos indicus*), inhabit the Borana plateau of southern Ethiopia, semiarid and arid lands of northern and rift valley provinces of Kenya, and western Somalia and Jubaland of southern Somalia (Rege and Tawah, 1999; Fig. 1).

Based on the total area of the Borana zone (Riche et al., 2009) and the total livestock population numbers (CSA, 2015), we calculated the latest livestock density of the area at 24.2 TLU (Tropical Livestock Unit) per km^2 (with 16.5 TLU/km^2, 2.7 TLU/km^2, 1.8 TLU/km^2, 1.2 TLU/km^2, and 2 TLU/km^2 of cattle, goat, sheep, donkey, and camel, respectively, based on FAO (1991) TLU conversion factors). This is under the assumption that all areas are accessible for grazing, except settlement areas, which overestimates cattle grazing areas. This livestock density value is similar to the estimated density of 23.5 TLU/km^2 (Homann et al., 2008), but much higher than

* Corresponding author. Present address: University of Hohenheim, Department of Agroecology in the Tropics and Subtropics (490f), Garbenstr. 13, D-70599, Stuttgart, Germany.

E-mail addresses: satukada@gmail.com (S. Tuffa), anna@treydte.com (A.C. Treydte).

http://dx.doi.org/10.1016/j.ecolmodel.2017.03.009
0304-3800/

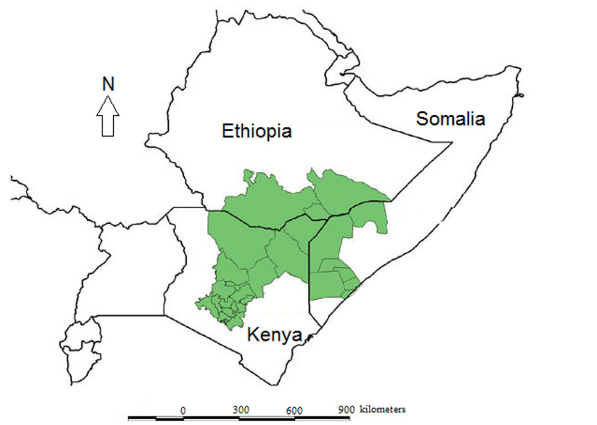

Fig. 1. Core habitat (green color) of the Boran cattle in east Africa in 2008. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Source: http://agtr.ilri.cgiar.org/agtrweb/documents/Maps/BreedMaps/boran/boran_dstrb.jpg.

estimates of 4–16 TLU/km^2 (Coppock, 1994) for the Borana rangelands.

Currently, cattle mortality rates due to drought have reached as much as approximately 70% (Forrest et al., 2014). Little is known about how the Boran cattle population reacts to such drastic dips in population sizes and how this stochasticity would affect population trajectories in the long run. Further, attempts to predict the pastoralists' decisions on selling animals as well as death rates caused by drought occurrence have been rare (Lybbert et al., 2000). Predictive age- and sex-cohorts modeling is of high interest in Borana as it can highlight how mortalities and sales strongly influence the herd development and resilience following drought (Upton, 1989).

1.2. Boran cattle adaptation to their environment and their current threat

The Boran cattle are more productive than other local cattle breeds, with quite high rates of reproduction, milk yield, and low mortality rates (Cossins and Upton, 1988a). The Boran cattle are adapted to the arid and semiarid environment of East Africa (Haile et al., 2011), particularly the semiarid Borana rangelands (Homann et al., 2004). Local herders such as Borana pastoralists strongly depend on these animals for their daily livelihoods (Coppock, 1994; Kamara et al., 2005; Zander et al., 2009a; Zander and Drucker, 2008); hence, cattle are the most important livestock species in the Borana pastoral system of Ethiopia and other semiarid regions (Forrest et al., 2014; Kahi et al., 2006; Tolera and Abebe, 2007). Boran cattle strongly contribute to the food security of the rural poor in areas where other agricultural land use systems would not be ecologically sustainable. However, the total dependency on animals has recently come under threat due to recurrent drought and human population pressure (Zander et al., 2009b) as well as increased occupation and privatization of preferred grazing land (Coppock, 1994; Desta and Coppock, 2002). Consequently, Boran cattle have recently undergone drastic population crashes (Angassa and Oba, 2007), which highlights the fragility and the lack of knowledge of their persistence within an increasingly unpredictable environment due to climate change. Further, the Boran breed is under threat from genetic erosion due to the admixture of other breeds that are used for restocking after drought (Alemayehu et al., 2002). To keep the Boran breed as an essential aspect of a sustainable animal production system, Zander et al. (2009b) suggested *in-situ* conservation that must be initiated to maintain the traditional social structures and their livestock. However, little is known about the resilience of Boran cattle and their population dynamics in the face of increasing drought due to climate change (He et al., 2014). Our study wanted to shed light on the population dynamics of this highly threatened but important breed in the Borana rangelands under different drought scenarios.

1.3. Carrying capacity of the Borana rangelands

Estimation of carrying capacity is an important requirement for understanding the long-term sustainability of rangelands and the survival probability of the livestock populations inhabiting the area. The potential carrying capacity is usually determined by the availability (quantity and quality) of feed and the stocking rate, which provides the maximum sustainable livestock yield (Eltringham, 1979 cf Fritz and Duncan, 2004). In semiarid rangelands, such as the Borana system, a fixed carrying capacity as predicted in a stable equilibrium model is unlikely (Gillson and Hoffman, 2007) because this does not take the spatial heterogeneity and climate variability of semiarid rangelands into consideration. Hence, equilibrium (density-dependent) models should be replaced by non-equilibrium (density-independent) models as emphasized by rangeland management today for most semiarid rangelands (Vetter, 2005). The latter employs opportunistic management strategies and mobility rather than estimating a stable carrying capacity. In low-rainfall years, primary productivity is limited and animals will compete for the little forage available (Gillson and Hoffman, 2007). The population cannot persist indefinitely within a certain environment without density dependence occurring (Godfray, 2009). Understanding stochastic population dynamics requires an understanding of the relations between density-dependent (demographic stochasticity) and density-independent (environmental stochasticity) factors.

In semiarid grazing systems, like Borana rangelands, environmental variability has a primary effect on herbivore population dynamics (Illius and O'Connor, 2000). Mobility and resting of pasture had been the main strategy used to manage risk and use the range resources communally and efficiently (Flintan et al., 2011). However, Borana pastoral herd mobility has been weakened (Homann et al., 2004), which has led to rangeland degradation (Nyangito et al., 2008). A recommended stocking strategy under variable rainfall must be urgently provided, which can be achieved by simulation modeling for the current system, assuming no possibility for mobility (Vetter, 2005). In the Borana rangelands when stocking rates are high, the herd is most vulnerable to drought-induced mortality (Desta and Coppock, 2002), which can impose even higher damage to available key plant resource areas (Illius and O'Connor, 1999). The pattern of cattle mortality has closely followed rainfall variability and drought-induced cattle mortality has been caused by pre-drought cattle body condition as a result of feed scarcity (Angassa and Oba, 2007; Starfield, 1990).

In such an unstable system, stochastic models will help to predict scenarios in which rainfall variability could impact population sizes (Otto and Day, 2007). While many population models take carrying capacity into account, which limits population growth (Schärrer et al., 2014), few studies have acknowledged the varying nature of a rangelandís carrying capacity (Campbell et al., 2006; Walker et al., 1987), depending on environmental factors and increasing herbivore population pressure (Angassa and Beyene, 2003; Halley and Iwasa, 1998). Hence, there is an urgent need to quantify and balance available resources and grazing pressure to minimize drought-induced losses and consecutive rangeland degradation.