Pre- and Post-Degradation Management of Rangelands: Implications for Sustainable Management

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Abstract
Rangeland degradation directly affects livestock production, resulting in food insecurity and ecological instability. A shift in vegetation from grass to woody plants has severely affected cattle production in Ethiopian rangelands. Those grass species that are perceived by the pastoralists as highly palatable and desirable are currently decreasing in both quality and quantity. A reason for this decline has been claimed to be degradation owing to overgrazing and climate change. While appropriate management of livestock density in rangelands is essential for sustainable production and grassland ecosystem health, the management of dryland ecosystems is mired in controversy due to the complexity of the ecosystem. This region is categorized as a non-equilibrium environment, though at times it experiences equilibrium characteristics, which makes the management of the Borana rangelands highly complex. A better understanding of grass productivity and its controlling factors in modern savanna ecosystems could be a key to understanding the productivity of savannas and to predict responses to future climatic changes. The development of effective management strategies for responding to climatic variability is often impeded by the lack of a systematic framework for analyzing livestock stocking policies and management practices. Further, effective decision making requires an understanding of the important biotic and abiotic components of rangeland systems, such as the response of rangeland vegetation to environmental stressors: climatic change and herbivorous population dynamics. Previous vegetation studies of the Borana rangelands focused mainly on taxonomic descriptions and rangeland condition assessments. Reseeding of degraded rangelands is a potential management option in eastern African rangelands to enhance the resilience of rangelands. Therefore, it is high time to understand how the native perennial grass individuals respond to increased herbivory under higher drought frequency after reseeding.

Introduction
Resilience and sustainable use of rangelands depend on pre- and post-degradation management. Sustainable rangeland use can be achieved by maintaining its productivity. Herbivory and drought are the two main stressors (Acharya, Rasmussen, and Eriksen 2012; Baruch and Jackson 2005) reducing the primary production of rangelands (Fay et al. 2000) and hence, related ecosystem services. In semiarid rangelands, herbivore populations can be kept at their varying carrying capacity through encouraging animal harvesting when forage production decreases to avoid rangeland degradation as pre-degradation management. Degraded areas can also be restored through reseeding with appropriate local species to enhance rangeland resilience, particularly given the current and projected impacts of climate change to cope with the rapid disappearance of species and ecosystem services. However, it is unclear how grass species currently used in the reseeding respond to the combined effects of herbivory and drought and how grazing cattle populations change under the current and the predicted increasing drought frequency.

The Borana rangeland, Ethiopia, had been highly productive and an important forage resource for livestock. However, its productivity has been reducing as a result of degradation, mainly caused by recurrent drought, land-use change, livestock overgrazing and bush encroachment (Angassa 2002; Gemedo-Dalle, Maass, and Isselstein 2006c, 2006a, 2006b; Haile, Assen, and Ebro 2010; Tefera, Snyman, and Smit 2007). Reseeding as a post-degradation management strategy for the restoration of degraded rangelands and their ecosystem services has been urgently recommended. This is particularly urgent as in the face of the human population increase a high demand for meat as a protein source is expected (FAO 2003) and mitigation strategies to capture CO_2 from the atmosphere (Cook, Ma and Brain 2013) in the face of climate change are needed. Rangeland restoration as post-degradation management through reseeding of palatable grass species can improve both structural and functional vegetation characteristics, which will also enhance ecosystem services. In Borana, particularly two grass species (*C. ciliaris* and *C. gayana*) are important for cattle productivity as they are highly palatable and native to the study area. These two species further have vast global coverage, highlighting their potential for post-degradation rangeland management.

As cattle have been referred to as the true "economic engine" of the system, emphasizing the sustainable productivity of cattle is a crucial aspect (Coppock et al. 2014). For pre-degradation management, we hence modeled cattle population dynamics under varying carrying capacity and stochastic environmental conditions, which has never been done before in the semi-arid Borana rangeland ecosystem. This region is categorized as non-equilibrium environment, though at times it experiences equilibrium (Desta and Coppock 2002), which makes the management of the Borana rangelands highly complex. We combined the two concepts, and readers may refer to other papers (Desta and Coppock 2002; Sasaki 2010; Vetter 2005) to understand how the two concepts integrate into a semiarid ecosystem. Modeling cattle population dynamics is essential for capturing changes in population responses to climate change in a variable social and ecological environment at a large temporal scale.

The lifestyle of people in the pastoral environment is dictated by two major concepts. In the dryland ecosystem, the driving factor of primary production is the climate while in humid ecosystems, herbivory and anthropogenic activities drive primary production (Fig. 1).

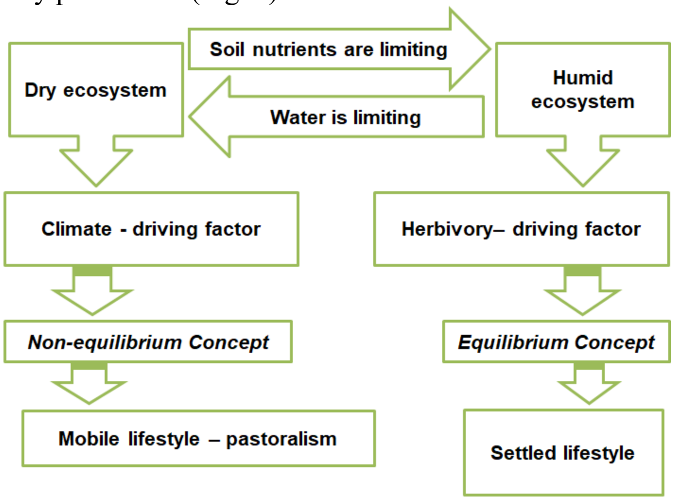

Figure 1 Schematic representation of characteristics of the pastoral environment

Methods and Study Site

Responses of two dominant perennial grass species (*Cenchrus ciliaris* and *Chloris gayana*) frequently used in reseeding to simulated herbivory and rainfall regimes were assessed in pot and field plot experiments on young grasses. Further, we addressed how herbivory influences biomass allocation and C storage in mature tufts of these two native grass species under ambient rainfall conditions (for details see Tuffa et al. 2017, 2018).

Further, we developed and evaluated a novel Boran cattle population trajectory model integrating non-equilibrium and equilibrium concepts by building stochasticity into the model, allowing droughts to occur randomly within model runs in Berkeley Madonna software, with different long-term average drought frequencies scenarios (See also Tuffa & Treydte 2017 for detailed algorism of the model).

Results

The responses of biomass and C storage showed contrasting results across grass age as well as species. Generally, the clipping/grazing strongly triggered the belowground biomass allocation and enhanced C storage of *C. ciliaris* tufts while *C. gayana* tufts differed only slightly (Tuffa et al. 2017). In both mature grass species, however, clipping highly reduced aboveground biomass and C storage. In contrast, for the young grass seedlings, moderate and light clipping triggered regrowth and, hence, biomass and C storage in both above- and belowground parts. Meanwhile, reduced irrigation showed the same effect on biomass allocation and C storage in both study grass species. Lower irrigation highly reduced biomass and C in both above- and belowground parts (results are published and a reader may refer to Tuffa et al. 2017, 2018).

The model result indicated that the overall population size was highly sensitive to the sale of the juvenile as well as mature female cattle when drought hit the system (Tuffa and Treydte 2017).

Discussion

Our experiments established the first interactive effect of herbivory and rainfall on the biomass allocation and C storage of mature and young grasses in the semiarid Borana rangelands, Ethiopia. Clipping/grazing further highly enhanced the belowground biomass and carbon storage, boosting the ability of grass to compete for water and nutrients (Engel et al. 1998). The enhanced belowground biomass due to herbivory was also observed in Spain (Garcia-Pausas et al. 2011), Argentina (Larreguy, Carrera, and Bertiller 2014; Pucheta et al. 2004) and the Netherlands (Veen et al. 2014). This might be attributed to the reallocation of resources away from the site of damage into storage organs after herbivory which reduces the chance of resources being lost to herbivores (Gómez et al. 2010).

In contrast to mature grasses, the aboveground biomass and carbon storage in newly established study grasses was higher under moderate clipping compared to the control, which concurs with studies from the Netherlands (Veen et al. 2014), USA (Frank, Kuns, and Guido 2002) and in Mediterranean rangelands (Herrero-Jáuregui, Schmitz, and Pineda 2016). The enhanced aboveground biomass might be attributed to greater photosynthetic capacity in younger leaves after clipping compared to the unclipped control (Nowak and Caldwell 1984) and the overcompensation phenomenon (McNaughton 1983). Clipping further stimulated the belowground biomass of newly established grasses, which concurs with many studies (Helland 1998; Piñeiro et al. 2010; Pucheta et al. 2004; Smoliak, Dormaar, and Johnston 1972; Veen et al. 2014). Knowledge of these interacting factors is deemed essential for policymakers to develop a sound rangeland management policy that can enhance the C storage potential of degraded rangelands under climate change and, hence, the mitigation and adaptation strategies through improved post-restoration of degraded areas.

The stochastic population modeling under varying carrying capacity in the face of increasing drought scenarios indicated the livelihood challenges ahead for the pastoral community. For sustainable use of the rangeland resources, cattle populations must be limited timely and grass productivity must be enhanced as pre-degradation management of rangelands. Management should focus on lowering cattle herd crashes through the increasing sale of mature males that increases feed availability to females during drought years in the Borana Rangelands as well as enhancing the resilience capacity of rangelands through maintaining healthy conditions and restoring degraded areas (Sternberg et al. 2000; Tuffa and Treydte 2017). Further, drought early-warning systems and market information must be strengthened so that pre-planned selling can be realized for the fair and sustainable use of the animal resource. Pastoralists would benefit from this approach as they could sell their animals before drought wipes out their cattle in huge numbers. The results of this study can be used by policymakers to develop an appropriate strategy that helps the pastoral community to be proactive in coping with drought by reducing its impacts on the cattle population

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