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Research Paper

Rangeland vegetation diversity and transition pathways under indigenous pastoralist management regimes in southern Ethiopia

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ABSTRACT

Woody plant encroachment on the rangelands has been identified as a major threat to subsistence livestock herding globally. Among various determinants, indigenous pastoralist management regime strongly affects rangeland vegetation dynamics at a fine spatial scale. However, mechanisms of how different vegetation functional groups respond to livestock grazing under complex indigenous management regimes are yet to be explored. By integrating plant survey with GPS-tracking of cattle movement, we investigate rangeland vegetation diversity and spatial distribution of grazing intensity in an indigenous pastoralist community in southern Ethiopia, and explore patterns of plant-livestock interaction. The results indicate that vegetation structure and composition are significantly different under three distinct indigenous land use types. Spatial distribution of grazing intensity is heterogeneous under indigenous rangeland management regimes. Both plant diversity and richness are lower given moderate grazing intensity. While herbaceous cover is generally lower at locations with heavier grazing pressure, moderate grazing intensity is associated with the lowest woody cover. The findings imply that maintaining moderate grazing intensity helps to balance pastoralist livelihoods and resource sustainability.

1. Introduction

Savanna ecosystems, defined by the co-dominance of trees and grasses, cover one-fifth of the world's land surface and are of great ecological and socioeconomic importance (Riginos, 2009). These lands support a large number of pastoralists whose livelihoods primarily depend on forage resources (Wiegand et al., 2006). However, in recent decades, species composition and vegetation structure of savanna have gone through significant transitions towards greater woody plant cover (Anadón et al., 2014; Briggs et al., 2005; Buitenwerf et al., 2012; Daryanto et al., 2013; Gartzia et al., 2014; Gillson and Hoffman, 2007; Naito and Cairns, 2011). Establishment of woody plants on open rangelands has strong impacts on ecosystem processes, influencing nutrient cycling, carbon sequestration, and eco-hydrology, while leaving edaphic legacies that would persist even if woody plants are removed (Rundel et al., 2014).

On the rangelands of Borana Zone in southern Ethiopia, bush encroachment, namely the proliferation of woody plants including shrubs and trees, has been intensifying over the past decades (Angassa, 2014). Increase in woody plant density results in impenetrable thickets and suppresses the growth of grasses and other herbs that are valuable for cattle grazing, thus reducing rangeland carrying capacity (Dalle et al., 2005). Such bush encroachment process has tremendous impact on a large and rapidly growing population on the rangelands. To Boran pastoralists whose livelihoods primarily depend on subsistence cattle herding, bush encroachment is likely to threaten their food security (Coppock, 2016).

Specific factors determining vegetation states and transition pathways have long been a matter of debate. Precipitation, fire, grazing, soil, and atmospheric CO_2 concentrations have all been described as crucial in the origin, maintenance, and shift of vegetation in tropical rangeland systems (Archibold, 1995; Bourlière, 1983; Cole, 1986; Huntley and Walker, 1982; Mistry, 2000; Buitenwerf et al., 2012; Eldridge et al., 2011; Wigley et al., 2010). However, within a single climate zone, complex mosaics of open and closed canopy rangelands can exist, suggesting that controls other than climate are important at a finer spatial scale (Beard, 1953; Bowman, 2000). Among them, grazing and fire are considered critical factors that contribute to patches of rangelands with different compositional and structural characteristics (McNaughton, 1983, 1985). This is particularly true in the Borana rangeland system in which pastoralists play a significant role in changing disturbance factors. For centuries, their active use of fire was

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critical to maintain an open landscape with scattered trees and shrubs. The official ban on fire, which took effect since the 1970s, removed an important disturbance factor in regulating woody plant growth (Angassa and Oba, 2008). Although the ban was lifted in the 2000s, the effect of fire on controlling woody plant encroachment has been diminished during the decades of fire suppression (Gordijn et al., 2012), leaving grazing as the primary disturbance factor at the local level.

Despite the significance of grazing in shaping rangeland vegetation dynamics, its fine-scale quantitative assessment is largely missing. Grazing intensity was commonly derived from secondary sources such as livestock census data (Allred et al., 2012; Staver et al., 2009), calculated from comparing the difference of biomass inside and outside enclosures (Lázaro et al., 2016), or inferred from the percentage of consumed forage (Ash et al., 2011). Distance from settlement or enclosure was also used as indicator of grazing intensity, which was qualitatively described as high, medium, and low (Angassa, 2014; Tefera et al., 2007). Consequently, pastoralists' spatial resource utilization pattern is generally summarized as a piosphere (Lange, 1969), which consists of a "sacrifice zone" that is subject to severe resource exploitation, followed by a "transition zone" that shifts into a nearly homogeneously grazed zone, which gradually merges into undisturbed natural vegetation that is hardly influenced by grazing. All these assessments, however, could hardly capture fine-scale spatial variation of grazing intensity, which impedes our understanding on how rangeland vegetation evolves given different management strategies.

The issue of lacking quantitative measurement of grazing intensity results in poor understanding of inherently complex indigenous management of livestock herding in Borana. Rather than rushing to the greenest patch of rangelands, pastoralists have specific rules to regulate spatio-temporal access to forage resources within their community (Wario et al., 2016). Therefore, knowledge on fine-scale grazing intensity distribution is necessary to understand plant-livestock interaction in indigenous pastoral systems. In addition, plant surveys also need to be guided by local pastoralists, because outsiders hardly know how pastoralists practice livestock herding in their communal rangelands. Without such local ecological knowledge, there is a lack of solid evidence to infer the relationship between grazing and vegetation characteristics, and generate any effective rangeland management policy.

The objective of this research is to investigate vegetation diversity and transition pathways under indigenous herding management regimes in southern Ethiopia. By conducting vegetation survey and GPS-tracking of livestock movement in a pastoralist community, we aim to 1) evaluate how species composition and vegetation structure vary under three local land use types; 2) explore how grazing pressure is distributed spatially within the home range of tracked cows; and 3) examine variation in vegetation composition and structure along the grazing intensity gradient in the pastoralist community.

2. Methods

2.1. Study site

Borana Zone is located in southern Ethiopia, with elevation varying from 500 m to 2500 m. Its climate is arid or semi-arid, with relatively cool annual temperatures (19–24 °C) and a mean annual rainfall ranging from 300 mm in the lowland up to 1000 mm in the highland. Intra-annual precipitation is bimodal, with 60% occurring during the primary rain season (April-May) and 30% during the secondary one (October-November). Local livelihood is primarily supported by subsistence livestock herding, with a total livestock population fluctuating around one million heads (Coppock, 2016).

The major vegetation type in Borana is tropical savanna, with a spectrum of woody plant cover ranging from 5% to 75% (Coppock, 1994). The Borana rangelands were considered sustainable even until several decades ago, characterized by surplus stands of perennial grasses (Cossins and Upton, 1987). The issue of woody plants encroachment was first identified in Borana in the 1970s, when the government banned the use of fire, and human and livestock populations began to increase and concentrate around newly-developed water points. As competition from grasses and fire disturbance was largely removed, woody plants proliferated under favorable conditions, and thereafter, dominated the landscape (Coppock, 1994). Previous studies revealed that common woody genera include *Acacia*, *Commiphora*, *Combretum*, *Cordia*, *Terminalia*, *Boswellia*, *Cadaba*, *Grewia*, *Delonix* and *Boswellia*, while common herbaceous genera include *Cenchrus*, *Cynodon*, *Themeda*, *Pennisetum*, *Enteropogon*, *Sporobolus*, *Panicum*, *Chloris*, *Aristida*, *Heteropogon* and *Hyparrhenia* (Angassa and Baars, 2000; Gemedo-Dalle et al., 2005).

We conducted this study in a pastoralist community in Sarite (37°35′ – 37°44′E; 4°44′ – 4°56′N), which is 65 km west of Yabello, the administrative center of Borana Zone (see Fig. A1 in Appendix A in Supplementary material). The settlement is established on the edge of Rift Valley at an elevation around 1000 m. Pastoralists are largely sedentarized in this area, and they herd livestock in nearby rangelands throughout the year (Liao et al., 2017). The presence of mosaics of grassland and woodland in this community provides a remarkable opportunity to investigate the relationship between vegetation characteristics and indigenous rangeland management regime.

2.2. Vegetation survey

In order to measure plant species composition, richness, and cover in the herbaceous, shrub, and tree layers, we conducted vegetation survey in three different local land use types. The first type, known as *mata tika* in the local language, is the major grazing area where most livestock herding practices occur. The second type, known as *kalo*, is rangeland enclosure composed of fenced patches of communal rangeland reserves saved for dry-season consumption. The third type, known as *qaye*, is the area around settlements where villages and crop fields are established.

We carried out systematic transects in our survey in July, 2013, which was six weeks after the primary rain season. Pastoralists first guided the research team to a representative location in each land use type. Then we selected a random base point, and identified the rest plot locations systematically based on this random start (see Fig. A2 in Appendix A in Supplementary material). We chose systematic layout of transect lines (Burnham et al., 1980) rather than a completely randomized one, because certain randomly generated points can fall into inaccessible locations (i.e. crop fields, dense thickets). In addition, systematic layout of transect lines provides an even coverage of the study area, whereas a randomized design may miss certain areas. We surveyed nine plots in each land use type. Vegetation species were sampled according to functional group: the full extent of each plot (100 m^2) was used to acquire tree species data, a 25-m^2 subplot nested within the plot was used for shrubs, and a 1-m^2 subplot was used to survey herbs. Survey locations were recorded by a handheld GPS instrument. The number of individuals of each species in each functional group was counted as a measure of species abundance, and the projected percent cover of each functional group was estimated visually in the field (Kent, 2012). The three land use types, which are on top of vertical soil (Coppock, 1994), are less than 7.5 km from each other, with elevations between 954 m and 1032 m. Therefore, other than grazing intensity, there is little variation in environmental conditions among the surveyed plots in the three land use types in this study.

2.3. GPS-tracking

To select representative participant households for GPS collar deployment, we stratified the number of cattle owned by each household in the community. We excluded households whose cattle herd size fell within the bottom 35% of the community to ensure that selected households primarily relied on subsistence livestock herding as a