Traditional Grazing Management Practices Affect Vegetation Dynamics in the Somali Pastoral Ecosystem of Ethiopia

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Abstract

Pastoralist grazing management practices play a vital role in maintaining rangeland productivity and biodiversity. However, the degradation of rangelands and loss of ecosystem services have raised concerns about the future of pastoralism as a form of land use. Despite their importance, we have limited knowledge about the effect of traditional grazing management practices on vegetation attributes, such as species composition, richness, diversity, herbage biomass, and density, and canopy cover. To address this knowledge gap, we studied the changes in vegetation attributes under three traditional grazing management practices in the Somali pastoral ecosystem of Ethiopia. We found a significant difference in herbaceous and woody vegetation attributes among the grazing management practices ($p < 0.001$). Enclosures supported higher herbaceous species diversity and abundance of desirable species, such as Chloris gayana, Chrysopogon aucheri, Cynodon dactylon, and Themeda triandera, compared to open grazing and browsing management sites. The herbage biomass was three times higher in enclosures than in open grazing and twice higher than in browsing management practices. However, browsing management practices supported significantly higher levels of wood biomass, density, and canopy cover than the other management practices. Our results suggest that transitioning from open grazing to the enclosure and browsing management practices can lead to higher plant productivity, which supports the local pastoral economy in the Somali rangeland of Ethiopia. Thus, dryland restoration programs should consider traditional indigenous knowledge for ensuring the sustainability of future rangeland productivity and biodiversity conservation.

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Abstract

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studied the changes in vegetation attributes under three traditional grazing management practices in the Somali pastoral ecosystem of Ethiopia. We found a significant difference in herbaceous and woody vegetation attributes among the grazing management practices ($p < 0.001$). Enclosures supported higher herbaceous species diversity and abundance of desirable species, such as *Chloris gayana, Chrysopogon aucheri, Cynodon dactylon* , and *Themeda triandera* , compared to open grazing and browsing management sites. The herbage biomass was three times higher in enclosures than in open grazing and twice higher than in browsing management practices. However, browsing management practices supported significantly higher levels of wood biomass, density, and canopy cover than the other management practices. Our results suggest that transitioning from open grazing to enclosure and browsing management practices can lead to higher plant productivity, which supports the local pastoral economy in the Somali rangeland of Ethiopia. Thus, dryland restoration programs should consider traditional indigenous knowledge for ensuring the sustainability of future rangeland productivity and biodiversity conservation.

Keywords

Grazing management practices, Vegetation attributes, Rangeland productivity, Biodiversity conservation, Somali pastoral ecosystem, Ethiopia

Introduction

Rangelands are crucial part of the global ecosystem, covering an estimated at 54% of the world's terrestrial area (Teillard *et al.* , 2016). They are home to a wide variety of plants, animals, and microbes that are of ecological, economic, and cultural significance (Seid, Kuhn and Fikre, 2016). Rangeland also provides about 70% of the global forage for both domestic and wild ungulates through grazing and browsing (Derner et al., 2006). In Africa, rangeland coverage is estimated about at 43% of the total land area, and at 62% of Ethiopia's total landmass, making them a primary source of feed for ruminants, and an important habitat for dry-land biodiversity. However, the arid and semi-arid rangeland ecosystems face degradation from poor management, population growth, deforestation, continuous overgrazing, as well as land use and climate changes (Oba and Kotile, 2001; Maitima*et al.* , 2004; Miehe *et al.* , 2010). The loss of traditional indigenous knowledge and the decline in participation of the elders in rangeland management are the leading causes of this degradation (Oba, 2012; CARE, 2015), resulting in the decline of rangeland resources and biodiversity, negatively impacting forage production and conservation efforts.

Pastoralism, with its inherent traditional rangeland management practices, has shaped rangeland environments for thousands of years. Traditional grazing management practices have a significant impacts on the vegetation attributes of rangelands, such as composition, diversity, and biomass yield (Abate et al., 2010; Angassa et al., 2010; Angassa & Beyene, 2003; Briske et al., 2008; Gordon & Iii, 2017). For example, the pastoralists in east Africa have been using enclosures to enhance plant productivity and establish mixed forage more effectively (Angassa and Oba, 2010a, 2010b; Haftay*et al.* , 2013; Wairore *et al.* , 2016). Several studies (e.g. Teshome Abate et al., 2009; Abule et al., 2007; Beyene & Kenee, 2008; FAO, 2017; Terefe et al., 2010) show that a livestock mobility grazing strategy favors biodiversity conservation and sustainable rangeland management. Conversely, areas with limited mobility may experience overgrazing, which endangers biodiversity conservation and reduces biomass yield. Excessive grazing can also decrease the fuel load, resulting in less intense fires and less damage to trees, leading to an increase in woody vegetation (McGinty, Baldwin and Banner, 2009; Bikila, Tessema and Abule, 2016; Mekuriaw, Mengistu and Tegegne, 2019). Thus, balancing traditional indigenous knowledge and involving elders in rangeland management is essential for ensuring the sustainability of rangelands and positively impacting rangeland ecosystems, livestock production, and the livelihoods of the pastoral communities.

The Somali Regional State in Ethiopia is predominantly a pastoral ecosystem with 90% of its area being rangeland (Gezahegn, 2006). In this region, there are around 800 endemic plant species out of the total 1600 found in the country, which makes up a quarter of Ethiopia's flora (Barkhadle, Ongaro and Pignatti, 1994).

Pastoralists in this area use various traditional rangeland resource management strategies such as enclosures and splitting of herds. Enclosures are one of the various management and rehabilitation strategies that are used to improve species diversity, cope with drought and ecosystem productivity. They also split their herds based on patchy resource distribution to ensure optimum resource utilization, as different domestic animals have different feed preferences. For example, the dominant animals in browsing complex areas are goats and camels, while cattle and sheep are raised in grazing complex areas. However, the potential benefits of these alternative management practices have often been overlooked by extension and research services, and little is known about changes in vegetation attributes resulting from these grazing practices. Therefore, this study investigates the effects of three grazing management practices (enclosure, open grazing, and browsing lands) on herbaceous and wood species composition, richness, diversity, biomass yield, and wood density and canopy cover.

Materials and Methods

Description of the Study Areas

The study was conducted in the Jigjiga field site (9.356784 N, 42.795519W) of the Somali Regional State of Ethiopia (Figure 1), which is part of a pastoral ecosystem. This area experiences two rainy seasons: the main season occurs from July to September, and the shorter one is from March to April. The average annual rainfall in the area is 660 mm (Gebremedhn *et al.* , 2022) and the soils are mainly sandy loams (Alemie and Gebremedhin, 2019). The temperature is generally high throughout the year, with mean minimum values around 20 °C and mean maximum values around 35 °C (Gezahegn, 2006). The natural vegetation of the area is Acacia wooded grasslands, with *Chrysopogon aucheri and Eragrostis spp,* being the most dominant grass species and *Acacia ethbaica, Acacia busse, and Vachellia nitlotica* . are being the most dominant woody species of the study area (Hailu 2017). The land-use system in the area is primarily pastoral, with the local community being nomadic and relying heavily on livestock grazing for their livelihoods.

Site selection and sampling design

Before selecting the study plots and sampling techniques, a preliminary survey was conducted with local natural resource management experts and elders who had extensive knowledge of grazing management practices in the study area. Based on their input, three traditional rangeland management practices were chosen for this study: enclosures, communal open grazing, and browsing land. (i) Enclosures are used for hay production, which is cut and carried to the livestock when there is a feed shortage for grazing in the open communal grazing areas. (ii) Communal open grazing areas are characterized by open grass vegetation with scattered trees, and are used for extensive livestock grazing throughout the year. (iii) Browsing land, also known as "bay land" and is dominated by bush vegetation and is used for camel and goat browsing. The communal open grazing area represents the most common land-use system in the Somali rangelands. For a detail description of the management systems of the field sites see Gebremedhn et al., (2022).

The transect survey method was used for sampling vegetation attributes across the three different management practices. Specifically, nine square plots of 400 m^2 each were established at an interval of 5 km for grazing land from Harishin to Kebri Beyah rangelands of the Jigjiga zone (Figure 1). Similarly, nine 400 m^2 square plots were laid at an interval of 1 km for browsing land from Awebere rangelands of the same zone (Figure 1). Whereas for sampling enclosure sites, three 400 m^2plots were randomly placed within each of the three private enclosures aged 20 to 30 years, for a total of nine plots (three plots within every three enclosures). This methodology allows for representative sampling of vegetation attributes within different management practices and was chosen as it can help to identify differences and similarities between them.

Vegetation Sampling

To quantify the structure of woody vegetation, we measured tree/shrub densities, canopy diameters, canopy heights, and stem heights of identified woody species in each 400 m^2 plot. Canopy cover was calculated using the average of the two longest canopy diameters perpendicular to each other and parallel to the ground, following the method of Greig- Smith (1983). Stem height was measured as the total height of the plant stems from the ground level to the highest foliage. For species with multiple stems, each stem was measured separately, and the average was taken. Height measurements and canopy lengths and widths were conducted for the whole plant by measuring multiple stems as if it was one tree. To estimate woody aboveground biomass (AGB) in a non-destructive way, we used biomass regression equations (allometric equations) developed by Hasen-Yusuf et al. (2013).

For sampling herbs vegetation, we placed five sub-quadrats of 1 m^2 in a zigzag pattern (i.e., four at all corners and one at the middle position of each 400 m^2 plot, (as shown in Figure 2), making a total of 135 plots. From each of the 1 m^2 quadrats, we collected samples of species, richness, composition and biomass. We determined species richness as the sum of all plant species present in the 1 m^2 quadrats. The nomenclature of the plant species followed the Flora of Ethiopia (Hedberg and Edwards 1995). We estimated herbaceous species frequency by dividing the total number of quadrats in which the species occurred by the total number of quadrats studied in the 1 m^2quadrats. The recorded species were categorized into three desirability classes based on their preference for grazing by livestock animals, using local ecological knowledge derived from herders and documented literature (Jerry et al. 1989). Additionally, we identified all herbaceous vegetation within the plots as either grass or non-grass species (forbs) following Behnke (1986). We estimated aboveground herb biomass by harvesting live and dead material at ground level. We weighed the harvested samples in the field to obtain fresh weight. Thirty percent of the harvested samples from each quadrat were placed in a paper bag for later dry matter analysis. This harvested biomass was dried in an oven at 105°C for 48 hours and then weighed to obtain the dry matter. All measurements were made from September to December for all study plots when the vegetation was at its peak flowering stage.

Data Analysis

All statistical analyses were carried out using R Statistical Software version 4.1.1. (R Core Team 2020). To determine the impact of traditional grazing management practices on herbaceous species composition, we used Canonical Correspondence Analysis (CCA) test on the frequency of herbaceous species present in the 1 m^2plots, and the "anova.cca" function in the *vegan* package in R Statistical Software (Ter, 1986). CCA is a multivariate method that examines the relationship between species and their environment (Amin*et al.* , 2023).The ordination diagram generated from CCA describes the differential habitat preferences of taxa based on gradients. To determine the impact of traditional grazing management practices on woody species composition, we used the Analysis of Similarities (ANOSIM) test on the number of each woody species counted in the 400 m^2 plots, and the "anosim" function in the vegan library R Statistical package. ANOSIM is a non-parametric test that compares groups of samples based on any distance measure (Clarke and Ainsworth, 1993). We also performed Analysis of Variance (ANOVA) tests on species richness, biomass, woody density, and canopy cover using the "aov" function to determine the effects of traditional grazing management practices. The student–Newman–Keuls post hoc test for differences in means, performed using the SNK.test function under the*agricolae* package (version 1.4.0), was used to compute significant differences among management practices.

Results

Species richness and composition

In the study area, a total of 47 herbaceous species were recorded. The herbaceous species richness was significantly higher (ANOVA: $F = 60.61$, $df = 2$, $p < 0.001$) in the enclosure land sites compared to the

grazing and browsing sites. The Shannon diversity index for herbaceous species was estimated at 3.07, 2.92, and 2.78 for the enclosure, grazing, and browsing areas, respectively. On the other hand, the woody species richness was significantly lower (ANOVA: $F = 13.61$, $df = 2$, $p < 0.001$) in the enclosure land sites compared to the grazing and browsing sites (Table 1). The Shannon diversity index for woody species was estimated at 1.22, 1.36, and 1.25 for the enclosure, grazing, and browsing areas, respectively.

The distribution of herbaceous species composition varied significantly (ANOVA: $F = 11.145$, $df = 2$, permutations = 999, $p < 0.001$) among sites with different grazing management practices. The CCA analysis (Figure 3) showed some clear clustering of herbaceous species in association with the different grazing management practices. Notably,*Chrysopogon aucheri, Chlor* is *gayana, Digitaria abyssinicum* , and *Themeda triandera* species were widely distributed in the enclosure management sites. Whereas *Tragus berteronianus* and *Eragrostis* sp. species were highly distributed in the open grazing sites. In contrast, *Abutilon fruticosum, Hibiscus asperhook* , and *Tragus racemosus* species were more prevalent in the browsing management sites (Figure 3).

The distribution of desirable herbaceous species was greater in the enclosure's sites than in other management sites (Table 2). Among herbaceous species, desirable species of *Chloris gayana, Chrysopogon aucheri, Cynodon dactylon, and Themeda triandera* were distributed by 88.9%, 100%, 64.00%, and 93.33% respectively in the enclosure sites. In contrast, the distribution of undesirable herbaceous species was higher in grazing and browsing sites than in the enclosure sites. In the browsing site the less desirable species of *Tragus racemosus and Sida sp* were highly distributed by 56.67% and 46.67% respectively.

Moreover, we identified a total of five Acacia species and one Vachellia species. The composition of these woody species varied significantly (ANOSIM: $R = 0.58$, permutations = 999, $p < 0.001$) depending on the type of grazing management practices implemented in the area.*Acacia etbaica* was the dominant species in the browsing (Bay) management sites. Whereas *Acacia busie* was the dominant species *in* the enclosure and open grazing sites respectively (Table 3).

Wood species density and canopy cover

The density of woody species varied significantly (ANOVA: $F = 146.51$, $df = 2$, $p < 0.001$) depending on the grazing management practices in the study sites. The browsing sites had a higher woody density compared to the grazing and enclosure sites (refer to Table 1). In addition, the canopy cover of woody species also differed significantly (ANOVA: $F = 31.45$, $df = 2$, $p < 0.001$) depending on the grazing management practices, with lower values observed in the enclosure sites.

Vegetations biomass

Significantly high (ANOVA: $F = 9.98$, $df = 2$, $p < 0.001$) herbage biomass was found in the enclosure sites than in the other two grazing management systems (Table 1). However, the woody biomass was significantly high (ANOVA: $F = 13.61$, $df = 2$, $p < 0.001$) in the browsing land sites than in the grazing and enclosure sites (Table 1).

Discussion

In our study, we observed substantial disparities among the three grazing management practices analyzed. In the following sections, we will delve into these distinctions by examining the herbaceous vegetation structure, woody vegetation structure, and vegetation biomass associated with each practice. By providing a comprehensive overview of these differences, we aim to highlight the implications of each management strategy on the overall health and sustainability of rangeland productivity and biodiversity conservation.

Herbaceous vegetation structure

Herbaceous species accumulation estimates for enclosures, open grazing, and browsing areas were 30, 24, and 20, respectively (Table 2). These results are consistent with prior research (Angassa et al. 2010; Hailu 2016; Mekuria et al. 2018; Yayneshet, et al 2009), which demonstrated the efficacy of enclosure management in improving rangeland vegetation. Furthermore, the prevalence of preferred herbaceous species, such as *Chloris gayana, Chrysopogon aucheri, Cynodon dactylon, and Themeda triandera* , and *Themeda triandera* , was higher in enclosures than in other management sites (Table 2). The decrease in these desirable species under grazing and browsing management practices might be due to overgrazing. Gemedo-Dalle et al. (2006) suggested that alterations in community composition resulting from grazing pressure could signal rangeland deterioration. Supporting this hypothesis, our study found a greater distribution of undesirable herbaceous species in grazing and browsing areas compared to enclosures. Similarly, Miehe et al. (2010) observed a marked increase in low-quality herbaceous plants at a grazed site relative to a non-grazed site in Senegal's savannah ecosystem. The current study's finding of a higher proportion of perennial herbaceous species in enclosure management sites aligns with Bilotta et al. (2007), who reported that perennial species dominated lightly grazed areas, while annual forbs and weedy species prevailed in heavily grazed locations.

Apart from overgrazing, local elders in group discussions highlighted recurring droughts as the primary factor contributing to the deterioration of rangelands in the study area, a finding supported by Kassahun et al. (2008). This degradation has resulted in the loss of perennial, palatable, and productive grasses, essential for livestock production in rangelands (Tuffa, 2022). In response, Somali pastoralists have implemented rangeland enclosures, primarily aimed at preserving forage during extended dry seasons or drought periods, while also promoting conservation. Furthermore, these enclosures provide households with the opportunity to generate income by selling pasture or hay.

Recent policy changes by the Somali Regional government have reclassified private rangeland enclosures as communal land, as land ownership in Ethiopia is vested in the government and the public. Consequently, local communities have expressed their discontent and resisted the regional government's actions. Pastoral households with a higher proportion of grazers are particularly inclined to claim enclosures more than others (Fekadu Beyene, 2009). Successful interventions, however, rely on the genuine engagement of pastoralists; otherwise, negative consequences may arise.

Our study provides evidence that the establishment of enclosures in response to periodic droughts, biodiversity conservation, and rangeland productivity is an appropriate management strategy. Therefore, it is essential to recognize the participation of pastoral communities in environmental monitoring and decision-making as a fundamental aspect of effective rangeland management. Their knowledge and its outcomes can significantly contribute to the development of local policies (Oba, 2012).

Woody vegetation structure

In our study area, woody species richness was found to be relatively low, with only six species identified. This contrasts with the findings from the Borona pastoral ecosystem of Ethiopia, where Tefera, Snyman, and Smit (2007) documented approximately 54 woody plant species in the Southern Ethiopian Borona rangelands. Similarly, Gilo and Kelkay (2017) reported about 39 woody species within the same region. The pastoralists in our study area are aware of the potential dangers posed by woody species and often clear most shrubs and trees not favored by livestock from their rangelands. This practice may contribute to the low species richness observed in our. Moreover, during group discussions, pastoralists in the study area expressed concerns regarding the threats to native trees caused by the high reliance on fuelwood and charcoal.

Browsing land management practices appear to have a negative impact on woody species richness and diversity, while also promoting higher density levels. The average wood densities per hectare in browsing, open grazing, and enclosure areas were estimated at 1125, 3742, and 50, respectively. Woody vegetation canopy covers were approximately 94%, 30%, and 10% for browsing, open grazing and enclosure areas, respectively. Numerous studies (Ayana Angassa & Oba, 2008; Gilo & Kelkay, 2017; Gobelle & Gure, 2018;

Tefera et al., 2007; Woods et al., 2019; Yusuf et al., 2011) have demonstrated that, over the past century, the balance between plant life forms has shifted in favor of trees and shrubs across many East African rangelands. This transformation of open grasslands into dense woody cover is referred to as bush encroachment, which negatively affects understory herbaceous grass growth and hinders human and livestock mobility (Angassa & Oba, 2010a; Dalle et al., 2006; Walker et al., 1981). Undesirable woody species also pose a threat to the biodiversity and stability of rangeland ecosystems (Gemedo, 2006). Richter, Snyman, and Smit (2001) found that a density threshold of over 2500 tree equivalents per hectare is required for woody species to be considered a bush encroachment risk.

In the current study, the density and canopy cover of woody species in enclosure and open grazing areas were not extensive enough to be classified as a woody-encroached state that significantly suppresses herbaceous species. However, browsing land management practices exhibited encroachment by wood vegetation layers, with canopy cover estimated at 94%. Additionally, elders participating in group discussions observed an increase in woody density and cover in communal open grazing areas compared to past decades. Somali pastoralists view this increase in wood density as indicative of rangeland degradation, resulting in an imbalance in the grass-to-bush ratio, and consequently, a decrease in palatable herbaceous species diversity and productivity. Supporting this notion, the low number of herbaceous species richness in browsing management practices in our study may be due to wood vegetation encroachment. Furthermore, O'Rourke and van Wijngaarden (1987) noted that grazing is eliminated in East African rangelands when bush cover reaches 90%. In recent decades, the Borana plateau's grazing system has become increasingly unsuitable due to range degradation caused by woody plant encroachment (Negasa *et al.* , 2014). As a result, Borana pastoralists have transitioned from cattle herding to goat and camel herding.

The long-standing practice of Somali pastoralists to diversify herd composition based on patchy resource distribution and balance resource utilization has proven to be an effective management decision. Consequently, policymakers and extension workers should acknowledge and incorporate pastoralists' experiences and knowledge, which have been utilized for generations to manage rangelands. Alternatively, they should develop effective and applicable strategies for controlling woody encroachment.

Vegetation biomass

The herbage biomass within enclosures was three times greater than in open grazing areas and twice as much as in browsing land management practices (Table 1). This increase in herbage biomass at enclosure management sites may be attributed to the decrease in grazing pressure, allowing for the accumulation of soil organic matter during rest periods. Consistent with our findings, studies conducted in Borana and other pastoral regions in Ethiopia have confirmed that periodically resting grazing lands enables herbaceous forage species to regenerate from the soil seed bank, thus increasing biomass yield (Behnke, 1986; Abebe *et al.* , 2006; Angassa *et al.* , 2010; Abdulatife Ibrahim, 2016; Mohammed, Abule and Lissahanwork, 2017; Nyberg *et al.* , 2019). In contrast, the woody biomass in enclosures was approximately half that of open grazing areas and five times less than browsing land management practices (Table 1). This finding diverges from Gilo and Kelkay (2017), who reported higher aboveground woody biomass in enclosure management practices compared to other rangeland management strategies in the Barona rangelands of Ethiopia. Gufu Oba et al., (2001) similarly observed higher aboveground biomass in grazing enclosures than in open grazing areas. Sawadogo et al., (2005) also noted a decline in aboveground biomass under intensive grazing management when compared to rangeland enclosures.

Conclusion

Our study demonstrates that transitioning from open grazing to enclosure and browsing management practices can enhance plant productivity and foster better forage establishment in the Somali rangelands of Ethiopia. Specifically, we discovered that enclosures exhibit greater herbaceous species richness, abundance

of desirable species, and biomass in comparison to grazing and browsing management sites. Conversely, browsing areas displayed significantly higher woody biomass, density, and canopy cover than the other grazing management practices. As a result, we advocate for the promotion of traditional pastoralist knowledge and practices, which entail dividing herds and assigning browser animals (camels and goats) to bush-rich areas and grazers (cattle and sheep) to open grazing areas. Embracing traditional enclosure grazing management practices is essential for maintaining the natural environment and preserving rangeland ecosystem biodiversity. Consequently, rangeland restoration approaches should incorporate indigenous rangeland management practices to ensure the sustainable utilization of rangeland resources while upholding the social and cultural values of the community.

Data availability statement

The data that support the findings of this study will be openly available in Dryad

Reference

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