Heliyon 9 (2023) e22133

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Grazing intensity effects on rangeland condition and tree diversity in Afar, northeastern Ethiopia

Mengeste Mathewos, Amsalu Sisay, Yonas Berhanu *

School of Animal and Range Sciences, Hawassa University, P.O. Box. 05, Hawassa, Ethiopia

A R T I C L E I N F O

Keywords:
Range condition
grazing intensity
species composition
Diversity (Hill numbers)
Pastoralists' perceptions

A B S T R A C T

This study assessed the effects of different grazing pressures (light, moderate and heavy) on rangeland condition and woody species diversity in northeastern Ethiopia. Rangeland condition was analyzed using common protocols for the assessment of semi-arid rangelands. A total of 4 grasses, 5 herbs, 1 sedge and 14 tree and/or shrub species were identified. Results show that grazing intensity had detrimental effects on condition of the rangeland, and caused undesirable changes in herbaceous species composition. The contribution of undesirable plants to herbaceous aboveground biomass was particularly high (40 %) compared to the 30 % contributed by highly desirable species. Nearly all measures of range condition were negatively affected by grazing. Grass composition, number of seedlings and age distribution, basal and litter cover, soil erosion and compaction decreased significantly as grazing intensity increased. Species richness and diversity (Hill numbers) of woody plants were reduced significantly by grazing. The overall condition of the rangeland was generally poor. The pastoralists perceived that recurring droughts, heavy continuous grazing and inappropriate management interventions, and bush encroachment were the main contributing factors that led to overgrazing and rangeland deterioration in the area. In conclusion, our study shows that livestock grazing in northeastern Ethiopia degrade range condition and woody vegetation, and its effects are sever under moderate and heavy grazing. Management measures such as resting of the rangelands preferably with stock exclusions for 6–12 months or protecting heavily degraded or sensitive areas from livestock activity and reseeding may be the viable options to mitigate declines in range conditions.

1. Introduction

Livestock grazing on native pastures is an important and widespread land use on Earth. It provides nourishment for nearly 800 million food-insecure people, and various other products, and cultural services [1]. However, livestock grazing is regarded as one of the main causes of degradation on arid and semi-arid rangelands worldwide [2]. Grazing can lead to undesirable changes in species composition or functional groups, a loss in vegetation cover and biomass [3–5]. Grazing induced trampling also compacts soil, increases erosion, and reduces water infiltration [6]. However, these effects depend greatly on the intensity of grazing, with stronger effects under increasing levels of grazing [3,7].

Understanding of vegetation change and responses to grazing pressure is essential to clarify the influence and inform management actions. This study focuses on a semi-arid rangeland in Afar region in northeastern Ethiopia for which there is a limited amount of

* Corresponding author.
E-mail address: yonasb@hu.edu.et (Y. Berhanu).

https://doi.org/10.1016/j.heliyon.2023.e22133
Received 5 June 2023; Received in revised form 27 October 2023; Accepted 5 November 2023
Available online 11 November 2023

primary research. The Afar rangelands account for about 10 % (or 10 million ha) of Ethiopia's land mass [8] and provide livelihoods to 1.8 million pastoralists [9]. The Afar pastoralists traditionally practised strategic management of herds and range resources to avoid local overstocking of the scarce dry season grazing areas. They utilized different grazing areas in the dry and wet seasons, which, in combination with resting has played a key role in maintaining and managing the native vegetation [10]. Over the past six decades, however, grazing across the region has increased significantly, due in part to pressures from a growing human population and conversion to cultivated agriculture [11]. Consequently, the few rangelands that remain are subjected to overgrazing or prolonged use which will likely lead to their loss. Additionally, owing to the fast population growth [11] and associated demands for livestock products, the intensity and scale of grazing is likely to increase in the region, with subsequent ramifications for the remaining rangelands.

A number of studies have addressed the effects of disturbances such as fire, bush encroachment and drought on vegetation conditions, and ecosystem functions in Ethiopia [8,12]. Relatively few studies have evaluated the effects of grazing on rangeland condition and plant diversity. Furthermore, there is a shortage of work aimed specifically at arid and semi-arid lands in the northeastern Ethiopia.

Designing or identifying management options that maintain land in good condition or restore land that has deteriorated requires knowledge on how vegetation responds to varying degrees of grazing intensity and a host of environmental factors [7,13]. In the present study area, however, the effects of these factors on rangeland condition and the pastoralists view on vegetation changes remain poorly understood, mainly due to the remoteness of the area and poor infrastructure. It has been widely acknowledged that studying rangeland plants responses to grazing effects or any environmental factor should integrate the empirical knowledge of local communities with ecological methods [14–16]. Such an approach has proven to be effective in informing viable management system for both conservation and sustainable use of arid rangelands [17]. This study was thus conducted to (i) assess the effects of grazing pressure (i.e. areas exposed to different grazing intensities) on the condition of rangeland in Ewa district of the Afar rangelands; and (ii) understand pastoralists' perception about the existing rangeland resource base, vegetation change and possible causes underlying this change. We hypothesized that grazing would lead to declines in rangeland condition and woody plant diversity in the semi-arid rangelands of northeastern Ethiopia. To test our hypothesis, we examined the effect of increasing grazing intensity by livestock on a range condition attributes (e.g. grass composition and litter cover), and two diversity parameters (i.e. species richness and diversity (Hill numbers)).

2. Materials and methods

2.1. Study area

The study area is in the northern Afar rangelands, Ewa district (Fig. 1). Ewa is situated in the eastern foothills of the northern

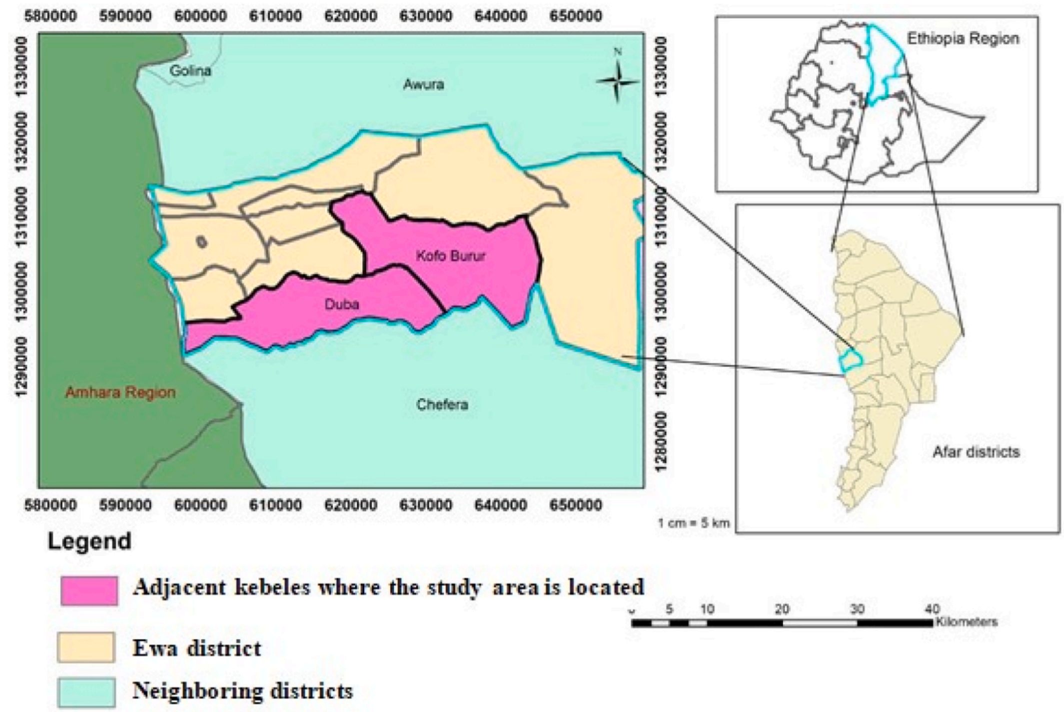

Fig. 1. Location of the study area.

Ethiopian highlands (11°49′20″ N and 39°37′59″ E), where the topography is mostly flat with some rolling hills reaching elevations up to 1080 m. The climate is semi-arid with a mean annual temperature ranging from 22.5 °C to 37.5°. The mean annual rainfall varies from 700 to 850 mm, which is distributed for the most part between mid-July and mid-September. The soils are predominantly sandy and silty. According to FAO soil classification, soils of the Afar region are Lithic and Eutric Fluvisols [18]. The vegetation consists of scattered clumps of semi-desert shrubs, acacia woodland, grassland and wooded grasslands [8]. The grassland consists predominately of the genera *Chrysopogon,* while the genera *Acacia (*e.g.*, Acacia nilotica, A. nubica, and A. tortilis),* and *Prosopis* dominate the shrub and woodlands. Livestock (mainly goats, sheep and cattle) grazing has been practiced in the area for centuries [11]. In recent decades, the expansion of agriculture, population pressure and change in land use has led to more intense use of shrinking rangelands. As a result, the rangelands in the study area expected to be overgrazed or deteriorated. Traditionally, the Afar land use system was based on the use of extensive rangelands [11] based on settled home herds and the mobile herd management system [19]. Animals graze freely on communal rangelands during the day, and kept unclosed in resting points during the night. Although the degree and distance of movements varies between the mobile and home herds, home-based animals follow similar daily grazing movements. Every day, animals move away from resting places at encampments, hamlets or villages, to graze from morning to evening and herded back at night. Also, as all animals left unenclosed at night (per. obs.), they may night-graze on their own surrounding resting points. As a result, concentration of herbivores tends to be highest near these resting points. A particular focus of this study was to examine the extent of occurring changes in condition of the range and woody vegetation of the district due to livestock grazing and analyze whether these responses vary with topographic positions.

2.2. Site selection and sampling design

This study was conducted across a grazing gradient (i.e. extending outward from residents/camp sites) identified in a purposively selected communal grazing area located between 2 adjacent kebeles (the lower administrative layer in Ethiopia). This shared rangeland has been used for grazing for hundreds of years. Systematically stratified sampling technique was used to sample this heterogeneous land mass. Accordingly, the site was selected based on information gathered from local herdsmen (traditional range scouts) and corroborated with preliminary field observation. The site was further stratified into 2 elevation zones, upland (850–1050 m asl) and lowland (650–850 m asl). At each elevation zone, three levels of grazing intensity labeled qualitatively as light (<25 % use), moderate (25–50 % use) and heavy grazing (>50 % use) were identified [20]. Then, field observations were conducted along paths frequented by the livestock selected to accommodate the three markedly different grazing levels defined above. Presence of the grazing gradient was confirmed by a decrease in the density of dung with increasing distance from resting points [21,22]. The boundaries of the three grazing zones were defined along each trail and three parallel transects, each 3–5 km in length, were then established perpendicular to the boundary (edge) of each grazing site (Fig. A1). Transects were connected end-to-end, with orientation of each transect determined randomly. Along each transect, we placed five 400 m^2 (20 m × 20 m) plots (to record all woody plants) every 500 m, within which we randomly located 2 smaller (1 m × 1 m) quadrats (for herbaceous plants assessment) (Fig. A1). This approach (i.e. the systematic samplings of quadrats within each transect) helps to detect more species and vegetation units more efficiently and precisely than simple random sampling [23]. Transects, in the present study, were served as replicates. Neighboring transects and plots were >500 m and 1000 m apart to allow for independence of sampling. Overall, we sampled 90 plots (2 elevations x 3 grazing intensities x 3 transects x 5 plots) for the woody vegetation assessment and 180 quadrats (2 elevations x 3 grazing intensities x 3 transects x 10 quadrats) for the herbaceous plants.

2.3. Vegetation sampling

Vegetation attributes were collected for the woody (comprising all trees and shrubs >1 m height) layer (i.e., woody plant density and diversity) and for the herbaceous layer (i.e., range condition measures). Woody vegetation attributes were sampled within each main plot (i.e. 400 m^2) whereas the herbaceous layer attributes were assessed within the small quadrats. Nested quadrat methods are widely utilized in rangeland research because they can efficiently sample vegetation and soil characteristics in multiple spatial scales (e.g., 1 m^2 or 10 m^2 nested within the main plot) [24–26]. The number of plant species and plant density of each species in each plot was counted to quantify (i) species richness (S), and (ii) diversity. Species diversity of the woody layer was calculated using the Hill number approach that integrates both species richness and species abundances into a single metric [27,28]. This approach has also the advantage of accounting for the number of species that are common or dominant in a community than other diversity indices [27,29]. Vegetation data were collected at the end of the main rain (in August to September 2020) when grassland community biomass peaked.

2.4. Measures of range condition

Because the study area is a semi-arid environment, rangeland condition was analyzed using common protocols developed for the assessment of semi-arid rangelands in southern Africa [30]. Within the smaller quadrats, we measured seven attributes: grass composition, basal cover, litter cover, seedlings number and age category, soil erosion and compaction (table A1). A maximum score of 10 points each was given for 3 of the factors and a maximum score of 5 points each for the remaining 4 factors, summing to a maximum possible score of 50 points. The overall range condition rating was interpreted as very poor (≤10), poor (11–20), fair (21–30), good (31–40), and excellent (41–50) points.

Grass composition (1–10 points). The grass species were grouped into ecological classes which were defined on the basis of how the plants respond to grazing, using the Dyksterhuis procedures [31]. The classification was adapted from Baars et al. [30]. Accordingly, the species were divided into highly desirable species likely to decrease with heavy grazing pressure, desirable species likely to increase with heavy grazing pressure, less desirable species likely increase with moderate grazing and undesirable species likely to increase or invade with heavy grazing pressure. Information was gathered from pastoralist on palatability of particular species. A species with high palatability was considered a decreaser, whereas a species with medium palatability was considered an increaser. Scores were based on visual estimation of percentage of decreasers or increasers (table A1) within each quadrat. Vegetation was clipped from within the 1 m^2 quadrat to determine biomass.

Basal cover (0–10 points) and litter cover (0–10 points). Visual estimates of basal cover and litter cover was conducted in every quadrat, which was divided into 8 sub-subplots. All plants in the 1 m^2 were removed and transferred to the eighth in order to facilitate visual estimations of basal cover. Only living plant parts were considered for basal estimation. The rating for basal cover for tufted species was considered 'excellent' when the eighth was completely filled (12.5 %) and 'very poor' when the cover was less than 3 %. The rating for litter cover within the same plot was considered 'excellent' when it exceeded 40 % and 'poor' at less than 10 % litter cover.

Number of seedlings (0–5 points) and age distribution (1–5 points). The number of seedlings was counted from three areas equal to the size of an A4 sheet paper (30 × 21 cm) chosen at random. The category 'no seedling' was given 0 point and >4 four seedlings was given the maximum score of 5 points. Similarly, the size distribution, which was considered to reflect the age distribution of plants, was estimated based on visual observation of the size of the grass tussocks. When all age categories (young, medium aged and old) of plants of the dominant species were present, the maximum score of 5 points was given. Young and medium aged plants were defined as having approximately 20 and 50 %, respectively, of the biomass of old and mature plants of the dominant species. When there were only young plants, the minimum score of 1 point was applied.

Soil erosion (0–5 points) and soil compaction (1–5 points). Soil erosion and compaction were evaluated within the smaller quadrats subjectively by visual observations. The assessment of soil erosion was based on the amount of pedestals (higher parts of soils, held together by plant roots, with eroded soil around the tuft and in severe cases, the presence of pavements (terraces of flat soil, normally without basal cover, with a line of tufts between pavements). If there was no soil movement, a maximum score of 5 point was given and a minimum score of 0 was applied in situations where gully formation was observed. Soil compaction was evaluated based on the amount of crust formation of surface soil. If there was no compaction, a maximum score of 5 was given and the rating was decreased with increasing capping of the soil.

2.5. Interview data

To elucidate pastoralists' perceptions of rangeland condition, long-term vegetation changes and its causes, we did semi-structured interviews with 80 herdsmen and focus group discussions with 40 village elders in various villages of the two kebeles. The later informants were traditional range scouts who were knowledgeable of the spatial patterns of land use during the previous three to four decades. As the interview participants were relatively homogeneous in terms of natural habitat, a heavy reliance on shared grazing lands, similar production systems and ethnic composition (largely of Afar pastoralists), the sample size for the interview data was considered adequate.

2.6. Statistical analysis

One-way ANOVA using a generalized linear mixed effect model was performed to test the fixed effect of grazing intensity (light, moderate, and heavy grazing) on range condition measures and woody species diversity parameters (richness and Hill numbers). The analysis was done for each elevation zone separately. In our analysis, transects were considered as replicates (random factors) for the among-grazing treatments comparisons. In this study, it was not possible to avoid the problem of pseudo-replication for practical reasons [32]. The mixed effects model was thus applied to control for the likely presence of autocorrelation between transects [33]. The LSD test was used for comparison of treatment means at $P < 0.05$. Means for measured range condition and diversity variables were compared between elevation zones using a paired *t*-test. Descriptive statistics such as percentages were also used to describe herbaceous vegetation composition. All statistical analyses were performed in SPSS 25.0. Questionnaire data were descriptively summarized.

3. Results

3.1. Composition of the herbaceous layer

A total of 4 species of grasses, 5 herbs, and 1 species of sedge were found in Ewa semi-arid rangeland. Among the herbaceous species encountered, 8 species (3 grasses, 1 sedge and 4 herbs) were common in both elevation zones and 1 grass like species only occurred in the lowland whereas 1 herb species was only in the upland. The recorded herbaceous species and their desirability (palatability) are shown in Table 1. Overall, the contribution of undesirable plants to herbaceous aboveground biomass was particularly high (40 %) compared to the 30 % contributed by highly desirable species (Fig. 2), which may be an indication of deteriorating condition of the rangeland. Most species were also annual herbs (Table 1).

3.2. Grazing effects on herbaceous biomass and rangeland condition

Grazing intensity had a significant effect on herbaceous species biomass with heavily grazed sites having a significantly lower biomass than either lightly (<25 % use) or moderately grazed (25–50 % use) sites ($P < 0.05$; Table 2). There was even no measurable herbaceous biomass left in the heavy grazed sites of both elevations due to heavy grazing and sever trampling. Grazing also negatively affected nearly all measures of range condition. Significant differences were detected among grazing intensities for all parameters measured in upland site (LG > MG > HG) ($P < 0.05$; Table 3). Grass composition, number of seedlings and age category, and basal cover scores decreased consistently with increasing grazing in lowland site. However, ratings for litter cover, soil erosion and soil compaction showed no significant differences among grazing intensities at this location ($P > 0.05$; Table 3). The total score showed that the condition of the rangeland at all 3 grazing intensity classes at both elevations fell into the category of 'poor' to 'very poor' range condition. The total score, however, varied significantly between the grazing levels. The highest score was for lightly grazed site (15.46) and lowest for heavily grazed site (3.74) in the upland. Similar trend was observed for the lowland one.

3.3. Effect of grazing intensity on woody plant diversity

There was a strong grazing effect on the two diversity measures. While there were highly significant differences in tree species richness and diversity, measured as Hill numbers, among grazing pressure levels in the upland site (P < 0.05) no significant differences were observed on both diversity parameters among grazing levels at the lowland elevation (P > 0.05; Table 5). Overall, regardless of differences in topographic positions, species richness and diversity both tended to decrease as grazing intensity increased. A total of 14 species of woody and/or shrubs species were recorded in both elevations (Table A5).

3.4. Effect of topography on range condition and woody species diversity

No differences were observed between upland and lowland sites for nearly all range condition measures and the total score ($P >$ 0.05, Table 4). However, in most of the parameters and the total score, the lowland site showed slightly higher values than the upland. Conversely, the upland site contained significantly higher number of tree species, and species diversity than the lowland one ($P < 0.05$, Table 6).

3.5. Herders' perception on rangeland condition and vegetation change

Information obtained through human perception is useful in linking changes in land use, diversity and rangeland degradation. Accordingly, discussion of the rangeland condition led to analysis of the present condition (and changes over time) of range in the study area. Based on their own subjective judgment, when the pastoralists were asked about the current condition of their rangelands, the majority (62.5 %) of them believed that the condition of their rangelands was in a very poor condition, while 28.7 % of the rangelands of the study area were perceived as poor and 6.2 % in fair condition (Table A2). The possible reasons mentioned for this poor state of the rangelands were drought (shortage of rain), heavy continuous livestock grazing and inadequate management systems/interventions. The local herdsmen further identified bush encroachment as the factor determining rangeland condition (Table A4). When pastoralists were asked about changes in rangeland condition (in terms of cover, distribution and quality) that they have noticed over time, nearly all of the respondents believed that rangelands have declined over time. It was agreed (reported by more than three-quarters of the respondents) that the decline in vegetation condition was prevalent in the past 16−20 years (Table A3). Regarding their opinion of changes in plant species composition in the study area, the elders participated in group discussion reported the presence of significant changes in vegetation composition, particularly for the desirable to undesirable species ratio (decline in abundance of desirables species and an increase unwanted plants), of the rangelands over the past decades.

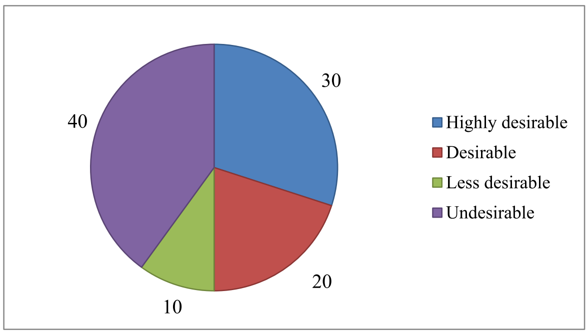

Fig. 2. Proportions (%) of desirability of herbaceous species in Ewa rangeland, Afar, Ethiopia.

Table 1
Herbaceous species recorded in Ewa rangeland, Afar, Ethiopia.

Vernacular name (Afar language)	Scientific name	Life Form	Desirability
Durfu	*Chrysopogon plumulosus Hochst*	Perennial grass	HD
Edoletenkisi	*Chloris barbata*	Perennial grass	HD
Democracy	*Parthenium hysterophorus*	Herb/annual	UD
Fi'a	*Cyperus esculentus*	Perennial sedge	D
Olayito	*Aerva javanica* (Burm. fil.)	Perennial herb	UD
Aytiadoyta	*Tetrapogon tenellus (Roxb) chior*	Annual grass	D
Kokadawuto	*Amaranthus spinosus* L.	Annual herb	UD
Mussa	Dactyloctenium aegyptium (L.) Will	Annual/short-lived perennial grass	HD
Bunkat	*Tribulus terrestris*	Annual herb	LD
Bang	*Xanthium orientale*	Annual herb	UD

HD=Highly Desirable; D = Desirable; LD = Least Desirable; UD=Undesirable.

Table 2
Mean herbaceous biomass (kg/ha) under different grazing intensities in Ewa rangeland, Afar, Ethiopia.

Grazing intensity	Upland	Lowland
Lightly grazed	125.33(26.1)^{c}	281.33(105.10)^{b}
Moderately grazed	49.33(25.32)^{b}	77.33(51.32)^{a}
Heavily grazed	0.00(0.00)^{a}	0.00(0.00)^{a}
Overall mean	58.22(57.62)	119.56(138.80)
P-value	0.008	0.019

Means within columns with different letters are significantly different (Fisher's LSD test, $P < 0.05$). Numbers in bracket are standard deviation.

Table 3
Mean score of the rangeland condition assessment in Ewa rangeland, Afar, Ethiopia.

Grazing intensity	Upland								
	GC	NS	AC	BC	LC	SE	SC	TS	RC
LG	1.33 (0.23)^{c}	0.73 (0.23)^{a}	1.00 (0.20)^{a}	1.93 (0.50)^{c}	1.67 (0.70)^{b}	4.20 (0.80)^{a}	4.60 (0.70)^{a}	15.46 (1.60)^{c}	Poor
MG	0.87 (0.23)^{b}	0.47 (0.12)^{a}	0.73 (0.23)^{a}	0.93 (0.12)^{b}	0.80 (0.00)^{a}	3.13 (0.42)^{a}	3.87 (0.12)^{a}	10.80 (1.40)^{b}	Poor
HG	0.00 (0.00)^{a}	0.00 (0.00)^{b}	0.00 (0.00)^{b}	0.00 (0.00)^{a}	0.00 (0.00)^{a}	1.87 (0.46)^{b}	1.87 (0.64)^{b}	3.74 (1.00)^{a}	Very poor
P-value	0.005	0.013	0.01	0.005	0.019	0.025	0.017	0.001	
	Lowland								
	GC	NS	AC	BC	LC^{ns}	SE^{ns}	SC^{ns}	TS	
LG	1.27 (0.31)^{a}	1.20 (0.35)^{b}	1.13 (0.50)^{b}	2.20 (0.40)^{c}	1.07 (1.22)	4.47 (0.76)	4.67 (0.31)	16.01 (1.61)^{c}	Poor
MG	0.80 (0.53)^{a}	0.27 (0.23)^{a}	0.53 (0.31)^{ab}	1.26 (0.61)^{b}	0.27 (0.46)	3.60 (0.00)	4.27 (0.12)	11.00 (1.70)^{b}	Poor
HG	0.00 (0.00)^{b}	0.00 (0.00)^{a}	0.00 (0.00)^{a}	0.00 (0.00)^{a}	0.00 (0.00)	3.93 (0.64)	4.47 (0.12)	8.4 (2.10)^{a}	Very poor
P-value	0.021	0.005	0.032	0.01	0.321	0.315	0.221	0.042	

LG = Lightly grazed; MG = Moderately grazed; HG=Heavily grazed; GC = Grass composition; NS= Number of seedlings; AC= Age category; BC= Basal cover; LC= Litter cover; SE= Soil erosion; SC= Soil compaction; TS = Total score. RC=Range condition class. Standard deviation in parentheses. Means within columns with different letters are significantly different (Fisher's LSD test, $P < 0.05$). ^{ns}not significant. Note that for GC, NS, AC, BC, LC, SE, SC and TS the values used in the analysis were scores. High score of soil erosion, for example, implies absence or less erosion.

Table 4
Mean score of the rangeland condition assessment for upland versus lowland locations in Ewa rangeland, Afar, Ethiopia.

Parameter	Upland	Lowland	Overall mean	*P*-value
Grass composition^{ns}	0.73(0.61)	0.69(0.63)	0.71(0.60)	0.719
Number of seedlings^{ns}	0.40(0.35)	0.49(0.58)	0.44(0.47)	0.466
Age category^{ns}	0.58(0.47)	0.56(0.57)	0.57(0.51)	0.719
Basal Cover^{ns}	0.96(0.88)	1.16(1.02)	1.06(0.93)	0.719
Litter Cover	0.82(0.80)^{b}	0.44(0.81)^{a}	0.63(0.81)	0.037
Soil Erosion^{ns}	3.07(1.13)	4.00(0.62)	3.53(1.01)	0.059
Soil compaction	3.44(1.31)^{a}	4.47(0.24)^{b}	3.96(1.06)	0.042
Total Score^{ns}	10.1 (5.20)	11.5 (3.90)	10.90 (4.53)	0.123
Range condition class	Poor	Poor	Poor	

Values are averages with standard deviation in parentheses. Means within rows with different letters are significantly different (*t*-test, $P < 0.05$). ^{ns}not significant. The total rating was interpreted as follows: very poor (≤10); poor (11–20); fair (21–30); good (31–40); and excellent (41–50) points.

Table 5
Tree species richness and diversity (Hill numbers) under different grazing intensities (within elevation zone).

Grazing intensity	Upland		Lowland	
	Richness	Diversity	Richness^{ns}	Diversity^{ns}
LG	5.33(0.10)^{a}	3.90(0.62)^{a}	0.53(0.42)	1.15(0.20)
MG	3.53(1.92)^{a}	3.90(0.62)^{a}	0.20(0.20)	1.00(0.00)
HG	0.53(0.42)^{b}	1.10(0.17^{b}	0.00(0.00)	1.00(0.00)
Overall mean	3.13(2.37)	2.65(1.50)	0.24(0.33)	1.00(0.00)
P-value	0.037	0.024	0.124	0.160

Values are averages with standard deviation in parentheses. Means within columns with different letters are significantly different (Fisher's LSD test, $P < 0.05$). ^{ns}not significant.

Table 6
Mean tree species richness and diversity (Hill numbers) in upland and lowland elevations of Ewa rangeland, Afar, Ethiopia.

Parameter	Upland	Lowland	Overall mean	*P*-value
Species richness	3.13(2.37)^{b}	0.24(0.33)^{a}	1.69(2.21)	0.003
Diversity	2.65(1.50)^{b}	1.10(0.12)^{a}	1.85(1.31)	0.01

Values are averages with standard deviation in parentheses. Means within rows with different letters are significantly different (*t*-test, $P < 0.05$).

4. Discussion

4.1. Grazing intensity effects on range condition

This study investigated whether grazing intensity has a strong effect on multiple attributes of range condition and woody vegetation diversity in the semi-arid rangelands of northeastern Ethiopia. Our results demonstrate that grazing intensity had detrimental effects on herbaceous species biomass and nearly all measures of range condition assessed in this study. Intensive communal grazing, which is a common feature of most smallholder grazing systems in Africa [34,35], often causes a decline in herbaceous biomass production [4,5]. The highest herbaceous forage biomass observed on the study area, 281 kg DM/ha on lightly grazed site at lowland elevation (Table 2), was much lower than reported for arid/semi-arid rangelands elsewhere in Ethiopia [36] and East Africa [37].

Our results also show indication of changing abundances in the composition of herbaceous plants to undesirable species, which is an indication of overgrazing or rangeland deterioration [34,38], unless urgent intervention is taken to recover those plant populations that are in decline. Undesirable plants generally made up most of the herbaceous biomass with highly desirables contributing 30 % and desirables 20 %. The pastoralists also confirmed that similar changes have been occurring in the area. According to the pastoralists, abundance of valuable grasses has been decreasing, whereas that of unwanted herbaceous and woody species has been increasing over time. The herders' perceived drought (shortage of rain), heavy continuous livestock grazing and inadequate management practice as the major factors causing decline of the valuable species.

Also, we found that grass composition, number of seedlings and age category, basal cover, litter cover, soil erosion and soil compaction decreased as grazing intensity increased, but no significant effect was observed for some of the range condition measures at lowland site. Soil erosion and compaction scores were low under heavy grazing, particularly in the upland zone, which can be explained by low litter and basal cover. In arid and semi-arid regions, heavy grazing and trampling damage often associated with a reduction in basal cover and standing biomass, and an increase in bare soil, thereby exposing the soil to erosion [4,39,40] consistent with the observation made in the current study.

The total score of 10.9 suggests that the general rangeland condition of the study area was poor, which could be attributed the lower basal and litter cover, as well as other range condition factors. Nearly all measures of range condition were reduced significantly by grazing. Tessema et al. [4] reported similar effects of grazing for semi-arid savannas of Ethiopia, Gamoun [41] for desert rangelands of Tunisia, and Kioko et al. [42] for the semi-arid rangelands of Kenya. They interpret this as an overgrazing impact leading to rangeland deterioration. Results from the group discussions and interview, in which pastoralists participated in describing the condition and trends of their rangeland vegetation, also showed that the majority of them viewed that the state of their rangeland was in a very poor condition. Recurring droughts (shortage of rain), heavy continuous grazing (due to increased confined grazing and poor grazing practices) and inappropriate management interventions, and bush encroachment were among the factors to a perceived decline in condition of the rangelands in the area.

4.2. Effects of grazing on woody vegetation

Grazing pressure affected the two measures of woody species diversity although its effect was small at the lowland site. Regardless of differences in topographic positions, species richness and diversity both tended to decrease as grazing intensity increased, suggesting that the rangeland of the study district is becoming degraded at an alarming rate through overgrazing and poor grazing practices. Lower species diversity in the present study in general and at the moderate and heavily grazed sites in particular suggests that the impacts of intensive grazing and trampling is likely prevented species occurrence. Selection of palatable plants and trampling damage during early stages of the plants may have also reduced the woody vegetation cover and richness [43]. Suppressive effects of livestock grazing on woody species diversity have been observed in other semi-arid rangelands of Ethiopia [44]. In contrary to range condition factors, significantly lower values for both woody diversity measures at the lowland site suggests that browse species growing at lower elevations of the study area may be more palatable than those in the uplands [45].

4.3. *Implications for pastoral production and range management*

The study showed that the rangelands in the semi-arid northeastern Ethiopia are heavily deteriorated due to grazing. Increased grazing intensity had detrimental effects on the condition of the rangeland and woody plants diversity. The overall condition of the rangeland was generally poor. Increasing grazing intensity significantly reduced herbaceous species biomass, grass composition, number of seedlings and age distribution, basal cover, and woody plant diversity. The current situation has severe implications for both rangeland ecosystems and human communities, altering the matrix of vegetation in previously grazed lands and, subsequently, the character of historically pastoral communities. Our study is timely because it provides governments (local and national) with vital information on the likely effects of current grazing practices on rangeland condition and woody plant community in semi-arid rangeland ecosystems, which are likely to experience increasing livestock production and conservation challenges over the coming decades [46]. Thus, there is a need to take measures that could improve local rangeland condition or restore vegetation impacted by grazing.

Although their effect was not assessed in the current study, management measures such as resting the rangelands preferably with stock exclusions for 6–12 months or protecting heavily degraded or sensitive areas from livestock activity and reseeding may be the viable options to enable recovery of degraded rangelands in the northeastern Ethiopia. For example, resting, or removal of grazing for strategic periods (growing season, or up to a year) of recovery, has been recommended as an effective strategy to eliminate or reduce negative impacts of grazing [e.g., 47]. Management measures that provide rest to vegetation at critical times can help maintain land in good condition or help facilitate the recovery of key forage species or degraded lands [47]. Such practices have proven to be effective in restoring heavily degraded lands in Tigray region, northern Ethiopia [48]. Resting pasture from grazing, and establishment of local exclosures have long been practised by the Borana pastoralists in semi-arid southern Ethiopia, which can be used as a lesson for intervention in the present study area [49,50].

4.4. *Limitations of the study*

Our data obtained from the vegetation survey and herders' perceptions suggest that livestock grazing may have detrimental effects on northeastern Ethiopian semi-arid ecosystems. The data were collected from a single location and for a growing season. The detrimental effects of grazing may thus be applicable to parts of this region – that is, they cannot necessarily be generalized to other locations. Moreover, the analyses did not take into account other factors, such as fire, herbivore type, bush encroachment and climate change, which could play a role either in further exacerbating or in ameliorating the detrimental effects of grazing [39,51]. Further model-assisted explorations, complemented with long-term grazing experimentation in different locations would expand the recommendation domain and allow a better understanding of the likely effects of grazing on arid and semi-arid ecosystems of Ethiopia.

5. Conclusion

Overall, our study showed that increased grazing intensity had negative effects on the condition of the rangeland and caused undesirable changes in plant communities. Consistent with our hypothesis, increasing grazing intensity significantly reduced herbaceous species biomass, grass composition, number of seedlings, age category, basal cover, and woody plant diversity. Therefore, to sustain the pastoral production system in the area, the current poor condition of the rangeland should be reversed. As such, the community should be aware that overstocking or prolonged use is causing range deterioration, and implementation of management measures such as resting of the rangelands preferably with stock exclusions for 6–12 months or protecting heavily degraded or sensitive areas from livestock activity and reseeding (preferably with manure or organic mulch addition) may be the viable options to mitigate declines in range conditions resulting from increasing grazing pressures. Management of natural resources is necessarily a site-and objective-specific endeavor. It is thus essential to strengthen the traditional resource management systems, and provide technical and technological supports to pastoralists. The economic importance of the livestock production for the Afar people will remain a feature in the future and livestock production could even be expanded throughput this dry rangeland where crop production is limited [11]. Average growth rate for cattle and goats in Ethiopia (including the pastoralists areas), for example, is 3.8 and 6.7 %, respectively, annually [52]. Hence, it is always important to monitor the rangelands to avoid further deterioration and the resultant threat to herders' livelihoods.

Data Availability Statement

Data will be made available on request from the corresponding author (Y.B).

CRediT authorship contribution statement

Mengeste Mathewos: Writing – original draft, Methodology, Investigation, Formal analysis, Conceptualization. **Amsalu Sisay:**

Writing – review & editing. **Yonas Berhanu:** Writing – review & editing, Formal analysis.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

This paper is based on research conducted in completion of the MSc degree by the first author and received no fund. The authors are grateful to the Afar pastoralists for their unreserved co-operation, warm hospitality and sharing of their indigenous knowledge.

Appendix A. Appendix

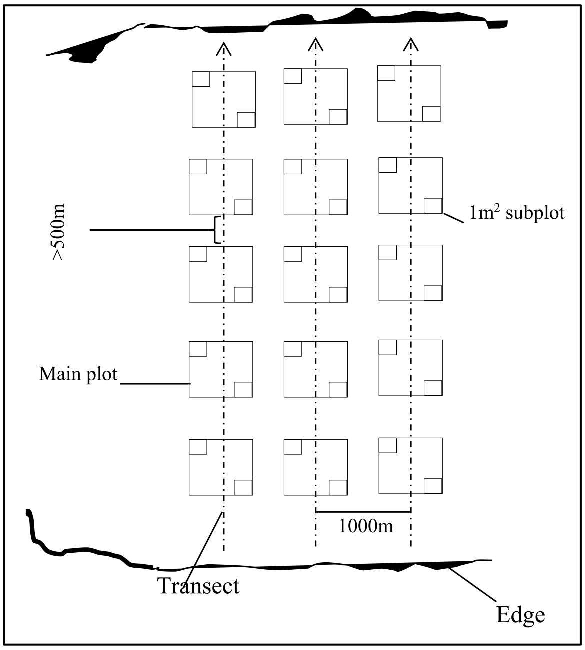

Fig. A1. Schematic (not to scale) diagram of transects and plots. Transects were established across each grazing zone in a systematic fashion (see text). The main quadrats were spaced approximately evenly along each transect but specific locations were random.

Appendix Table A1 Criteria for the scoring of the different factors determining range condition.

Score	Grass composition	Grass basal cover	Litter cover	Number of seedlings[1]	Age distribution	Soil erosion	Soil compaction
10	91–100 % decreasers	>12 %, no bare areas	>40 %				
9	81–90 % decreasers						
8	71–80 % decreasers	>9 %, evenly distributed	11–40 %, evenly distributed				
7	61–70 % decreasers	>9 %, occasional bare spots					
6	51–60 % decreasers	>6 %, evenly distributed	11–40 %, unevenly distributed				
5	41–50 % decreasers	>6 %, bare spots		>4 seedlings	young, medium, old	no soil movement	no compaction
4	10–40 % decreasers, ≥30 % increasers	>3 %, mainly perennials	3–10 %, mainly grasses	4 seedlings	two size categories present	slight sand mulch	isolated capping
3	10–40 % decreasers, <30 % increasers	>3 %, mainly annuals		3 seedlings	only old	slope-sided pedestals	>50 % capping
2	<10 % decreasers, ≥50 % increasers	1–3%	3–10 %, weeds/tree leaves	2 seedlings	only medium	steep-sided pedestals	>75 % capping
1	<10 % decreasers, <50 % increasers	<1 %	<3 %	2 seedlings	only young	pavements	almost 100 % capping
0		0 %	0 %	no seedlings		gullies	

Table A2
The current rangeland condition as perceived by herders in the study area.

Rangeland condition	Upland (n = 40)	Lowland (n = 40)	Overall (n = 80)
Excellent(% respondents)	2.5	0	1.3
Good	0	2.5	1.3
Fair	7.5	5	6.2
Poor	25	32.5	28.7
Very Poor	65	60	62.5

Table A3
Trends in rangeland (cover, distribution, and quality) condition in Ewa rangeland, Afar, Ethiopia.

Variable	Upland (n = 40)	Lowland (n = 40)	Study area (n = 80)
Declining trends in rangeland condition (%)			
Yes	97.5	100	98.7
No	2.5	0	1.3
Since when (%)			
Before 5–10 years ago	10	10	10
Before 11–15 years ago	12.5	15	13.8
Before 16–20 years ago	77.5	75	76.2

Table A4
Causes of rangeland degradation as ranked by the pastoralists in Ewa rangeland, Afar, Ethiopia.

Causes	Study area(Overall) (n = 80)	
	Weighted value[1]	Rank[a]
Recurrent droughts (shortage of rain)	0.32	1
Heavy continuous grazing	0.30	2
Bush encroachment	0.15	4
Inappropriate management system	0.23	3

[a] 1 = Most important; 4 = Least important.

[1] Sum of weighted scores was developed to obtain the final ranking of the causes of range degradation and calculated as: weighted sum = sum of [(4 × number of responses for 1st rank + 3 × number of responses for 2nd rank. …. + 1 × number of responses for 4th)] divided by (4 × total responses for 1st rank + 3 × total responses for 2nd rank. … + 1 × total responses for 4th rank).

Table A5
List of trees and shrub species recorded in the study area.

Vernacular name (Afar language)	Scientific name	Life Form
Adgento	*Acacia seyal*	Tree
Keselto	*Acacia nilotica*	Tree
E'ebi	*Acacia tortilis*	Tree
Udayito	*Balanites aegyptiaca*	Tree
Kusra	*Ziziphus spina-christi*	Tree
Maegharto	*Acacia melifera*	Tree
Adayito	*Salvadora persica*	shrub
Gerento	*Acacia nubica*	Tree
Segento	*Tamarix aphylla*	Tree
Gela'ato	*Calotropis procera*	Shrub
Adengelita	*Cadaba rotundifolia*	Shrub
Gersa	*Dobera glabra*	Tree
Ayrobit	*Senna obtusifolia*	Shrub
Bunayito	*Senna occidentalis*	Shrub

Source: [30]. 1Number of seedlings on A4 paper area.

References

[1] M. Herrero, et al., Biomass use, production, feed efficiencies, and greenhouse gas emissions from global livestock systems, Proc. Natl. Acad. Sci. U. S. A. 110 (52) (2013) 20888–20893, https://doi.org/10.1073/pnas.1308149110.
[2] D.D. Briske, Rangeland Systems Processes, Management and Challenges, 2017.
[3] D.J. Eldridge, A.G.B. Poore, M. Ruiz-colmenero, M. Letnic, S. Soliveres, Ecosystem structure, function, and composition in rangelands are negatively affected by livestock grazing, Ecol. Soc. Am. 26 (4) (2016) 1273–1283.
[4] Z.K. Tessema, W.F. de Boer, R.M.T. Baars, H.H.T. Prins, Changes in soil nutrients, vegetation structure and herbaceous biomass in response to grazing in a semi-arid savanna of Ethiopia, J. Arid Environ. 75 (2011) 662–670, https://doi.org/10.1016/j.jaridenv.2011.02.004.

[5] L. Yan, G. Zhou, F. Zhang, Effects of different Grazing intensities on grassland production in China: a meta-analysis, PLoS One 8 (12) (2013), https://doi.org/10.1371/journal.pone.0081466.
[6] D.J. Eldridge, J. Ding, S.K. Travers, A global synthesis of the effects of livestock activity on hydrological processes, Ecosystems 25 (8) (2022) 1780–1791, https://doi.org/10.1007/s10021-022-00746-9.
[7] G.P. Asner, A.J. Elmore, L.P. Olander, R.E. Martin, A.T. Harris, Grazing SYSTEMS,ECOSYSTEM responses, and global change, Annu. Rev. Environ. Resour. 29 (2004), https://doi.org/10.1146/annurev.energy.29.062403.102142, 261−99.
[8] H. Shiferaw, et al., Modelling the current fractional cover of an invasive alien plant and drivers of its invasion in a dryland ecosystem, Sci. Repor 9 (1576) (2019) 1–12, https://doi.org/10.1038/s41598-018-36587-7.
[9] CSA, "Population projection of Ethiopia for all regions at wereda level from 2014 – 2017, CSA (Central Statistical Agency of Ethiopia)," 3 (1) (2013) 28 [Online]. Available: http://www.csa.gov.et/images/general/news/pop_pro_wer_2014-2017_final.
[10] E. Abule, H.A. Snyman, G.N. Smit, Comparisons of pastoralists perceptions about rangeland resource utilisation in the Middle Awash Valley of Ethiopia, J. Environ. Manag. 75 (2005) 21–35, https://doi.org/10.1016/j.jenvman.2004.11.003.
[11] J. Helland, Afar Resilience Study. Feinstein International Center (Tufts University) and Afar Region Disaster Prevention, Preparedness and Food Security Coordination Office, Afar Regional State, Ethiopia, 2015. Working Paper #6.
[12] A. Angassa, B. Sheleme, G. Oba, A.C. Treydte, A. Linstädter, J. Sauerborn, Savanna land use and its effect on soil characteristics in southern Ethiopia, J. Arid Environ. 81 (June) (2012) 67–76, https://doi.org/10.1016/j.jaridenv.2012.01.006.
[13] A. Angassa, A. Tolera, A. Belayneh, The Effects of Physical Environment on the Condition of Rangelands in Borana, vol. 40, 2006, pp. 33–39.
[14] A. Angassa, Community-based knowledge of indigenous vegetation in arid african landscapes, Cons. J. Sustain. Dev. 8 (1) (2012) 70–85.
[15] G. Baumann, How to Assess Rangeland Condition in Semiarid Ecosystems ? the Indicative Value of Vegetation in the High Atlas Mountains, Morocco, 2009.
[16] H.G. Roba, Global Goals, Local Actions: A Framework for Integrating Indigenous Knowledge and Ecological Methods for Rangeland Assessment and Monitoring in Northern Kenya, Doctoral Thesis, Noragric, UMB, Norway, 2008.
[17] A.C. Grice, K.C. Hodgkinson, GLOBAL RANGELANDS:Progress and Prospects, CABI Publishing, 2002.
[18] E. Elias, Soils of the Ethiopian Highlands: Geomorphology and Properties. CASCAPE Project, ALTERA, Wageningen University and Research Centre (Wageningen UR), 2016.
[19] I.I.R.R. Pfe, DF, Pastoralism and Land: Land Tenure, Administration and Use in Pastoral Areas of Ethiopia, 2010.
[20] G. Oba, E. Post, P.O. Syvertsen, N.C. Stenseth, Bush cover and range condition assessments in relation to landscape and grazing in southern Ethiopia, Landsc. Ecol. 15 (6) (2000) 535–546, https://doi.org/10.1023/A:1008106625096.
[21] K.W. Tate, E.R. Atwill, N.K. Mcdougald, M.R. George, Spatial and temporal patterns of cattle feces deposition on rangeland, J. Range Manag. 56 (5) (2003) 432–438.
[22] S.E. Jordan, K.A. Palmquist, W.K. Lauenroth, I.C. Burke, S.E. Jordan, Small effects of livestock grazing intensification on diversity, abundance, and composition in a dryland plant community, Ecol. Appl. 32 (e2693) (2022) 1–15, https://doi.org/10.1002/eap.2693.
[23] B.K. Williams, E.D. Brown, Sampling and analysis frameworks for inference in ecology, Sampl. Anal. Fram. inference Ecol. 10 (March) (2019) 1832–1842, https://doi.org/10.1111/2041-210X.13279.
[24] F.S. Gilliam, Effects of harvesting on herbaceous layer diversity of a central Appalachian hardwood forest in West Virginia, USA, For. Ecol. Manage. 155 (1–3) (2002) 33–43, https://doi.org/10.1016/S0378-1127(01)00545-X.
[25] J. Ghorbani, A. Taya, M. Shokri, H.R. Naseri D.A. Assistant, Comparison of Whittaker and Modified-Whittaker plots to estimate species richness in semi-arid grassland and shrubland, Desert 16 (2011) 17–22.
[26] Minnesota Department of Natural Resources, A handbook for collecting vegetation plot data in Minnesota: the relevé method, Minnesota Cty. Biol. Surv. Minnesota Nat. Herit. Nongame Res. Program, Ecol. L. Classif. Progr., no. Biological Report 92 (2013) 57.
[27] A. Chao, et al., Rarefaction and extrapolation with Hill numbers: a framework for sampling and estimation in species diversity studies, Ecol. Monogr. 84 (1) (2014) 45–67, https://doi.org/10.1890/13-0133.1.
[28] L. Jost, The relation between evenness and diversity, Diversity 2 (2) (2010) 207–232, https://doi.org/10.3390/d2020207.
[29] M. Roswell, J. Dushoff, R. Winfree, A conceptual guide to measuring species diversity, Oikos 130 (3) (2021) 321–338, https://doi.org/10.1111/oik.07202.
[30] R.M.T. Baars, J.C. Chileshe, D.M. Kalokoni, Technical note: range condition in the high cattle density areas in the Western Province of Zambia, Trop. Grasslands 31 (1997) 569–573.
[31] E.J. Dyksterhuis, Condition and management of rangelands based on quantitative ecology, J. Range Manag. 2 (1949) 104–115.
[32] S.H. Hurlbert, "PSEUDO replication and the design of ecological field, EXPERIMENTS '," 54 (2) (1984) 187–211.
[33] L.F. Chaves, An entomologist guide to demystify pseudoreplication : data analysis of field studies with design constraints, J. Med. Entomol. 47 (3) (2010) 291–298, https://doi.org/10.1603/ME09250.
[34] M.D. Turner, P. Hiernaux, E. Schlecht, M.D. Turner, P. Hiernaux, E. Schlecht, The distribution of grazing pressure in relation to vegetation resources in semi-arid west Africa : the role of herding, Ecosystems 8 (6) (2005) 668–681, https://doi.org/10.1007/sl0021-003-0099-y.
[35] E. Abule, H.A. Snyman, N.G. Smit, Rangeland evaluation in the middle Awash valley of Ethiopia : I . Herbaceous vegetation cover, J. Arid Environ. 70 (2007) 253–271, https://doi.org/10.1016/j.jaridenv.2006.12.008.
[36] D. Gemedo, Evaluation of forage quantity and quality in the semi-arid Borana lowlands, southern oromia, Ethiopia, Trop. Grasslands-Forrajes Trop. 8 (2) (2020) 72–85, https://doi.org/10.17138/tgft(8)72-85.
[37] R.P. Ruvuga, et al., Evaluation of rangeland condition in miombo woodlands in eastern Tanzania in relation to season and distance from settlements, J. Environ. Manag. 290 (2021), 112635, https://doi.org/10.1016/j.jenvman.2021.112635.
[38] D. Gemedo, B.L. Maass, J. Isselstein, Rangeland condition and trend in the semi-arid Borana lowlands, southern Oromia, Ethiopia, African J. Range Forage Sci. 23 (1) (2006) 49–58, https://doi.org/10.2989/10220110609485886.
[39] F. de Bello, J. Lepš, M.-T. Sebastià, Grazing effects on the species-area relationship : variation along a climatic gradient in NE Spain, J. Veg. Sci. 18 (2007) 25–34, https://doi.org/10.1111/j.1654-1103.2007.tb02512.x.
[40] L. Dong, et al., Assessing the impact of grazing management on wind erosion risk in grasslands: a case study on how grazing affects aboveground biomass and soil particle composition in Inner Mongolia, Glob. Ecol. Conserv. 40 (November) (2022), e02344, https://doi.org/10.1016/j.gecco.2022.e02344.
[41] M. Gamoun, Grazing intensity effects on the vegetation in desert rangelands of Southern Tunisia, J Arid L 6 (3) (2014) 324–333, https://doi.org/10.1007/s40333-013-0202-y.
[42] J. Kioko, J.W. Kiringe, S.O. Seno, Impacts of livestock grazing on a savanna grassland in Kenya, J. Arid Land 4 (1) (2012) 29–35, https://doi.org/10.3724/SP.J.1227.2012.00029.
[43] M. Huang, et al., Grazing exclusion altered the pattern of the soil seed bank but not the aboveground vegetation along an altitudinal gradient in alpine grassland, L. Degrad Dev. 33 (2022) 3901–3913, https://doi.org/10.1002/ldr.4432.
[44] W. Mekuria, M. Yami, Changes in woody species composition following establishing exclosures on grazing lands in the lowlands of Northern Ethiopia, African J. Environ. Sci. Technol. 7 (1) (2013) 30–40, https://doi.org/10.5897/AJEST11.378.
[45] D.L. Coppock, The Borana Plateau of Southern Ethiopia: Synthesis of Pastoral Research, Development and Change, 1980-91, lLCA (lnternational Livestock Centre for Africa), Addis Ababa, Ethiopia., 1994.
[46] USGS & USAID, A Climate Trend Analysis of Ethiopia, 2012 [Online]. Available: http://pubs.usgs.gov/fs/2012/3123/.
[47] A.J. Ash, et al., Grazing management in tropical savannas: utilization and rest strategies to manipulate rangeland condition, Soc. Range Manag. 64 (3) (2011) 223–239, https://doi.org/10.2111/REM-D-09-00111.1.
[48] W. Mekuria, E. Veldkamp, M. Haile, J. Nyssen, Effectiveness of exclosures to restore degraded soils as a result of overgrazing in Tigray , Ethiopia, J. Arid Environ. 69 (2007) 270–284, https://doi.org/10.1016/j.jaridenv.2006.10.009.

[49] A. Angassa, G. Oba, Effects of grazing pressure , age of enclosures and seasonality on bush cover dynamics and vegetation composition in southern Ethiopia, J. Arid Environ. 74 (1) (2010) 111–120, https://doi.org/10.1016/j.jaridenv.2009.07.015.
[50] T.B. Solomon, H.A.Ã. Snyman, G.N. Smit, Cattle-rangeland management practices and perceptions of pastoralists towards rangeland degradation in the Borana zone of southern Ethiopia, J. Environ. Manag. 82 (2007) 481–494, https://doi.org/10.1016/j.jenvman.2006.01.008.
[51] D.J. Eldridge, M. Delgado-Baquerizo, S.K. Travers, J. Val, I. Oliver, Do grazing intensity and herbivore type affect soil health? Insights from a semi-arid productivity gradient, J. Appl. Ecol. 54 (3) (2017) 976–985, https://doi.org/10.1111/1365-2664.12834.
[52] F. Bachewe, B. Minten, F. Tadesse, A.S. Taffesse, The evolving livestock sector in Ethiopia growth by heads , not by productivity #122 (2018).