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Managed Area Enclosure (Kallo) in the Afar Dry Rangelands Enhances Plant Diversity and Sustains a Healthy Rangeland

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ABSTRACT: Rangelands support livelihoods of half a billion people globally, but they are among the most degraded ecosystems particularly in arid and semi-arid regions such as in the Afar region of Ethiopia. Using resilience and state-and-transition Models (STM) frameworks, this study evaluates the ecological effectiveness of traditional rangeland management system (Kallo) in supporting healthy rangeland management. This study compared within and outside the area enclosure in terms of plant species diversity, community composition and functional indicators using field-based vegetation surveys and quantitative analysis including a generalized linear model, Shannon diversity, and Bray–Curtis dissimilarity. These results showed a marked contrast between states where enclosed areas supported high diversity of plant species and families (62 species across 18 families) and only six species were recorded outside the Kallo. Species richness and diversity were significantly higher inside the enclosure ($P < 0.001$), and community composition differed strongly between treatments (Bray–Curtis dissimilarity = 0.91). The functional analysis revealed the dominance of perennial grasses (82% cover) and decreaser species such as *Cenchrus ciliaris*, indicating a relatively stable and productive state. In contrast, the presence of increaser and degradation-associated species, along with moderate representation of annual grasses, suggests a transitional but resilient system. Moreover, tree stem density (305.9 stems ha^{-1}) and a rangeland condition index (RCI = 1.07) further confirmed good ecological condition within the enclosure. Invasive alien species were often recorded, but their cover is extremely low (<1%) indicating the resilience of enclosure area and their limited ecological impact. The findings of this study showed that traditional enclosure-based management systems can facilitate ecosystems recovery toward a desirable rangeland state by enhancing biodiversity and strengthening ecosystem resilience. Finally, integration of functional indicators within the resilience and STM frameworks provides a valuable tool for assessing rangeland condition and informing sustainable management in dryland ecosystems.

Key words: Afar Rangelands, Plant Functional Types, Rangeland Condition Index, Rangeland Restoration, State-and-Transition Model

INTRODUCTION

Rangelands are among the largest terrestrial biomes globally covering nearly 80 million square kilometers or 54% of land cover of the Earth (UNCCD 2024; Briske et al., 2026). They support biodiversity, provide diverse ecosystem services, and livelihood means for millions of pastorals and agro-pastoral communities (Ritchie and Roser 2019). Rangelands are generally inherently dynamic systems and particularly in dry environments shaped by interactions among climatic variabilities, grazing intensity and management practices (Reid et al., 2014). In the Horn of Africa region, particularly in the Afar region of Ethiopia, rangelands are affected by severe degradation typically characterized by vegetation denudation, severe soil erosion and low primary productivity (Belay Zerga, 2015; Aderaw Tsegaye, 2024; Belay Zerga, 2025). Consequently, the Afar Rangeland ecosystem functioning and the resilience of pastoral systems are threatened affecting livelihoods.

In contemporary rangeland ecology, there is a shifting trend from linear, equilibrium-based models to the interpretation of such dynamic systems through the lens of resilient theory (Holling, 1973; Briske et al., 2017). Resilient theory conceptualizes ecosystems as complex and adaptive systems existing in multiple stable states. Rangeland as dynamic systems are affected by several factors including disturbance driven processes and nonlinear vegetation processes leading to co-existence of multiple equilibria. Therefore, degradation may not simply be a gradual decline, but it may entail threshold driven transition between alternative states. Productive rangelands dominated by perennial grasses and a healthy stem density could shift towards degraded systems characterized by annul species dominance, bare grounds or a system dominated by invasive alien species when ecological thresholds are exceeded (Walker & Abel, 2002; Bestelmeyer et al, 2003; Briske et al., 2017). The Afar Rangeland are severely affected by disturbances such as drought, flooding, overgrazing and unsustainable practices and once the ecological thresholds are crossed, they may be difficult to reverse due to reinforcing feedback such as soil degradation and depletion of seed banks (Belay Zerga, 2015; Aderaw Tsegaye, 2024; Belay Zerga, 2025).

In this paper, state-and-transition models (STMs), which is widely adopted frameworks, are used to put into practice these concepts for describing discrete vegetation states, transitions among them, and the drivers regulating these dynamics (c). In this study system, a desirable system is typically characterized by perennial grass dominance, high species diversity, high productivity, resilient system to invasion and stable soil conditions. The undesirable alternative stable state is characterized by annul grass dominance, low species diversity, low productivity and severe degradation of landscapes.

Here, this study attempted to frame a well-known traditional rangeland management system in Afar region called Kallo as an example of adaptive strategy that may enhance resilience and affect state dynamics. Kallo is an indigenous range management practice in Afar where grazing is seasonally excluded to allow recovery of vegetation for accumulation of forage for dry seasons (Dika Godana 2016). Such area enclosures can be interpreted as management intervention that facilitate ecosystems recovery pathways through vegetation recovery and reinforcement of ecological feedback to sustain desirable states (Briske et al., 2017). A few empirical evidence indicates that area enclosures improve vegetation cover, biomass production and ecosystems functioning (Mohammed Abdulatife, 2016; Mengeste Mathewos et al., 2023). This paper tries to investigate the influence of area enclosure on species diversity, community composition and functional resilience.

To apply resilience and STM frameworks, functional indicators such as plant life forms, species functional classifications (decreasers, increasers, degradation-associated species), and the ratio of annual to perennial grasses were used. These are well recognized as sensitive proxies for rangeland condition (Liniger et al., 2011; Holechek et al., 2011; Briske, 2017) and they provide robust ecological indicators to capture system state and their trajectories. Therefore, the dominance of perennial grasses is considered as stable and productive states, while increases in annual and disturbance-adapted species showed reduced resilience and potential transitions toward degraded states (Walker et al., 1981; Tainton, 1999). Moreover, in the Afar rangelands, invasive alien species such as *Prosopis juliflora* and *Parthenium hysterophorus* have been widely documented (Hailu Shiferaw et al., 2004; Pittroff, 2019). Biological invasions may function as drivers of regime shifts and could reinforce undesirable states from STM perspectives.

Therefore, this study integrated species diversity, community structure, and functional indicators within resilience theory and state-and-transition frameworks to evaluate the ecological effectiveness of a long-established *Kallo,* an area enclosure system in the Afar rangelands of northeastern Ethiopia. This study provides a comprehensive assessment of how a traditional enclosure-based management system influences rangeland condition and ecological trajectories. Specifically, the study aims to: (i) assess the impacts of enclosure on plant species diversity by comparing alpha and beta diversity inside and outside the enclosure; (ii) examine the diversity, composition, and cover-abundance of plant growth forms and functional types within the enclosure; and (iii) evaluate rangeland condition using functional indicators, including the ratio of annual to perennial grasses, tree stem density, and a composite rangeland condition index. The findings will contribute to advancing ecological indicator-based approaches for monitoring rangelands in arid and semi-arid regions by providing empirical evidence supporting indigenous management systems as practical pathways for enhancing rangeland resilience and for sustaining pastoral livelihoods.

Materials and Methods

Description of the study area

This study was conducted in Chifra district of Zone 1 of the Afar regional state on a privately owned area enclosure locally called (Kallo). Kallo is a privately or community-managed enclosure area where free grazing is excluded during the wet season to allow vegetation recovery and to be saved for dry periods or for weakling livestock in the Afar Region of Ethiopia (Dika Godana 2016). The location of the study area is near Chifra town, about six km from the main road. The survey was conducted with a team of five people, including a research assistant, the owner of the Kallo, and two local assistants in October 2021.

The district has about 173,374 ha of land area (APADB, 2006) and it is primarily rangeland. It has bimodal rainfall with unpredictable and erratic distribution, with long rain season between June and September and a short rainy day between March and April. The average annual rainfall of the district ranges from 400 to 600 mm and the average annual temperature is 29°C (APADB, 2016). The population of the district is estimated to be approximately 127,884 based on a 2022 projection (https://www.citypopulation.de/en/ethiopia/admin/afar/ET020106__chifra/).

The enclosure (Kallo) has been managed for over 30 years. The management practice exercised was traditional fencing and exclusion of grazing by livestock during the wet season. Once a year, the owner harvests the grasses for hay, serving as a yearlong feed for his livestock. The total area of the Kallo is 18 hectares. The area is found on flat land with negligible altitudinal variation, with a maximum altitude of 965 masl and a minimum altitude of 940 masl.

Data Collection

A systematic approach was employed to survey the area using a transect method and using five established transect lines from North-South directions. Along each transect line, 2 – 4 square quadrats (each size: 5 × 5 m) were laid depending on the landscape setting and the length of the transects. Moreover, additional sampling plots outside the enclosure were surveyed to compare inside and outside the area enclosures at a random distance from the enclosure boundary. An equal number of quadrats were surveyed within and outside of the area enclosure.

Along the transect, all plants were surveyed from the quadrates and elevation and GPS points were recorded. A well-known procedure of Braun-Blanquet was used to survey all plants were their cover-abundance were recorded following the listing of all plant species, either using their scientific names or their vernacular names.

Plant identification and verification in the herbarium

During the survey, all plant species were recorded in the field using their scientific names or vernacular names. Following the field survey, representative plant specimens were collected for proper botanical identification at the National Herbarium in Addis Ababa University. Once at the National Herbarium, the specimens collected were first sun-dried for five days, then to avoid insect contamination, samples were placed in an oven for five days and then deep freezer at -7^{0}c for five days before further identifications. Once dry, the specimens were sorted and found against the curated herbarium specimens and identified, using the Ethiopian Flora Volumes. Only those specimens that fulfilled herbarium admission quality standards were admitted as reference specimens and stored in the National Herbarium. A total of 62 specimens were brought to the herbarium with their duplicates.

DATA ANALYSIS

Species composition

Species cover–abundance data were organized into a community matrix, with samples as rows and species as columns. An environmental variable indicating enclosure status (inside vs. outside) was then appended to the community data. Beta diversity between enclosure treatments was quantified using *Bray–Curtis* dissimilarity, calculated with the *vegdist* function in the *vegan* R package. The resulting dissimilarity matrix stands for pairwise differences in community composition between enclosure treatments, with values ranging from 0 (identical species composition) to 1 (completely dissimilar composition). Moreover, the dissimilarity in plant species composition between inside and outside areas of the enclosure was statistically tested by using Permutational Multivariate Analysis of Variance (PERMANOVA) with the *adonis2* function in the *vegan* package. The significance of the difference was assessed using 999 permutations.

The patterns of plant species composition with enclosure status (inside vs. outside) were visualized using Non-metric Multidimensional Scaling (NMDS). NMDS ordination was performed on the species cover–

abundance community matrix using the Bray–Curtis dissimilarity within the *metaMDS* function of the *vegan* package. This approach reduces multidimensional community data into two axes while preserving the rank order of dissimilarities, allowing for visual interpretation of differences in species composition between inside and outside sites. All the data analyses were performed using the R program (version 4.5.2, R Core Team, 2025).

Species richness

Species richness is the count of the number of species recorded from each quadrat along the transects, both within and outside the area enclosure. The effect of enclosure area on plant species richness was evaluated using a generalized linear model (GLM) with a Poisson distribution. However, the data were right-skewed, and assessment of overdispersion using the ratio of residual deviance to residual degrees of freedom showed moderate overdispersion. To account for overdispersion in the count data, a negative binomial generalized linear model (GLM) was fitted using the MASS package in R. The negative binomial model includes an added dispersion parameter that allows the variance to exceed the mean, making it more appropriate for over-dispersed count data. Model fit was compared using Akaike's Information Criterion (AIC), which showed that the negative binomial model (AIC = 149.42) provided a better fit than the Poisson model (AIC = 150.82). The Shannon–Wiener species diversity was computed, and the assumption of normality was assessed by visually inspecting the distribution of species diversity using a histogram. The effect of enclosure area on species diversity was then analyzed using an independent two-sample t-test; one-way analysis of variance (ANOVA), with enclosure area treated as a categorical predictor using the car package.

Plant life form classification

To characterize community structure and functional composition the vegetation was classified into five major plant life forms: trees, shrubs, climbers, grasses, and forbs following widely used physiognomic and functional schemes (Raunkiaer, 1934; Mueller-Dombois & Ellenberg, 1974). Trees were defined as woody plants typically exceeding 5 m in height with a single dominant stem, while shrubs were woody plants generally below 5 m and often multi-stemmed. Climbers, including lianas and vines, were recorded as plants relying on external support to ascend toward the canopy. Herbaceous species were divided into grasses (graminoids) and forbs (broad-leaved non graminoids herbaceous vegetation).

During field sampling, all recorded plant species within each plot were assigned to one of these life form categories based on field observations and standard floristic guides. The relative abundance and cover of each life form category were then calculated to assess vegetation structure and functional composition across sites.

Tree stem density estimation

Woody vegetation cover was assessed using stem density, expressed as the number of stems per hectare (stems ha^{-1}). All woody plants, including trees and shrubs, were counted within each sampling plot. Standard vegetation sampling procedures (Mueller-Dombois and Ellenberg, 1974; Kent, 2012) were followed to account for species with multiple stems originating from a single root system and stems emerging at or near ground level. Stem density was calculated using the following formula:

$$\text{Stem density (stems per ha)} = \frac{\text{Total number of stems per plot}}{\text{Plot area (m}^2\text{)}} \times 10{,}000,$$

where 10,000 is the conversion factor from square meters to hectares. This metric is widely used to assess rangeland conditions.

Occurrence and frequency of invasive alien species and grass species

The distribution and spread of invasive alien plant species and grass species were quantified using frequency-based occurrence measures. Presence–absence data were collected for all identified invasive plant and grass species within each sampling plot to assess their spatial distribution across the study area.

The frequency of each species was calculated as the proportion of sampling plots in which the species occurred, expressed as a percentage and was computed using the formula:

$$\text{Frequency (\%)} = \frac{\text{Number of plots in which the species occurs}}{\text{Total number of sampling plots}} \times 100$$

This metric provides an estimate of the spatial distribution and relative commonness of invasive species and grass species across the study area (Kent, 2012; Magurran, 2004).

Functional classification of grass species and assignment to rangeland condition indicator categories

Grass species were assigned to annual and perennial functional groups and used as indicators of rangeland condition, reflecting differences in vegetation stability, productivity, and response to disturbance. In the field species were identified and categorized based on their life cycle using standard floras and ecological references (Mueller-Dombois and Ellenberg, 1974; Briske, 1996). All grasses were assigned to either annual or perennial based on field identification and literature review. The relative cover and abundance of each group were calculated and expressed as proportions of total grass cover. The annual-to-perennial grass ratio was employed as an indicator of rangeland condition, with a higher abundance of annual grasses reflecting disturbed or degraded states associated with grazing pressure and environmental stress. In contrast, the predominance of perennial grasses was considered characteristic of more stable, resilient, and ecologically functional rangeland states.

Furthermore, following an established rangeland ecology framework widely applied in dryland systems (Pellant et al., 1999; Tainton 1999; FAO 2011; Holechek et al., 2011; Briske, 2017), all recorded grass species were classified into functional indicator categories as: decreasers, increasers (I&II), degradation associated species. This functional classification is based on their documented ecological responses to disturbance factors such as grazing pressure and environmental variabilities.

Due to lack of extensive research on African Rangeland grasses, and wherever species-specific classifications were not explicitly available in the literature, the assignments of functional traits, including life history (annual vs. perennial), growth form, and known responses to grazing and disturbance, were based on established ecological principles (Liniger et al., 2011 and Briske 2017

To quantify rangeland condition, species were assigned weights according to their indicator category and reflecting the relative ecological importance of each group in maintaining rangeland functionality (Pellant et al., 1999; Holechek et al., 2011). Details are found in Table 1 below.

Table 1. Weighting Scheme for Rangeland Condition Index (RCI) and characteristics of each indicator category.

Indicator Category	Characteristics	Weight	References
Decreasers	Highly palatable and productive perennial grasses. Dominate under low grazing pressure. Decline with increasing disturbance. Indicators of healthy rangeland	+2	Pellant et al., (1999) and Holechek et al., (2011).
Increaser I	Moderately grazing-tolerant and May increase under light to moderate grazing	+1	
Increaser II	More tolerance of heavy grazing or disturbance and Often persist under reduced ecological condition Indicators of heavy grazing and disturbance	0	
Degradation-associated	Typically, annuals or low value perennials. Increase under severe disturbance, overgrazing, or soil degradation. Indicators of degraded rangeland conditions	−1	

Rangeland Condition Index (RCI)

RCI is an important single metric that reflects the ecological condition of the rangeland. The calculated RCI based on the wight given to each species were done using the following formula:

$$\mathrm{RCI} = \frac{(2\times \mathrm{D})+(1\times \mathrm{I}_1+(0\times \mathrm{I}_2)+(-1\times \mathrm{Deg})}{\text{Total cover}}$$

, where D stands for Decreasers, I_1 for Increasers I, I_2 for Increasers II and Deg stands for Degradation associated species. For interpretation, RCI > 1.0 indicates a rangeland in a good condition, RCI between 0.5 – 1.0 for Moderate and RCI < 0.5 poor (Pellant et al., 1999). The numbers in the formula stand for weights given (Table 1) for each functional category.

RESULTS

Species richness

Comparison of within and outside the area enclosure showed interesting results (Figure 1). When compared in terms of number of species and families, only 6 plant species categorized into 4 plant families were recorded outside the enclosure while within the enclosed area 62 species categorized under 18 plant families were recorded. Moreover, all plant species recorded outside the enclosure area were also recorded within the enclosure.

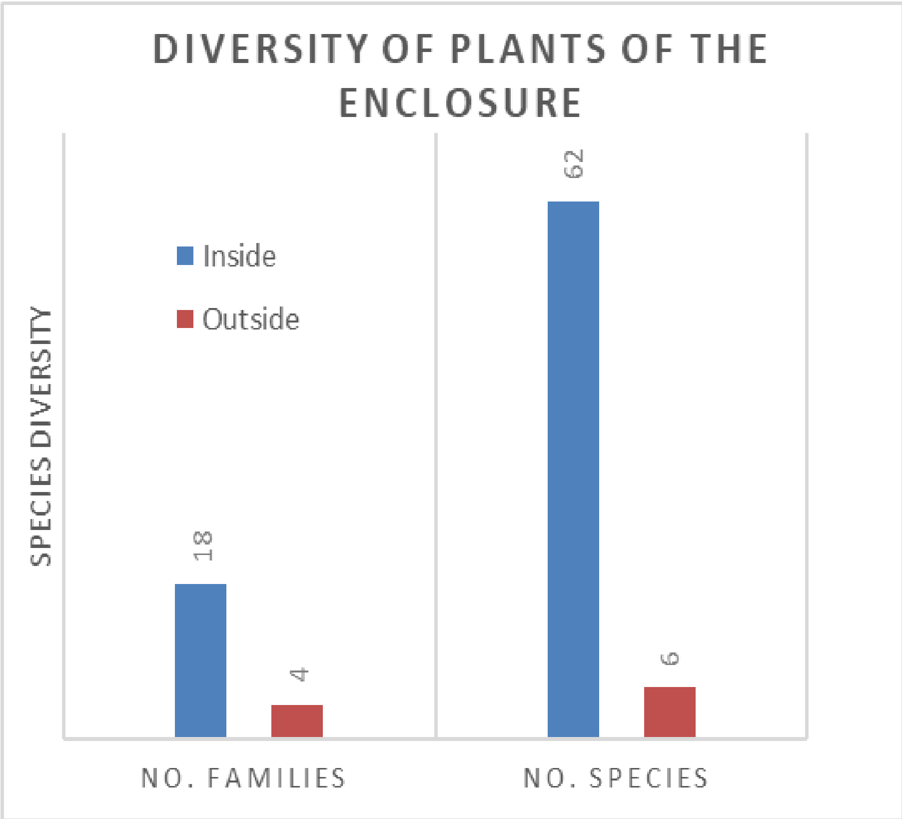

Figure 1. Number of plant families and plant species recorded within and outside the area enclosure from the study area.

Moreover, the negative binomial generalized linear model showed that area enclosure had a significant effect on the species' richness, as it was lower outside the area enclosure compared to inside ($P < 0.001$, Figure 2A). Similarly, the result of a Welch Two Sample t-test showed that Shannon–Wiener species diversity was significantly higher inside area enclosures than outside ($P < 0.001$, Figure 2B), showing that both species richness and diversity were strongly influenced by enclosure area.

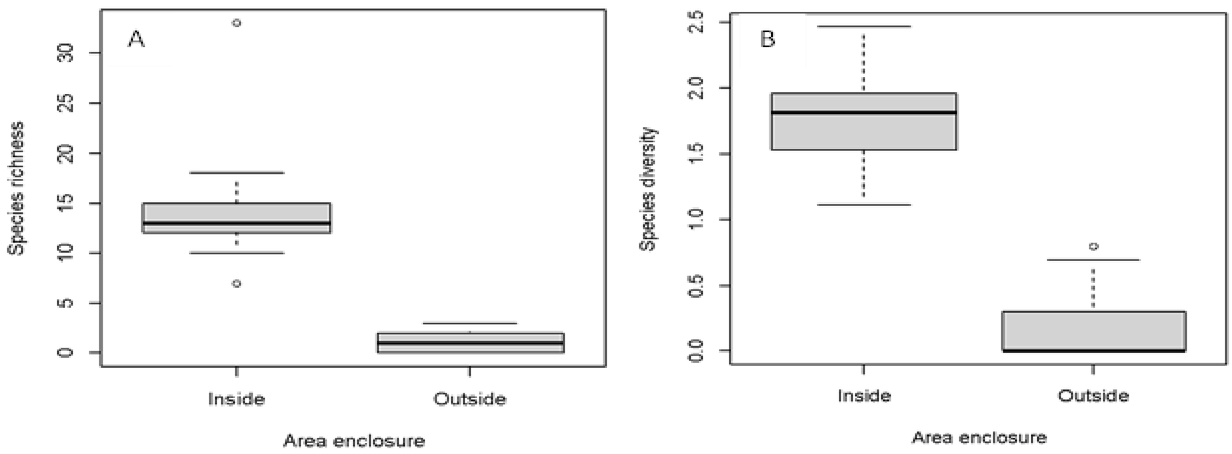

Figure 2. Boxplots show differences in (A) Species richness, standing for the number of species per site; (B) Species diversity, calculated using Shannon diversity.

Species composition

The result of Bray–Curtis dissimilarity analysis showed a high dissimilarity (0.91 in species composition between inside and outside the enclosure sites. The Adonis2 test revealed that plant species composition differed significantly between enclosed and non-enclosed sites ($F_{(1,26)}$ = 7.58, P = 0.001). The NMDS ordination of plant species composition revealed a clear separation between sites inside and outside the enclosure. This pattern suggests that species composition differs between enclosed and non-enclosed areas, with the NMDS axes capturing the variation in community structure across the two treatments (Figure 3).

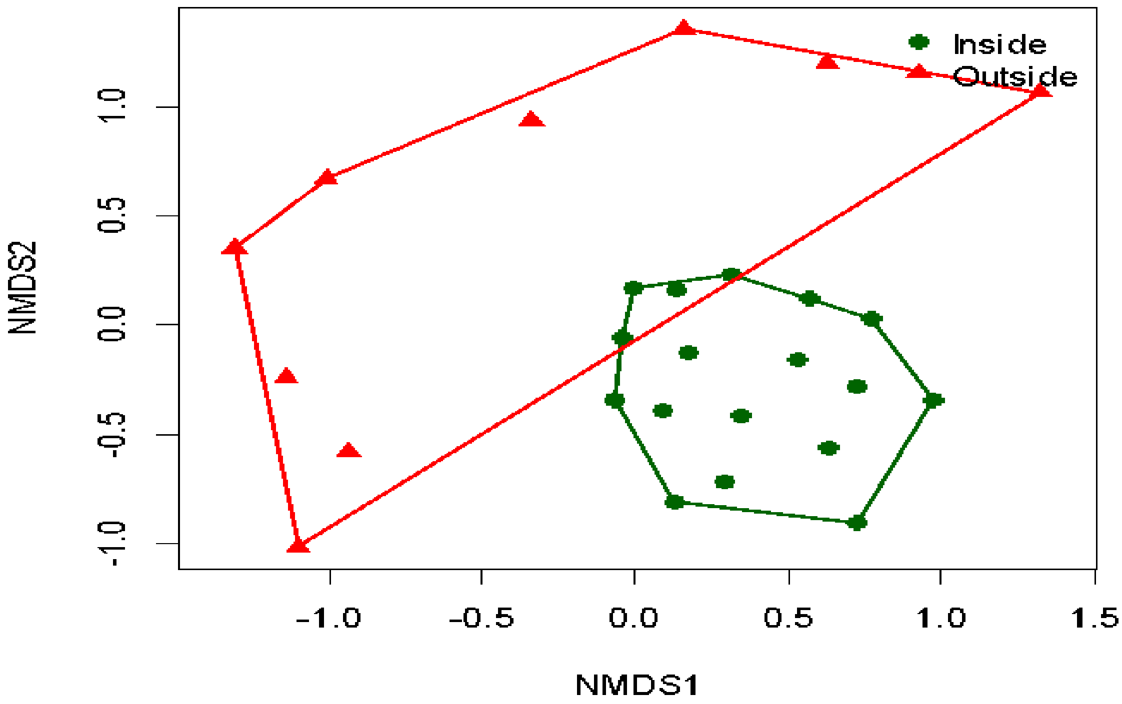

Figure 3. NMDS ordination of plant species composition inside and outside the enclosure. Points stand for sample sites (Inside = circle, outside = triangle), with convex hulls highlighting group spread showing differences in species composition between enclosed and non-enclosed sites.

Species richness within the Kallo

In the Kallo Poaceae is the dominant plant family with 20 species, followed by Fabaceae with 8 species, Acanthaceae with 4 species, and Cucurbitaceae with 3 (Figure 4). Majority of plant families were represented by just 1 species. Whereas in terms of cover abundance, Poaceae is by far the most dominant plant family with 65% of the total cover, followed by Fabaceae with 18% of the total cover abundance. The rest of the plant families contribute the remaining percentages (Figure 4).

Analysis of plant growth forms within the enclosure shows the dominance of grass followed by forbs. These two life forms make up 80% of cover abundance and 66% of species occurrence frequency within the Kallo (Figure 6). Of 80% cover-abundances, grass contributed 65%, while forbs take the remaining 15%. There were only 6 tree species that contributed about 15% of the total coverage, while 15 shrub species covered only 3% of the total cover-abundance of the Kallo. Only two climbers with about 2% coverage were found in the study area (Figure 5). Furthermore, partitioning the vegetation into woody and herbaceous categories showed that herbaceous species dominated the plant community, accounting for 82% of the total vegetation cover and comprising 43 species, whereas woody species represented only 18% of the total cover and 19 species (Figure 6

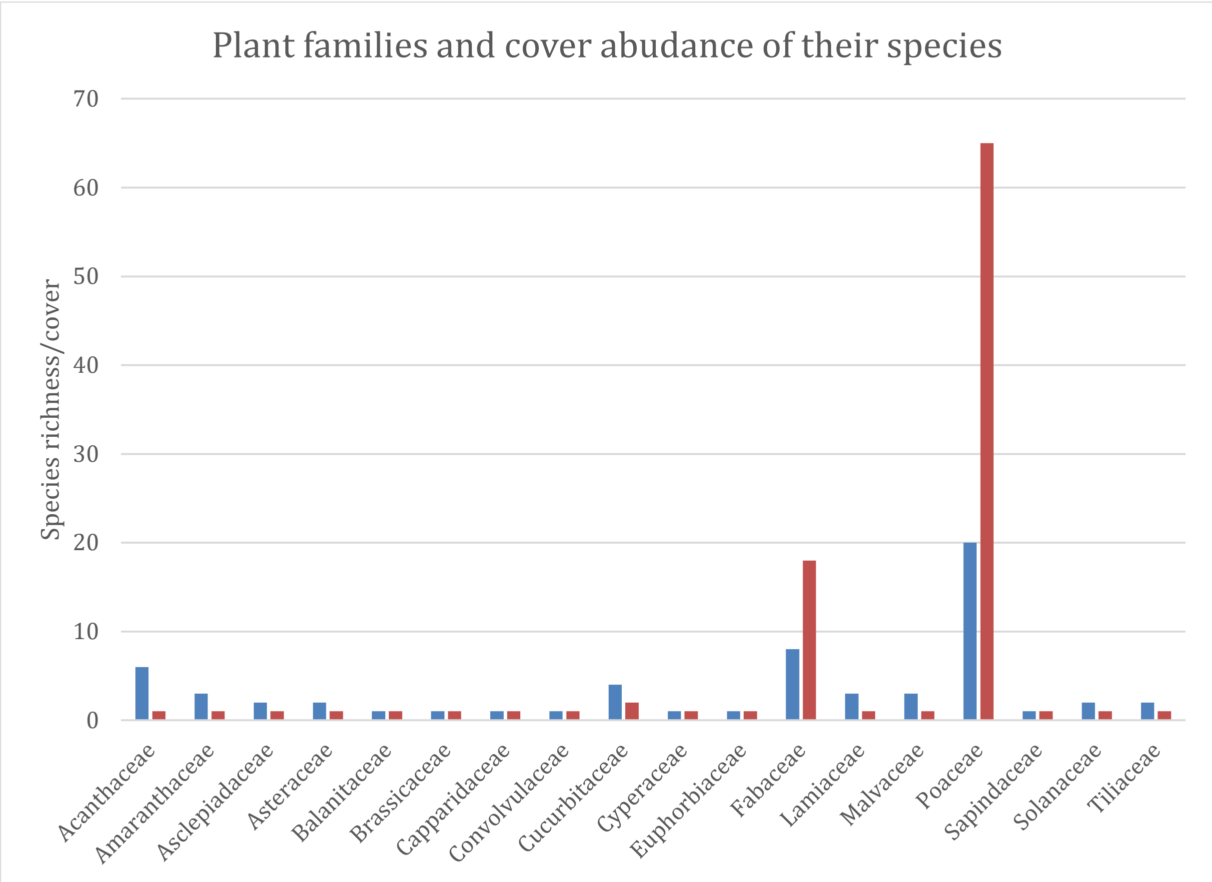

Figure 4. Cover-abundance of plant species in identified plant families. The figure shows that Poaceae is the dominant plant family in terms of species richness and cover abundance, followed by Fabaceae.

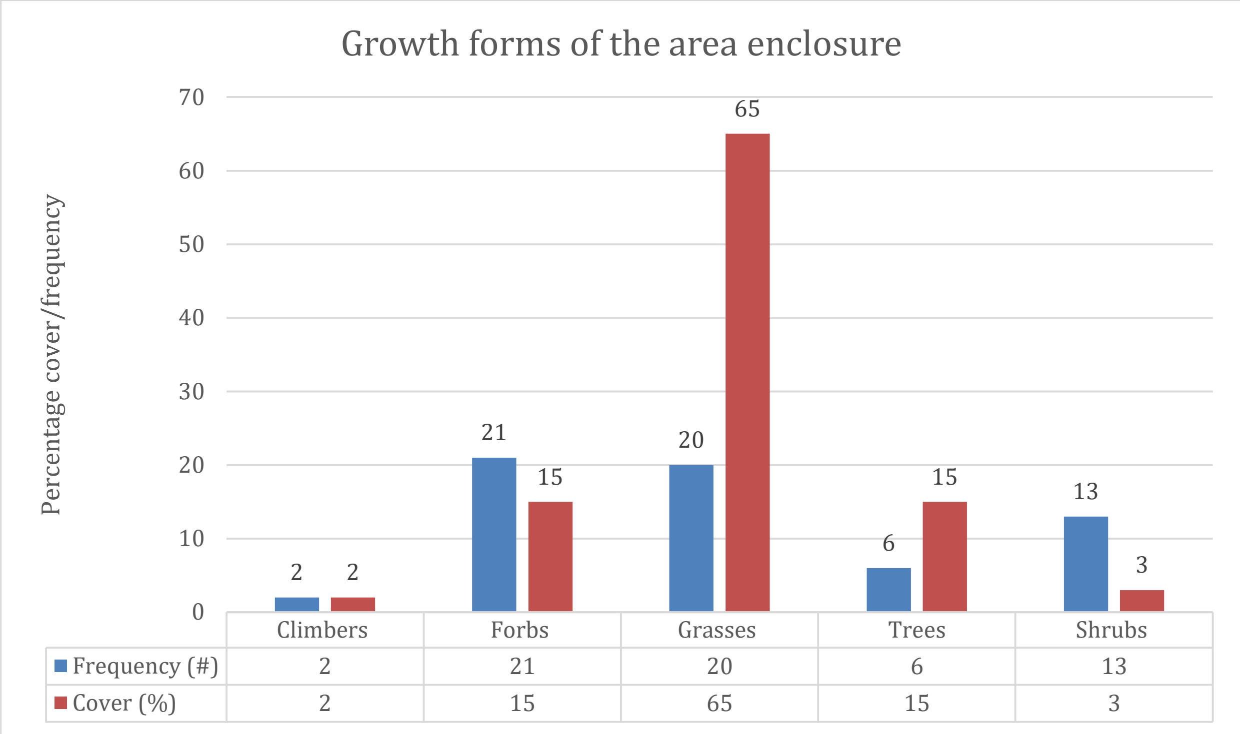

Figure 5. Cover abundance and frequency of occurrence of plant growth forms in the study area.

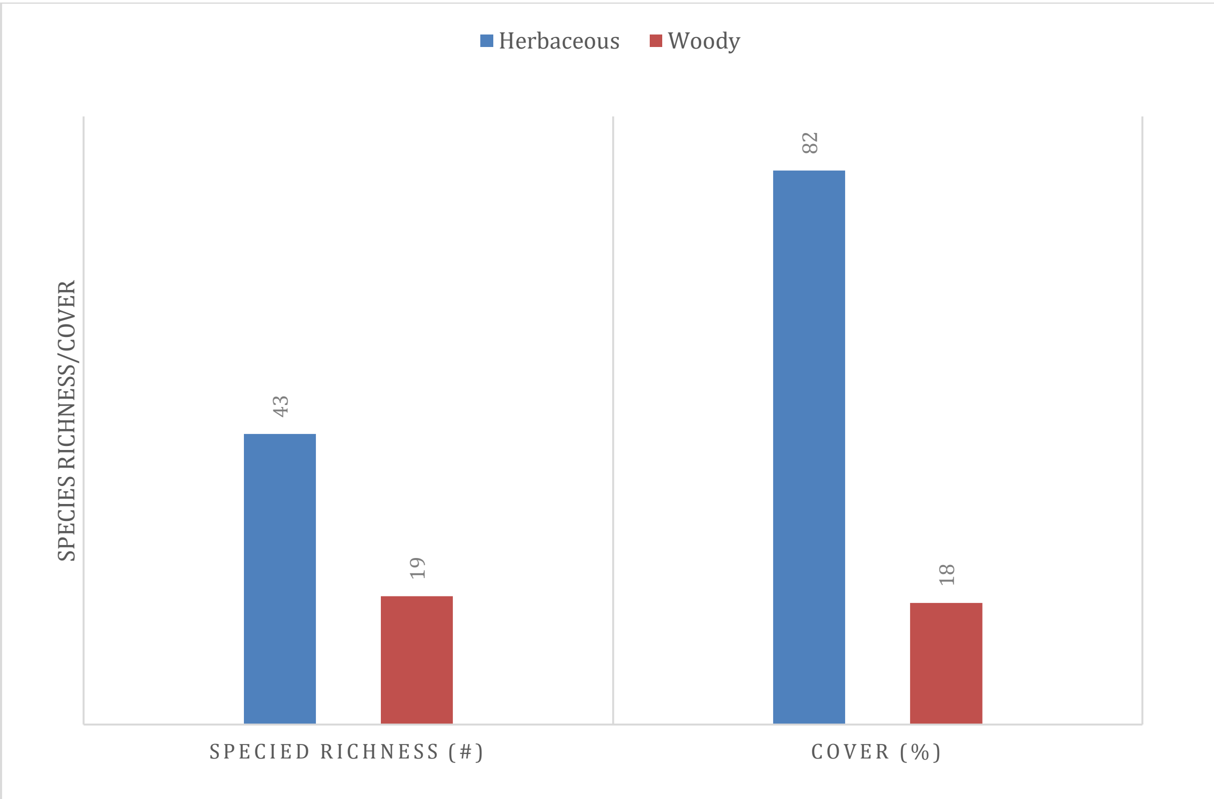

Figure 6. Richness and cover abundance of woody species as compared to herbaceous vegetation in the study area.

In terms of invasive alien species, three recorded invasive plants were recorded in and outside of the Kallo (Figure 7). One of the invasive plants, *Parthenium hysterophorus L.*, was recorded in nearly 95% of the plots surveyed even though its percentage coverage is extremely low (<1%) in all plots. Similarly, the remaining two invasive plants occur nearly in 24% of the plots and with a similar extremely low area coverage.

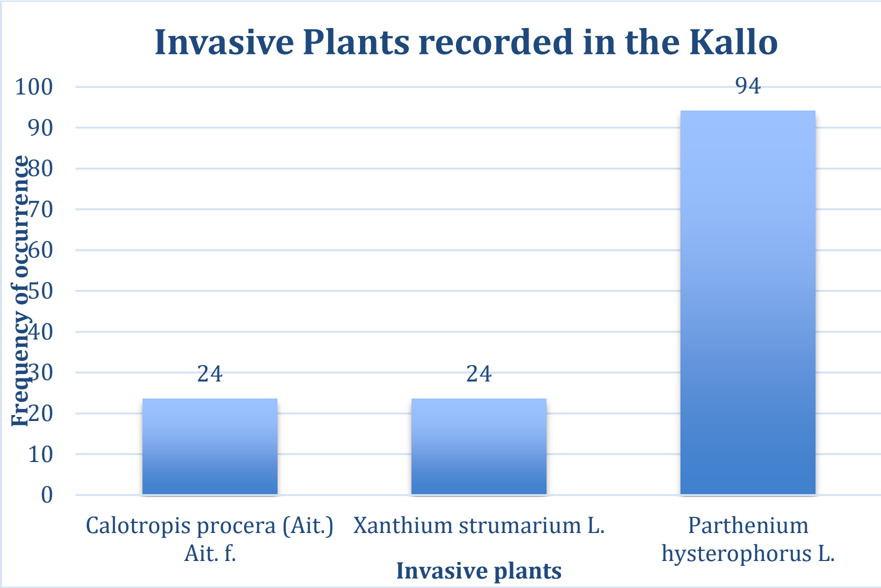

Figure 7. Frequency of occurrence of invasive alien species in the study area.

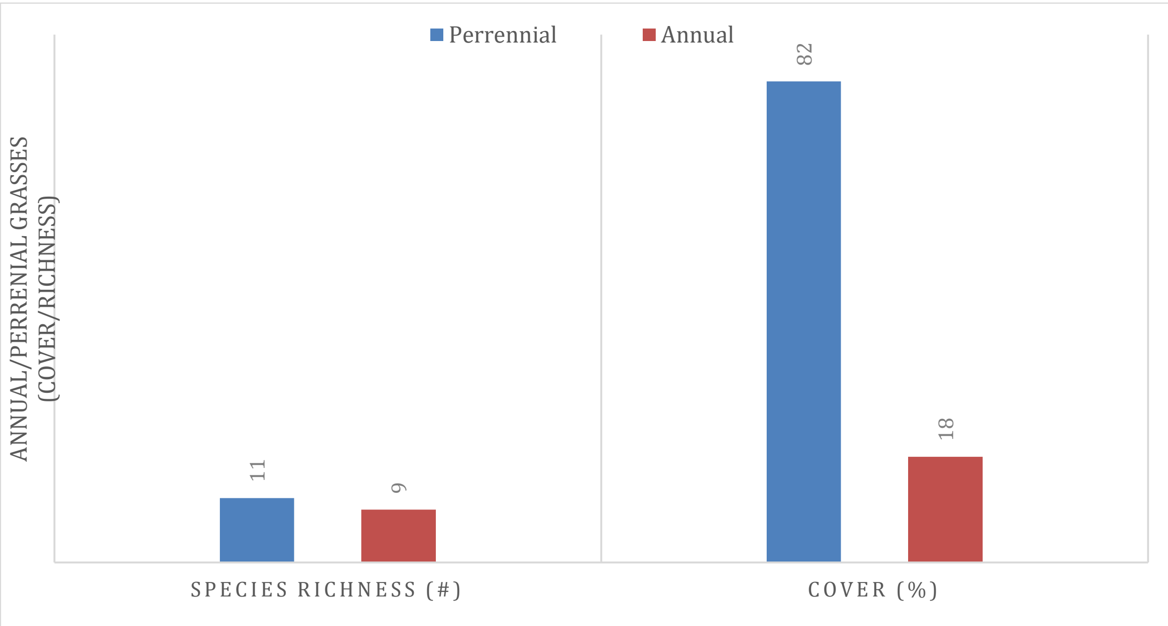

Figure 8. The proportion of Annual vs. Prerenal grasses in the study area, both in terms of cover abundance and species richness.

Grass species functional composition and range land condition

A total of 20 grass species were recorded composed of 55% perennial and 45% annual life forms, except one species which is a weak perennial (*Dactyloctenium scindicum*) depending on the ecological conditions (Figure 8). Two perennial grasses species dominated total vegetation cover. These are *Cenchrus ciliaris* with a total cover (sum) of 605% and *Cynodon dactylon* with 260%, together accounting for a substantial proportion of total grass biomass. When averaged to per plot, they contributed respectively 35% and 15% of the vegetation cover per plot (Table 2).

The functional classification (Table 2) revealed a clear dominance of decreaser species such as *Cenchrus ciliaris, Chloris macrostachya, Cynodon dactylon*, *Chloris prieurii, Chloris prieurii and Chrysopogon plumulosus.* The result also showed a moderate representation of increaser species such as *Andropogon canaliculatus* and *Brachiaria jubata*. Even though degradation-associated species, including *Aristida adoensis* and *Tragus racemosus*, had a moderate frequency, they contributed relatively low overall coverage.

The species richness of annual grasses (45%) is proportional to the richness of perennial species, however, in terms of total coverage, they contributed only 18%. The Kallo had a good mix of both categories and functionally structured grass community. Furthermore, the tree stem density, which is one of the metrics used to assess the health status of rangeland as given in Equation 1 (Methods section), is 305.9 stems/ha, showing good condition of the Kallo.

Based on Table 2 below, calculated Rangeland Condition Index (RCI) was **1.07.** The value of RCI > 1 is an indicator of a rangeland in a good ecological condition. This may reflect the strong dominance of decreaser species and a relatively low contribution of degradation n-associated species.

Table 2. Functional Classification of Grass species and Assignment to Rangeland Condition Indicator Categories.

No.	Scientific Name	Life Form	Indicator Category	Frequency of occurrence (%)	Cover (sum across sampled plots)	Ecological Basis	References
1	*Andropogon abyssinicum*	Annual	Increaser II	24	40	Opportunistic annual responding to disturbance	Briske (2017).
2	*Andropogon canaliculatus*	Perennial	Increaser I	12	15	Moderate grazing tolerance	Tainton (1999).
3	*Aristida adoensis*	Perennial	Degradation-associated	29	25	Common in overgrazed systems	Holechek et al. (2011).
4	*Brachiaria jubata*	Perennial	Increaser I	24	20	Grazing-tolerant perennial	Liniger et al., (2011).
5	*Brachiaria ramosa*	Annual	Increaser II	12	40	Disturbance-adapted annual	Briske (2017).
6	*Cenchrus ciliaris*	Perennial	Decreaser	82	605	Key indicator of good rangeland condition	Holechek et al. (2011) & Liniger et al., (2011).
7	*Chloris macrostachya*	Perennial	Decreaser / Increaser I	18	7	Stable under moderate grazing	Tainton (1999).
8	*Chloris prieurii*	Perennial	Decreaser / Increaser I	18	15	Functional semi-arid grass	Liniger et al., (2011).
9	*Chrysopogon plumulosus*	Perennial	Decreaser	6	5	Associated with intact vegetation	Tainton (1999).
10	*Cynodon dactylon*	Perennial	Increaser II	53	260	Grazing-tolerant species	Holechek et al. (2011).
11	*Dactyloctenium aegyptium*	Annual	Degradation-associated	18	15	Indicator of disturbance	Briske (2017).
12	*Dactyloctenium scindicum*	Short-lived	Degradation-associated	6	1	Weak perennial/annual	Liniger et al., (2011).

						behavior	
13	*Eragrostis aethiopica*	Annual	Increaser II	18	15	Opportunistic annual	Briske (2017).
14	*Eragrostis biflora*	Annual	Degradation-associated	24	16	Linked to degraded soils	Holechek et al. (2011).
15	*Hyparrhenia rufa*	Perennial	Decreaser	24	4	Dominant in good-condition savanna	Tainton (1999).
16	*Sorghum arundinaceum*	Annual	Increaser II	18	3	Disturbance-responsive annual	Briske (2017).
17	*Sporobolus pellucidus*	Perennial	Increaser II	12	2	Grazing-tolerant species	Liniger et al., (2011).
18	*Tetrapogon cenchriformis*	Annual	Increaser II	29	80	Disturbance-adapted annual	Briske (2017).
19	*Tetrapogon tenellus*	Annual	Increaser II	18	3	Short-lived opportunistic grass	Briske (2017).
20	*Tragus racemosus*	Annual	Degradation-associated	6	1	Indicator of heavy grazing	Holechek et al. (2011).

DISCUSSION

Plant species diversity

Comparative assessment of the within and outside enclosure (Kallo) depicted a significant difference in terms of species diversity and composition, indicating denudation of the rangeland areas outside of area enclosures. Moreover, the result clearly shows variations in community structure as shows in Figure 3, where inside and outside the Kallo showed little overlap in community structure. The level of denudation of Afar rangelands in Ethiopia is reported to have become a critical environmental crisis (Aderaw Tsegaye, 2024). According to this study, severe loss of vegetation cover, soil erosion, and the reduction of biological productivity characterize an extremely level of degradation. Over the past few decades, substantial portions of these arid and semi-arid rangelands lands in this region have been converted into barren land, threatening the traditional pastoralist livelihood system (Belay Zerga, 2025). This result clearly supports this finding, where outside of the Kallo, this study documented extreme erosion and gully formation due to the absence of vegetation cover (Figure 9).

Plant species diversity of Kallo

Plant Species diversity of the Kallo, which are often community-based enclosures or designated areas that are protected from grazing during wet seasons so that vegetation recovers to be saved for dry periods, is extremely high. Recording 62 plant species categorized into 18 plant families within an area of 18 hectares shows that such area enclosures in the Afar rangelands of Ethiopia are highly effective promoting the recovery of plant biodiversity and in reversing rangeland degradation when compared to open communal grazing areas. It seems area enclosures allow for the regeneration of native flora, particularly palatable perennial grasses and herbaceous species, by restricting human and livestock interference as reported by another study in Afar (Mohammed Abdulatife, 2016).

The Poaceae family is one of the most dominant plants in the Kallo with 20 species followed by Fabaceae, which has 6 species. This result is supported by other studies that also documented a similar pattern such as (Jatani Garbole et al., 2025) that documented 19 herbaceous species in the study area in Afar rangeland, with grasses making up the majority (68.5%). Similarly, experimental studies also showed the dominance of Poaceae family in Afar rangelands (Mengeste Mathewos et al., 2023). Mohammed Abdulatife (2016) conducted a study to investigate the impact of enclosure on plant cover dynamics and biomass production in Ewa district of the Afar region and he documented 13 species of grasses, 2 species of legumes and 4 species of other herbs further supporting out findings. A study conducted in Chifra district of zone one of the Afar Regional State, similar district where the Kallo this study is located, of the total 35 herbaceous species recorded in the study district, 25 of them (71%) were found to be grasses and the remaining 10 (29%) were non-grass herbaceous species (Mohammed Abdulatife and Abule Ebro, 2015).

Furthermore, this study documents 8 species of Fabaceae family dominated by Acacia species, which are now reclassified as either Vachellia or Senegalia. These species were *Vachellia nilotica* (L.) P.J.H. Hurter & Mabb. (formerly *Acacia nilotica*), *Senegalia oerfota* (Forssk.) P.J.H. Hurter (formerly *Acacia oerfota*, *Senegalia senegal* (L.) Britton (formerly *Acacia senegalia)*, and *Vachellia tortilis* (Forssk.) Galasso & Banfi (formerly *Acacia tortilis)*. Similarly, studies in the Afar rangelands in areas such as in Ewa and Amibara districts, these species are often found (Dagnachew Bezaredie et al., 2023).

Of the five plant growth forms (Figure 5), grass and forbs are the dominant growth forms followed by trees and shrubs while climbers take a small proportion. This finding is also supported by earlier reports such as dominance of herbaceous later (grasses and forbs) (Ayana Angassa, 2014; Haftay Gebremedhn, 2023). This result on proportion of herbaceous and woody vegetation (Figure 7) clearly show that the Kallo is in good condition. Healthy rangelands typically have a healthy woody coverage where trees and shrubs coexist with grass and forbs providing ecological services like shade, biodiversity, and brows without dominating the landscape (Sangeda and Maleko., 2018). The Kallo is a healthy rangeland, which is often characterized as "open," with sparse trees and shrubs that allow sufficient sunlight for forage production (Jatani Garbole et al., 2025)

The Afar rangeland is reported to be highly invested with invasive alien plant species (Hailu Shiferaw 2004; Hibret Demisse 2009; Rezene Bekele and Taye Tessema 2014; Selamnesh Tesfaye 2015; Negussie Zeray et al., 2017; and Pittroff, W. 2019). However, in this study were found only three Invesive Alien Plant (IAPs) in the study area, these were: *Calotropis procera* (Ait.) Ait. f., *Xanthium strumarium* L. and *Parthenium hysterophorus* L. and however, the most invasive plant in the area, which is *Prosopis juliflora* was not recorded. Even though they often occur in the Kallo (Figure 7), in terms of their coverage they are extremely low, showing the unsuitability of healthy rangeland for invasion as several studies cited here showed.

Figure 9. Photo plates showing the extent of degradation caused by erosion in the study area. Gulley erosion so strong it fell down trees on the border of the Kallo. (Photo credit: Author, October 22, 2021).

Grass species functional composition and range land condition

The ratio of annual vs. perennial grasses was used as an indicator of rangeland conditions where higher proportion of annual grass species show disturbance, degradation, or increased grazing pressure, while the dominance of perennial grass shows a relatively stable and healthy rangeland system. This analysis framework is widely proven and adopted in wider studies particularly in data scare areas such as the Afar Rangeland systems (Walker et al., 1981; Holechek et al., 2011; Liniger et al., 2011; Briske, 2017).

This analysis (Table 2) showed that perennial grass decreaser species such as *Cenchrus ciliaris* were the most dominant, suggesting that the study area supports a relatively stable and productive rangeland system. This finding is supported by several literature (Holechek et al., 2011; Liniger et al., 2011; Briske, 2017) where *Cenchrus ciliaris* is widely recognized as a key indicator of well-managed and healthy semi-arid rangelands due to its high forage value, drought tolerance, and persistence under moderate grazing. Moreover, its ecological importance in enhancing productivity and sustaining soil stability has been widely documented in these studies.

However, there was considerable presence of increaser species such as *Cynodon dactylon* that shows ongoing grazing pressure. This species contributes significantly to ground cover and productivity of the Kallo, yet its proliferation is often associated with grazing-tolerant dynamics rather than best ecological condition. *C. dactylon* is tolerant to defoliation and it spread rapidly through vegetative reproduction, and it is reported to increase under heavy grazing reflecting grazing intensity (Holechek et al., 2011; and Briske, 2017). This finding reflects the management practice of the Kallo, where through the traditional practices, seasonal controlled grazing and hey harvesting takes place by the owner and thus the rapid increment of *C. dactylon* could be attributed to the management practice.

The presence of the third category, degradation-associated species, such as *Aristida adoensis* and *Tragus racemosus*, although limited in cover, points to the presence of localized disturbance and a potential start of degradation processes. Studies show species within the genus *Aristida* become dominant under conditions of overgrazing or reduced soil fertility (Tainton, 1999; Holechek et al., 2011). Similar studies also report that *Tragus racemosus* is commonly associated with disturbed and heavily grazed sites. Moreover, the relatively high proportion of annual grass species suggests temporal instability and sensitivity to rainfall variability or incidences of flush floods or grazing intensity (Walker et al., 1981; Briske, 2017). In the study area, the presence of disturbance was clearly visible (Figure 9) and thus supporting the findings above that showed the increment of annual grass under disturbance and variable climatic conditions, reflecting reduced ecosystem resilience and altered vegetation dynamics.

Generally, the Kallo is dominated by perennial grasses which are known to contribute to soil stability, high primary productivity, and ecosystem resilience, while annuals grasses tend to proliferate under conditions of disturbance and resource fluctuation. The use of this functional classification provided a robust basis for evaluating the health status of the Kallo and it helps in informing sustainable rangeland management strategies (Holechek et al., 2011; and Briske, 2017). Based on this evaluation, the study Kallo is in a transitional but resilient state.

CONCLUSION

This study proves the utility of functional vegetation indicators in assessing rangeland conditions in arid and semi-arid ecosystems of the Horn of Africa. The clear differences in species composition and diversity between area enclosure (Kallo) and open grazing areas highlight the extent of vegetation denudation in the communal rangelands and the effectiveness of the Kallo in supporting extremely high plant diversity. The healthy composition and coverage of trees and a balanced representation of plant growth forms with the dominance of perennial grasses such as, the decreaser species, *Cenchrus ciliaris*, shows a relatively stable and resilient system. Concurrently, the presence of degradation-associated taxa, the increaser species such as *Cynodon dactylon*, and a relatively high proportion of annual grasses reflects the existence of ongoing disturbance and environmental variability in the study area. These patterns confirm that the ratio of annual to perennial grasses when combined with species functional classification provides a robust and sensitive indicator of rangeland condition.

These findings underscore that area enclosure-based rangeland management could increase or enhance plant diversity and support biodiversity, minimize risks of invasion with invasive alien species, enhance ecosystem resilience, and may support sustainable rangeland management. Moreover, the study contributes to the development of practical, indicator-based frameworks for monitoring rangeland conditions in data scarce dryland regions of the Horn of Africa or elsewhere in the global south. Finally, this work substantiates the effectiveness of the traditional range management system (Kallo system) of the Afar pastoralists showing that the local community has long understood a traditional 'adaptive management system' aimed at balancing grazing pressure with long-term rangeland sustainability. The results clearly support the integration of controlled grazing, seasonal resting, and Kallo based management practices to support perennial grass dominance and prevent degradation. It is recommended that Kallo based management offers a practical pathway towards sustainability of pastoral livelihoods in dryland systems.

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