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Hezron, Elkana

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Roles of *Maasai Alalili* Systems in Sustainable Conservation of Fodder Species of East African Rangelands☆

Elkana Hezron*, Issakwisa B. Ngondya, Linus K. Munishi

Department of Sustainable Agriculture, Biodiversity and Ecosystem Management, School of Life Sciences and Bioengineering, The Nelson Mandela African Institution of Science and Technology, Arusha, Tanzania.

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ABSTRACT

Alalili systems are among the indigenous rangeland management strategies that face pressures from unsustainable land use practices and impacts of climate change. We aimed to establish the vascular fodder plants' composition and abundance, compared with historical vegetation data to understand their evolution and trends to inform sustainable management of rangelands in northern Tanzania. The vegetation composition of the northern Tanzania rangelands surveyed before the 1980s was compared to empirical data from a vegetation survey of *Alalili* in 2022. A cross-sectional design using purposive and stratified random sampling techniques was applied during the field survey. The quadrat count method was used to estimate the composition and diversity of fodder taxa in *Alalili* systems. Secondary data from the northern Tanzania rangelands before the 1980s were collected through a systematic literature review. Key informant interviews, focused group discussions, and household surveys were used to gather information about the community's knowledge of historical quality changes in the rangelands. Our results indicate that, before the 1980s, the rangelands of northern Tanzania had relatively higher fodder species composition (127 woody and 119 herbaceous species) than the *Alalili* systems in 2022 (119 woody and 82 herbaceous species). Fodder species composition and diversity were relatively higher in communal than in private *Alalili* ($t = 4.18$, $P < 0.001$). At the same time, the species density was lower in communal than in private *Alalili* ($t = -2.7272$, $P = 0.008$). This work suggests that *Alalili* systems still hold substantial diverse fodder plants that most northern Tanzanian rangelands used to harbor before the 1980s. Therefore, they can be considered reservoirs of vital fodder species that can be used to restore degraded rangeland areas in northern Tanzania and elsewhere.

Introduction

Conservation of biodiversity through the incorporation of traditional and indigenous silvo-pastoral management strategies in semi-arid areas has been reported to contribute much in restoring degraded rangelands and regeneration of threatened fodder species (Milton and Barnard, 2003; Mengistu et al., 2018; Godde et al., 2020; Manzano, 2021). Recent reports have evidenced significant biodiversity support from semi-arid rangelands that abound more than 50% of the global production from livestock resources (Naah and Braun, 2019; Malunguja et al., 2020; Hezron and Nyahongo, 2021; Wiethase et al., 2023). Researchers emphasize a critical relationship between pastoral community livelihoods and the fodder/forage species diversity within healthier rangelands through sustained utilization of traditional pasture reserves (Sangeda and Maleko, 2018; Selemani, 2020). Biodiversity resources within semi-arid rangelands are faced with various pressures and uncertainties emanating from increased human and livestock populations and climate change (Isbell et al., 2017; APW, 2020; Harrison, 2020; Kariuki et al., 2021). Such pressures signal threats to the global community about the degrading suitability, stability, and sustainability potential of biodiversity resources leading to declined provisioning of ecosystem goods and services – particularly lack of assured food security to the biota (MEA, 2005; Giupponi and Leoni, 2020; Mpondo et al., 2021). These pressures are converting rangelands into unproductive bush lands thus jeopardizing livestock

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* Correspondence: Elkana Hezron, Department of Sustainable Agriculture, Biodiversity and Ecosystem Management, School of Life Sciences and Bioengineering, The Nelson Mandela African Institution of Science and Technology, NM-AIST, P. O. BOX 447, Arusha, Tanzania.

E-mail address: elkana.hezron@nm-aist.ac.tz (E. Hezron).

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productivity as well as wildlife conservation (Hare et al., 2020; Mdegela et al., 2022; Tolera, 2022; Wiethase et al., 2023). For instance, in the Australian rangelands increased climate variability has resulted in declining pasture productivity and reduced forage quality (Eldridge and Beecham, 2017). Also, rangelands in European countries have been facing an average of 42% decline due to more frequent droughts, invasions by weeds and pests, and increased livestock heat stress (Jiang et al., 2019; Manzano, 2021; Schils et al., 2022). Since the early 1980s, the rangeland performance and productivity in the United States of America (USA) are reported to have deteriorated by 15% due to fragmentation pressures evolving from both anthropogenic activities and natural catastrophes (Schallner et al., 2020). Likewise, African rangelands that for centuries have been acting as refugia for traditional livestock raising and habitats of many native wildlife species, are faced with degradation pressures resulting from overgrazing and overstocking (Georgiadis et al., 2007; Homewood et al., 2009; Ameso et al., 2018; Mengistu et al., 2018).

Tanzanian rangelands that comprise more than 74% of the total land are also threatened by both anthropocentric and natural environmental pressures (NTRI, 2019; Babune and Mshuda, 2020; Selemani, 2020; Wiethase et al., 2023). Specifically, the northern Tanzania rangelands including the *Maasai* steppe and their corresponding biodiversity are reported to receive growing pressures from degradation as a result of the increasing human population (Schallner et al., 2020), social-cultural transformations (Hezron et al., 2024) and climate change (Nelson, 2012; Goldman and Riosmena, 2013; Olekao, 2017). Such stresses are predicted to double in the coming 25 yr resulting in increased soil erosion and reduced ecosystem services and thus posing an extinction threat to useful fodder plants (MEA, 2005; Cleland, 2011; Western et al., 2015; Mengistu et al., 2018; NTRI, 2019). Currently, special attention is being given to determining proper rangeland management strategies that will enhance biodiversity adaptation and resilience of fodder species against human and environmental stresses (Lind et al., 2020). Indigenous and local conservation strategies, such as *Kalo*, *Ngitili*, and *Alalili* systems (Saruni, 2019; Selemani, 2020), have cultural significance and can play vital roles in the management of pastoral lands (Hezron et al., 2024). The management methods and conservation strategies employed are regarded as appropriate for promoting quick vegetation recovery in the degraded rangelands (Angassa et al., 2010; Nyberg et al., 2019; Malunguja et al., 2020).

Alalili, a traditional silvo-pastoral conservation system indigenous to *Maasai* communities through which certain portions of rangelands are conserved during the wet season for improved natural regeneration of vegetative biomass useful for grazing during dry seasons (Hezron et al., 2024), is a sustainable conservation practice needed to manage rangeland areas (Mwilawa et al., 2008; Saruni, 2019). It is regarded as a beneficial resource that provides fodder for both livestock and wildlife, sites for pollinators conservation, climate change mitigation sites through carbon sequestration, and nature-based strategy for restoring degraded rangelands in both Kenya and Tanzania (Selemani, 2020; Mpondo et al., 2021; AET, 2022). It is further reported to play useful economic, traditional, and social-cultural roles from which *Maasai* pastoral communities are benefiting (Saruni, 2019).

Like other biodiversity resources in rangelands, fodder species managed through *Alalili* systems are susceptible to loss and extinction pressures (Goldman and Riosmena, 2013; Selemani, 2020). Existing literary works recognize less information about fodder species inventory, species composition in terms of richness, species density, and fodder species diversity within *Alalili* systems (Mapinduzi et al., 2003; Mwilawa et al., 2008; Sangeda and Maleko, 2018). On the other hand, while their insect pollinators' species diversity status has been determined (Mpondo et al., 2021), the vegetation part is lacking. A lack of this information limits rangeland managers' ability to undertake appropriate measures to enhance rangeland regeneration strategies for sustained fodder availability and suitability (Cleland, 2011; Sangeda and Maleko, 2018). Therefore, this study aimed to estimate fodder species composition, and distribution in terms of density, species diversity, and the effective number of species across types of *Alalili* systems and life forms. It compared the historical fodder species composition of the rangelands in northern Tanzania before the 1980s (Greenway and Vesey-Fitzgerald, 1969; Anderson and Herlocker, 1973) to the current information status of remnant rangeland patches of the *Alalili* systems surveyed in 2022. It assessed the pastoral community's knowledge of historical quality changes in the rangelands of northern Tanzania. This study is generating a shred of evidence that will guide conservation action and establish roadmaps for future rangeland restoration projects.

Table 1
Sample size for household survey in each district across the study area.

District	Longido	Monduli	Ngorongoro	Simanjiro	Kiteto	Total
N	30	34	30	45	40	**179**
n	24	27	24	36	32	**143**

Methods

Study design and sampling techniques

A preliminary survey was conducted in the five districts located in northern Tanzania (Fig. 1). This was followed by the identification and categorization of the *Alalili* (by the local key informants) existing in the area and the sampling of the studied subset employed stratified random sampling approach as described in Hezron et al., (2024). This sampling strategy depicted 40% of the total number of identified *Alalili* in the study area. Three nested quadrats of 20×20 m, 5×5 m, and 1×1 m for trees, shrubs, and herbaceous plants respectively (Kisoza, 2013; Giupponi and Leoni, 2020) were established at the center of each sample *Alalili* for determining fodder plants' diversity. Households that have long-term residences (before the 1980s) near the *Alalili* in the landscape were randomly sampled according to Slovin's formula as shown in equation 1 (Rono, 2018) for community-level interviews as reported by Blake et al. (2018) and Rabinovich et al. (2019).

$$n = \frac{N}{1 + N.(e^2)} \quad (1)$$

Whereby n is the sample size, N stands for the total number of target households that dwell around sampled *Alalili* systems in each district, and e^2 stands for the squared level of precision (i.e., squared 5% or 0.05). The calculated sample sizes for each district are presented in Table 1.

Data collection

Fodder plants' composition from the surveyed Alalili systems in northern Tanzania

All *Alalili* sample sites were visited and the three nested quadrats of 20×20 m, 5×5 m, and 1×1 m were established at the center of each sample *Alalili* for determining fodder plants' diversity (Kisoza, 2013; Giupponi and Leoni, 2020). Fodder plants were categorized into two classes for identification and counting: woody plants (shrubs and trees) and herbaceous plants (grasses and forbs). Both herbaceous and woody fodder species were identified in situ with the help of a botanist, while voucher specimens of species that were not readily identified were sent to the Tanzania Plant Health and Pesticides Authority (TPHPA) for identifi-

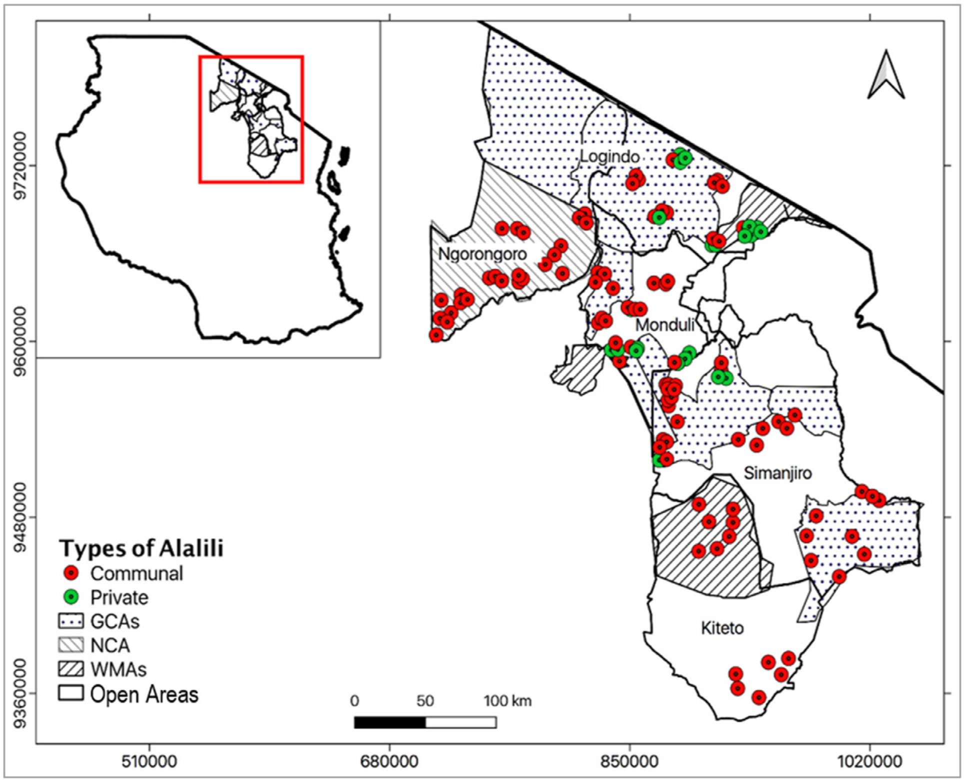

Figure 1. A map portraying the surveyed *Alalili* systems across different land use categories in rangelands of northern Tanzania where the study was conducted.

cation (Egeru et al., 2014; Malunguja et al., 2020). Moreover, historical secondary data obtained via a literature review confirmed on fodder potential of the surveyed plant species for each *Alalili* (Greenway and Vesey-Fitzgerald, 1969; Anderson and Herlocker, 1973; Loth, 1999; Roothaert, 2000; Foo et al., 2021). The plants in the reviewed literature were determined as fodder based on the information obtained from databases of the World Agroforestry Center, Research for Life, EBSCOhost, and EMERALD through search engines of Google Scholar and Web of Science (Athumani et al., 2023).

Past fodder plants' composition in rangelands of northern Tanzania

Historical fodder plants' composition before the 1980s was gathered through a systematic literature review as described by Athumani et al., (2023). These were reviewed at the expense of validating the current fodder plants collected from the *Alalili* systems during our field survey of 2022. The main literature including articles that gave useful secondary data suitably reporting the historical fodder plants' composition in rangelands of northern Tanzania were randomly selected in consideration to search responses (Greenway and Vesey-Fitzgerald, 1969; Anderson and Herlocker, 1973). Searching of the relevant literature on northern Tanzania rangelands was considered a global coverage. A review of historical data was conducted from May 2022 to April 2023 that confirmed on fodder potential of reviewed plant species to both livestock and wildlife. The review was based on the relevance of information whereby databases from the World Agroforestry Center, Research for Life, EBSCOhost, and EMERALD through search engines of Google Scholar and Web of Science were accessed. Important keywords for searching the reference materials comprised of "fodder plants of northern Tanzania," "native fodder species in *Maasai* steppe," "fodder shrubs and trees," "herbaceous fodder species of northern Tanzania rangelands," "the vegetation of Manyara and Arusha regions" as well as "the flora of Ngorongoro."

Historical changes in rangelands of northern Tanzania

Community's knowledge of historical pasture changes in northern Tanzania rangelands since the 1980s, the established drivers of fodder changes, and the possible solutions were gathered through key informant interviews (KIIs), focused group discussions FGDs), and household surveys (HHS) (Blake et al., 2021). The interview sessions were guided by checklists and questionnaires generated from evidence of degradation of landscapes (Blake et al., 2018). The interviews considered heads of each particular household whose age was above 40 yr for enhanced collection of relevant and accurate historical data. The community members were engaged in the focused group discussion through 3-d meetings targeting households that dwell around sampled *Alalili* systems in each sample district (Kelly et al., 2020).

Data analysis

Fodder plants' composition was estimated as an abundance (number of species observed in an area, that is, *Alalili* systems within land use categories) and species richness (number of observed species within a particular taxa, i.e., genus and family) (Gotelli and Chao, 2013; Egeru et al., 2014; Malunguja et al., 2020; Tutunga, 2021). Graphical and tabular methods were used to compare the historical fodder plants' composition of the northern Tanzania rangelands before the 1980s to the existing fodder plants' composition collected from the *Alalili* systems (Athumani et al., 2023). While species density was computed as the number of species per unit area as in equation 2 (Tutunga, 2021), species diversity was computed by using the Shannon-Wiener diversity index (H') as in equation 3 (Tolera, 2022) and the effective number of species (ENS) was computed as per equation 4 (Jost, 2006).

$$\text{Species density} = \frac{Total\ number\ of\ individuals\ of\ species}{Total\ sample\ quadrat\ area} \quad (2)$$

$$\text{Species diversity}\ \left(\mathrm{H}'\right) = -\sum Pi(lnPi) \quad (3)$$

whereby H' stands for Shannon-Wiener diversity index, and *Pi* stands for the proportion of individuals found in the i[th] species.

$$\text{Effective number of species} = Exp\left(H'\right) \quad (4)$$

whereby *Exp* stands for exponential and *H'* stands for Shannon-Wiener diversity index (Jost, 2006; Zisadza-Gandiwa et al., 2013).

Two sample t-test was used to understand the variation in fodder plants' composition between the historical data of northern Tanzania rangelands before the 1980s and that of *Alalili* systems as well as fodder species density, diversity, and effective number of species between types of *Alalili* systems. Analysis of variance (ANOVA) was used to understand the variation of such aspects by life forms across *Alalili* systems. Before analysis, the Shapiro-Wilk test and Levene's test for normality and homogeneity of variance respectively were conducted. The extent of variation and correlation within and between variables respectively was tested by a generalized estimating equations (GEE) model equations 5 and 6 applied through R version 4.2.3 (Feng et al., 2014). Aspects of type of *Alalili*, life form, land use, age and size of *Alalili*, and stocking rate (animal unit equivalent – AUE) were considered as factors whereby the baseline variables were Communal *Alalili*, forbs, and GCA respectively. A *p*-value of $P < 0.05$ was considered significant.

$$\begin{aligned}\text{geeglm}(\text{formula} &= \text{Sp.Diversity} \sim \text{Type of } Alalili + \text{Life form} \\ &+ \text{Land Use} + \text{Age} + \text{Area}, \\ \text{family} = \text{gaussian}(), \text{data} &= \text{A}, \text{id} = \text{Type of } Alalili, \text{corstr} \\ &= \text{"exchangeable"})\end{aligned} \quad (5)$$

$$\begin{aligned}&\text{geeglm}(\text{formula} = \text{Sp.Diversity} \sim \text{Type of } Alalili + \text{AUE}, \\ &\text{family} = \text{gaussian}(), \text{data} = \text{A}, \text{id} = \text{Type of } Alalili, \text{corstr} = \text{"exchangeable"})\end{aligned} \quad (6)$$

Data concerning the community's knowledge of historical quality changes in the rangelands of northern Tanzania since the 1980s, the established drivers of changes in fodder plants, and the possible solutions were analyzed by the Chi-square test and the descriptive narrative analysis technique (Thuv, 2023).

Results

This study categorized two types of *Alalili*, that is, private and communal *Alalili* systems. The two types of *Alalili* were spatially distributed in the four land use categories (GCA, NCA, open areas, and WMA) (Fig. 1). These pastures are utilized for grazing during the dry season. As such, they serve as useful in situ fodder/forage banks when there are limited pasture resources for livestock in the open grazing rangelands. Apart from serving as forage resources for livestock during the dry season, they are useful drivers in reducing the impacts of overgrazing and environmental degradation.

Fodder plants' composition across vegetative taxa and life forms

The historical studies in the northern Tanzania rangelands before the 1980s documented a total of 127 woody fodder species that belonged to 96 genera and 55 families. In comparison, the *Maasai Alalili* systems had a total of 119 woody fodder species that belonged to 83 genera and 43 families. On the other hand, herbaceous fodder plants of the northern Tanzania rangelands before the 1980scomprised a total of 119 species that belonged to 74 genera and 17 families, while the *Maasai Alalili* systems had a total of 82 fodder herbs under 61 genera and 25 families (Table 2).

Common fodder plants of both the historical rangelands before the 1980s and Alalili

In the northern Tanzania rangelands before the 1980s, the highest woody fodder plant composition was observed in families Fabaceae (20 tree species and five shrub species), Malvaceae (two tree species and seven shrub species), Moraceae (six tree species and two shrub species), Capparaceae (five shrub species), Boraginaceae (one tree species and four shrub species), and Burseraceae (four tree species). The most common woody fodder species reported were *Acacia* sp., *Balanites aegyptiaca*, *Dichrostachys cinerea*, *Commiphora africana*, *Grewia* sp., *Maerua triphylla*, *Solanum incanum*, *Zanthoxylum chalybeum*, *Ximenia caffra*, *Sclerocarya birrea*, *Albizia* sp., *Dalbergia* sp., *Lippia javanica*, *Ormocarpum kirkii*, and *Combretum mole* (Appendix A). Grass-like plants were the second life form in fodder plants' composition featured with two families: Poaceae (58 species) and Cyperaceae (four species). The most common fodder grass-like plants included *Cynodon* sp., *Themeda triandra*, *Panicum maximum*, *Cenchrus ciliaris*, *Aristida* sp., *Pennisetum mezianum*, *Chloris gayana*, *C. pycnothrix*, *Setaria pumila*, *Cyperus sp.*, and *Eragrostis cilianensis*. Forbs was the least life form in plants' composition comprised of families Asteraceae (14 species), Acanthaceae (11 species), Malvaceae (six species), and Amaranthaceae (five species). The forb fodder species that were commonly reported included *Abutilon mauritianum*, *Barleria eranthemoides*, *Achyranthes aspera*, *Dyschoriste hildebrandtii*, *Ocimum* sp., *Sida rhomboidei*, *Justicia* sp., *Leucas* sp., and *Tribulus terrestris* (Appendix B).

Likewise, in the *Maasai Alalili* systems, woody fodder plants were the leading life forms having highest species composition under families Fabaceae (26 tree species and nine shrub species), Malvaceae (two tree species and eight shrub species), Capparaceae (four tree species and five shrub species), Burseraceae (five tree species), and Boraginaceae (one tree and four shrub species) (Appendix C). The most common woody fodder species featuring the *Maasai Alalili* included *Balanites aegyptiaca*, *Commiphora africana*, *Maerua triphylla*, *Dichrostachys cinerea*, *Solanum incanum*, *Grewia* sp., *Zanthoxylum chalybeum*, *Ximenia caffra*, *Acacia tortilis*, *A. nilotica*, *A. drepanolobium*, *Sclerocarya birrea*, *Albizia* sp., *Lonchocarpus eriocalyx*, *Lippia javanica*, *Ormocarpum kirkii*, and *Combretum mole*. Grass-like plants were the second life form in terms of fodder composition featured with two families: Poaceae (28 species) and Cyperaceae (two species). The most common fodder grasses were *Cenchrus ciliaris*, *Cynodon* sp., *Themeda triandra*, *Panicum maximum*, *Cyperus* sp., *Pennisetum mezianum*, *Aristida* sp., *Chloris* sp., *Setaria pumila*, *Eragrostis cilianensis*, and *Brachiaria deflexa*. Forbs was the least life form in vegetative composition under families Acanthaceae (eight species), Asteraceae (six species), Fabaceae (six species), and Lamiaceae (five species). Forb fodder species that commonly appeared in the *Maasai Alalili* systems comprised the following: *Dyschoriste hildebrandtii*, *Tribulus terrestris*, *Justicia* sp., *Barleria eranthemoides*, and *Achyranthes aspera* (Appendix D).

Fodder species composition

Generally, there was no significant variation between the fodder species composition of the *Alalili* systems studied in 2022 and the historical fodder species composition of the northern Tanzania rangelands before the 1980s ($t = -1.4904$, $df = 3.5$, $P = 0.220$). However, the historical data from the northern Tanzania rangelands show a relatively higher species composition of fodder plants (61.50 ± 2.10) than the current information collected from *Alalili* systems (50.25 ± 7.25). The relative variation observed between historical data of the fodder species composition from rangelands and that of the *Alalili* systems was extended to other taxonomic groups (families and genera) (Fig. 2). On the other hand, fodder species composition depicted no significant variation across life

Table 2
Summary of fodder plants composition across taxa and life forms.

Life form	Number of Families		Number of Genera		Number of Species	
	Before 1980′s	*Alalili* in 2022	Before 1980′s	*Alalili* in 2022	Before 1980′s	*Alalili* in 2022
Tree	30	21	46	36	67	59
Shrubs	25	22	50	47	60	60
Forbs	15	23	44	42	57	52
Grass	2	2	30	19	62	30
Statistics	t = 0.283, P = 0.796		t = 2.793, P = 0.068		t = 1.582, P = 0.212	

Source: Field work (2022) (Greenway and Vesey-Fitzgerald, 1969) (Anderson and Herlocker, 1973).

Table 3
Summary of fodder species composition across types of *Alalili* and life forms.

Life form	Types of *Alalili*		Statistics
	Communal (±SE)	Private (±SE)	
Grass	15.8 ± 1.31[ab]	6.75 ± 3.12[b]	t = 2.66, P = 0.028
Forb	19 ± 6.03[a]	8.5 ± 3.75[b]	t = 1.48, P = 0.019
Shrub	24 ± 4.92[a]	9.25 ± 4.42[b]	t = 2.23, P = 0.047
Tree	24.5 ± 5.12[a]	10 ± 4.34[ab]	t = 2.49, P = 0.039
Statistics	($F_{(3)}$ = 0.794, P = 0.521)	($F_{(3)}$ = 0.125, P = 0.944)	

SE, Standard error.
The different superscript alphabets “a, b, and c”; depicts mean areas that are significantly different ($p < 0.05$).

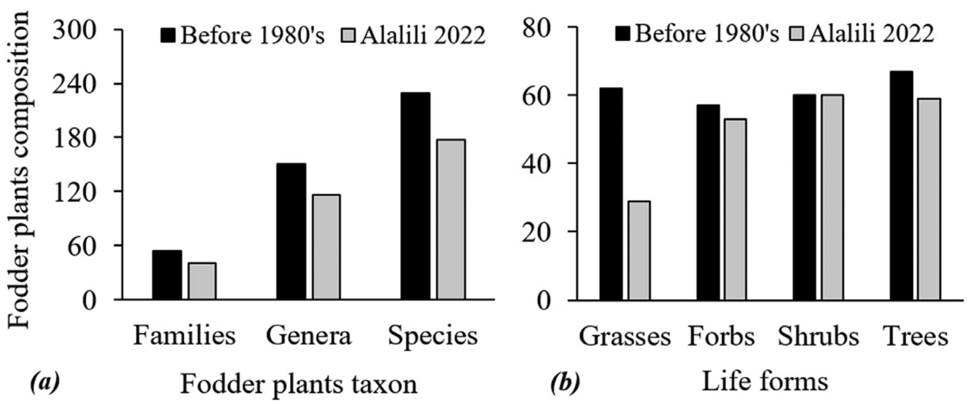

Figure 2. Fodder plants composition across (A) taxonomic groups (B) life forms.

forms ($F_{(3)}$ = 0.8, P = 0.553). However, grass-like plants, forbs, and trees demonstrate a relative variation in species composition between times before the 1980s and that of 2022 in contrast to shrubs that had similar plants’ composition in both the rangelands before the 1980s and *Maasai Alalili* systems (Fig. 2).

While a comparison of the fodder plants’ composition for three taxonomic groups was generally done between historical data from the northern Tanzania rangelands before the 1980s and the current *Alalili* systems, the subsequent results are narrowed into plants’ composition at species level across types of *Alalili* and life forms.

Fodder species composition across types of Alalili *systems and life forms*

Species composition between communal and private *Alalili* systems varied significantly both in collective terms (t = 4.18, df = 30, $P < 0.001$) and in the specific life forms as shown in Table 3. Communal *Alalili* systems depicted the highest number of grass-like plants, forbs, shrubs, and trees (28, 47, 53, and 57 species respectively) compared to that of private *Alalili* systems (16, 30, 25, and 27 for grass-like plants, forbs, shrubs, and tree species respectively). Unlike private *Alalili* which were richest in forbs (30 species), communal *Alalili* were richest in trees (57 species).

Fodder species density

Herbaceous fodder species density across life forms

Generally, the density of herbaceous fodder species (grass-like plants and forbs) varied significantly in studied rangelands (t = -4.4059, df = 139.39, $P < 0.001$). The overall mean density of fodder grass species was 6498 ± 765 individuals/ha, while that of forbs was 2644 ± 425 individuals/ha. Of all grass-like plant species, *Cynodon dactylon* had the highest density (62,773 individuals/ha) followed by *Cenchrus ciliaris* (37,899 individuals/ha) and *Chloris pycnothrix* (27,815 individuals/ha), while the lowest density was depicted by *Panicum sanguineum* (168 individuals/ha) and *Cynodon nlemfuensis* (84 individuals/ha). For the forbs, *Dyschoriste hildebrandtii* had the highest density (13,109 individuals/ha) followed by *Gutenbergia cordifolia* (9916 individuals/ha) and *Tribulus terrestris* (9076 individuals/ha), while the lowest density was depicted by *Tephrosia elata* and *Zaleya pentandra* each one comprised with 84 individuals/ha.

Herbaceous fodder species density across types of Alalili

There was a significant difference in density of herbaceous fodder species between communal and private *Alalili* systems (t = -3.5304, df = 75.361, $P < 0.001$), whereby private *Alalili* had the highest mean density of herbaceous fodder species compared to

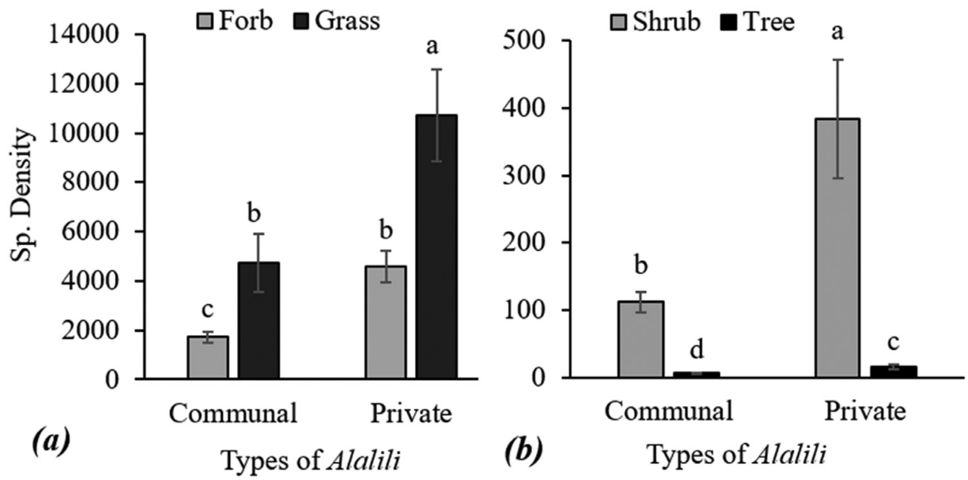

Figure 3. Differences in fodder species density across surveyed types of *Alalili* (A) Herbaceous species (B) Woody species.

communal *Alalili* (Fig. 3A). Moreover, grass-like plant species density varied significantly from that of forbs within private *Alalili* systems (t = -2.2682, df = 102.73, P = 0.025) as well as within communal *Alalili* systems (t = -4.4355, df = 79.058, $P < 0.001$) (Fig. 3A).

Woody species density across life forms

There was a significant variation in woody species (shrubs and trees) density in the studied rangelands (t = 6.2708, df = 118.38, $P < 0.001$). The overall mean density of fodder shrub species was 185 ± 28 individuals/ha, while that of trees was 9 ± 1 individuals/ha. Of all shrub species, *Solanum incanum* had the highest density (3736 individuals/ha) followed by *Dichrostachys cinerea* (3727 individuals/ha) and *Sansevieria ehrenbergii* (2237 individuals/ha), while the lowest density was depicted by *Lannea triphylla* (6 individuals/ha). For the tree species, *Acacia drepanolobium* had the highest density (153 individuals/ha) followed by *Acacia nilotica* (130 individuals/ha) and *Balanites aegyptiaca* (121 individuals/ha). The lowest densities for trees were represented by *Cassipourea mollis*, *Thespesia garckeana*, *Dichrostachys cinerea*, and *Dobera loranthifolia*. Each of these aforementioned tree species had an average density of one individual/ha.

Woody fodder species density across types of Alalili

There was a significant variation in density of woody species between communal and private *Alalili* systems (t = -2.7272, df = 77.577, P = 0.008), whereby private *Alalili* had the highest mean density of woody fodder species compared to communal *Alalili* (Fig. 3B). Moreover, there was a significant variation in species density between shrubs and trees found within private *Alalili* systems (t = 3.5107, df = 100.35, $P < 0.001$) as well as within communal *Alalili* (t = 6.8584, df = 100.68, $P < 0.001$) (Fig. 3B).

Overall fodder species diversity

While there was a significant variation in fodder species diversity between communal and private *Alalili* systems (t = 7.64, df = 30, $P < 0.001$), no significant variation in fodder species diversity was encountered across life forms ($F_{(3, 15.4)} = 0.271$, $P = 0.846$). However, the diversity index of forbs, grass-like plants, shrubs, and trees was observed to be relatively higher in communal *Alalili* compared to private *Alalili* systems (Fig. 4). Furthermore, there was no significant variation in fodder species diversity between land uses ($F_{(3, 14.1)} = 0.445$, $P = 0.724$), although GCA was observed to have relatively higher species diversity index than other land uses (Fig. 4). The variation between the factors can be accessed from the summary statistics of the GEE equations provided in the Supplementary Tables 1 and 2. The diversity of species was significantly affected by both the age and size (in terms of hectares) of *Alalili*. However, age depicted a negative correlation while size depicted a positive correlation (Supplementary Table 1). On the other hand, the stocking rate in terms of animal unit equivalent (AUE) depicted a significant positive correlation with the fodder species diversity (Supplementary Table 2).

Fodder species diversity within types of Alalili systems

Species diversity index depicted no significant difference across life forms within both communal ($F_{(3)} =$ 1.333, $P = 0.310$) and private *Alalili* systems ($F_{(3)} = 0.2$, $P = 0.894$) (Fig. 5). On the other hand, while communal *Alalili* depicted no significant variation across land uses ($F_{(3)} = 2$, $P = 0.168$), private *Alalili* systems depicted a significant variation of species diversity index across land uses ($F_{(3)} = 5$, $P = 0.018$). Communal *Alalili* systems had the highest diversity index of trees, while private *Alalili* had the highest diversity index of forbs (Fig. 5).

The effective number of fodder species

Although there was a significant variation in the effective number of species between communal and private *Alalili* systems (t = 6, df = 18, $P < 0.001$) as presented in Table 4, the effective number of species showed no significant variation across surveyed land uses ($F_{(3)} = 0.47$, $P = 0.750$). Also, the effective number of species didn't vary significantly ($F_{(3)} = 0.40$, $P = 0.710$) across life forms (Table 5).

Community's knowledge of rangeland changes over the past decades

An average of 73% of respondents reported that fodder qualities in rangelands are declining compared to the situation in the past 40 yr, while 20% of respondents proposed that there are no observable changes. On the other hand, 7% of respondents were not sure about the changes, while none of the respondents reported an increase in rangeland qualities. All land use categories depicted the highest proportions of respondents who reported declining rangeland qualities compared to those who reported an unchanging status of rangeland qualities (Fig. 6). Community members depicted that rangeland is losing its ever-existing fodder and foraging qualities due to inappropriate use of land, invasive species, changes in socio-cultural practices, and abandonment of the local-based rangeland management strategies. Some respondents pinpointed that:

HHS-SIMA-22: "*The government adopted Western strategies of managing the rangeland from the colonial rules while underrating our local-based and traditional ways we used in sustaining*

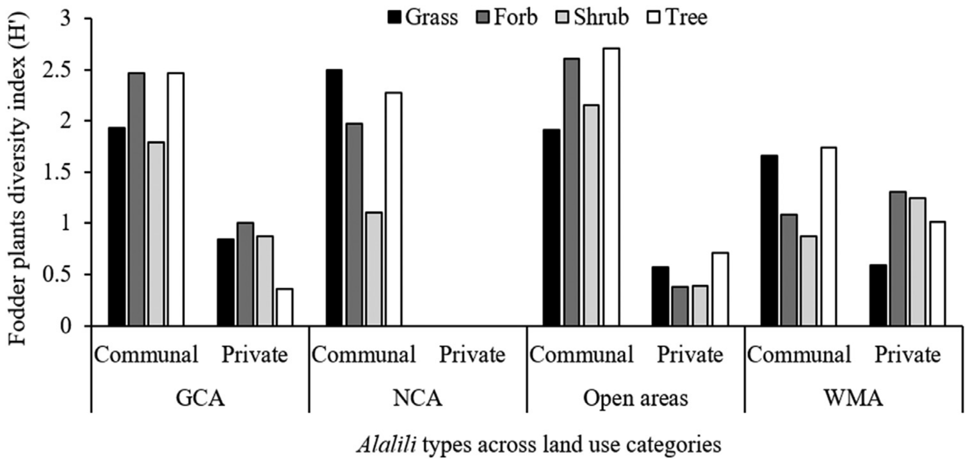

Figure 4. Overall fodder species diversity in the surveyed *Alalili* systems of northern Tanzania.

Table 4
Effective number of fodder species across types of *Alalili* systems.

Life form	ENS across types of *Alalili*		Statistics
	Communal (±SE)	Private (±SE)	
Grass	7.75 ± 1.5[ab]	1.47 ± 0.5[c]	t = 3.94, $P = 0.008$
Forb	8.89 ± 2.5[a]	1.97 ± 0.8[c]	t = 2.74, $P = 0.036$
Shrub	5.02 ± 1.4[ab]	1.84 ± 0.7[c]	t = 1.97, $P = 0.047$
Tree	10.52 ± 1.9[a]	1.56 ± 0.6[c]	t = 4.45, $P = 0.004$
Statistics	$F_{(3)} = 0.62$, $P = 0.237$	$F_{(3)} = 0.13$, $P = 0.940$	

ENS, effective number of species; SE, standard error.
The different superscript alphabets "a, b, and c"; depicts mean areas that are significantly different ($p < 0.05$).

Table 5
Effective number of fodder species across life forms and land uses.

Life form	ENS across land uses				Statistics
	GCA (±SE)	NCA (±SE)	Open areas (±SE)	WMA (±SE)	
Forb	7.26 ± 4.5	3.61 ± 3.6	7.53 ± 6.1	3.34 ± 0.4	
Grass	4.59 ± 2.3	6.07 ± 6.1	4.25 ± 2.5	3.52 ± 1.7	$F_{(3)} = 0.47$,
Shrub	4.2 ± 1.8	1.51 ± 1.5	5.06 ± 3.6	2.94 ± 0.5	$P = 0.750$
Tree	6.59 ± 5.2	4.85 ± 4.8	8.47 ± 6.4	4.23 ± 1.5	
Statistics	$F_{(3)} = 0.18$, $P = 0.905$	$F_{(3)} = 0.20$, $P = 0.889$	$F_{(3)} = 0.14$, $P = 0.931$	$F_{(3)} = 0.53$, $P = 0.684$	

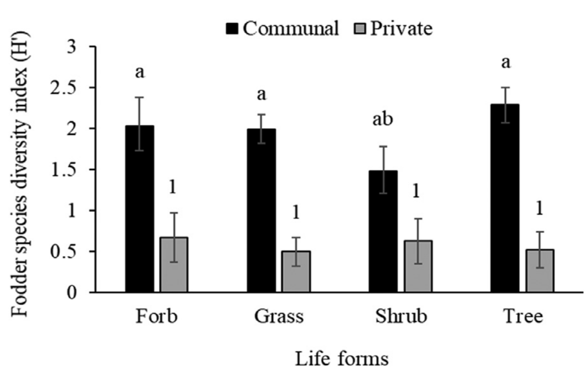

Figure 5. Fodder species diversity across life forms within types of *Alalili*.

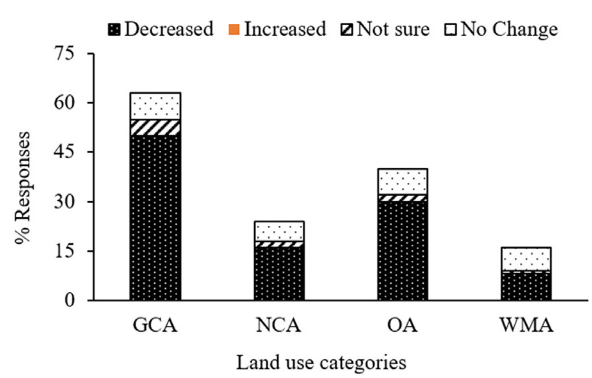

Figure 6. Changes in rangeland observed for the past 40 yr.

the forage resources in our rangeland. We, the Maasai pastoral communities, acknowledge the modern technologies introduced to us although they seem not to integrate our indigenous and local practices that have been traditional practices in our native land" (HHS/Alalili survey/Simanjiro District/October 2022).

FGD-LONG-03: "*The globalization and modern technologies have replaced our local-based rangeland conservation technologies since the colonial era, make our communities loose tie with traditional knowledge and practices. In the recent past, we have realized that those modern methods are nothing but bringing confusion among pastoralists and become chaotic during their implementation as you can see the rangeland productivity is currently declining compared to that before the 1980s. With the adoption of such modern methods, we are currently facing pasture scarcity, and if available, it is just for a very short duration of grazing. Therefore, some of us are opting alternative ways to sustain livelihood and family necessities by adopting crop production and selling some portions of the pasture reserves to* *immigrants who are not pastoralists*" (FGD/Alalili survey/Longido District/May 2022).

KII-MOND-08: "*Most of our grazing areas that were previously owned by us have been taken by the government authorities and are currently regarded as wildlife-protected areas. We recall that we had good historical moments of co-existing with wildlife and were capable of sustaining our livestock with pastures regardless of the interaction we had with wildlife. Nowadays we are restricted from accessing the pastures. The remaining grassland areas are faced with bush invasions which we don't know where they came from leading to the loss of the most preferable herbage and grass-like fodder species that were highly nutritious for our livestock. Our livestock is faced with high mortality risk because of poor grazing lands that we currently have*" (KII/Alalili survey/Monduli District/June 2022).

Some of the reported invasive species observed by the local communities were identified and comprised of *Senna occidentalis*, *S. bicapsularis*, *Gutenbergia cordifolia*, *Dichrostachys cinerea*, *Calotropis gigantea*, *Tagetes minuta*, and *Solanum incanum*.

Discussion

Fodder species conservation within rangelands through Traditional Ecological Knowledge (TEK) and Indigenous Local Knowledge (ILK) is of paramount significance in sustaining biodiversity for ensured sustainable livelihood (Bruchac, 2014; Lind et al., 2020; Selemani, 2020). Rangelands are important not only in ensuring forage suitability but also resilience as well as in providing several foraging choices to both livestock and wildlife (Schallner et al., 2020). Studies associated with species composition and diversity within traditionally conserved pastures reveal improved provision of equitable ecosystem goods, functions, and services to the surrounding communities (Mapinduzi et al., 2003; Sangeda and Maleko, 2018). However, the scarcity of fodder species inventory within traditional practices lowers their recognition and exposes them to anthropogenic and environmental pressures (Malunguja et al., 2020; Schallner et al., 2020). This study has established a fodder species inventory for both the northern Tanzania rangelands before the 1980s (Greenway and Vesey-Fitzgerald, 1969; Anderson and Herlocker, 1973) and that of the *Maasai Alalili* systems into two main categories: woody plants (Appendix A and C) and herbaceous plants (Appendix B and D) for sustained management of their vegetative heterogeneity (Plieninger et al., 2015) across types of *Alalili* and surveyed land uses. Following the degradation pressure and changes in rangeland quality as reported by the local communities from the results section, this study provides an alarming message to rangeland managers about the endangered suitability, stability, and sustainability potential of fodder plants.

The results revealed a relatively high fodder plants' composition across vegetative taxa in the northern Tanzania rangelands before the 1980s compared to that of the *Alalili* systems in 2022 suggesting a degradation and loss of fodder plants in the rangelands of northern Tanzania. The observed variation of fodder grass species composition from high in the northern Tanzania rangelands (before the 1980s) to low in the *Alalili* systems (2022) coupled with little change observed in forbs, shrubs, and trees portrays local extinction threats to herbaceous fodder species possibly due to bush encroachment and increased herbivory intensity (Hare et al., 2020; Mdegela et al., 2022; Tolera, 2022; Wiethase et al., 2023). However, the study revealed that *Alalili* systems still hold substantial diverse fodder plants that rangelands used to host way back before the 1980s (Greenway and Vesey-Fitzgerald, 1969; Anderson and Herlocker, 1973). They act as reservoirs for these important fodder species that can be used to restore degraded areas which have recently been transformed by degradation drivers including overstocking, overgrazing, rangeland encroachment from both humans and bushes, climate change as well as LULCC (Mapinduzi et al., 2003; Kilongozi et al., 2005; Mwilawa et al., 2008; Olekao, 2017; Selemani, 2020; Mpondo et al., 2021). Thus, studies about fodder species composition, density, diversity, and an effective number of species across life forms, types of *Alalili* systems as well and land use categories within rangelands are of paramount importance for sustainable rangeland management (Loth, 1999; Roothaert, 2000; Toombs et al., 2010). This being the first documentation of such biodiversity parameters within *Maasai Alalili* systems, it acts as a baseline data to inform future *Alalili* management decisions for sustained livestock and wildlife health while acting as a tool for assessing fodder species extinction threats.

Fodder species across life forms

This work depicted a relatively high woody fodder species composition over herbaceous fodder plants in both the northern Tanzania rangelands before the 1980s and the *Alalili* systems suggesting that primary production of the herbaceous fodder species is threatened by bush encroachment (Sangeda and Maleko, 2018; Mussa et al., 2022). The highest species density depicted by *Acacia drepanolobium*, *Solanum incanum*, *Dichrostachys cinerea*, and *Sansevieria ehrenbergii* signifies bush encroachment due to anthropogenic disturbances including overgrazing (Hare et al., 2020; Wiethase et al., 2023). Woody species have been reported to occupy disturbed landscapes by out-competing the growth of herbaceous fodder plants while reducing fodder biomass, forage quantity, and quality (Ngondya et al., 2017; Borges et al., 2022). The higher fodder tree and shrub species composition in *Alalili* silvopastoral systems might deteriorate the understory forage species – especially in the case of shade-intolerant forbs and grasses (Mdegela et al., 2022; Tolera, 2022). The effects are associated with large canopies of the woody fodder species that reduce the amount of light and rain required to reach the understory herbaceous fodder plants (Baker et al., 2020). Moreover, the high density of non-preferred herbaceous fodder species, such as *Gutenbergia cordifolia* and *Tribulus terrestris*, suggests that *Alalili* systems are heavily disturbed by both anthropogenic and environmental pressures and thus threaten their suitability and sustainability (Pacanoski et al., 2014; Ngondya et al., 2017). This is also supported by the results of this study that depicted a negative correlation effect observed between fodder species diversity and the age of the *Alalili* system suggesting that the level of disturbance is high in recent times. For sustainable fodder production in *Maasai Alalili* systems, there is a need to promote the growth of herbaceous fodder species through domestication and moderate herbivory while reducing competitive effects by increasing desirable herbaceous fodder species composition and diversity (Lusigi et al., 1984; Olff and Ritchie, 1998; Jawuoro et al., 2017).

Fodder species across types of Alalili

We further observed a relatively higher fodder species composition, diversity, and effective number of species within communal than private *Alalili* systems. This might be due to conservation negligence over private *Alalili* among the *Maasai* pastoral communities (Goldman, 2011; Nelson, 2012; URT, 2014) as they are transitioning from pastoral to agricultural communities (Mörner, 2006; Homewood et al., 2009). Similarly, the prioritization of communal *Alalili* conservation over private *Alalili* by community-based organizations and the Tanzanian land, wildlife, and livestock policies (ILRI and CGIAR, 2017; NTRI, 2019; Robinson, 2020) can be another reason for the abandonment of private *Alalili* systems. On the other hand, heavy grazing intensity throughout a year within private *Alalili* systems could be an added driving factor for reduced composition and species diversity in them (Liniger and Mekdaschi Studer, 2019; Mpondo et al., 2021; Rogers et al., 2021; Tutunga, 2021; Mussa et al., 2022; Wiethase et al., 2023). Such incidences are likely threatening the integrity of fodder plants in private *Alalili* compared to that of communal *Alalili* systems. The observed variation in species composition and diversity proposes a radical loss of foraging stability in private *Alalili* systems predicting an extinction threat to both fodder plants and the *Alalili* systems themselves (Cleland, 2011). Due to lower species composition and diversity, the homogeneity of fodder plant communities is expected to increase within private compared to communal *Alalili* systems. The increased fodder plants homogeneity will potentially affect the foraging choices for both livestock and wildlife (McGranahan and Kirkman, 2013; Smith et al., 2020). Therefore, private *Alalili* portrays a potential failure to maintain and sustain the primary production of fodder plant species for grazing mammals that existed for decades (Ellis and Swift, 1988; Olekao, 2017; Sangeda and Maleko, 2018) thus immediate restoration efforts are needed to reverse them (Mwilawa et al., 2008; Goldman and Riosmena, 2013; Mengistu et al., 2018; Carrick and Forsythe, 2020; Selemani, 2020).

Fodder species across land uses

We found that both species diversity and the effective number of species did not vary across land use categories. This suggests that regardless of their varied conservation purposes, all surveyed land uses have equitable *Alalili* silvo-pastoral conservation potential to fodder plants (Goldman and Riosmena, 2013; Selemani, 2020). The results prove that *Alalili* systems are still valued among the *Maasai* pastoral and agro-pastoral communities in the studied region though currently stressed by changes in their traditional, cultural practices and social norms (McCabe et al., 2010; Sangeda and Maleko, 2018). The observed relatively higher number of forbs, grass-like plants, and shrubs species in GCA contrary to its low fodder species density compared to other land use categories suggests the suitability and sustainability potential of *Alalili* within GCA compared to NCA, open areas, and WMA (Olekao, 2017; Wiethase et al., 2023). The promotion of *Alalili* conservation systems for moderate herbivory intensity in the GCA might be another reason for the observed variation in the biodiversity parameters (Olff and Ritchie, 1998; Nelson, 2012; Sangeda and Maleko, 2018). A shift from pastoralism to crop cultivation within open areas and WMA associated with heavy grazing and high stocking density in NCA are other factors that lead to pasture decline concerning reduced grazing land size and rangeland encroachment (Homewood et al., 2009; Archer et al., 2017; Hezron et al., 2024). NCA depicted a relatively low tree species composition than any other land uses. This suggests the variation between management strategies devoted to the Ngorongoro Conservation Area authority and that of villagers (Goldman, 2011; Nelson, 2012).

Conservation implication of the established fodder species inventory

The resilience of *Alalili* systems has been demonstrated by our study due to a relatively high composition, diversity, and effective number of fodder species observed in them closer to that of rangelands before the 1980s (Smith et al., 2020; Rogers et al., 2021). High species density of diversified fodder plants in the families Fabaceae, Malvaceae, Capparaceae, Burseraceae, Boraginaceae, and Zygophyllaceae for woody species, as well as Acanthaceae, Asteraceae, Lamiaceae, Poaceae, and Cyperaceae for herbaceous species, affirms forage resilience of *Alalili* systems. Several studies have proven that the availability of fodder plants of the mentioned families confer resilience to fluctuating environmental pressures and foraging stability of various rangelands in semi-arid ecosystems (Lusigi et al., 1984; Naah and Braun, 2019; Sharma et al., 2023). Herbaceous fodder plants, such as *Cynodon dactylon*, *Cenchrus ciliaris*, *Themeda triandra*, *Setaria sphacelata*, *Aristida kenyensis*, *Hyparrhenia rufa*, *Indigofera* spp., *Ocimum basilicum*, and *Barleria eranthemoides*, depicts perennial properties thus assuring herbage fodder availability in different seasons (Jawuoro et al., 2017; Rogers et al., 2021; Mdegela et al., 2022). Apart from being threatened by environmental stresses, annual herbage species such as *Chloris gayana*, *C. pycnothrix*, *Eragrostis cilianensis*, *Digitaria macroblephara*, *Tribulus terrestris*, *Indigofera brevicalyx,* and *Commelina benghalensis* provides multiple foraging choices to livestock in the seasons with abundant pastures (Jawuoro et al., 2017; Naah and Braun, 2019). The high composition of fodder plants of the mentioned families is demonstrating an enormous ecological amplitude for them being well adapted toward nutrient constraints (Sebata et al., 2005). They are supported by leguminous plants such as *Acacia* spp., *Albizia anthelmintica*, *Dalbergia melanoxylon*, *Lonchocarpus eriocalyx*, and *Ormocarpum trichocarpum* in the family Fabaceae that institute high N-fixation process in most of the tropical vegetation ecosystems (Singh et al., 2017; Liu et al., 2018).

Conclusion

Studies about rangeland management and the related conservation initiatives conducted in northern Tanzania for more than 15 yr suggest that TEK and ILK, such as the *Maasai Alalili* system, is an important tool for restoring the degrading rangelands and securing threatened fodder plants (Mapinduzi et al., 2003; Kilongozi et al., 2005; Mwilawa et al., 2008; Olekao, 2017; Selemani, 2020; Mpondo et al., 2021). However, fodder quality assessment, including their suitability and health management, has been done in the rangelands with partial recognition of fodder species inventory within *Alalili* systems (Lind et al., 2020; Malunguja et al., 2020; Selemani, 2020) thus jeopardizing their sustainability. Such negligence over *Alalili* has gradually maximized the risk of underestimating the importance of fodder plants in ensuring pasture availability, regeneration of degraded rangelands, and climate change mitigation by outweighing their benefits and values.

This research highlights how anthropogenic disturbances, bush encroachment, herbivory intensity, invasive species, and fodder species homogeneity are threatening the survival of private and communal *Alalili* systems. Letting the prevalence of the aforementioned pressures would lead to an enormous degradation of rangelands. Moreover, separating rangeland conservation technologies, private from communal *Alalili* systems, would lessen their stability and deter their effectiveness in sustaining foraging choices for livestock and wildlife that will devastate the livelihood of the pastoral communities. Therefore, rangeland management initiatives through the integration of both private and communal *Alalili* systems in the landscapes of northern Tanzania are of paramount significance. We recommend that further studies on assessing the domestication potential of the remnant fodder plants across rangelands of northern Tanzania should be conducted with the adoption of the *Maasai Alalili* conservation systems. The impacts of invasive species, drought conditions, and anthropogenic disturbances on the survival of fodder plants in *Alalili* systems should be evaluated considerably to maintain their ecosystem health and reduce their extinction threats.

Declaration of competing interests

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.

CRediT authorship contribution statement

Elkana Hezron: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Validation, Visualization, Writing – original draft, Writing – review & editing. **Issakwisa B. Ngondya:** Conceptualization, Data curation, Formal analysis, Methodology, Project administration, Resources, Supervision, Visualization, Writing – review & editing. **Linus K. Munishi:** Conceptualization, Formal analysis, Investigation, Methodology, Project administration, Resources, Supervision, Validation, Writing – review & editing.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.rama.2024.10.007.

Appendix A. An inventory of woody fodder taxa that existed before 1980's in rangelands of northern Tanzania (Source: (Greenway and Vesey-Fitzgerald, 1969) (Anderson and Herlocker, 1973)).

Family	Genus	Species	Life form
Acanthaceae	Ecbolium	*Ecbolium* sp.	Shrub
	Justicia	*Justicia cordata*	Shrub
		Justicia elliotii	Shrub
	Ruellia	*Ruellia megachlamys*	Shrub
	Ruttya	*Ruttya fruticosa*	Shrub
Amaranthaceae	Sericocomopsis	*Sericocomopsis hildebrandtii*	Shrub
		Sericocomopsis sp.	Shrub
Asteraceae	Aspilia	*Aspilia mossambicens*	Shrub
	Pluchea	*Pluchea dioscoridis*	Shrub
Boraginaceae	Cordia	*Cordia gharaf*	Shrub
		Cordia goetzei	Shrub
		Cordia ovalis	Shrub
	Heliotropium	*Heliotropium* sp.	Shrub
Cannabaceae	Celtis	*Celtis Africana*	Shrub
		Celtis zenkeri	Shrub
	Trema	*Trema guineensis*	Shrub
Capparaceae	Cadaba	*Cadaba farinosa*	Shrub
	Capparis	*Capparis fascicularis*	Shrub
	Maerua	*Maerua angolensis*	Shrub
		Maerua triphylla	Shrub
	Thylachium	*Thylachium africanum*	Shrub
Ebenaceae	Diospyros	*Diospyros abyssinica*	Shrub
Euphorbiaceae	Acalypha	*Acalypha fruticosa*	Shrub
	Croton	*Croton scheffleri*	Shrub
	Euphorbia	*Euphorbia* sp.	Shrub
Fabaceae	Acacia	*Acacia hockii*	Shrub
	Aeschynomene	*Aeschynomene schimperi*	Shrub
	Crotalaria	*Crotalaria imperialis*	Shrub
	Indigofera	*Indigofera* sp.	Shrub
	Rhynchosia	*Rhynchosia* sp.	Shrub
Labiatae	Coleus	*Coleus igniarius*	Shrub
Lamiaceae	Hoslundia	*Hoslundia opposita*	Shrub
		Hoslundia sp.	Shrub
	Ocimum L.	*Ocimum* sp.	Shrub
	Premna	*Premna holstii*	Shrub
Malvaceae	Abutilon	*Abutilon angulatum*	Shrub
	Grewia	*Grewia tembensis*	Shrub
		Grewia trichocarpa	Shrub
		Grewia villosa	Shrub
	Hibiscus	*Hibiscus micranthus*	Shrub
	Pavonia	*Pavonia* sp.	Shrub
	Triumfetta	*Triumfetta flavescens*	Shrub
Moraceae	Cardiogyne	*Cardiogyne africana*	Shrub
	Ficus	*Ficus natalensis*	Shrub
Olacaceae	Ximenia	*Ximenia americana*	Shrub
Passifloraceae	Adenia	*Adenia volkensii*	Shrub
Phyllanthaceae	Phyllanthus	*Phyllanthus sepialis*	Shrub
Portulacaceae	Portulaca L.	*Portulaca* sp.	Shrub
Putranjivaceae	Drypetes	*Drypetes natalensis*	Shrub
Rubiaceae	Gardenia	*Gardenia jovistonantis*	Shrub
	Tarenna	*Tarenna graveolens*	Shrub
	Vangueria	*Vangueria acutiloba*	Shrub
Rutaceae	Vepris	*Vepris uguenensis*	Shrub

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(*continued*)

Family	Genus	Species	Life form
Salicaceae	Dovyalis	*Dovyalis xanthocarpa*	Shrub
Salvadoraceae	Salvadora	*Salvadora persica*	Shrub
Solanaceae	Solanum	*Solanum betaceum*	Shrub
		Solanum incanum	Shrub
Ulmaceae	Chaetacme	*Chaetacme aristate*	Shrub
Verbenaceae	Lantana	*Lantana* sp.	Shrub
	Lippia L.	*Lippia javanica*	Shrub
Anacardiaceae	Lannea	*Lannea stuhlmannii*	Tree
	Sclerocarya	*Sclerocarya birraea*	Tree
Apiaceae	Steganotaenia	*Steganotaenia araliacea*	Tree
Apocynaceae	Rauvolfia	*Rauvolfia caffra*	Tree
Araliaceae	Cussonia	*Cussonia holstii*	Tree
Arecaceae	Phoenix	*Phoenix reclinata*	Tree
Bignoniaceae	Kigelia	*Kigelia africana*	Tree
Boraginaceae	Cordia	*Cordia Africana*	Tree
Burseraceae	Commiphora	*Commiphora baluensis*	Tree
		Commiphora campestris	Tree
		Commiphora engleri	Tree
		Commiphora merkeri	Tree
Canellaceae	Warburgia	*Warburgia ugandensis*	Tree
Cannabaceae	Celtis	*Celtis Africana*	Tree
		Celtis zenkeri	Tree
	Trema	*Trema guineensis*	Tree
Combretaceae	Combretum	*Combretum molle*	Tree
	Terminalia	*Terminalia brownie*	Tree
Ebenaceae	Diospyros	*Diospyros abyssinica*	Tree
	Euclea	*Euclea schimperi*	Tree
Euphorbiaceae	Croton	*Croton macrostachys*	Tree
		Croton megalocarpus	Tree
Fabaceae	Acacia	*Acacia albida*	Tree
		Acacia brevispicata	Tree
		Acacia clavigera ssp. usambarensis	Tree
		Acacia drepanolobium	Tree
		Acacia etbaica	Tree
		Acacia hockii	Tree
		Acacia lahai	Tree
		Acacia mellifera	Tree
		Acacia seyal var. fistula	Tree
		Acacia sieberiana	Tree
		Acacia tortilis ssp. spirocarpa	Tree
		Acacia xanthophloea	Tree
	Albizia	*Albizia anthelmintica*	Tree
		Albizzia gummifera	Tree
	Cassia	*Cassia singueana*	Tree
	Crotalaria	*Crotalaria imperialis*	Tree
	Dalbergia	*Dalbergia melanoxylon*	Tree
	Delonix	*Delonix elata*	Tree
	Lonchocarpus	*Lonchocarpus bussei*	Tree
	Tamarindus	*Tamarindus indica*	Tree
Guttiferae	Garcinia	*Garcinia livingstonei*	Tree
Malvaceae	Dombeya	*Dombeya rotundifolia*	Tree
	Sterculia	*Sterculia stenocarpa*	Tree
Meliaceae	Ekebergia	*Ekebergia capensis*	Tree
	Trichilia	*Trichilia roka*	Tree
Moraceae	Chlorophora	*Chlorophora excelsa*	Tree
	Ficus	*Ficus exasperata*	Tree
		Ficus natalensis	Tree
		Ficus sycamorus	Tree
		Ficus vallischoudae	Tree
		Ficus wakefieldii	Tree
Myrtaceae	Syzygium	*Syzygium guineense*	Tree
Opiliaceae	Opilia	*Opilia campestris*	Tree
Phyllanthaceae	Bridelia	*Bridelia micrantha*	Tree
Putranjivaceae	Drypetes	*Drypetes natalensis*	Tree
Rhamnaceae	Ziziphus	*Ziziphus pubescens*	Tree
Rhizophoraceae	Cassipourea	*Cassipourea malosana*	Tree
Rubiaceae	Vangueria	*Vangueria acutiloba*	Tree
	Zanthoxylum	*Zanthoxylum chalybeum*	Tree
Santalaceae	Osyris	*Osyris compressa*	Tree
Sapindaceae	Allophylus	*Allophylus rubifolius*	Tree
	Blighia	*Blighia unijugata*	Tree
Ulmaceae	Chaetacme	*Chaetacme aristate*	Tree
Urticaceae	Obetia	*Obetia pinnatifida*	Tree
Zygophyllaceae	Balanites	*Balanites aegyptiaca*	Tree

Appendix B. An inventory of herbaceous fodder taxa that existed before 1980's in rangelands of northern Tanzania (Source: (Greenway and Vesey-Fitzgerald, 1969) (Anderson and Herlocker, 1973))

Family	Genus	Species	Life form
Acanthaceae	Barleria	*Barleria eranthemoides*	Forb
	Blepharis	*Blepharis tanganyikensis*	Forb
	Dyschoriste	*Dyschoriste hildebrandtii*	Forb
	Hypoestes	*Hypoestes forskalii*	Forb
	Justicia	*Justicia betonica*	Forb
		Justicia debilis	Forb
		Justicia elliotii	Forb
		Justicia exigua	Forb
		Justicia flava	Forb
		Justicia matammensis	Forb
	Monechma	*Monechma* sp.	Forb
Aizoaceae	Zaleya	*Zaleya* sp.	Forb
Amaranthaceae	Achyranthes	*Achyranthes aspera*	Forb
	Aerva	*Aerva javanica*	Forb
	Amaranthus	*Amaranthus* sp.	Forb
	Celosia	*Celosia* sp.	Forb
	Cyathula	*Cyathula* sp.	Forb
Asteraceae	Aspilia	*Aspilia mossambicensis*	Forb
	Aster	*Aster hyssopifolius*	Forb
	Bidens	*Bidens pilosa*	Forb
	Dicoma	*Dicoma* sp.	Forb
	Erlangea	*Erlangea* sp.	Forb
	Helichrysum	*Helichrysum* sp.	Forb
	Pluchea	*Pluchea dioscoridis*	Forb
		Pluchea ovalis	Forb
		Pluchea sp.	Forb
	Sonchus	*Sonchus* sp.	Forb
	Sphaeranthus	*Sphaeranthus suaveolens*	Forb
		Sphaeranthus ukambensis	Forb
	Spilanthes	*Spilanthes mauritiana*	Forb
	Vernonia	*Vernonia* sp.	Forb
Commelinaceae	Commelina	*Commelina* sp.	Forb
Convolvulaceae	Ipomoea	*Ipomoea* sp.	Forb
Cucurbitaceae	Cucumis sp.	*Cucumis* sp.	Forb
Euphorbiaceae	Euphorbia	*Euphorbia* sp.	Forb
Fabaceae	Aeschynomene	*Aeschynomene schimperi*	Forb
	Crotalaria	*Crotalaria* sp.	Forb
	Medicago	*Medicago laciniata*	Forb
	Rhynchosia	*Rhynchosia* sp.	Forb
	Trifolium	*Trifolium rupellianum*	Forb
Gisekiaceae	Gisekia	*Gisekia* sp.	Forb
Lamiaceae	Hoslundia	*Hoslundia opposita*	Forb
	Leucas	*Leucas* sp.	Forb
	Ocimum L.	*Ocimum basilicum* L.	Forb
		Ocimum gratissimum L.	Forb
		Ocimum suave	Forb
Malvaceae	Abutilon	*Abutilon mauritianum*	Forb
	Hermannia	*Hermannia* sp.	Forb
	Pavonia	*Pavonia patens*	Forb
	Sida	*Sida cuneifolia*	Forb
		Sida ovata	Forb
		Sida rhomboidea	Forb
Nyctaginaceae	Boerhavia	*Boerhavia diffusa*	Forb
	Commicarpus	*Commicarpus* sp.	Forb
Talinaceae	Talinum	*Talinum* sp.	Forb
Zygophyllaceae	Tribulus	*Tribulus* sp.	Forb
		Tribulus terrestris	Forb
Cyperaceae	Cyperus	*Cyperus immensus*	Grass
		Cyperus laevigatus	Grass
		Cyperus papyrus	Grass
		Cyperus rigidifolius	Grass
Poaceae	Andropogon	*Andropogon greenwayi*	Grass
	Dactyloctenium	*Dactyloctenium aegyptium*	Grass
	Digitaria	*Digitaria macroblephara*	Grass
		Digitaria milanjiana	Grass
		Digitaria scalarum	Grass
		Digitaria setivalva	Grass
		Digitaria velutina	Grass

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Family	Genus	Species	Life form
	Diheteropogon	*Diheteropogon amplectens*	Grass
	Diplachne	*Diplachne fusca*	Grass
		Diplachne jaegeri	Grass
	Enteropogon	*Enteropogon macrostachyus*	Grass
	Eragrostis	*Eragrostis aspera*	Grass
		Eragrostis cilianensis	Grass
		Eragrostis superba	Grass
		Eragrostis tenuifolia	Grass
	Harpachne	*Harpachne schimperi*	Grass
	Heteropogon	*Heteropogon contortus*	Grass
	Hyparrhenia	*Hyparrhenia rufa*	Grass
	Leersia	*Leersia hexandra*	Grass
	Leptocarydion	*Leptocarydion vulpiastrum*	Grass
	Odyssea	*Odyssea jaegeri*	Grass
		Odyssea paucinervis	Grass
	Panicum	*Panicum maximum*	Grass
		Panicum meyerianum	Grass
		Panicum repens	Grass
	Pennisetum	*Pennisetum mezianum*	Grass
		Pennisetum salifex	Grass
		Pennisetum stramineum	Grass
	Phragmites	*Phragmites mauritianus*	Grass
	Psilolemma	*Psilolemma jaegeri*	Grass
	Setaria	*Setaria pallidifusca*	Grass
		Setaria pumila	Grass
		Setaria sphacelata	Grass
		Setaria verticillata	Grass
	Sporobolus	*Sporobolus africanus*	Grass
		Sporobolus consimilis	Grass
		Sporobolus fimbriatus	Grass
		Sporobolus homblei	Grass
		Sporobolus ioclados	Grass
		Sporobolus marginatus	Grass
		Sporobolus pyramidalis	Grass
		Sporobolus spicatus	Grass
	Themeda	*Themeda triandra*	Grass
	Tragus	*Tragus berteronianus*	Grass
	Urochloa	*Urochloa geniculate*	Grass
		Urochloa panicoides	Grass
	Aristida	*Aristida adscensionis*	Grass
		Aristida sp.	Grass
	Bothriochloa	*Bothriochloa insculpta*	Grass
	Brachiaria	*Brachiaria deflexa*	Grass
	Cenchrus	*Cenchrus ciliaris*	Grass
	Chloris	*Chloris gayana*	Grass
		Chloris pycnothrix	Grass
		Chloris roxburghiana	Grass
		Chloris virgata	Grass
	Cymbosetaria	*Cymbosetaria sagittifolia*	Grass
	Cynodon	*Cynodon dactylon*	Grass
		Cynodon plectostachyus	Grass

Appendix C. Woody fodder taxa across surveyed *Alalili* of northern Tanzania in 2022

Family	Genus	Species name	Life form
Acanthaceae	Ecbolium	*Ecbolium tanzaniense*	Shrub
	Hypoestes	*Hypoestes aristata*	Shrub
Amaranthaceae	Cyathula	*Cyathula orthacantha*	Shrub
	Sericocomopsis Schinz	*Sericocomopsis hildebrandtii*	Shrub
Anacardiaceae	Lannea	*Lannea triphylla*	Shrub
	Rhus	*Rhus natalensis*	Shrub
Apocynaceae	Adenium	*Adenium obesum*	Shrub
	Carissa	*Carissa spinarum*	Shrub
	Gomphocarpus	*Gomphocarpus semilunatus*	Shrub
Asparagaceae	Asparagus	*Asparagus africanus*	Shrub
	Sansevieria	*Sansevieria ehrenbergii*	Shrub
Asteraceae	Aspilia	*Aspilia mossambicensis*	Shrub
	Conyza	*Conyza pyrrhopappa*	Shrub
	Vernonia	*Vernonia glabra*	Shrub
Boraginaceae	Cordia	*Cordia monoica*	Shrub
	Cordia	*Cordia sinensis*	Shrub
	Ehretia	*Ehretia amoena*	Shrub
	Heliotropium	*Heliotropium steudneri*	Shrub
Capparaceae	Boscia	*Boscia mossambicensis*	Shrub
	Cadaba	*Cadaba farinosa*	Shrub
	Capparis	*Capparis tomentosa*	Shrub
	Maerua	*Maerua decumbens*	Shrub
		Maerua triphylla	Shrub
Combretaceae	Combretum	*Combretum molle*	Shrub
Convolvulaceae	Ipomoea	*Ipomoea hildebrandtii*	Shrub
		Ipomoea mombassana	Shrub
Euphorbiaceae	Acalypha	*Acalypha fruticosa*	Shrub
	Croton	*Croton dichogamus*	Shrub
	Euphorbia	*Euphorbia cuneata*	Shrub
Fabaceae	Acacia	*Acacia ancistrocarpa*	Shrub
		Acacia brevispica	Shrub
	Crotalaria	*Crotalaria laburnifolia*	Shrub
	Dichrostachys	*Dichrostachys cinerea*	Shrub
	Indigofera	*Indigofera arrecta*	Shrub
	Ormocarpum	*Ormocarpum kirkii*	Shrub
	Rhynchosia	*Rhynchosia minima*	Shrub
	Senna	*Senna obtusifolia*	Shrub
		Senna occidentalis	Shrub
Lamiaceae	Clerodendrum	*Clerodendrum hildebrandtii*	Shrub
	Leonotis	*Leonotis leonurus*	Shrub
	Ocimum L.	*Ocimum gratissimum* L.	Shrub
Malvaceae	Abutilon	*Abutilon mauritianum*	Shrub
	Grewia	*Grewia bicolor*	Shrub
		Grewia forbesii	Shrub
		Grewia platyclada	Shrub
		Grewia similis	Shrub
		Grewia tembensis	Shrub
		Grewia villosa	Shrub
	Hibiscus	*Hibiscus micranthus*	Shrub
	Pavonia	*Pavonia patens*	Shrub
Portulacaceae	Portulaca L.	*Portulaca mucronata*	Shrub
Rhamnaceae	Ziziphus	*Ziziphus mucronata*	Shrub
Rhizophoraceae	Cassipourea	*Cassipourea mollis*	Shrub
Salvadoraceae	Salvadora	*Salvadora persica*	Shrub
Sapindaceae	Allophylus	*Allophylus serratus*	Shrub
Solanaceae	Lycium	*Lycium europaeum*	Shrub
	Solanum	*Solanum betaceum*	Shrub
		Solanum incanum	Shrub
Sterculiaceae	Melhania	*Melhania velutina*	Shrub
Verbenaceae	Lantana	*Lantana trifolia*	Shrub
		Lantana ukambensis	Shrub
	Lippia L.	*Lippia javanica*	Shrub
		Lippia kituiensis	Shrub
Anacardiaceae	Lannea	*Lannea triphylla*	Tree
	Rhus	*Rhus natalensis*	Tree
	Sclerocarya	*Sclerocarya birrea*	Tree
Apocynaceae	Acokanthera	*Acokanthera oppositifolia*	Tree
Asteraceae	Brachylaena	*Brachylaena* sp.	Tree
Boraginaceae	Cordia	*Cordia sinensis*	Tree

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Family	Genus	Species name	Life form
Burseraceae	Commiphora	*Commiphora africana*	Tree
		Commiphora campestris	Tree
		Commiphora habessinica	Tree
		Commiphora schimperi	Tree
		Commiphora ugogensis	Tree
Capparaceae	Boscia	*Boscia angustifolia*	Tree
	Cadaba	*Cadaba farinosa*	Tree
	Maerua	*Maerua parvifolia*	Tree
		Maerua triphylla	Tree
Celastraceae	Maytenus	*Maytenus senegalensis* (Lam.)	Tree
Combretaceae	Combretum	*Combretum molle*	Tree
	Terminalia	*Terminalia prunioides*	Tree
Euphorbiaceae	Euphorbia	*Euphorbia cuneata*	Tree
Fabaceae	Acacia	*Acacia abyssinica*	Tree
		Acacia brevispica	Tree
		Acacia drepanolobium	Tree
		Acacia etbaica	Tree
		Acacia kirkii	Tree
		Acacia lahai	Tree
		Acacia mellifera	Tree
		Acacia nilotica	Tree
		Acacia nubica	Tree
		Acacia robusta	Tree
		Acacia senegal	Tree
		Acacia seyal	Tree
		Acacia stuhlmanii	Tree
		Acacia tortilis	Tree
		Acacia xanthophloea	Tree
	Albizia	*Albizia anthelmintica*	Tree
		Albizia gummifera	Tree
		Albizia harveyi	Tree
	Dalbergia	*Dalbergia boehmii*	Tree
		Dalbergia melanoxylon	Tree
	Dichrostachys	*Dichrostachys cinerea*	Tree
	Entada Adans.	*Entada abyssinica*	Tree
	Lonchocarpus	*Lonchocarpus eriocalyx*	Tree
	Millettia	*Millettia usaramensis*	Tree
	Ormocarpum	*Ormocarpum kirkii*	Tree
		Ormocarpum trichocarpum	Tree
Loganiaceae	Strychnos	*Strychnos potatorum*	Tree
Malvaceae	Dombeya	*Dombeya rotundifolia*	Tree
	Thespesia	*Thespesia garckeana*	Tree
Olacaceae	Ximenia	*Ximenia caffra*	Tree
Rhamnaceae	Ziziphus	*Ziziphus mucronata*	Tree
Rhizophoraceae	Cassipourea	*Cassipourea mollis*	Tree
Rubiaceae	Catunaregam	*Catunaregam spinosa*	Tree
	Vangueria	*Vangueria tomentosa*	Tree
Rutaceae	Zanthoxylum	*Zanthoxylum chalybeum*	Tree
Salvadoraceae	Dobera Juss.	*Dobera loranthifolia*	Tree
	Salvadora	*Salvadora persica*	Tree
Sapindaceae	Haplocoelum Radlk.	*Haplocoelum foliolosum*	Tree
Solanaceae	Lycium	*Lycium europaeum*	Tree
Zygophyllaceae	Balanites	*Balanites aegyptiaca*	Tree

Appendix D. Herbaceous fodder taxa across surveyed *Alalili* of northern Tanzania in 2022

Family	Genus	Species name	Life form
Acanthaceae	Barleria	*Barleria eranthemoides*	Forb
	Blepharis	*Blepharis tanganyikensis*	Forb
	Dyschoriste	*Dyschoriste hildebrandtii*	Forb
	Justicia	*Justicia betonica*	Forb
		Justicia debilis	Forb
		Justicia exigua	Forb
		Justicia flava	Forb
Aizoaceae	Zaleya	*Zaleya pentandra*	Forb
Amaranthaceae	Achyranthes	*Achyranthes aspera*	Forb
	Cyathula	*Cyathula orthacantha*	Forb

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Family	Genus	Species name	Life form
	Psilotrichum	*Psilotrichum elliotii*	Forb
Asparagaceae	Sansevieria	*Sansevieria ehrenbergii*	Forb
Asteraceae	Aspilia	*Aspilia mossambicensis*	Forb
	Conyza	*Conyza pyrrhopapa*	Forb
	Gutenbergia	*Gutenbergia cordifolia*	Forb
	Hirpicium Cass	*Hirpicium diffusum*	Forb
	Sphaeranthus	*Sphaeranthus ukambensis*	Forb
	Vernonia	*Vernonia glabra*	Forb
Commelinaceae	Commelina	*Commelina benghalensis*	Forb
Convolvulaceae	Ipomoea	*Ipomoea mombassana*	Forb
Euphorbiaceae	Acalypha	*Acalypha crenata*	Forb
	Euphorbia	*Euphorbia inaequilatera*	Forb
Fabaceae	Crotalaria	*Crotalaria laburnifolia*	Forb
	Dolichos L.	*Dolichos kilimandscharicus*	Forb
	Indigofera	*Indigofera arrecta*	Forb
		Indigofera brevicalyx	Forb
	Neonotonia	*Neonotonia wightii*	Forb
	Tephrosia	*Tephrosia elata*	Forb
Gentianaceae	Enicostema Blume	*Enicostema axillare*	Forb
Geraniaceae	Monsonia	*Monsonia angustifolia*	Forb
Gisekiaceae	Gisekia	*Gisekia pharnaceoides* L.	Forb
Lamiaceae	Becium	*Becium obovatum*	Forb
	Leucas	*Leucas grandis*	Forb
		Leucas tettensis Vatke	Forb
	Ocimum L.	*Ocimum basilicum* L.	Forb
		Ocimum gratissimum L.	Forb
Malvaceae	Melhania	*Melhania velutina*	Forb
	Sida	*Sida cuneifolia*	Forb
		Sida ovata	Forb
		Sida rhomboidea	Forb
Nyctaginaceae	Commicarpus	*Commicarpus plumbagineus*	Forb
Passifloraceae	Adenia	*Adenia gummifera*	Forb
Phyllanthaceae	Phyllanthus	*Phyllanthus maderaspatensis*	Forb
Polygonaceae	Oxygonum	*Oxygonum sinuatum*	Forb
Portulacaceae	Portulaca	*Portulaca oleracea*	Forb
Rubiaceae	Spermacoce	*Spermacoce latifolia* Aubl	Forb
		Spermacoce princea	Forb
Zygophyllaceae	Tribulus	*Tribulus terrestris*	Forb
Cyperaceae	Cyperus	*Cyperus dives*	Grass
		Cyperus rotundus	Grass
Poaceae	Aristida	*Aristida kenyensis*	Grass
	Brachiaria	*Brachiaria decumbens*	Grass
		Brachiaria deflexa	Grass
	Cenchrus	*Cenchrus ciliaris*	Grass
	Chloris	*Chloris gayana*	Grass
		Chloris pycnothrix	Grass
		Chloris virgata	Grass
	Cynodon	*Cynodon dactylon*	Grass
		Cynodon nlemfuensis	Grass
		Cynodon plectostachyus	Grass
	Dactyloctenium	*Dactyloctenium aegyptium*	Grass
	Digitaria	*Digitaria macroblephara*	Grass
	Diheteropogon	*Diheteropogon amplectens*	Grass
	Eragrostis	*Eragrostis cilianensis*	Grass
	Hyparrhenia	*Hyparrhenia rufa*	Grass
	Panicum	*Panicum maximum*	Grass
		Panicum sanguineum	Grass
	Pennisetum	*Pennisetum mezianum*	Grass
	Setaria	*Setaria pumila*	Grass
		Setaria sphacelata	Grass
	Sporobolus	*Sporobolus africanus*	Grass
		Sporobolus consimilis	Grass
		Sporobolus ioclados	Grass
		Sporobolus pyramidalis	Grass
	Themeda	*Themeda triandra*	Grass
	Tragus	*Tragus bethonica*	Grass
	Urochloa	*Urochloa panicoides*	Grass
	Zea	*Zea maize*	Grass

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