RESEARCH

Plant species composition and diversity depending on piospheres and seasonality in the southern rangelands of Kenya

S. O. Jawuoro[*], O. K. Koech, G. N. Karuku and J. S. Mbau

Abstract

Introduction: Scarcity of water in the rangelands of Kenya has led to the introduction of piospheres. Previous research has however produced contrasting results on the effects of piospheres and seasonality on Shannon-Wiener's diversity index, and therefore, this information is still deficient. In this study, the impact of these piospheres on plant species composition, diversity, and richness was assessed.

Methods: Vegetation sampling was done during both the long rains (April) and the dry season (August). Three piosphere types (dam, trough, and a seasonal river) were studied using 0.25 m^2 quadrats to sample vegetation at intervals of 20 m along 100-m transects. Four 100-m transects were used per piosphere (north, east, south, and west directions). Shannon-Wiener's diversity index was used to determine species richness and composition. Two-way ANOVA was used to determine if piospheric distance had an effect on species diversity, richness, and evenness using GenStat 15th edition.

Results: A total of 22 grasses and 29 forbs were recorded in the study area. The most abundant grasses near the piospheres were *Eragrostis tenuifolia* (12.9%) and *Cynodon dactylon* (10.6%). *E. tenuifolia* is an increaser species and was therefore most abundant in areas of severe grazing while *C. dactylon* has been known to be tolerant to grazing. The most abundant forbs were *Crotalaria brevidens* (37.5%). The Shannon-Wiener diversity index significantly increased ($F = 25.07$, $P = 0.001$) with distance from the three piospheres owing to the high grazing intensity near the piospheres and was significantly different between piospheres, being higher ($F = 10.05$, $P = 0.001$) at 20 m from the river (1.2 ± 0.1) compared to a similar distance from the dam (0.9 ± 0.1) and the trough (0.8 ± 0.2). This was probably because the trough was smaller in size compared to the other piospheres, thereby concentrating more grazing animals per unit area and causing a greater impact on plant species.

Conclusions: The study demonstrated that species diversity, richness, and evenness were low near the piospheres due to heavy grazing. Similarly, the lowest species diversity, richness, and evenness were recorded near the trough compared to the dam and the river. This study therefore recommends that range reseeding and rest period be done to rehabilitate degraded areas and facilitate plant regeneration. Larger piospheres should also be used to minimize animal impact per unit area.

Keywords: Piosphere, Species composition, Shannon-Wiener diversity, Species richness, Rangelands

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Introduction

Piosphere is defined as the radial pattern of differential grazing and the associated animal impact which develops around the water points (Lange 1969; Todd 2006). These patterns formed around piospheres form a basis for studying the effects of livestock grazing and differentiating them from other environmental factors (Todd 2006). Piospheres have an effect on both soil and vegetation. Impacts on soil include, among others, alterations to soil nutrients such as organic carbon, total nitrogen and pH (Smet and Ward 2006; Shahriary et al. 2012), soil compaction, reduction of soil aggregate stability and changes in soil texture. The effects on vegetation include increased shrub mortality, plant defoliation, alterations to species composition and demography (Riginos and Hoffman 2003), and changes in herbaceous vegetation (Egeru et al. 2015). Plant defoliation by livestock and wildlife grazing around these piospheres increases palatable species' mortality, thereby reducing their ability to favorably compete with less palatable alien and exotic species (Hunt et al. 2002; Shahriary et al. 2012). Further, trampling reduces seed production and seedling establishment in the rangelands (Chaichi et al. 2005; Amiri et al. 2008). Grazers also change rangeland vegetation through deposition of urine and feces and by dispersing plant seeds and propagules (Shahriary et al. 2012).

The attempt to create a generalized pattern of effect of piospheres on vegetation across the world is based on the perception that plant species with similar morphological and physiological traits should respond similarly when exposed to grazing (Brooks and Matchett 2006; Todd 2006). Piospheric studies on species composition, richness, and diversity indices have been done in most parts of the world including Australia (Landman et al. 2012), Asia (Shahriary et al. 2012), Southern Africa (Todd 2006), Northern Africa (Tarhouni et al. 2007), and Uganda (Egeru 2014; Egeru et al. 2015). Nevertheless, there have been no studies conducted in Kenya, especially in the southern rangelands where water interventions have been widely undertaken to alleviate water shortage and enhance pastoral livelihoods (Opiyo et al. 2015). It is known that haphazard introduction of piospheres without ecological considerations lead to rangeland degradation (Brooks and Matchett 2006). This study therefore sought to establish the effect of piospheres on plant species composition, diversity, and richness in the southern rangelands of Kajiado County, Kenya, in order to provide insights for designing water intervention strategies that will enhance pastoral livelihoods without adversely affecting vegetation.

Methods

Study area

The study was done in Kiserian area, Kajiado County, Kenya, located within 36° 5′ and 37° 5′ east and 1° and 3° south (Fig. 1). The range of altitude in this county
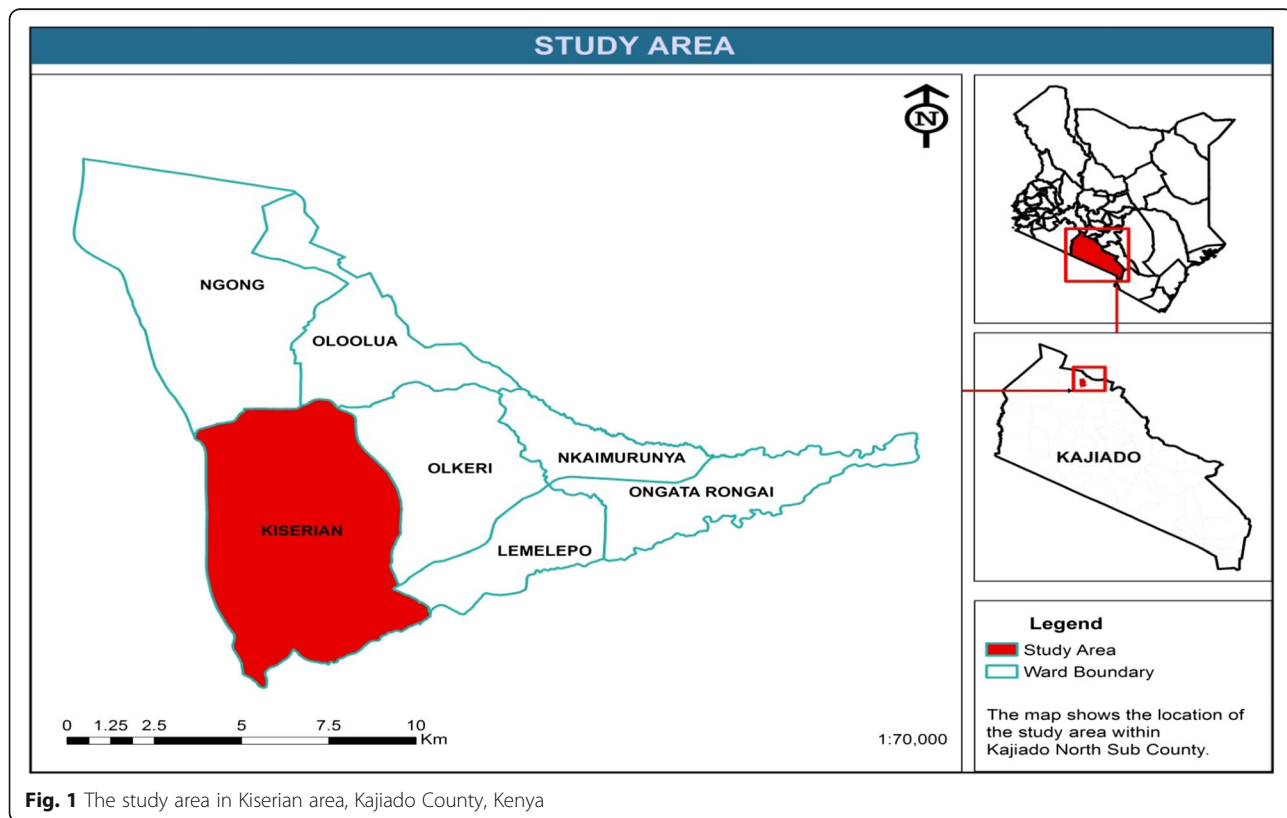

Fig. 1 The study area in Kiserian area, Kajiado County, Kenya

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ranges between 1580 and 2460 masl. The annual rainfall received ranges from 300 to 1250 mm/year (Kareri 2013). Rainfall is bimodally distributed. The long rains (first rains) fall between March and May whereas the short rains (second rains) are received from October to December (Ogutu et al. 2013). The minimum and maximum mean diurnal temperatures are 10 and 24 °C respectively (Krhoda 2002). The ratio of rainfall to evapotranspiration in the area is <0.65 (Middleton and Thomas 1997). Kiserian is a semiarid area found within agro-ecological zone IV. Soils are mainly vertisols, sticky when wet, and forming large cracks during dry seasons (de Leeuw et al. 1991; Ombogo 2013). The most widespread plant species are *Acacia mellifera*; *Acacia tortilis*, *Acacia nubica*, *Acacia ancistroclada*, *Acacia nilotica*, *Commiphora riparia*, *Commiphora africana*, and *Balanites aegyptiaca* are the most common species (Bekure 1991).

According to the national census of the Kenya Republic (2010), about 202,651 people live in Kajiado County with a population growth rate estimated to be 4.5%. Most of the residents are traditionally pastoralists (Ogutu et al. 2013). However, due to emerging socio-economic opportunities and climate change, formal employment, cultivation, group ranching, and trade have been adopted in order to diversify income sources (Kioko and Okello 2010).

Research design
A randomized block design was used for this research with four watering points forming blocks while plots (5) were the distances from water points. Quadrats (0.25 m^2) were the main sampling points, placed at intervals of 20, 40, 60, 80, and 100 m within a 100-m transect from the watering point. Each treatment was replicated four times in the east, west, north, and south directions from the watering points. Two troughs, a dam, and a seasonal river of similar durations of use and management type were assessed. The troughs were smaller in size compared to the dam and the river and could have an impact by increasing grazing pressure around it due to greater animal concentration. The river was a natural water system and was therefore used as a control to provide a basis of comparison with the artificially created water sources (dam and trough).

Vegetation sampling
Plant species diversity, richness, and evenness are affected by climatic variables such as rainfall. Vegetation sampling was therefore done in April during the long rains (wet season) and August during the dry season. Similarly, seasonal rivers are also affected by rainfall, and as such, differences in plant species diversity, richness, and evenness were expected between wet and dry spells.

However, dams and troughs were in use during both seasons, and therefore, no significant changes were expected in the vegetation attributes determined. Transects were done starting at 10 m away from the piosphere, to minimize edge effects, and stretched a distance of 100 m. Four transects were used per piosphere. Plant species were assessed after every 20 m within 0.5 m by 0.5 m quadrats, and available species counted and recorded. Species composition was determined using their relative densities as described by Krebs (1989), using the formula

$$\left(\frac{n_i}{N}\right) \times 100 \tag{1}$$

where n_i is the quantity of individual species per quadrat, while N is the total quantity of species within the same quadrat.

Species diversity was determined using Shannon-Wiener's diversity index as described by Krebs (1989). Shannon-Wiener's diversity index (H')

$$H' = -\sum \left[\left(\frac{n_i}{N}\right) \times \ln\left(\frac{n_i}{N}\right)\right] \tag{2}$$

where n_i is the number of individuals of each species, N is the total number of individuals (or amount) for the site, and ln is the natural log of the number.

Species richness (S) was calculated as the total number of species per quadrat while Pielou evenness was calculated as described by Krebs (1989).

$$J = \frac{H©}{\ln(H©)_{max}} \tag{3}$$

where H' is Shannon-Wiener's diversity index for the quadrat and $H©_{max}$ is the natural log of species richness (S).

Statistical analysis
Statistical analyses were performed using GenStat 15th edition. Two-way ANOVA was used to determine if there were significant differences between means of species diversity, richness, and evenness at various piospheric distances, piospheres, and seasons. Comparison of means was done to determine if there were significant differences between treatment pairs. Tukey's HSD test was used to compare the means. Significance was obtained at $P \leq 0.05$.

Results
Species composition
The relative densities (%) of grasses at various piospheric distances are shown in Table 1. A total of 51 herbaceous species were recorded. Among the 22 grass species recorded, 15 grass species were recorded in the dry season while 21 grass species were recorded during the wet

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Table 1 Relative densities (%) of grass species at various piospheric distances

Species (N = 22)	Distance (m)	Relative density (%)									
		Dry season					Wet season				
		20	40	60	80	100	20	40	60	80	100
Aristida adoensis		1.3	5.8	0.5	1.9	0.9	NP	0.9	4	1	4.1
Bothriochloa insculpta		11.5	6.6	3.6	4.8	5.5	4.4	5	2	7.6	6.9
Brachiaria lacnatha		NP	NP	NP	NP	NP	1.3	NP	NP	NP	1.4
Chloris pycnothrix		7.1	3.9	2.1	0.9	2.3	4.4	NP	2.8	1	NP
Cymbopogon excavatus		NP	NP	NP	NP	NP	3.9	0.9	3.2	1	3.4
Cymbopogon vallidus		1.7	0.9	2.6	1.9	2.7	NP	NP	NP	NP	NP
Cynodon dactylon		11.1	6.2	2.6	3.9	2.7	10.1	5.4	3.6	2.1	NP
Digitaria macroblephara		NP	NP	NP	NP	NP	NP	1.8	8	NP	NP
Digitaria milanjiana		NP	NP	NP	NP	NP	NP	NP	1.6	1.5	NP
Digitaria scalarum		2.6	1.3	19.3	21.3	0.9	7.9	10	NP	14.2	NP
Eragrostis tenuifolia		16.4	13.3	11.5	9.7	7.4	9.3	7.7	NP	3.6	2
Eriochloa fatmensis		0.8	NP	NP	NP	NP	7.7	6.3	11.2	NP	1.4
Hyparrhenia hirta		2.6	1.7	1.6	5.8	1.8	2.2	0.5	NP	1.1	2.7
Hyperrhenia lintonii		2.2	NP	2.1	3.8	0.5	1.3	3.6	29.7	3.6	9.6
Michrocloa kunthii		NP	0.8	1	NP	0.5	NP	0.5	NP	5.6	NP
Pennisetum mezianum		1.3	NP	NP	0.97	NP	NP	1.8	NP	NP	NP
Setaria holstii		25.7	24.3	26	21.3	37.7	13.6	17.2	NP	18.8	32.9
Setaria sphacelata		NP	NP	4.7	1.93	NP	1.3	3.6	29.7	3.6	9.6
Setaria verticillata		NP	NP	NP	NP	NP	8.4	NP	NP	NP	NP
Sporobolus discosporus		NP	NP	NP	NP	NP	1.3	0.5	NP	NP	NP
Sporobolus pyramidalis		NP	1.9	3.6	1.93	5.6	NP	NP	NP	0.5	NP
Themeda triandra		15.1	29.2	18.7	19.3	30.2	23.4	36.2	29.7	38.1	34.3

NP not present

season. We found 18 perennial grasses, and 4 were annual grasses. The most dominant annual grasses (with the highest relative densities) were *Chloris pycnothrix* and *Eragrostis tenuifolia* whereas *Themeda triandra*, *Setaria holstii*, *Aristida adoensis*, *Bothriochloa insculpta*, *Cynodon dactylon*, and *Hyparrhenia hirta* were the most dominant perennial grasses. *Cynodon dactylon*, *Eragrostis tenuifolia*, *Eriochloa fatmensis*, *Chloris pycnothrix*, and *Setaria verticillata* were more pronounced near the watering points.

There were 29 forbs recorded during both dry and wet seasons (Table 2). Of these, 27 were recorded during the dry season while 25 forbs were recorded during the wet season. The most dominant forbs were *Indigofera spicata*, *Indigofera volkensii*, *Launaea cornuta*, and *Glycine wightii*. Among the 29 forbs recorded, 10 belonged to family Fabaceae, representing 36% of the total, while six were members of family Acanthaceae representing 18%. The Lamiaceae and Labiatae families had two species each, forming 15% of the total number of forbs recorded. One species each was recorded for families Phyllanthaceae, Polygalaceae, Asteraceae, Malvaceae, Tiliaceae,

Euphorbiaceae, and Solanaceae, each family being 4% of the total forb population observed. Forbs were more pronounced around the water points.

Shannon-Wiener diversity index, species richness, and Pielou evenness

Plant species diversity, richness, and evenness at various distances from the dam, the trough, and the river are shown in Table 3. Shannon-Wiener's diversity index significantly increased ($F = 25.07$, $P = 0.001$) with piospheric distance and was significantly different ($F = 10.05$, $P = 0.001$) between piospheres, being (1.2 ± 0.1) at 20 m from the river compared to a similar distance from the dam (0.9 ± 0.1) and the trough (0.8 ± 0.2). There was no significant difference ($F = 0.24$, $P = 0.622$) in Shannon-Wiener's diversity index between the wet and dry seasons. Moreover, the interactions between treatments (distance × season × piosphere) were not significant ($F = 0.45$, $P = 0.889$).

Similarly, species richness (S) significantly increased ($F = 17.05$, $P = 0.001$) with distance from all the three piospheres. Although higher species richness was

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Table 2 Relative densities (%) of forbs at various piospheric distances

Species (N = 29)	Family distance (m)	Relative density (%)									
		Dry season					Wet season				
		20	40	60	80	100	20	40	60	80	100
Ajuga remota	Labiatae	NP	1.5	NP	NP	NP	9.4	NP	4.3	NP	NP
Alyscarpus rogusus	Fabaceae	8.3	7.7	NP	NP	3.1	0.9	3.3	6.4	1.2	3.2
Barleria acanthoides	Acanthaceae	NP	1.5	NP	2.9	NP	0.9	1.1	1.1	NP	1.1
Becium obovatum	Labiatae	NP	NP	NP	NP	1.5	1.9	2.2	2.1	1.1	13.8
Corchorus olitorius	Tiliaceae	NP	NP	2.2	NP	NP	NP	NP	NP	NP	NP
Crotalaria brevidens	Fabaceae	37.5	15.4	32.6	33.3	30.8	NP	NP	NP	1.2	NP
Crotolaria pycnostachya	Fabaceae	NP	1.5	NP	2.9	3.1	2.8	1.1	2.3	NP	NP
Dyschoriste radicans	Acanthaceae	1.4	12.3	10.9	7.3	6.2	NP	NP	3.2	NP	NP
Evolvulus alsinoides	Convulvulaceae	12.5	6.2	10.9	4.4	3.1	NP	1.1	NP	NP	NP
Euphorbia inequilatera	Euphorbiaceae	NP	1.5	NP	NP	NP	5.2	9.8	5.6	26.4	NP
Glycine wightii	Fabaceae	14.9	12.3	17.4	14.4	13.9	NP	1.1	1.1	NP	1.1
Hypoestes verticillaris	Acanthaceae	NP	1.5	NP	NP	NP	3.8	10.0	5.3	1.2	6.4
Indigofera brevicalyx	Fabaceae	5.6	1.5	2.2	15.9	4.6	1.4	NP	1.1	6.9	1.1
Indigofera spicata	Fabaceae	2.8	1.5	10	3.6	21.5	19.5	8.2	10.4	NP	22.3
Indigofera volkensii	Fabaceae	NP	26.7	NP	NP	1.5	19.5	14.4	23.4	NP	22.3
Ipomea mombassana	Convulvulaceae	NP	1.5	NP	NP	NP	NP	14.7	10.4	12.6	8.5
Launaea cornuta	Asteraceae	5.7	1.1	3.2	3.1	2.1	3.7	NP	4.2	19.5	10.6
Leucas martinicensis	Lamiaceae	1.4	NP	NP	NP	NP	2.8	2.2	4.2	9.2	4.2
Ocimum basilicum	Lamiaceae	NP	3.1	2.2	1.5	NP	5.6	1.1	1.1	3.4	2.1
Phyllanthus maderaspatensis	Phyllanthaceae	1.4	NP	NP	NP	NP	NP	3.3	NP	3.5	NP
Polygala sphenoptera	Polygalaceae	1.4	NP	NP	1.5	3.1	NP	NP	NP	NP	NP
Rhynchosia minima	Fabaceae	1.4	NP	NP	NP	NP	NP	3.3	NP	2.3	1.1
Ruellia patula	Acanthaceae	4.2	4.6	4.4	7.3	6.2	NP	3.3	NP	2.3	1.1
Senna mimosoides	Fabaceae	NP	NP	2.2	NP	NP	2.8	2.2	1.1	2.3	NP
Sida cuneifolia	Malvaceae	NP	3.1	NP	NP	NP	2.8	2.2	1.1	2.3	NP
Solanum incanum	Solanaceae	1.4	NP	NP	2.4	1.5	4.7	3.3	NP	NP	NP
Thunbergia alata	Acanthaceae	NP	1.5	2.2	NP	NP	12.3	12.1	11.7	4.4	NP
Thunbergia elliotii	Acanthaceae	NP	NP	NP	NP	NP	NP	NP	NP	NP	1.1
Vigna membranaceae	Fabaceae	NP	NP	2.2	1.5	NP	NP	NP	NP	NP	NP

NP not present

observed at 20 m from the river and the dam (4.5 ± 0.5) compared to a similar distance from the trough (3.0 ± 0.5), species richness was not significantly different between piospheres ($F = 0.39$, $P = 0.536$) and seasons ($F = 3.25$, $P = 0.780$). Interactions between treatments (distance × season × piosphere) were also not significant ($F = 0.34$, $P = 0.950$).

Pielou evenness significantly increased ($F = 7.47$, $P = 0.001$) with distance from the three piospheres. However, Pielou evenness was not significantly different between piospheres ($F = 3.05$, $P = 0.052$) but was higher at 20 m near the dam (0.8 ± 0.5) compared to a similar distance from the trough (0.7 ± 0.1) and the river (0.7 ± 0.1). Species evenness was also not significantly different between

the wet and dry seasons ($F = 0.24$, $P = 0.629$). Besides, there was no significant interactions between treatments (distance × season × piosphere) ($F = 0.75$, $P = 0.648$).

Discussion

Species composition

More grass species were observed during the wet season compared to the dry season. This was because some of the ephemerals like *S. verticillata* were present only during the wet season. Ephemerals are grass species which regenerate immediately after the rains (Verdoodt et al. 2010; Lugusa et al. 2016), emerging where decreaser species have been depleted as a result of heavy grazing and are therefore a sign of poor range condition (Oluwole

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Table 3 Plant species Shannon-Wiener diversity index, richness, and Pielou evenness (mean ± SE) at various piospheric distances

Dry season							Wet season				
Piosphere	Distance (m)	20	40	60	80	100	20	40	60	80	100
Dam	Diversity	0.9 ± 0.1a	1.2 ± 0.1a	1.1 ± 0.4a	1.5 ± 0.1a	1.8 ± 0.1a	0.7 ± 0.1a	0.9 ± 0.2ab	1.16 ± 0.1bc	1.5 ± 0.2 cd	1.7 ± 0.3d
	Richness	4.5 ± 0.5a	5.5 ± 1.1ab	6.5 ± 0.3bc	7.3 ± 0.5bc	8.0 ± 0.0c	4.8 ± 1.1a	5.6 ± 0.8a	6.25 ± 0.9a	7.0 ± 0.7a	7.5 ± 0.5a
	Evenness	0.8 ± 0.5ab	0.8 ± 0.1a	0.87 ± 0.1ab	0.9 ± 0.2ab	0.9 ± 0.1b	0.8 ± 0.1a	0.8 ± 0.2a	0.84 ± 0.2a	0.9 ± 0.2a	0.9 ± 0.1a
Trough	Diversity	0.8 ± 0.2a	0.9 ± 0.1a	1.3 ± 0.2ab	1.3 ± 0.1ab	1.6 ± 0.3b	1.1 ± 0.1a	1.4 ± 0.2ab	1.5 ± 0.1b	1.6 ± 0.1b	1.7 ± 0.1b
	Richness	3.0 ± 0.5a	3.8 ± 0.3ab	5.0 ± 0.8ab	4.8 ± 0.5ab	5.3 ± 1.0b	4.3 ± 0.5a	5.3 ± 1.1a	5.8 ± 0.8a	6.3 ± 0.4a	6.5 ± 0.7a
	Evenness	0.7 ± 0.1a	0.7 ± 0.1a	0.8 ± 0.1ab	0.8 ± 0.3ab	0.9 ± 0.3b	0.7 ± 0.1a	0.8 ± 0.2b	0.9 ± 0.1b	0.9 ± 0.1b	0.9 ± 0.1b
River	Diversity	1.2 ± 0.1a	1.3 ± 0.2ab	1.6 ± 0.1bc	1.7 ± 0.1c	1.9 ± 0.8c	1.2 ± 0.2a	1.3 ± 0.1ab	1.6 ± 0.1ab	1.6 ± 0.1ab	1.7 ± 0.9b
	Richness	4.5 ± 0.5a	4.5 ± 0.3a	4.3 ± 1.1a	5.5 ± 0.5ab	7.5 ± 0.9b	3.0 ± 0.4a	3.5 ± 0.7ab	4.5 ± 0.3bc	5.3 ± 0.2bd	6.5 ± 0.3d
	Evenness	0.7 ± 0.1a	0.8 ± 0.1a	0.7 ± 0.2a	0.9 ± 0.1a	0.9 ± 0.1a	0.6 ± 0.1a	0.8 ± 0.04b	0.8 ± 0.0b	0.9 ± 0.1b	0.8 ± 0.1b

Means with different letters in the same row are significantly different ($P \leq 0.05$)

et al. 2008). *Eragrostis* spp., for instance, are increaser species, increasing in abundance where there is severe grazing that leads to range degradation (Du Toit 2009). These results corroborate Egeru et al. (2015) who observed 34 species during the wet season and 26 species during the dry season in Karamoja sub-region of Uganda. As reported by Sabiiti and Teka (2004) and Machogu (2013), *Chloris*, *Hyparrhenia*, *Aristida*, and *Sporobolus* spp. are some of the most pronounced grasses in the East African rangelands due to their self-seeding ability, tolerance to drought, and spreading capacity.

The results suggest that most grasses were more prevalent away from the piospheres, while forbs were predominant near the piospheres. This was probably because most grasses were decreaser species and therefore susceptible to grazing. *Aristida* spp., *Hyparrhenia* spp., *Bothriochloa* spp., *T. triandra*, and *S. holstii* are decreaser species (Angassa 2014). Grazing alters species composition within the rangeland ecosystems (Todd 2006; Wu et al. 2009). High grazing pressure reduces the density of palatable plants forcing the animals to forage on species of low nutrition value (Amiri et al. 2008). As such, most preferred plant species cease to grow, giving way for the proliferation of forbs (Chaichi et al. 2005; Loydi et al. 2012). Similar observations were made by Hoshino et al. (2009) who reported that species composition changes along grazing gradients are characterized by changes in density and cover of life forms, and annual species and forbs replace perennial grasses near the piospheres. The results are consistent with Mudongo et al. (2016) who observed that continuous grazing led to diminished perennial grass population and increase in forbs and woody species in the Kalahari rangelands of Botswana. Furthermore, the findings under this study corroborate those of Mureithi et al. (2010) who reported a prevalence of forbs under heavy grazing in the Njemps Flats of Kenya. Similar observations were also made by

Todd (2006) in the Nama-Karoo rangelands of Southern Africa where forbs and annual grasses replaced palatable perennial grasses due to heavy grazing near the piospheres. *C. dactylon* was, however, more pronounced near the water points. This was because *C. dactylon* can withstand heavy grazing, is extremely tolerant to fire, and adapts to various climatic and edaphic conditions, in addition to being tolerant to both salinity and flooding (Rita et al. 2012; Egeru et al. 2015). In a related study in the Sonamarg area of the Kashmir Himalayas, Mir et al. (2015) also observed that the importance value index of *C. dactylon* significantly increased during peak grazing seasons. *Cynodon dactylon*, *Chloris pycnothrix*, *Eragrostis tenuifolia*, and *Sporobolus discosporus* decreased with distance away from the piospheres. These findings corroborate the observations of Oluwole et al. (2008) that *C. dactylon*, *Sporobolus* spp., and *Eragrostis* spp. increase near the piospheres.

Shannon-Wiener diversity index, species richness, and Pielou evenness

Trampling and defoliation observed near the piospheres could justify the significantly lower plant species diversity, richness, and evenness. Due to higher animal concentration near the piospheres, there was greater plant defoliation that hampered seed germination, plant growth, and development. Besides, increased trampling slowed down plant regeneration upon grazing therefore reducing species richness and diversity. Further, hoof action could have led to soil compaction hindering infiltration of water and consequently low plant growth (Mapfumo et al. 2000). As reported by Amiri et al. (2008), soil compaction also triggers depletion of soil organic matter, which hampers the growth of plant species. Defoliation, excretion, and seed dispersal by grazing animals influence plant diversity (Duncan 2005). Animal excreta improve nutrient and water cycling which favors growth of palatable species and augment soil organic

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matter leading to fertile range soils that provide optimum condition for plant growth and improved rangeland health and productivity (Todd-Brown et al. 2014). Light or moderate herbivory increase plant diversity. Continuous grazing leads to overuse of forage, reducing their quality and quantity particularly during the reproductive stage. Heavy herbivory has been known to result in death of species and repetitive reproductive failure (Brooks and Matchett 2006; Todd 2006). Besides, overgrazing hampers seed germination and consequently inhibits plant growth and development further reducing vegetation cover, soil hydraulic conductivity, and nutrients available to plants (Amiri et al. 2008). These findings corroborate those of Angassa (2014) who observed that 80% of herbaceous species exhibited a high vulnerability to grazing in the Borana region of Southern Ethiopia. Shahriary et al. (2012) also reported a decrease in species richness with increased grazing intensity around the piospheres of Iran. Similarly, Socher et al. (2013), Meyers et al. (2014), and Haynes et al. (2013) also observed that heavy grazing reduces plant species diversity richness and evenness. Mureithi et al. (2014) also reported that diversity of herbaceous species abundance and richness was higher in mildly to moderately grazed areas compared to heavily grazed areas in Northwestern Kenya. Besides, Todd (2006), while conducting a similar study in the Nama-Karoo rangelands of South Africa, observed that there were twice as many species further from the piospheres as nearer the piospheres.

No significant difference in plant diversity, richness, and evenness was observed between seasons. This could be due to the fact that 18 out of the 22 grass species observed were perennials (Table 1) and had life-spans of more than a season. The four annuals observed (*C. pycnothrix, E. tenuifolia, E. fatmensis,* and *S. verticillata*) were not sufficient to produce a significant difference. Similarly, at least 25 out of the 29 forbs were observed during both dry and wet seasons (Table 2), with the exception of *Thunbergia elliotii* and *Polygala sphenoptera* which were not recorded in the wet season and *Corchorus olitorius* and *Becium obovatum* which were not recorded in the dry season. The findings could be attributed to the fact that the study area was mainly dominated by *S. holstii* and *T. triandra* (Table 1) which are perennial grasses. Most forbs observed were also perennial and survived for more than a season. Pre-dominance of perennial grasses during dry and wet seasons was also observed by Egeru et al. (2015) in the Karamoja sub-region of Uganda. As noted by Kasale (2013) and Wesuls et al. (2013), perennial grasses possess a self-seeding characteristic, are tolerant to drought, and have a spreading capacity that enable them to develop good cover and hence survive both seasons.

Differences in landscape use, however, led to significantly higher plant diversity being observed around the seasonal river compared to the dam and trough. It was observed that livestock grazed as they walked along the river thereby evenly distributing grazing pressure as opposed to around the dam and trough where animals concentrated around the same point. The river was long and therefore provided the grazing animals with a large surface area for foraging. This evenly distributed grazing pressure along the river reducing animal impact on vegetation, hence the higher species diversity. Similar results were observed by Egeru et al. (2015) in the Karamoja sub-region of Uganda who attributed the observations to varying use of landscape, piosphere location, and herder characteristics. The results further corroborate those Hu et al. (2015) that herd movements impacted on species composition, diversity, and richness.

Implications for management

The results from this study point to consistent and severe alterations in plant composition and diversity that are possibly attributable to the cumulative long-term consequences of piosphere-concentrated grazing. The impact could potentially be greater, owing to the proliferation of piospheres in the Kenyan rangelands as a water intervention measure. Range managers should therefore seek conservation measures that can sustainably protect forage species that are sensitive to grazing. Grazing exclusions have been known to preserve plant species composition in most rangelands of the world Todd (2006). This is because these rest periods allow for plant regeneration and seed bank restoration after seasons of intense trampling and defoliation.

Conclusions

The study demonstrated that areas near the piospheres have been heavily grazed by animals thereby reducing plant species Shannon-Wiener diversity and richness. It is recommended that grazing animals be placed under strict monitoring to reduce the amount of time spent around the piospheres. Alternatively, range reseeding should also be done to rehabilitate the areas that are already degraded. These are expected to improve livestock production and enhance pastoral livelihoods.

Authors' contributions

JS designed the study, collected the data, and participated in the data analysis and drafted manuscript write-up and revision. KO was part of the study design, data cleaning, analysis, and manuscript write-up and revision. KG was part of the study design, data analysis and presentation, and manuscript editing. MJ was part of the research design and methodology,

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and data analysis and contributed to the result write-up and manuscript editing. All authors read and approved the final manuscript.

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