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Piospheric influence on forage species composition and abundance in semi-arid Karamoja sub-region, Uganda

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Abstract

Piospheres in semi-arid areas are gradients of animal impacts around watering holes. Few studies have examined the impact dynamics of herbaceous and woody species composition and abundance in relation to piospheres in East Africa. In this study, we identified the trend in piosphere development, assessed piosphere use and change indicators, and identified herbaceous and woody plant structure in relation to piospheres in the Karamoja sub-region, Uganda. Results revealed that piosphere development has been reactionary to drought and/or insecurity events and increased rapidly in the last decade. A diversity of herbaceous and woody plants exists around the piospheres. Use and change indicators revealed high trampling and grazing intensity, high presence of erosion signs and low litter cover. Gradient distance had both positive and negative effects on trampling intensity, percent exposure and plant height, respectively. A negative and positive effect of gradient distance was also observed on different herbaceous and woody forage species leading to the identification of both increaser and decreaser species around the piospheres. Therefore, as concentrated use of the piospheres continues unabated, an outward ripple effect leading to loss and/or increase of undesirable herbaceous and woody species will be felt. This will have an impact on the composition and abundance dynamics of desirable forage species in the sub-region.

Keywords: Distance; Herbaceous; Protected kraals; Waterholes; Woody

Background

East Africa's pastoralists occupying semi-arid lands rely on the exploitation of native forage resources to sustain their livestock production. In these areas, water and forage are thus important resources (Awa et al. 2002). However, semi-arid regions are characterised with limitations of water and forage that often trigger crisis situations during extreme climatic events, in particular during a drought. The availability of any one of these resources at any given location in a semi-arid landscape will determine the level of herbivore influence on vegetation dynamics at both spatial and temporal scales (Yu and Wu 2010; Wesuls et al. 2013). The intensity of herbivore influence is dependent on the spatio-temporal patterns of foraging decisions (Landman et al. 2012). Proximity to water, topography and the availability of food have been identified as key determinants of foraging decisions at landscape level (Bailey and Provenza 2008; Ash et al. 2004). These foraging decisions have impacts on biological diversity because herbivore foraging affects various aspects of vegetation dynamics (Landman et al. 2012). Further, adaptive components such as deferred resting of grazing sites to protect forage plants during critical life stages are important in influencing vegetation dynamics (Linstädter et al. 2013).

In arid and semi-arid ecosystems, where standing surface water is scarce, the introduction of artificial watering sources has significant ecological effects (Brooks et al. 2006). This is because these artificial water sources introduce focused grazing and activity patterns around them (Andrew 1988). It is these activity patterns that introduce the disturbance gradient called '*a piosphere*' (Lange 1969). Thus, a piosphere is an indicator of the localized impact of grazing on vegetation and soils. It has a radiating zone of attenuating animal impact away from a concentrator such

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as water, mineral licks and bedding grounds among others (Washington-Allen et al. 2004). Piospheres can be created by both wild and domesticated animals (Brooks et al. 2006) and can be visualized as a hub, in which distances from the hub can be marked off with concentric rings. The space between the concentric rings will represent the available foraging area at that distance from the hub-water source (Derry 2004).

Piosphere influence resulting from activity gradients has been largely studied with a focus on large herbivores such as elephants (Landman et al. 2012; Sternberg 2012). Distance-dependent effects including declines in perennial plants and species richness as well as structural diversity of perennial plants have been observed (Brooks et al. 2006; Landman et al. 2012). Further, their influence on soil nutrients (Stumpp et al. 2005), landscape degradation (James et al. 1999), soil compaction and erosion (Mugerwa et al. 2014), and variation in biomass defoliation and trampling (Shahriary et al. 2012) has been observed. Also, changes in forage species composition with increased presence of unpalatable perennial shrubs beyond the zone of extreme degradation coupled with a decrease in the abundance of palatable native perennial grasses have been documented (James et al. 1999). Further, Hoshino et al. (2009) showed that vegetation changes along the grazing gradient are characterized with changes in cover of life forms, particularly perennial species being replaced by annual species in close proximity to the piospheres. Further, an ecological niche of vegetation communities with fast growth characteristics that are well adapted to intense and frequent grazing and are also associated with forage of high nutritional quality has been observed to flourish within the sacrifice zone around the water points (Moreno García et al. 2014).

Much as these studies have shown herbivore effects associated with piospheres, a dearth of information necessary to facilitate the management of piosphere impacts in Karamoja sub-region pertains. Information specific to the effects of piospheres created by domestic livestock is particularly important in the management of rangelands as they tend to create spatial patterns on an otherwise homogeneous vegetation (Adler and Hall 2005; Brooks et al. 2006). This is important in most semi-arid regions where piosphere development has been undertaken. In particular, information regarding the ecological effects of these piospheres on forage resources is lacking. Therefore, this study was set out to examine the effect of piospheres on forage species composition and abundance as indicators of their potential influence on forage dynamics in the sub-region. Specifically, this study was set out to (i) identify the trend in piosphere development and assess the status of use and change indicators, and (ii) identify herbaceous and woody plant structure in relation to piospheres in Karamoja sub-region.

Materials and methods

Study area

Located in northeastern Uganda (Fig. 1), Karamoja sub-region is a semi-arid region characterized by unpredictable rainfall and high temperatures (Dyer et al. 2008; Mubiru 2010). The sub-region is dominated by savanna grasslands punctuated by isolated woodlands on the slopes and tops of mountains. The sub-region is dominated by ephemeral streams that flow east to west. Pastoral and agro-pastoral livestock herding forms the basis. The sub-region's topography consists of a low-lying plateau, rolling plains and broad rolling to flat plains rising to an altitude of 1,000 to 1,440 m in most locations. The sub-region's soils are from the Precambrian basement complex and consist of sands, loamy sands of low water holding capacity and black cracking cotton clays-vertisols (Nakileza et al. 1999). Traditionally, the Karamojong obtained water from hand-dug wells, pans, ponds, ephemeral streams and shallow wells dug at the river beds. Livestock is grazed on native forages at local, landscape and regional scale depending on season, availability of pasture and water in the grazing landscapes.

Piosphere mapping

Piospheres were mapped using a hand-held Global Positioning System (GPS). The mapping exercise specifically targeted water sources for livestock including dams, pans, valley tanks and rock catchments as well as protected kraals. Protected kraals refer to night kraaling areas (locally known as bomas) where security is provided to herders by the Uganda Peoples Defense Forces (UPDF). The purpose is to protect the livestock of disarmed herders and warriors from armed rustlers. The mapping exercise was conducted in all the seven districts in the sub-region including Moroto, Kotido, Abim, Kaabong, Nakapiripirit, Napak and Amudat. Piosphere attributes (applicable to waterhole) including the year of construction were collected. Protected kraal attributes included number of livestock and duration of the kraal at the current location. Additional spatial data on water sources was obtained from the Humanitarian Response Common Operational Datasets-Fundamental Operational Datasets (COD-FOD) data registry (https://cod.humanitarianresponse.info) of the United Nations Office for the Coordination of Humanitarian Assistance (UNOCHA). The data archived by the Humanitarian Response repository is a collection of data provided by UNOCHA obtained from different stakeholders working within northern Uganda. This data was essential in providing a comprehensive state of the spatial distribution of all water sources in Karamoja sub-region.

Assessment of use and change indicators of piosphere

In order to understand the state of waterhole and protected kraal piospheres, use and change indicators were

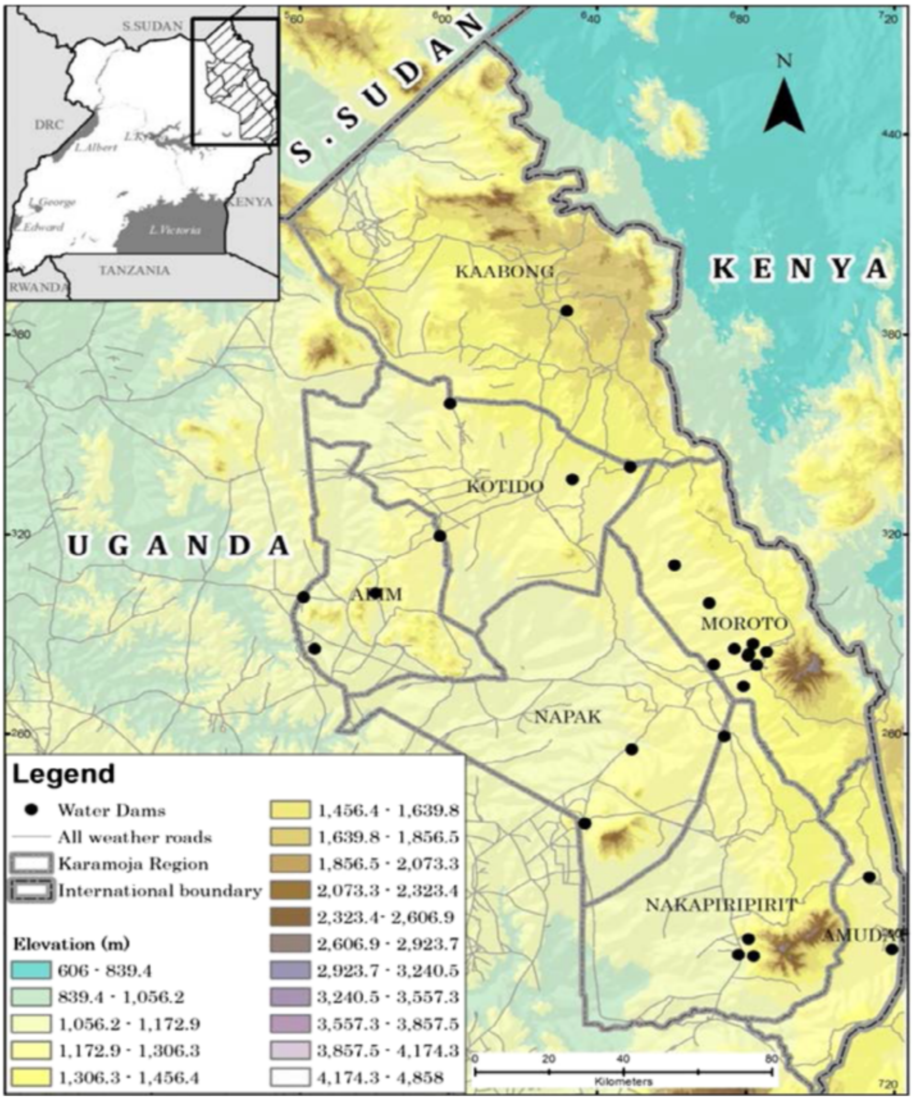

Fig. 1 Karamoja sub-region

assessed (Table 1). Use indicators that were assessed included trampling intensity and grazing intensity of both herbaceous and browse forage species. On the other hand, change indicators assessed included erosion features such as rills, gullies, pedestals, litter dams and soil surface hardness. This study adopted the Riginos and Herrick (2010) guidelines for rangeland health monitoring with few modifications.

Table 1 Use and change indicators and the assessment criteria

Indicator	Likert
Trampling intensity	Likert scale
	1 = very low, 2 = low, 3 = moderate, 4 = high, 5 = very high
Percent exposure	Likert scale
	1 = very low, 2 = low, 3 = moderate, 4 = high, 5 = very high
Plant height	Height
Signs of erosion (gullies, rills, litter dams, pedestals)	Dummy
Soil surface hardness	Likert
	1 = very soft, 2 = soft, 3 = moderately hard, 4 = hard, 5 = very hard

Effect of piospheres on forage species abundance

Herbaceous forage species data was collected within and around piospheres (protected kraal and waterhole). A total of nine waterholes were assessed (considering the generally uniform topography and soil types), four replicates in each district (Moroto and Kotido). The choice of waterholes for monitoring depended on accessibility and security status (briefing and clearance provided by the UPDF stationed near all major livestock water sources). We monitored four protected kraals including two in Kotido district, one in Moroto district and one in Nakapiripirit district, respectively. The protected kraals considered were those that had lasted at least two years in the same location.

A north-south and east-west transect approach was utilized. Each transect started 5 m away from the piosphere periphery (a piosphere periphery was defined as the edge of a waterhole rim-mound of soil that form sort of a barrier reef to provide for water accumulation) and stretched for a distance of 100 m. Herbaceous species were assessed after every 25 m within a 1-m nested quadrat. Available species were identified and tufts counted and recorded. On the other hand, woody species were assessed on a 5-m quadrat after every 25 m; all species present were identified, counted and recorded. Owing to the ephemeral nature of the streams in the sub-region that make accessibility to the different areas unpredictable during the wet season, waterholes considered for assessment were within a 10- to 15-km-foot walking distance from a motorable road (in at least the worst condition when the roads were cut off). All species that could not readily be identified on-site were transported to Makerere University for identification.

Data processing and analysis

Piosphere spatial data recorded using the GPS was downloaded using MapSource software and processed in ArcGIS 10.1 from where piosphere spatial distribution maps were developed. Descriptive and trend statistics of piosphere development (1924 to 2012), piosphere use and change indicators were generated using XL-STAT. In determining the influence of grazing intensity on piosphere use and change indicators, we utilised distance from the piosphere as a proxy indicator of grazing intensity. Distance as a proxy indicator of grazing intensity in piosphere analysis has previously been applied by Thomas and Twyman (2004) and Wesuls et al. (2013) in the Kalahari and Namibia semi-arid areas, respectively. The effect of grazing intensity on use indicators (trampling intensity, plant height and percent exposure) was assessed by performing a generalized linear regression. Prior to undertaking a log-linear regression, we used principal component analysis (PCA) to explore how distance influences herbaceous and woody species composition distribution at the piospheres. Species whose eigenvectors had the lowest eigenvalues were generally excluded from further analysis in the log-linear regression because they had the least information about the species distribution at the piospheres. In assessing the effect of grazing intensity on herbaceous and woody species abundance (because species abundance were counts), a log-linear regression was applied; this is because both herbaceous and woody species data were count data and best analysed using a log-linear Poisson regression. This method can deal with several difficulties inherent to observation data such as missing values, over- and under-sampling of particular strata, serial correlation and deviations from the Poisson distribution. Further, the method is capable of testing the effects of covariates on the changes so that the impact of activities on change can be investigated (Van Strien et al. 2004). Both generalized and log-linear regression analyses were performed in Gen-Stat 12th edition.

Results

Trends in piosphere development and spatial distribution

Spatially, seven concentration zones of water sources were mapped in Karamoja sub-region (Fig. 2) with a total of 1,271 water sources with 58 % of these being boreholes. Seventy-nine percent of the water sources documented were constructed in the last decade (2000 to 2012). Water sources purposely constructed for livestock constituted 11 % of the total water sources in the sub-region. Three phases of water source construction were observed: the first phase (1924 to 1979), second phase (1980 to 1999) and third phase (2000 to 2012); these represented 4.3 %, 16.7 % and 79 % of the water sources constructed in the region, respectively (Fig. 3).

Status of waterhole and protected kraal piospheres

On average, a low litter cover and high grazing intensity were observed around both the waterhole and protected kraal piospheres. The soil around the waterholes were generally loose and detached (Table 2). Despite the pronounced presence (86.3 %) of erosion signs around the waterholes, there was differentiated presence of erosion indicators (rills, gullies, litter dams and pedestals). For example, rills were present in only 39.1 % of the waterhole piosphere sampling plots. In the protected kraals, a low litter cover, high grazing intensity, high percent exposure, as well as presence of erosion indicators were observed. Compared to the waterholes, protected kraals depicted a very hard soil surface with a conspicuous absence of gullies (Table 3). The influence of grazing intensity on change indicators was tested using a generalized linear regression. Results showed that distance had a significant and positive influence on herbaceous plant height and grazing intensity as one moved away from the piosphere centre, the sacrifice zone (Table 4; also see Additional file 1: Figures A1 to A4). On the other hand, grazing intensity decreased outward.

Herbaceous and woody species composition

Thirty-four (34) and twenty-six (26) herbaceous grass species were recorded at the waterhole and protected kraal piospheres, respectively. In both the waterholes and protected kraals, *Cynodon dactylon* and *Chloris pychnothrix* were the most abundant species (Table 5).

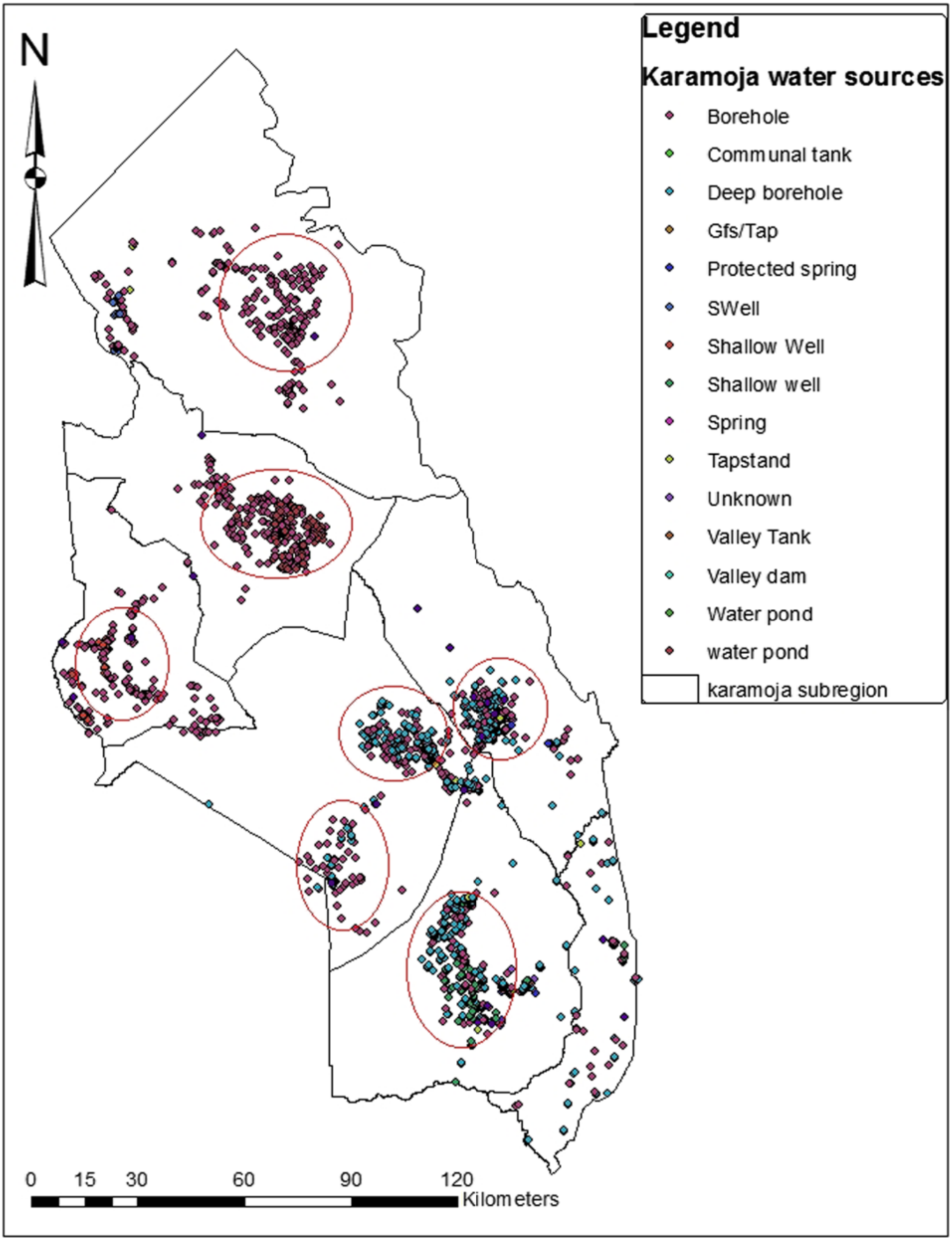

Fig. 2 Spatial distribution of water sources

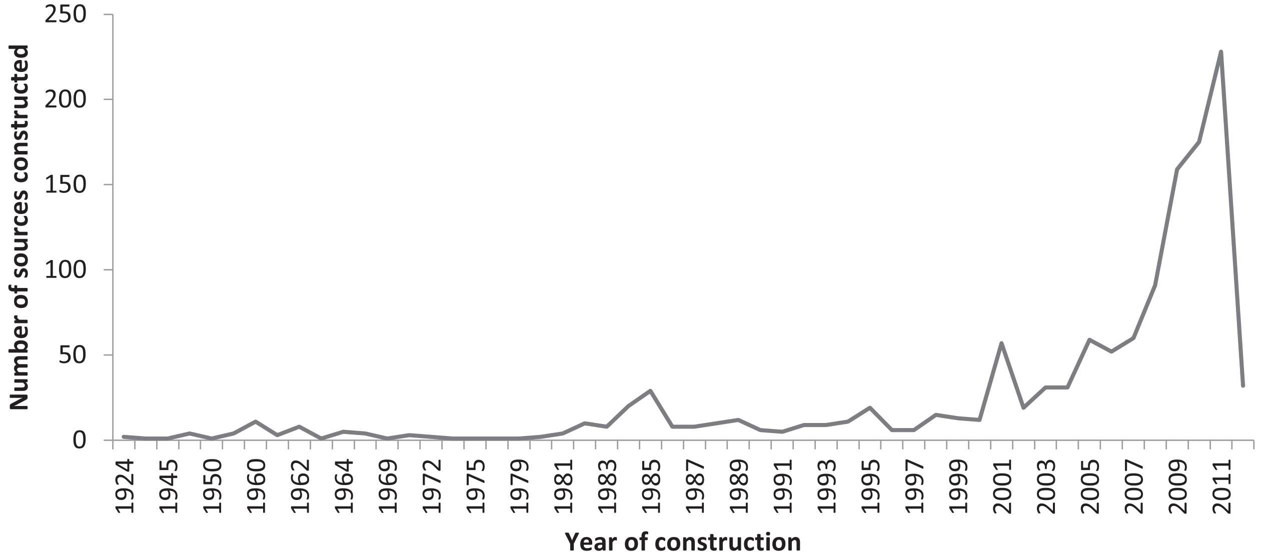

Fig. 3 Trends in water sources development in Karamoja

At the waterholes, we found *Aristida adscensionis*, *Cynodon nlemfuensis*, *Hyparrhenia rufa*, *Oxytenanthera abyssinica* and *Cenchrus ciliaris* to be the most abundant grass species. Meanwhile, *Paspalm scrobiculatum*, *Melinis repens*, *Digitaria vellutina* and *Eleusine Coracana* were the most abundant species observed around the protected kraals (Table 5). A total of 37 woody plants were identified at the waterhole piospheres (Table 6) with *Triumfetta annua* (14.3 %) and *Indigofera erecta* (3.8 %) being the most abundant woody species observed. There were however additional 58 other plant species (herbs and forbs) that were observed around the waterholes (Table 6). Thirty-four woody species were observed around the protected kraals in Karamoja. We also documented additional 38 other plant species (herbs and forbs) at the protected kraals. *Solanum incanum*, *Ormocarpum trichnocarpa* and *Lannea humilis* had high abundance at the protected kraals (Table 7).

Effect of piospheres on forage species abundance

Results showed that gradient distance has a significant effect on species composition and abundance at both waterhole and protected kraal piospheres in Karamoja (Fig. 4a, b, c, d). Table 8 (waterholes) presents a summary of model results that revealed that herbaceous species *Cynodon nlemfuensis*, *Hyparrhenia rufa*, *Aristida adscensionis*, *Oxytenanthera abyssinica*, *Hyparrhenia filipendula*, *Echinochloa haploclada*, *Chloris pychnothrix* and *Chloris virgata* significantly increased with distance away from the waterhole piosphere (Table 8; also see Additional file 2: Figures B1 to B14). This pattern revealed increasing distance dependence thus showing that these species have decreaser forage species characteristic (species that increase with a decrease in grazing pressure). Meanwhile, *Cynodon dactylon*, *Hyparrhenia newtonii*, *Sporobolus pyrimidalis* and *Sporobolus stapfianus* significantly decreased with an increase in gradient distance, thus indicative of increaser grass species.

Unlike with grass species, there were few woody species that were statistically significant at the waterhole piospheres (Table 9). Both positive and negative significant effects of gradient distance on forage species abundance in waterhole piospheres were observed (Additional file 3: Figures C1 to C7). *Acacia xanthopholea* was found to steadily establish itself as gradient distance from the focus increased. This trend was similarly observed with *Acacia drepanolobium*, *Euphorbia* spp., *Maerua pseudopetalosa* and *Triumfetta annua* (Table 9). This means that these woody plant species have increaser plant characteristics. On the other hand, species such as *Acacia senegal* and *Cassia obtusifolia* decreased as distance increased away from the piospheres.

Model results from the protected kraals revealed that *Melinis repens* and *Panicum maximum* significantly increased with gradient distance ($P \leq 0.05$), indicating that their abundance increased away from the protected kraal focus. On the other hand, *Cynodon dactylon*, *Brachiaria jubata* and *Echinochloa haploclada* decreased with an increasing distance away from the protected kraals ($P \leq 0.05$). Similarly, *Sporobolus stapfianus*, *Eragrostis superba*, *Digitaria vellutina* and *Setaria* spp. were significant and negatively influenced by distance. On the other hand, *Pennisetum mezainum*, *Brachiaria platynota*, *Melinis repens* and *Chloris pychnothrix* increased ($P \leq 0.05$) away from the piosphere (Table 10; also see Additional file 4: Figures D1 to D16). Model results for woody species at the protected kraals showed that *Acacia drepanolobium* increased away from the protected kraal hubs while *Solanum*

Table 2 Status of use and change indicators of waterhole piosphere

Use and change indicators	Distance outward from the piosphere				Overall average
	25 m	50 m	75 m	100 m	
Litter cover (%)					
Very low	63.6	61.3	51.5	50.0	56.6
Low	27.3	32.3	42.4	38.2	35.0
Moderately low	9.1	6.5	6.1	11.8	8.3
Trampling intensity (%)					
Overall trampling intensity	69.5	64.5	63.7	52.9	62.7
Very low	0.0	0.0	0.0	0.0	0.0
Low	16.1	0.0	3.2	11.8	7.8
Moderately low	6.5	19.4	12.9	73.5	28.1
High	67.7	74.2	74.2	14.7	57.7
Very high	9.7	6.5	9.7	0.0	6.5
Soil surface hardness (%)					
Soft	11.8	33.3	25.8	23.5	23.6
Moderately soft	8.8	3.3	6.5	5.9	6.1
Hard	14.7	13.3	9.7	17.6	13.8
Very hard	20.6	23.3	16.1	11.8	18.0
Loose	44.1	26.7	41.9	41.2	38.5
Erosion signs (%)					
Present	93.9	75.8	87.1	88.2	86.3
Not present	6.1	24.2	12.9	11.8	13.7
Rills (%)					
Present	69.7	21.2	29.0	35.3	39.1
Not	30.3	78.8	67.7	64.7	60.9
Gullies (%)					
Present	24.2	21.2	24.2	35.3	26.4
Not present	75.8	78.8	74.2	64.7	73.6
Litter dams (%)					
Present	30.3	24.2	24.2	35.3	28.6
Not present	69.7	75.8	74.2	64.7	71.4
Pedestals (%)					
Present	18.2	12.9	9.7	20.6	15.3
Not present	81.8	87.1	90.3	79.4	84.7
Percent exposure	70.2	63.1	64.7	64.9	65.7
Plant height (m)	0.4	0.6	0.8	0.9	0.7

incanum decreased with an increase in gradient distance at the protected kraals (Table 11; also see Additional file 5: Figures E1 and E2).

Discussion

Trends in piosphere development and spatial distribution

Waterhole development in Karamoja took three phases (1924 to 1979, 1980 to 1999, 2000 to 2012) with most of the current water sources constructed in the third phase. The first recorded water source development in the region was marked in 1924. According to Barber (1962), this appears to be the first colonial response to drought events in the region particularly emerging out of the late 1890s drought. These initial steps continued reaching the first peak period between 1948 and 1962. Knighton (2006) opined that in between 1924 and 1962, drought events were recorded in 1927 to 1930 and 1933 to 1934. Further, a series of drought events (multi-year) were observed in 1939 and 1943 to 1946. This period eventually came to be known as '*Lokwakoit*' - white bones indicating the severe

Table 3 Status of use and change indicators of protected kraal piosphere

Use and change indicators	Distance outward from the piosphere				Overall average
	25 m	50 m	75 m	100 m	
Litter cover (%)					
Very low	33.3	45.5	33.3	25.0	34.3
Low	66.7	54.5	66.7	75.0	65.7
Trampling intensity (%)					
Overall trampling intensity	100	100	90	75	91.3
High	0	0	10	25	8.7
Very high	100	100	90	75	91.3
Soil surface hardness (%)					
Hard	27.3	27.3	33.3	41.7	32.4
Very hard	63.6	63.6	58.3	50.0	58.9
Loose	9.1	9.1	8.3	8.3	8.7
Percent exposure		80.6	85.2	83.9	78.3
Plant height (m)	0.5	0.6	0.6	1.0	100

Erosion signs, rills, gullies, litter dams and pedestals were present in all the protected kraals

drought that killed cattle in great numbers (Gray 2013). As a result, a drive for the construction of dams was launched in 1941, thus explaining the increase in the importance of artificial water sources in the region particularly between 1948 and 1962. Similarly, the second phase emerged out of continued response to drought events of the 1970s and early 1980s. Like other drought events, these were similarly observed to have led to considerable collapse of livestock herds and caused food shortages as well as famine in the sub-region (Gray et al. 2003).

Like the first and the second phases, the third phase coincides with the 1999/2000 and 2008/2009 drought events that led to severe water shortages and livestock losses (Sundal 2009; Mubiru 2010). However, the third phase had another dimension: it corresponded to the Government of Uganda (GoU) reactivation of the disarmament programme. It is important to note that disarmament initiatives had hitherto been undertaken in 1945, 1953, 1954, 1960, 1964, 1984 and 1987, albeit with minimal success to write about (Powell 2010). The reactivated disarmament programme in the 2000s came with a difference in that GoU operationalized the development of water for production and livestock, with the protected kraal system, as strategies to ensure safety of the disarmed communities and promotion of peace (Stites et al. 2007; GoU 2007). The GoU, desperate to avert crisis, rapidly developed water sources and similarly increased the number of protected kraals to accommodate the disarmed communities' livestock. This led to the observed exponential increase in the number of piospheres (both waterholes and protected kraals) in the region in the last decade. In addition, the entry of several development organizations (both local and international) into the region in the last decade further accelerated the construction of several water sources. Most of the development organizations and partners were shifting their operations from northern Uganda following the return of relative peace after the defeat of the Lord's Resistance Army (LRA) insurgents.

Meanwhile, the spatial clustering that was observed in this study is attributable to the tremendous number of boreholes that were drilled to provide domestic water rather than water for livestock and/or for production. This

Table 4 Effect of piospheres on use and change indicators

Indicators	Equation of the model	R^2	*P* value
Waterhole piospheres			
Grazing intensity	$y = 75.54 - 0.208\times\text{Distance}$	0.863	0.07
Plant height (m)	$y = 0.29 + 6.61\text{E}{-}03\times\text{Distance}$	0.994	0.003
Protected kraal piospheres			
Grazing intensity	$y = 112.53 - 0.34\times\text{Distance}$	0.869	0.06
Plant height (m)	$y = 0.33 + 5.40\text{E}{-}03\times\text{Distance}$	0.722	0.04

Table 5 Relative abundance of grass species in the waterhole and protected kraal piospheres

Waterhole		Protected kraal	
Grass species	Relative abundance	Grass species	Relative abundance
Cynodon dactylon	19.4	*Chloris pychnothrix*	13.7
Chloris pychnothrix	12.1	*Cynodon dactylon*	13.1
Chloris virgata	9.3	*Sporobolus stapfianus*	10.9
Aristida adscensionis	7.3	*Bracharia jubata*	7.7
Cynodon nlemfuensis	5.2	*Hyparrhenia newtonii*	6.6
Setaria sphaceata	4.8	*Dactyloctenium aegyptica*	4.9
Sporobolus stapfianus	4.8	*Panicum maximum*	3.8
Echinochloa haploclada	4.8	*Brachiaria platynota*	3.8
Hyparrhenia filipendula	3.6	*Harpachne schimperi*	3.8
Sporobolus pyrimidalis	3.6	*Setaria* spp.	3.3
Hyparrhenia rufa	2.4	*Pennisetum mezainum*	3.3
Oxytenanthera abyssinica	2.4	*Hyparrhenia filipendula*	2.7
Pennisetum polystachion	2	*Paspalum scrobiculatum*	2.7
Microcloa kunthii	2	*Melinis repens*	2.7
Setaria pumila	1.6	*Eragrostis superba*	2.2
Bracharia jubata	1.6	*Digitaria vellutina*	2.2
Hyparrhenia newtonii	1.2	*Loudetia simplex*	1.6
Dinebra retroflexa	1.2	*Sporobolus pyrimidalis*	1.6
Pennisetum mezainum	1.2	*Eragrostis ciliaris*	1.6
*Ekoriebu**	1.2	*Echinochloa haploclada*	1.6
Cynodon plectostachyas	0.8	*Eleusine indica*	1.6
Cynodon polystachyus	0.8	*Hyparrhenia cymbria*	1.1
Setaria verticilola	0.8	*Loudetia kagerensis*	1.1
Cenchrus ciliaris	0.8	*Chloris virgata*	1.1
Eragrostis cilliaris	0.8	*Eleusine coracana*	0.5
Loudetia simplex	0.8	*Microcloa kunthii*	0.5
Eleusine indica	0.4		
Echinochloa kunthii	0.4		
Digitaria gazensis	0.4		
Dactyloctenium aeygptica	0.4		
Sorghum arundinacea	0.4		
Panicum atrosanguineum	0.4		
Panicum maximum	0.4		
Portulaca oleracea	0.4		

*A specie whose scientific name has not been identified

spatial clustering led to the disproportionate distribution of water sources in the sub-region, leading to high grazing intensity and localized degradation (Mugerwa et al. 2014). In addition, several water sources and protected kraals were developed in close proximity to settlements (manyattas) and croplands (personal observations). This also increased the concentration of locus zones with the piospheric concentration effect on grass and woody species gradually and rapidly evolving. It is generally acknowledged that while artificial water sources provide water for domestic stock, native and feral mammalian herbivores, they create grazing locus zones with differentiated impacts on vegetation cover (James et al. 1999). Further, when such developments become pronounced, they interfere with pastoral mobility; this was observed as herders barely move over long distances for extended periods in search of water and pasture. This is because their movements are now being controlled and defined by the locus of waterholes

Table 6 Relative abundance of browse species in the waterhole piospheres

Woody, herbs and forbs forage species	%	Other plant species	%	Other plant species	%
Triumfetta annua	14.3	*Cyathula orthacantha*	10.0	*Corchorus olitorius*	0.1
Ipomea kituiensis	5.4	*Lactuca capensis*	6.1	*Cucumis figarei*	0.0
Indigofera erecta	3.8	*Scleria* spp.	3.8	*Ocinia trilobata*	0.0
Ocimum canum	3.7	*Vernonia poskeana*	2.9	*Conyza florbeuda*	0.0
Solanum incanum	3.3	*Kalanchoe lanceolata*	2.6	*Euphorbia candlebrum*	0.0
Maerua pseudopetalosa	3.1	*Euphorbia* (Louro)	2.6	*Urena lobata*	0.0
Acacia nilotica	3.1	*Senseveria robusta*	2.3	*Glinus oppositifolius*	0.0
Cassia obtusifolia	3.1	*Hygrophilia auriculata*	2.1	*Hibiscus micranthus*	0.0
Acacia xanthopholea	2.2	*Minuta tagetes*	2.0	*Podocarpus falcalus*	0.0
Acacia drepanolobium	1.6	*Leucas martinicensis*	1.7	*Asystasia gigantica*	0.0
Justicia flavus	1.5	*Abutilon hirtum*	1.2	*Senecio abyssinica*	0.0
Cassia obtusifolia	1.2	*Euphorbia prostrata*	1.2	*Gamophocarpus frutecosum*	0.0
Balanite aegyptica	0.9	*Leonotis nepetifolia*	0.8	*Barleria submollis*	0.0
Commelina benghalensis	0.9	*Hibiscus micranthus*	0.8	*Amaranthus spp*	0.0
Vigna membranacea	0.6	*Dombeya burgessiae*	0.4	*Nesea auriculata*	0.0
Flueggea virosa	0.6	*Hibiscus serpens*	0.4	*Tamarindus indica*	0.0
Sida cordifolia	0.5	*Acanthospermum hispidium*	0.4	*Ruellia patula*	0.0
Cissus quadrangularis	0.5	*Sesamum agustifolium*	0.4	*Achyranthes aspera*	0.0
Sesbania sesban	0.4	*Crotalaria spp*	0.3	*Hypoestes forskahlii*	0.0
Dichrostachys cinerea	0.4	*Oxygonum sinuatum*	0.3	*Jasminium abyssinica*	0.0
Cadaba farinosa	0.3	*Alternanthera sessilis*	0.2	*Cyanotis arachnoidea*	0.0
Ormocarpus trichocarpa	0.3	*Asystasia somalensis*	0.2		
Sida cuneifolia	0.3	*Seseveria gigantea*	0.2		
Acacia Senegal	0.2	*Barleria submollis*	0.2		
Asparagus flagellaris	0.2	*Cyphostemma serpens*	0.2		
Cordia sinensis	0.2	*Aloe rwenzonrensis*	0.2		
Acacia mellifera	0.2	*Crossandra subacaulis*	0.2		
Commiphora africana	0.2	*Solanum cordifolia*	0.1		
Acacia sieberiana	0.1	*Solanum anguivi*	0.1		
Balanite grabra	0.1	*Portulaca oleracea*	0.1		
Grewia holstii	0.1	*Orbea dummeri*	0.1		
Acacia oerfota	0.1	*Otiophora pauciflora*	0.1		
Aeschynomene indica	0.1	*Hibiscus calyphyllus*	0.1		
Desmodium tortuosum	0.0	*Hibiscus abyssinicus*	0.1		
Lannea humilis	0.0	*Methalinia vlutina*	0.1		
Commelina difusa	0.0	*Sphaeranthui gomphrenoides*	0.1		
Caparis tormentosa	0.0	*Achyranthera aspera*	0.1		

and the potential for erecting protected kraals in the region. However, reducing the mobility of people and herds in response to environmental stress tends to promote high grazing pressure around the locus as well as undermining local strategies that facilitate recovery of the rangelands during drought intervals (Gray et al. 2003).

Status of waterhole and protected kraal piospheres

In this study, a high grazing intensity, high percent exposure and low litter cover were observed around the waterholes and protected kraals. The high percent exposure and low litter cover are attributable to the high grazing and trampling effect observed around the piosphere. These

Table 7 Relative abundance of browse species in the protected kraal piospheres

Woody, herbs and forbs forage plants	Relative abundance (%)	Other plant species	Relative abundance (%)
Solanum incanum	7.7	*Vernonia poskeana*	5.4
Ormocarpum trichocarpa	4.0	*Ocimum canum*	4.0
Lannea humilis	3.0	*Leucas martinicensis*	3.4
Cadaba farinosa	2.7	*Dombeya burgessiae*	3.0
Asparagus flagellaris	2.7	*Acanthospermum hispidium*	2.7
Cassia obtusifolia	2.7	*Crossandra subacaulis*	2.3
Grewia villosa	2.3	*Pavonia arabicum*	2.3
Zanthoxylum chalybeum	2.3	*Aspilia mossambicensis*	1.7
Grewia mollis	1.7	*Portulaca oleracea*	1.7
Grewia holstii	1.7	*Amaranthus hybridus*	1.3
Maerua decumbens	1.7	*Alternanthera sessilis*	1.3
Triumfetta annua	1.7	*Tridax procumbens*	1.0
Sida cordifolia	1.7	*Abutilon hirtum*	1.0
Balanite aegyptica	1.3	*Cyathula orthacantha*	1.0
Solanum taitense	1.3	*Lantana trifolia*	1.0
Acacia nilotica	1.3	*Crotalaria pychnostacys*	1.0
Indigofera erecta	1.3	*Elephantopus scaber*	1.0
Acacia drepanolobium	1.0	*Lactuca capensis*	0.7
Commiphora africana	1.0	*Oxygonum sinuatum*	0.7
Acacia xanthopholea	1.0	*Euphorbia tircalli*	0.7
Cordia sinensis	1.0	*Coccinia trilobata*	0.7
Rhus kwangoensis	1.0	*Cyanotis arachnoidea*	0.7
Vigna membranacea	1.0	*Oldenlandia herbacea*	0.7
Commelina benghalensis	1.0	*Justicia flavus*	0.3
Ipomea kituiensis	1.0	*Hibiscus micranthus*	0.3
Maerua pseudopetalosa	1.0	*Pentanisia ouranogyne*	0.3
Acacia senegal	0.7	*Hygrophilia auriculata*	0.3
Balanite gabra	0.7	*Orthisiphon spp*	0.3
Ximenia americana	0.7	*Otiophora pauciflora*	0.3
Acacia oerfota	0.7	*Euphorbia candlebrum*	0.3
Acacia mollisima	0.7	*Heliotropium steudneri*	0.3
Cleome gynandra	0.7	*Crotalaria aculeata*	0.3
Gymnema sylvestre	0.3	*Hibiscus diversifolius*	0.3
Sesbania sesban	0.3	*Hypoxis obtusifolia*	0.3
		Conyza floribunda	0.3
		Corchorus olitorius	0.3
		Stachterpheta spp	0.3
		Tagetes minuta	0.3

findings corroborate those of Dune et al. (2011) who established that trampling reduced plant cover, biomass and, at the highest rate, plant regeneration. It further exacerbated soil loss as a result of reduced vegetation cover and disturbed surface layers. The disturbed surface soil layers with loose soils were similarly documented in this study and could be attributed to the convergence effect of livestock from different kraals at the waterholes. Thus, the disturbed loose soil surface at the waterhole piospheres could help account for the observed erosion gullies. However, in the protected kraals, soil surface layers were generally very compact. This difference

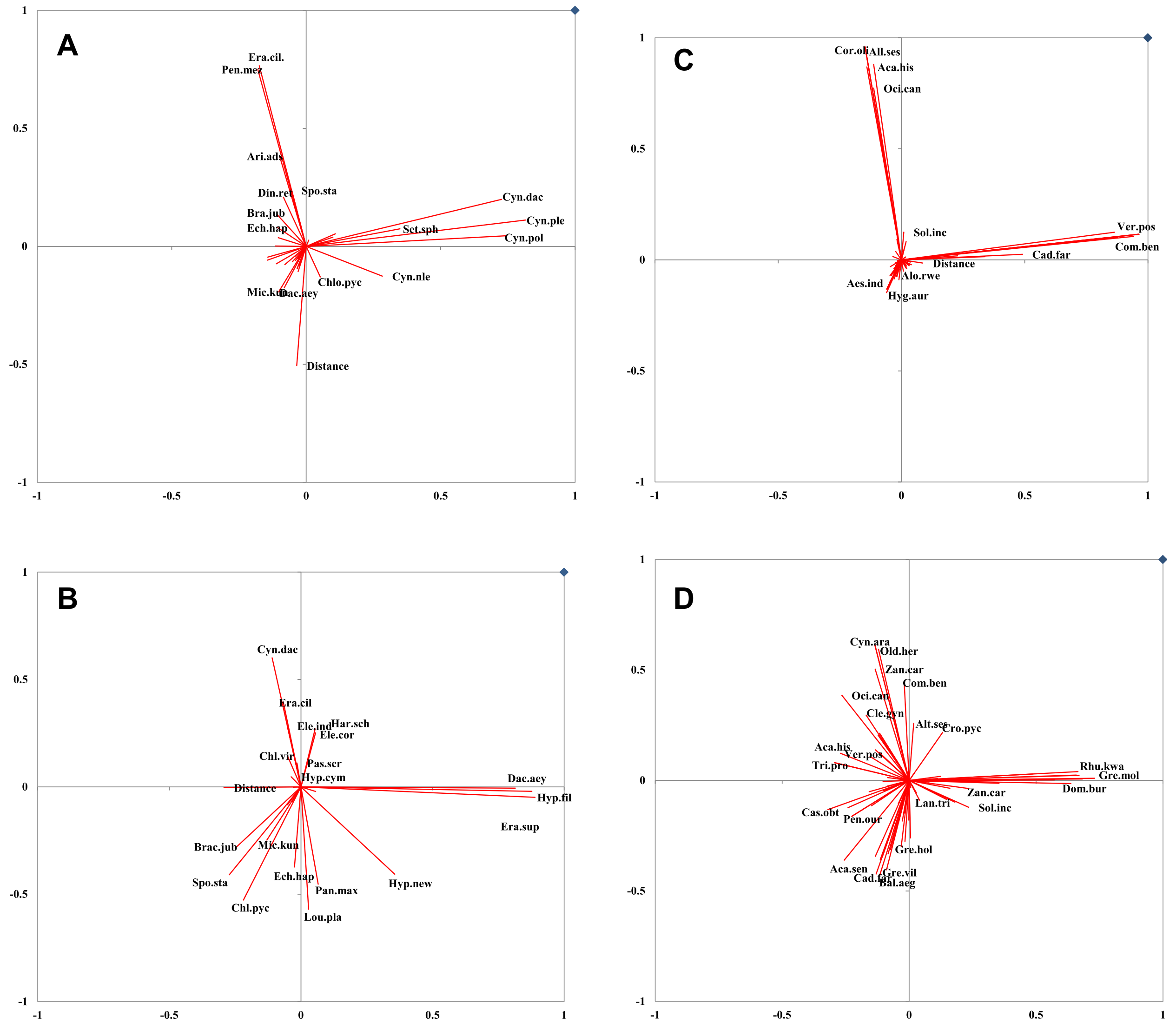

Fig. 4 **a** PCA of grass species at the waterholes. **b** PCA of grass species at the protected kraals. **c** PCA of woody species at the waterholes. **d** PCA of woody species at the protected kraals

Table 8 Waterhole piosphere effect on grass species

Herbaceous species	Equation of the model	*r*	Chi pr
Hyparrhenia filipendula	Ln(*y*) = 1.818 + 0.029 × Distance	0.983	0.001
Sporobolus pyrimidalis	Ln(*y*) = 3.592 – 0.013 × Distance	0.905	0.001
Sporobolus stapfianus	Ln(*y*) = 4.431 – 0.015 × Distance	0.878	0.001
Hyparrhenia rufa	Ln(*y*) = 2.027 + 0.009 × Distance	0.911	0.044
Oxytenanthera abyssinica	Ln(*y*) = 0.207 + 0.043 × Distance	0.980	0.001
Echinochloa haploclada	Ln(*y*) = 2.855 + 0.018 × Distance	0.891	0.001
Chloris virgata	Ln(*y*) = 2.551 + 0.032 × Distance	0.967	0.001
Cynodon dactylon	Ln(*y*) = 6.021 – 0.026 × Distance	0.888	0.001
Chloris pychnothrix	Ln(*y*) = 3.525 + 0.018 × Distance	0.948	0.001
Aristida adscensionis	Ln(*y*) = 2.962 + 0.008 × Distance	0.930	0.006
Cynodon nlemfuensis	Ln(*y*) = 2.432 + 0.028 × Distance	0.963	0.001

between waterhole and protected kraal piospheres could be attributed to variation in soil types and locations where the different piospheres are established. For example, protected kraals were generally located on raised lands with sandy loam soils while waterholes were situated on low-lying areas dominated by black cotton clay soils.

Table 9 Waterhole piosphere effect on woody species

Browse species	Equation of the model	*r*	Chi pr
Triumfetta annua	Ln(*y*) = 2.805 + 0.006 × Distance	0.927	0.05
Ocimum canum	Ln(*y*) = 3.761 – 0.0228 × Distance	0.883	0.001
Acacia xanthophlea	Ln(*y*) = 0.16 + 0.0131 × Distance	0.941	0.06*
Acacia senegal	Ln(*y*) = 2.018 – 0.019 × Distance	0.900	0.08*
Maerua pseudopetalosa	Ln(*y*) = 0.187 + 0.026 × Distance	0.960	0.001

*Significant at 10%

Table 10 Protected kraal piosphere effect on grass species

Herbaceous species	Equation of the model	*r*	Chi pr
Panicum maximum	$\text{Ln}(y) = 3.972 + 0.006 \times \text{Distance}$	0.926	0.001
Sporobolus stapfianus	$\text{Ln}(y) = 1.778 - 0.012 \times \text{Distance}$	0.935	0.022
Cynodon dactylon	$\text{Ln}(y) = 5.115 - 0.003 \times \text{Distance}$	0.907	0.036
Bracharia jubata	$\text{Ln}(y) = 3.765 - 0.009 \times \text{Distance}$	0.896	0.009
Eragrostis superba	$\text{Ln}(y) = 6.699 - 0.0519 \times \text{Distance}$	0.900	0.001
Eragrostis ciliaris	$\text{Ln}(y) = 3.365 - 0.014 \times \text{Distance}$	0.890	0.006
Echinochloa haploclada	$\text{Ln}(y) = 5.764 - 0.042 \times \text{Distance}$	0.889	0.001
Digitaria vellutina	$\text{Ln}(y) = 4.045 - 0.033 \times \text{Distance}$	0.882	0.001
Pennisetum mezainum	$\text{Ln}(y) = 0.632 + 0.035 \times \text{Distance}$	0.971	0.001
Melinis repens	$\text{Ln}(y) = 1.339 + 0.023 \times \text{Distance}$	0.955	0.001
Chloris pychnothrix	$\text{Ln}(y) = 4.296 + 0.0063 \times \text{Distance}$	0.925	0.001
Hyparrhenia newtonii	$\text{Ln}(y) = 3.612 + 0.013 \times \text{Distance}$	0.937	0.001
Hyparrhenia filipendula	$\text{Ln}(y) = 4.649 - 0.031 \times \text{Distance}$	0.838	0.001
Loudetia simplex	$\text{Ln}(y) = -2.461 + 0.093 \times \text{Distance}$	0.994	0.001
Brachiaria platynota	$\text{Ln}(y) = 4.429 + 0.004 \times \text{Distance}$	0.921	0.011
Dactyloctenium aegyptica	$\text{Ln}(y) = 2.964 - 0.032 \times \text{Distance}$	0.882	0.002

This pattern has been previously documented by Oba (2012) in a study among the Matheniko of Karamoja sub-region.

Unlike Sasaki et al. (2008) and Smet and Ward (2006) who observed that grazing-affected parameters respond in a nonlinear manner to distance, we found a strong and positive linearized response to distance. Our results corroborate the findings of Manthey and Peper (2010) who noted that within the first few metres, strong piosphere changes are detectable with strong linearized predictions that effectively describe the piosphere concept (Macchi and Grau 2012) that has similarly been observed in this study. Grazing intensity was observed to gradually decrease away from the piosphere as the herbaceous plant height increased away from the piosphere. This also corroborates the findings of Shahriary et al. (2012) who observed in the Iranian piospheres that height of palatable species increased significantly with distance from watering points. It has hitherto been observed that a piosphere consists of a ‘sacrifice zone’ directly at the hotspot that is free of vegetation. This zone is subsequently followed by a transition zone that shifts nearly homogenously to a grazed zone. This grazed zone merges gradually into undisturbed natural vegetation that is hardly influenced by grazing (Manthey and Peper 2010). While the piosphere zone has been depicted to be devoid of vegetation; this assertion was relatively feasible in the protected kraals piospheres. On the other hand, we observed a gradual pattern with the sacrifice zone having low vegetation but gradually improving outward as has been previously articulated by several authors (Andrew 1988; Tarhouni et al. 2010; Manthey and Peper 2010). According to Macchi and Grau (2012), piospheres represent rather paradoxical landscape patterns, where the supply of the key limiting factor in an ecosystem (in the case of this study, water and security in the protected kraals) results in biomass reduction and overall ecosystem degradation.

Table 11 Protected kraal piosphere effect on woody species

Herbaceous species	Equation of the model	R^2	$P \leq 0.05$
Acacia drepanolobium	$\text{Ln}(y) = 0.460 + 0.028 \times \text{Distance}$	0.963	0.001
Solanum incanum	$\text{Ln}(y) = 2.573 - 0.013 \times \text{Distance}$	0.891	0.007

Effect of piospheres on herbaceous and woody species abundance

This study observed a relatively high number of grass and woody species at waterholes and the protected kraals in Karamoja. This pattern could be attributed to (i) location differences, with waterholes being located at low-lying areas; (ii) convergence of livestock grazed in different landscapes leading to a pool of different species; and (iii) differences in plant resistance to piospheric effects including trampling, soil compaction and grazing intensity. According to Sternberg (2012), herder influences on pasture conditions can be obtained at piospheres; this is because livestock helps to shape piosphere dynamics in addition to other distinctive processes in the drylands. Plant species richness and density have been observed to vary with the piosphere type, size and distance from the grazing hotspot. For example, Zemmrich et al. (2007) established distance-plant density dependence in western Mongolia. Our results also corroborate with the findings of Teka et al. (2013) and Rajabov (2009) who observed differences in herbaceous species abundance and density along the gradient in Southern Ethiopia and in the piospheres of Uzbekistan, respectively. We observed that *Cynodon dactylon* had a high relative abundance in both the waterhole and protected kraal piospheres. *Cynodon dactylon* has been observed to be extremely tolerant to heavy grazing and withstand severe fires, adaptable to various soils and climate regimes, and is tolerant to salinity and flooding (Rita et al. 2012). Like *Cynodon*, *Chloris pychnothrix*, *Sporobolus stapfianus* belong to the *Chloridoideae* species group (Barboni et al. 2007). These species have been known to occur in abundance in heavily as well as lightly grazed grasslands (Abule et al. 2005). Further, Stride (1997) observed that these grasses also tend to increase near watering points because they are in a position to withstand severe over-grazing (Abule et al. 2007). Thus, this study's results are in agreement with such observations. We however note that a number of herbaceous species had a low abundance observed at the piospheres, indicating their limited ability to flourish in high grazing pressure.

Piosphere patterns are always detected in herbaceous species composition (Thrash and Derry 1999), and the species response to grazing is often varied (Wesuls et al. 2013). This study has shown differentiated species response to piosphere grazing. For example, some herbaceous species such as *Aristida adscensionis*, *Chloris pychnothrix*, *Chloris virgata*, *Cynodon nlemfuensis*, *Echinochloa haploclada* and *Hyparrhenia filipendula* increased away from the piosphere. This finding corroborates the findings of Zemmrich et al. (2007) in western Mongolia who established that as grazing pressure decreased, plant density per plot increased away from the zone of maximum grazing. It further corroborates the findings of Landsberg et al. (2002) who observed that watering points had a predominantly negative effect on species abundance on a regional scale. Decreasing trends in species with increasing proximity to watering points have been observed by several studies (Brooks et al. 2006; Todd 2006). Some of these species such as *Aristida adscensionis* have been identified by Abule et al. (2007) as less desirable grass species found in disturbed areas and indicative of poor rangeland condition.

On the other hand, herbaceous species such as *Sporobolus stapfianus*, *Sporobolus pyrimidalis*, *Cenchrus ciliaris*, *Brachiaria jubata*, *Dactyloctenium aegyptica*, *Eragrostis cilliaris*, *Echinochloa haploclada*, *Digitaria vellutina* and *Cynodon dactylon* decreased with distance away from the piosphere. This finding contrasts with the findings of Fusco et al. (1995) in which *Sporobolus* spp. was found to increase as distance from the waterhole increased. Similarly, Thrash and Derry (1999) noted that *Cynodon dactylon* has been observed to increase away from the piosphere. However, our results corroborate the earlier findings of Mansour et al. (2012) and Oluwole et al. (2008) who observed that species such as *Eragrostis* spp. and *Sporobolus* spp. are often considered as increaser II species; these species increase in abundance when the rangeland is over-utilised (Du Toit 2009). Our findings corroborate these earlier findings because herbaceous forage species *Eragrostis superba*, *Eragrostis ciliaris*, *Sporobolus stapfianus* and *Sporobolus pyrimidalis* were in close proximity to the piosphere. These species have previously been used as indicator species of rangeland degradation. For example, Mansour et al. (2012) discussed that rangeland condition can be classified using these increaser species; thus moderate condition can be identified using increaser I (e.g. *Hyparrhenia* spp.); poor-increaser II (e.g. *Eragrostis* spp. and *Hyparrhenia* spp.); and highly degraded-increaser III (e.g. *Aristida* spp.). This study has shown the existence of all these species in the piospheres of Karamoja, indicating existence of multiple states at the piospheres. The existence of increaser I (increase in abundance with under-utilization, e.g. *Hyparrhenia filipendula*, *Hyparrhenia rufa*) and increaser III (increase in abundance in areas that are selectively grazed, e.g. *Aristida adscensionis*) species in the study area can be explained by the observed variation in piosphere status. It is important to note that increaser III species such as *Aristida adscensionis* were only observed around the waterhole piospheres.

Differentiated occurrence of woody species with both increasing and decreasing patterns with proximity to and away from the piosphere was observed in this study. The increase of *Acacia drepanolobium*, *Acacia xanthophoclea*, *Maerua pseudopetalosa* and *Aspilia mossambicensis* away from the locus could be attributed to rapid regeneration ability that these woody species have after the establishment of the piosphere. However, they are also susceptible to decline in quantity as a result of increased grazing pressure because their mean presence declines with proximity to the piospheres. Thus, their ability to provide browse under high grazing pressure may be limited. Pastoralists in Amboseli Kenya, when building kraals (bomas) have been found to clear trees with 20 cm basal diameter and those less within 150 m from the boma (Muchiru et al. 2008); making such trees highly susceptible to cut and burn. In Karamoja, clearance at the protected kraal is mandatory not only for security reasons but also for the establishment of kraals because woody plants, particularly thorny *acacia*, provide building materials. On the other hand, when establishing waterholes, woody plant clearance is not as widespread as in protected kraals (personal observations). Our results corroborate the findings of Chamaille-Jammes et al. (2009) who observed lower woody cover average at close proximity to the piosphere with an outward increase. Further, like in the findings of Mphinyane (2001) in which *Acacia gerrardii*'s density increased with distance away from the piosphere (cattle post), several woody species (e.g. *Acacia drepanolobium*, *Acacia xanthopholea*, *Maerua pseudopetalosa* and *Triumfetta annua*) were found to increase outward with the gradient distance. However, it contrasts with the findings of Sternberg (2012) in a study in the Mongolian plateau which showed that vegetation was greater near water points and decreased with distance.

Some species such as *Acacia nilotica*, *Acacia senegal*, *Ocimum canum*, *Lannea humilis*, *Solanum incanum* and *Leucas martinicensis* however decreased with increase in gradient distance from waterholes. *Acacia nilotica* has been identified as type III increaser species (Strohbach 2000). In the Karamoja piospheres, these species that decreased away from the piosphere revealed a limited abundance in the rangeland. This corroborates species-wise findings of Strohbach (2000) in northern Oshikoto region of Namibia and Muchiru et al. (2008) in Amboseli, Kenya. Further, *Acacia nilotica* has been observed as a significant threat to native vegetation, as it leads to decline in cover and abundance of native species (Howes and McAlpine 2008). In Karamoja, we observed that *Acacia nilotica* had formed a bush and there was significant deficiency of herbaceous understory as well as other woody plants. A few tufts of both woody and herbaceous plants existed at the base of *Acacia nilotica* trees, but these were not accessible to livestock for grazing. Consequently, livestock, mainly goats and sheep, foraged on the outside branches up to their stretch height.

Notably, where mature *Acacia nilotica* trees existed (particularly along river banks), goats and sheep foraged on their pods. The negative slope observed with respect to *Acacia senegal* can be explained by traditional conservation practice in which it is preserved for resin locally used for its incense (no large commercial use in Karamoja has been documented as for example Sudan, e.g. Eisa et al. 2008). We also observed that around some waterholes, *Acacia senegal* was allowed to form a bush canopy to shield the dam from strong winds. According to Eisa et al. (2008), *Acacia senegal*'s availability is affected by fires that kill off seedlings and damage trees. In the case of Karamoja, cutting off large branches (in this case for establishing kraals/bomas), defoliation by goats and camels, and attack from fungi and termites can be probable explanations for the negative slope observed along the gradient distance; this needs further scientific investigation. Herbs with woody stokes such as *Solanum incanum* had a negative slope indicating a high mean density of plants in proximity to the piospheres. The high abundance of *Solanum incanum* in disturbed patches has been documented in Ithala Game Reserve, KwaZulu-Natal, and with close proximity to the watering point in southern Kalahari Duneveld, respectively (Hebbelmann 2013; Horn 2008).

Conclusions

This study has shown that piosphere development in Karamoja is clustered into eight density blocks. This pattern of piosphere development is reactionary, oscillating with major drought and security events in the region. We also observed a disproportionate spatial distribution of livestock water sources in the sub-region. Piosphere health is generally poor characterised by a persistence of high grazing and trampling intensity and existence of soil erosion. Consequently, differentiated localized degradation at the piosphere sacrifice zones is evident. Gradient distance has had differentiated influence on herbaceous and woody plant species around the piosphere zones, leading to emergence of decreaser and increaser herbaceous and woody species along the grazing gradient. Given the clustering and disproportionate spatial distribution of piospheres, it is only a matter of time before the ripple effect of piosphere degradation engulfs the sub-region. Protected kraals present a unique situation because their residence time at a location is shorter than that of waterholes (constructed waterholes will be permanent); thus, the mobility nature of these piospheres has potential to allow locations to recover and create 'islands of fertility' arising from livestock dung. We are of the view that an inquiry be extended into the nutrient distribution along the piosphere gradient for an extended distance to determine whether plant species variation changes with soil nutrients and landscape. Further, there is need to compare herbaceous and woody species abundance in former protected kraals and abandoned kraals to analyse plant recolonization in the piosphere zones. It will also be crucial to model piosphere dynamics structuring of herbaceous and woody plant composition and abundance in the region, because these will have influence on forage availability dynamics in the region.

Additional files

Additional file 1: Annex A: Relationship between grazing intensity, plant height and distance at the waterholes and protected kraals piospheres.

Additional file 2: Influence of gradient distance on different grass species at the waterholes in Karamoja.

Additional file 3: Influence of gradient distance on different woody species at the waterholes in Karamoja.

Additional file 4: Influence of gradient distance on different grass species at the protected kraals.

Additional file 5: Influence of gradient distance on different woody species at the protected kraals in Karamoja.

Competing interests

The authors declare that they have no competing interests.

Authors' contributions

EA carried out fieldwork, collated the data, and drafted the manuscript. OW, LM and MM provided overall guidance in the conceptualization of the research, data collection approaches and analysis process. JRST provided technical guidance on species classification and PCA analysis. All authors read and approved the final manuscript.

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