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IMPACT OF COMMUNITY CONSERVATION MANAGEMENT ON HERBACEOUS LAYER AND SOIL NUTRIENTS IN A KENYAN SEMI-ARID SAVANNAH

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ABSTRACT

The impact of community conservation management on a semi-arid savannah herbaceous vegetation and soil nutrient status was studied in the conservation and grazing zones of two community ranches in Laikipia County, Kenya. Land zoning was carried out in 1999 using participatory approaches to demarcate conservation areas excluded from livestock grazing, buffer areas for grazing and high-intensity use zones for both grazing and settlement. Collected data included cover, grass species composition, standing grass biomass and topsoil chemical characteristics using line transect and quadrant methods. The conservation zones had significantly higher herbaceous diversity, species richness and relative abundance of both annual and perennial grasses, basal cover and herbage and a lower percentage of bare ground compared with the continuously grazed zones. The conservation zones also had higher total organic carbon, organic nitrogen and exchangeable basic cations content, indicating improved soil nutrient status. The grazing zones exhibited loss of vegetation cover and reduction of forage production, with a decline in rangeland condition, whereas the conservation zones showed recovery and improvement of the rangeland condition. Long-term implementation of Natural resource management programme in community wildlife conservancies seems to drive the semi-arid savannahs to exist in two steady states and transitions under the influence of grazing. We recommend long-term monitoring of the impact of the community conservation model on the rangeland and timely incorporation of remedial measures such as shifting *bomas* (cattle corrals) across the grazing zones, aggressive rangeland rehabilitation of severely degraded areas through reseeding and random grass seed broadcast along stock routes. Copyright © 2014 John Wiley & Sons, Ltd.

KEY WORDS: conservation management; herbaceous vegetation; land zoning; livestock–wildlife interface rangeland condition

INTRODUCTION

Savannahs are characterised by the coexistence of trees and herbaceous vegetation, mostly grasses (Skarpe, 1992). They occupy a fifth of the earth's land surface, support a large portion of the world's human population and most of its livestock and wild herbivores (Sankaran *et al*., 2005). The semi-arid savannahs have been described as stable ecosystems around one or more steady states (Rietkerk *et al*., 1996) but are highly dynamic systems because of the factors such as rainfall, soil nutrient levels, fire and herbivory (Skarpe, 1992; Rutherford *et al*., 2012). The two extreme states often described in the semi-arid savannah grazing systems are (i) a state with ample herbaceous cover, perennial grasses and scattered trees (Scholes & Archer, 1997; Simioni *et al*., 2003); and (ii) a state with a poor cover of annual grasses, absence of perennial grasses, a high proportion of bare soil and/or often bush encroached (Roques *et al*., 2001; Rutherford *et al*., 2012). Moreover, there are feedbacks within these steady states that perpetuate or maintain stability (Rietkerk *et al*., 1996). The vegetation structure is influenced by the soil quality (Augustine, 2003; Verdoodt *et al*. 2009), grazing and fire regimes (Moussa *et al*., 2009).

Livestock herbivory can cause shifts in plant species composition by replacing highly palatable grasses with unpalatable species (Owen-Smith, 1999; Rutherford *et al*., 2012). Heavy grazing leads to excessive defoliation of herbaceous vegetation, reducing standing biomass, basal cover and plant species diversity, often triggered by a decline in net primary productivity, as the intensity of grazing increases (Cingolani *et al*., 2003; Friedel *et al*., 2003; Bilotta *et al*., 2007). The decline in net primary productivity under heavy grazing is attributed to a reduction of plant material available for photosynthesis. In the semi-arid savannahs of East Africa, there is consistent evidence of change in species composition along grazing gradients, often characterised by a reduction in tuft size, thus increasing bare ground cover, and replacement of perennial grasses by annual grasses and other less palatable herbaceous vegetation (O'Connor & Pickett, 1992). The response of grass species to grazing is important in determining grazing capacity (Galt *et al*., 2000). Three categories of grasses, that is, Decreaser, Increaser I and Increaser II, describe the health of rangeland (Trollope, 1990). Decreaser species dominate a rangeland in good condition and decrease with overgrazing or undergrazing. Increaser I species dominate in undergrazed or selectively utilised rangelands, and Increaser II species dominate in

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rangelands that are overgrazed. Under restoration and improved management, heavily utilised rangelands indicating overgrazing by the existence of Increaser II species can shift to a dominance of more palatable Decreaser species (Angassa, 2012).

By reducing the vegetation cover and standing biomass, and increasing bare soil patches, overgrazing and trampling by large herbivores also lead to physical and chemical soil degradation, which increases the risk of soil erosion (Skarpe, 1991; Bilotta *et al*., 2007). Through trampling, consumption and excreta deposition, large herbivores alter soil nutrient availability for plants, changing the soil nutrient cycling rates and redistribution of soil nutrients (Bardgett & Wardle, 2003). The nutrient content of soils on heavily grazed grasslands generally decreases through export of nutrients, especially that of phosphorus (Lavado *et al*., 1996; Jewell *et al*., 2007), although nutrients accumulate at former *bomas* (cattle corrals) long after they have been abandoned (Augustine *et al*., 2003). Deterioration of the soil fertility in turn hamper the establishment and growth of vegetation, especially grasses, leading to more rangeland degradation in feedback loops (King & Hobbs, 2006). Grazing also affects the carbon and nitrogen accumulations in the soil through modifying the C and N cycles (Han *et al*., 2008).

Pastoralists such as the Maasai of East Africa adapted to live in arid lands by designating wet and dry season grazing areas (Homewood & Rodgers, 1991; Butt 2010). Their use of the rangelands was based on mobility, splitting and dispersing livestock over the landscape during wet and dry seasons (Little *et al*., 2001; Butt 2010), to ensure limited dry concentrated continuous grazing. In most pastoral areas, there was abundance of wildlife in the past as the pastoral way of life enhanced the coexistence (Homewood & Rodgers, 1991). However, with time, the sphere of the pastoralists in East Africa is continually experiencing dramatic changes in land use and tenure, with broad consequences on the rangeland dynamics. The pastoralists have progressively lost most of their grazing land through land subdivision and competitive uses such as encroaching crop and farming, establishment of wildlife protection areas and settlements and mining (Galaty, 1994; Western & Wright, 1994; Heald, 1999). A collapse of the traditional extensive Maasai grazing system is hypothesised to have negative effects on the rangeland health. It has also led to habitat loss and degradation, leading to declining wildlife numbers outside African parks (Ottichilo *et al*., 2000; Western *et al*., 2009). In Kenya, the Maasai land was transformed from communal into group ranches in the 1960s (Graham, 1989). Group ranches are large parcels of land that were demarcated under the Land Adjudication Act of 1968 (Cap 284) and legally registered to one group (several families) duly constituted under the Land (group representatives) Act of 1968 (Cap 287). This further reduced the movement of Maasai livestock by largely confining them into group ranches. Under increased pressure from the group ranch members who wanted to own individual parcels of land, the trend in south-west Kenya is now towards subdivision of the group ranches, further transforming the land use from extensive seasonal grazing to continuous grazing, and intensive livestock grazing (Galaty, 1994; Burnsilver & Mwangi, 2007).

In all the pastoral rangelands of northern Kenya, there are no fences. It is one of the few places left in Africa that allows for the free movement of wildlife and livestock across a vast area that is protected by communities (NRT, 2012; STE, 2012). The establishment of community wildlife conservancies (CWCs) in this key livestock–wildlife interface is a milestone towards maintaining the *status quo*. It also aims to promote ecosystem recovery through grazing management and conservation of wildlife, habitats and migration corridors and improve pastoral livelihoods using the income from the eco-tourism enterprises within the conservancies. However, we hypothesise that total exclusion of livestock grazing in the core conservation zones and subsequent increase of grazing intensity and trampling in the grazing (and settlement) zones are also likely to create new trends in the long run. This study tested this hypothesis by evaluating the impacts of community conservation management on a semi-arid savannah herbaceous vegetation and soil nutrient status in Tiamamut and Kijabe group ranches. This was achieved by comparing functional herbaceous vegetation attributes (cover, biomass production, species richness and diversity) and soil chemical properties in the continuously grazed zones, regardless of seasonality, with the conservation zones where livestock grazing has been excluded for the last 10 years, grazed only by wildlife, or at times illegally by livestock.

MATERIALS AND METHODS

Study Area

Laikipia County (9666 km^2) is located in the northern-central part of Kenya (Figure 1). Most of the county is comprised of semi-arid rangelands, divided into a mosaic of privately, publicly and communally owned ranches. The semi-arid savannah vegetation is characterised by *Acacia tortilis*-grassland complex in areas at good range condition. Highly degraded areas, predominantly in the communal ranches, are characterised by the formation of smooth surface crusts in the absence of herbaceous cover or by encroachment of unpalatable weeds (mainly *Sanseviera intamida*, *Opuntia* spp. and *Ipomea* spp.) and undesirable species of Acacia (*A. mellifera*, *A. reficiens* and *A. etbaica*), which inhibit grass growth (Kinyua *et al*., 2009). Annual rainfall in the semi-arid savannah ranges from 300 to 600 mm. Rainfall increases at higher elevations in the south and is weakly trimodal, falling in April to May, August and November, with a pronounced dry season in January to March (Georgiadis *et al*., 2007). Wildlife has been eliminated from the wetter southern and south-western periphery of the county, much of which is cultivated. Wildlife is scattered at varying densities across the remaining approximately 7000 km^2, which they share with livestock in private ranches, game sanctuaries and communal pastoral land.

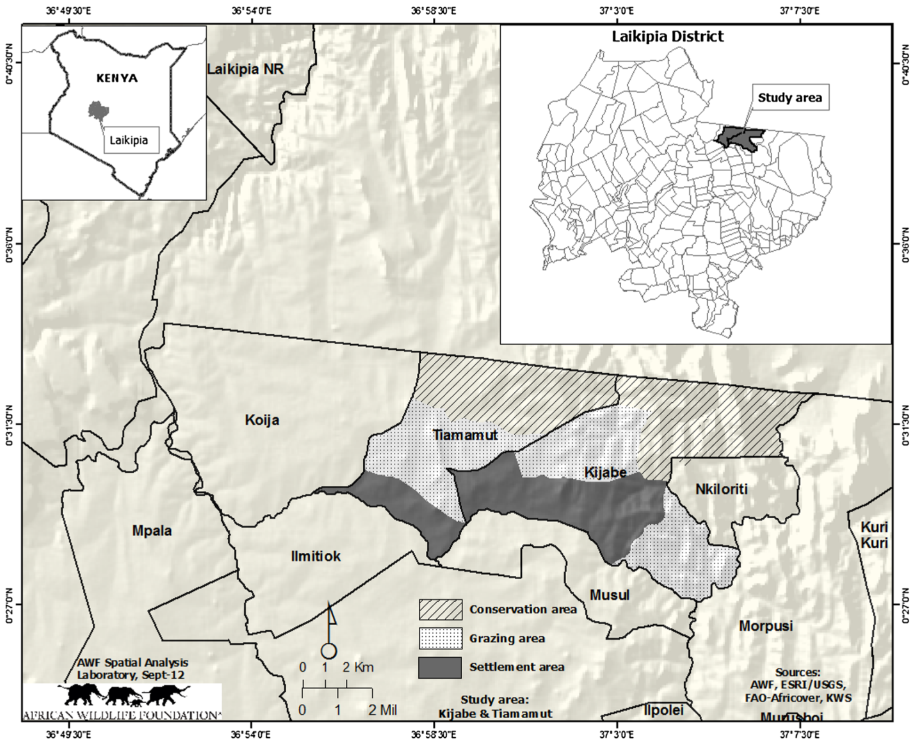

Figure 1. Study area showing Tiamamut and Kijabe group ranches in Laikipia and their respective land-use zones. This figure is available in colour online at wileyonlinelibrary.com/journal/ldr

This study was conducted in the conservation and grazing zones of Tiamamut and Kijabe community ranches, which are part of the Naibunga Wildlife Conservancy in Laikipia (Figure 1). The two community ranches are on the border between Laikipia and Isiolo Counties to the north. The terrain in both ranches is mostly non-dissected erosional plains rising to some rugged hilly areas in Kijabe. Both ranches are in agro-ecological zone VI (semi-arid to arid land with rainfall less than 700 mm) rated suitable for ranching (Jaetzold & Schmidt, 1983). The soils of the plain have a clay loam to sandy clay loam texture, sometimes with some gravel; they are well drained, moderately deep to very deep, dark reddish brown and friable. These soils are classified as Haplic Cambisols (chromic) and Haplic Luvisols (chromic), following the World Reference Bureau (IUSS Working Group WRB, 2007). Some patches of Vertisols also occur especially in the *lagga* (a dry river bed or low-lying areas of the landscape). The soils on the slopes in Kijabe group ranch form an association of Haplic Cambisols (chromic), Leptic Cambisols (eutric) and Lithic Leptosols following the WRB classification (IUSS Working Group WRB, 2007). At some places, soils are strongly eroded and crusted and have medium-to-low natural fertility (Ahn & Geiger, 1987).

Land-Use Zoning

Natural resource management (NRM) programme for the Naibunga Wildlife Conservancy were developed in 1999 (Henson *et al*., 2009; Sumba *et al*., 2007). Key players included the local communities, African Wildlife Foundation and a number of other conservation partners. The NRM planning process involved a landscape-scale systematic conservation planning including developing strategies to help the local communities benefit from nature tourism and resources on their land (Oguge, 2005) and to prevent further habitat loss in community ranches. The process entailed zoning land according to its ecological capacity and the most beneficial economic activity of a particular area. Community members demonstrated their commitment to conservation by participating in zoning their land into conservation, grazing and settlement zones. The management of zones took account of local ecological conditions and current uses (IUCN 1994).

The main zones were *core conservation* (*preservation*) *zone* – low-intensity use zone, areas with good wildlife habitat, water and usually the best places to find wildlife. Livestock grazing and human traffic is excluded; *buffer grazing zone* (*low-intensity*, *multiple-use zone for grazing and conservation*) – area used as a wildlife dispersal area and dry season grazing reserve for livestock and is a transition zone between the other two zones; *high-intensity use zone* (*for all other activities including settlement*) – includes the lands within the conservancy, which are outside the core conservation and buffer grazing zones. This area provides the local community with space for settlement, schools and shopping centres, as well as grazing. This study was conducted in the conservation and grazing zones. Before the NRM planning and land zoning, there were no major differences between Tiamamut and Kijabe group ranches. Both ranches had generally poor rangeland condition as livestock grazed everywhere within the ranches, leading to overgrazing.

After NRM planning and land zoning, livestock grazing is controlled by means of grazing by-laws enforced by the Group Ranch Grazing Committee and is only carried out in the grazing and settlement zones.

Sampling Strategy

Sampling for basal cover, standing biomass and species diversity involved the use of line transect and quadrant methods (Cook and Stubbendieck, 1986; Brady *et al*., 1995) along three 100 m transects laid in the conservation and grazing zones in each ranch, for both wet and dry seasons. Herbaceous cover was sampled by dropping a vertical point at every 1 m interval along the transects and recording the species hit, the nearest plant to the hit, or whether the hit was on bare ground, litter, dung or rock. A 0·5 m^2 quadrant frame was placed at 20 m intervals along the same transects to sample for frequency and herbaceous biomass production. All species rooted within the quadrant were identified and recorded before being clipped at 2 cm above ground level and put into paper bags and wet weight recorded. In the laboratory, the harvested material was separated into grasses or forbs life forms and oven dried at 70 °C for 48 h. A total of 60 quadrat samples were obtained for determination of herbaceous standing biomass in each ranch for both dry and wet seasons. Similarly, a total of 1200 hits were recorded from a total of six transects in each zone for both seasons and used for determination of herbaceous cover and species richness. Species ecological category (Decreaser, Increaser I or II) was assigned to the species hit. Sampling was carried out at the end of dry (February) and wet (May) seasons in 2011/12. Per cent basal cover by each of the life forms, per cent composition and relative abundance of the ephemeral and perennial grasses were estimated using Equations (1), (2) and (3), respectively.

$$cover\ of\ life-form\ A(\%) = \left(\frac{n^o hits\ of\ life-form\ A}{total\ n^o\ hits}\right)\times 100 \quad (1)$$

$$percent\ composition\ for\ species\ A = \left(\frac{total\ n^o\ hits\ species\ A}{total\ n^o\ hits}\right)\times 100 \quad (2)$$

$$relative\ abundance\ of\ functional\ group\ A\ (\%) = \left(\frac{n^o\ hits\ of\ functional\ group\ A}{total\ n^o\ hits\ of\ all\ species}\right)\times 100 \quad (3)$$

where n^o in Equations (1)–(3) equals the number of hits.

Species diversity was calculated using the Shannon–Wiener Diversity Index (S-W Div.) (H') (Shannon and Weaver, 1949), on the basis of the per cent species composition (Equation (4)). Shannon's diversity index is probably the most popular measure of species diversity because, in addition to taking into account species richness and evenness, it is highly flexible. The S-W Div. index takes into account the species composition (the number of species) and can be based on density, per cent cover, frequency and biomass measurements. S-W Div. (H') is expressed as

$$H' = -\sum_{i=1}^{n} \frac{n_i}{N} \log \frac{n_i}{N} \quad (4)$$

where n_i/N is the proportion of species i in the sample.

The status of soil nutrients was determined in each study site. Soil samples were collected up to 20 cm depth at the centre of every third quadrant for each transect (30, 60 and 90 m), making a total of nine samples per site. Analysis of soil pH (1:2·5), cation exchange capacity, exchangeable (Ca, Mg, K, Na) and total organic C, N and available P content (Olsen *et al*., 1954) was undertaken at the Laboratory of Soil Science at Ghent University in Belgium.

Data on herbaceous biomass production, basal cover, relative abundance of grasses and soil parameters were subjected to the analysis of variance (ANOVA) to determine the differences between the Tiamamut and Kijabe group ranches and their respective land zones. Where the Levene's F statistic was significant, implying dissimilar variances, a robust one-way ANOVA (Welch test) was used. Tukey and Tamhane's T2 post-hoc tests for equal and unequal error variances, respectively, were used to detect differences between the treatment means at $\alpha < 0{\cdot}05$. The transect lines and quadrants were used as replicates, reflecting the variability in herbaceous composition and standing crop within each land zone (the independent variable). All analyses were conducted using SPSS 19·0 software.

RESULTS

Effect of Land Zoning on Herbaceous Cover

Herbaceous layer in the study area is composed of a mixture of mainly annuals and perennial grasses, forbs and herbs. Results on per cent basal cover for the two community ranches are presented in Table I. There was a statistically significant difference between groups as determined by a one-way ANOVA for grasses ($F_{3,20} = 6{\cdot}792$, $p = 0{\cdot}002$), dung ($F_{3,20} = 4{\cdot}056$, $p = 0{\cdot}021$) and a robust one-way ANOVA for rock ($F_{Welch\ 3,20} = 6{\cdot}791$, $p = 0{\cdot}002$) cover, respectively. The Tukey's HSD post-hoc test revealed a significantly ($P < 0{\cdot}05$) higher grasses cover in Kijabe conservation zone (62 ± 5%) compared with Tiamamut grazing zone (38 ± 11%). There were no statistically significant differences between the grazing and conservation zones for grasses cover in Tiamamut (post-hoc $P = 0{\cdot}050$) and Kijabe ($P = 0{\cdot}980$), respectively. However, the conservation zones had a higher basal cover than grazing zones in both Tiamamut and Kijabe, respectively. The analysis did not reveal any statistically significant differences between groups for forbs, sedges, vascular plants, litter and bare ground cover in both Tiamamut and Kijabe community ranches (Table I). There was a trend towards higher forbs, vascular plants and litter cover in Tiamamut conservation than in the grazing zone. On the contrary, sedges, rock and bare ground cover was insignificantly lower in the conservation than in the grazing zone (Table I). In Kijabe, forbs, sedges and rocks cover was insignificantly ($P > 0{\cdot}05$) higher in conservation than in the grazing zone. On the other hand, there

Table I. Effect of land zoning on herbaceous cover ($n = 6$), relative abundance of grasses ($n = 6$) and herbage production (mean ± SD in parentheses; $n = 15$) in Tiamamut and Kijabe group ranches

	Tiamamut		Kijabe		$df_{1,2} = 3, 20$	
Land zone	Grazing	Conservation	Grazing	Conservation	F	P
Cover %						
Grasses	38 (11)a	53 (7)ab	55 (14)ab	62 (5)b	6·792*	0·002*
Forbs	3 (1·0)	7 (3·4)	3 (0·9)	5 (2·5)	6·631	0·623
Sedges	3 (1·2)	0·2 (0·1)	0·8 (0·5)	5 (2·4)	6·404	0·120
Vascular plants	0·2 (0·2)	1 (0·6)	0·8 (0·7)	0·2 (0·2)	6·788	0·632
Litter	15 (4)	22 (3)	16 (5)	14 (3)	1·752*	0·189*
Dung	4 (1·2)b	4 (2)b	2·5 (0·8)a	1·2 (0·7)c	4·056*	0·021*
Rock	17 (6)a	4 (4)b	7 (4)b	11 (2)c	6·791	0·002
Bare ground	22 (10)	9 (4)	15 (6)	5 (3)	1·632	0·201
Relative abundance %						
Annual Grasses	32 (7)b	21 (9)ab	27 (8)b	20 (2)a	10·373	0·007
Perennial Grasses	14 (5)a	24 (6)b	22 (8)b	32 (3)b	8·371*	0·001*
Herbage (Kg Dm ha^{-1})						
Grasses	432 (154)a	829 (300)c	642 (236)b	1523 (225)bcd	7·074*	0·043*
Forbs	22 (16)a	206 (113)b	233 (132)b	559 (336)c	8·585	0·020
Total	454 (162)a	1035 (404)c	875 (293)b	2082 (425)bcd	9·022	0·001

Robust one-way ANOVA (Welch test) and one-way ANOVA (marked by *). Means with different letters along the same row indicate significant ($P < 0·05$) differences; Tamhane T2 and Tukey's HSD (marked by *).

was a trend towards lower vascular plants, litter, dung and bare ground cover in the conservation than in the grazing zone (Table I).

Effect of Land Zoning on Herbaceous Biomass Production (Herbage)

There was a statistically significant difference between groups as determined by a one-way ANOVA for grasses herbage ($F_{3,20} = 7·074$, $P = 0·043$) and a robust one-way ANOVA for forbs ($F_{Welch\ 3,20} = 8·585$, $P = 0·020$) and total ($F_{Welch\ 3,20} = 9·022$, $P = 0·001$) herbage, respectively (Table I). A Tukey and Tamhane's T2 post-hoc test revealed significantly ($P < 0·05$) higher grasses (1523 ± 225 Kg Dm ha^{-1}) and total (2082 ± 425 Kg Dm ha^{-1}) herbage in Kijabe's conservation zone than Tiamamut and Kijabe grazing zones, respectively. There was a trend towards higher herbage for grasses, forbs and total herbage in Tiamamut conservation than in the grazing zone (Table I).

Effects of Land Zoning on Relative Abundance and Diversity of Herbaceous Plants

Twenty grasses, six forbs, one sedge and one herb species were encountered along transects (Table II; Figure 2). The conservation zones in both Tiamamut and Kijabe were mostly dominated by perennial grasses. Key decreaser species including *Cenchrus ciliaris*, *Panicum maximum* and *Themeda triandra* were encountered in Kijabe. There was a statistically significant difference between groups as determined by a robust one-way ANOVA for the relative abundance of both ephemeral ($F_{Welch\ 3,20} = 10·373$, $P = 0·007$) and perennial ($F_{3,20} = 8·371$, $P = 0·001$) grasses (Table I). A Tukey's post-hoc test revealed a significantly higher relative abundance of perennial grasses in Tiamamut conservation zone (24 ± 6%) compared with the grazing zone (14 ± 5%). There was no significant difference between the grazing and conservation zones for perennial grasses in Kijabe ($P = 0·094$).

Relative abundance of ephemeral grasses (32 ± 7; 21 ± 9%) was higher than that of perennial grasses (24 ± 7; 14 ± 5%) in Tiamamut conservation and grazing zones, respectively. In Kijabe, the grazing zone had a similar trend of a higher relative abundance of ephemeral grasses (27 ± 8%) than the perennial grasses (22 ± 8%), whereas the conservation zone had higher relative abundance of perennial grasses (32 ± 3%) compared with that of ephemeral grasses (20 ± 2%). There was a statistically significant difference in herbaceous species diversity between land-use zones as determined by one-way ANOVA in both wet ($F(3,8) = 5·250$, $p = 0·027$) and dry ($F(3,8) = 5·864$, $p = 0·020$) seasons (Table III). A Tukey's HSD post-hoc test revealed significant differences in between Tiamamut grazing and Kijabe conservation zones during both wet ($P = 0·035$) and dry ($P = 0·024$) seasons and between Tiamamut grazing (1·21 ± 0·15) and Tiamamut conservation (1·56 ± 0·09) zones during the dry season ($P = 0·033$). No statistically significant differences in species diversity were detected between Tiamamut grazing and conservation ($P = 0·212$) during the wet season or between the grazing zones in Tiamamut and Kijabe ranches during both wet ($P = 0·985$) and dry ($P = 0·098$) seasons.

Herbaceous species richness significantly varied with land use and season (Table III). No significant difference in species richness was detected by the one-way ANOVA between the land-use zones during the wet season. However, there was a significant difference between land use during the dry season as determined by one-way ANOVA ($F(3·8) = 5·415$, $p = 0·025$). A Tukey's HSD post-hoc test revealed a significantly ($P = 0·022$) higher species richness in Kijabe conservation zone (11·3 ± 1·5) than the Tiamamut conservation zone (5·3 ± 1·5). However, no statistically

Table II. Per cent herbaceous species composition (mean ± SD in parentheses; $n = 3$) in the conservation and grazing zones for both wet and dry seasons

	Land-use zone	Species ecological category	Tiamamut				Kijabe			
			Conservation		Grazing		Conservation		Grazing	
	Season		Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry
	Species composition									
Grasses	*Enteropogon macrostachyus* (*PG*)	Decreaser	2 (1·9)				3 (0·9)			
	Cenchrus ciliaris (*PG*)	Decreaser	3 (2·7)	2 (0·5)				2 (1·4)		
	Themeda triandra (*PG*)	Decreaser						4 (1·9)	4 (0·9)	
	Panicum maximum (*PG*)	Decreaser					3 (0·9)		2 (0·5)	
	Enneapogon macrostachyus (*AG*)	Increaser I						2 (1·7)		
	Penisetum mezianum (*PG*)	Increaser I								8 (1·4)
	Dactyloctenium aegyptium (*AG*)	Increaser I		2 (0·5)						
	Cynodon plectostachyus (*PG*)	Increaser I	5 (3·9)	3 (1·2)	7 (2·9)	7 (3·1)	4 (0·9)		7 (2)	7 (2)
	Pennisetum stramineaum (*PG*)	Increaser I	4 (1·5)		2 (0·5)	2 (0·5)	2 (0·4)		2 (0·5)	1 (0·1)
	Cynodon dactylon (*PG*)	Increaser II	28 (2·8)	16 (8·5)	15 (5)	10 (3·3)	9 (5·3)	1 (0·5)	15 (3·3)	15 (3)
	Digitaria macroblephara (*AG*)	Increaser II	10 (7·8)	4 (0·5)	6 (2·5)	4 (1·4)	29 (4·3)	10 (6·2)	6 (2·4)	4 (1)
	Aristida congesta (*AG*)	Increaser II					3 (2·1)	6 (2·4)	2 (0·9)	
	Aristida keniensis (*AG*)	Increaser II	2 (0·5)				1 (0·5)			
	Aristida adscensionis (*AG*)	Increaser II	4 (2·4)	2 (0·9)			2 (1·2)			
	Microchloa kunthii (*PG*)	Increaser II	10 (4·5)		2 (0·5)	1 (0·0)	7 (4·2)	3 (2·9)	4 (1·1)	1 (4)
	Chloris roxburghiana (*PG*)	Increaser II			3 (0·9)		3 (1·2)	2 (0·8)		
	Bothriochloa insculpta (*PG*)	Increaser II	1 (0·5)					29 (4·9)		
	Sehima nervosum (*PG*)	Increaser II	2 (3·3)							
	Sporobolus marginatus (*PG*)	Increaser II					2 (0·4)			
	Eragrostis tenuifolia (*AG*)	Increaser II			8 (1·4)	8 (2·5)	3 (0·5)		8 (1·4)	
Forbs	*Craterostigma plantgineum* (*EF*)	Increaser					3 (0·9)	5 (2·2)	4 (5·7)	3 (2·1)
	Maytenus putterlickioides (*EF*)	Increaser	4 (1·5)		13 (4·5)					
	Tragus barteronianus (*EF*)	Increaser					2 (0·9)	2 (1·4)		
	Harpachma schimperi (*EF*)	Increaser								
	Eustachys paspaloides (*EF*)	Increaser	3 (0·5)		2 (0·5)		3 (1·2)			
Sedges	*Cyperus sp*. (*Annual*)	Increaser	3 (0·5)							
Vascular plants	*Justicia exigua* (*AH*)	Increaser					2 (0·5)			
	Indigofera spicata (*PH*)	Increaser			4 (1·9)	2 (0·8)			3 (1·5)	2 (0·9)

Life form and functional group: AG, annual grass; PG, perennial grass; EF, ephemeral forb; AH, annual herb; PH, perennial herb.

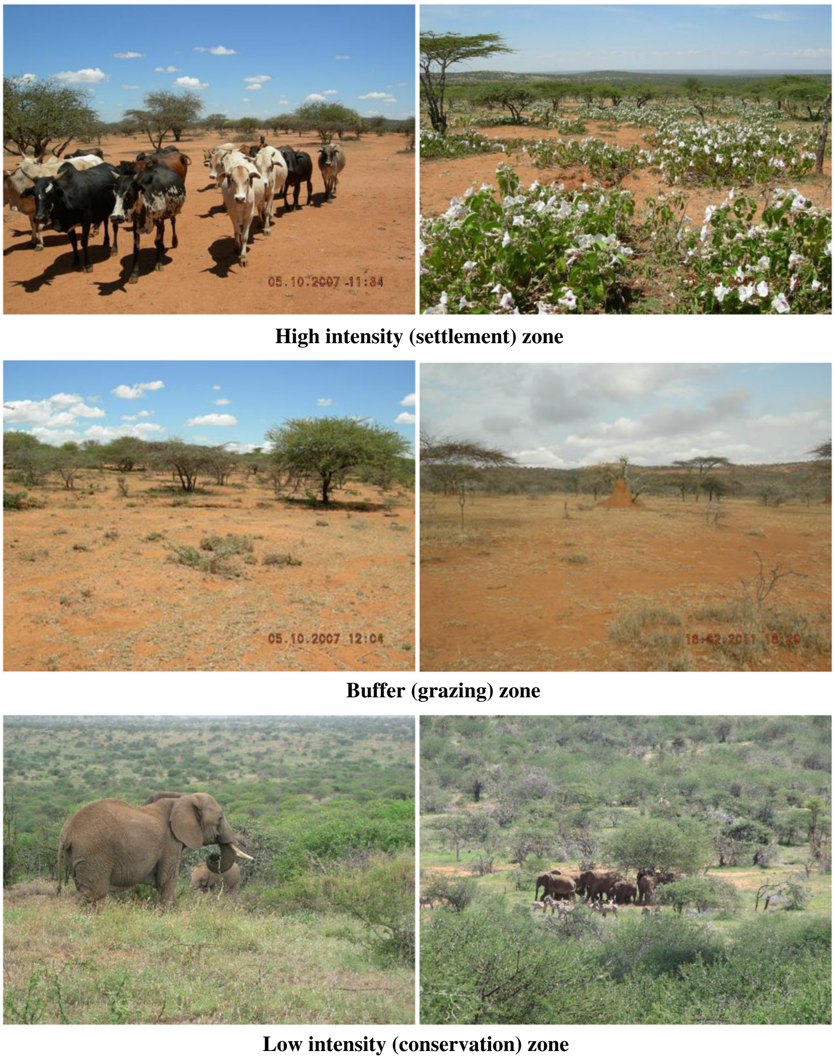

Figure 2. Pictorial view of the differences between various land-use zones in Kijabe (left) and Tiamamut (right) group ranches. This figure is available in colour online at wileyonlinelibrary.com/journal/ldr

significant differences in species richness were detected between Tiamamut grazing and conservation ($P = 0{\cdot}725$) and Kijabe grazing and conservation ($P = 0{\cdot}071$) zones during the dry season.

Effects of Land Zoning on Soil Properties

The measured parameters for soil properties showed that there were significant differences between grazing and conservation zones in Kijabe group ranch (Table IV). The mean contents of exchangeable calcium ($5{\cdot}29 \pm 1{\cdot}55$ cmol$_c$/kg), total carbon ($14{\cdot}6 \pm 5{\cdot}1$ g kg^{-1}), total nitrogen ($1{\cdot}28 \pm 0{\cdot}39$ g kg^{-1}), exchangeable magnesium ($1{\cdot}87 \pm 0{\cdot}62$ cmol$_c$/kg) and exchangeable potassium ($1{\cdot}14 \pm 0{\cdot}35$ cmol$_c$/kg) were highest in Kijabe conservation zone. Tiamamut grazing zone had the highest mean content of available phosphorous ($0{\cdot}55 \pm 0{\cdot}01$ g kg^{-1}) and lowest mean content of total nitrogen ($0{\cdot}67 \pm 0{\cdot}21$ g kg^{-1}) and organic carbon ($7{\cdot}5 \pm 1{\cdot}6$ g kg^{-1}), whereas the lowest exchangeable calcium ($3{\cdot}37 \pm 1{\cdot}19$ cmol$_c$/kg) was recorded in

Table III. Shannon–Weiner diversity index (SW-H′ ± SE in parentheses; $n = 3$) and species richness (mean ± SD; $n = 3$) in the conservation and grazing zones for both wet and dry seasons

		Tiamamut		Kijabe		ANOVA df$_{1,2}$ = 3, 8	
Attribute	Season	Grazing	Conservation	Grazing	Conservation	F	*P*
SW-H′	Wet	1·51 (0.44)a	2·08 (0.16)ab	1·60 (0·34)ab	2·42 (0,28)b	5·250	0·027
	Dry	1·21 (0.15)a	1·56 (0.09)ab	1·49 (0·13)b	1·59 (0,12)b	5·864	0·020
Species richness	Wet	7·1 (2)	7·7 (2.5)	10·3 (3·2)	12·7 (2·9)	2·801	0·109
	Dry	6·0 (3)a	5·3 (1.5)ab	6·7 (2·5)ab	11·0 (1·5)b	5·415	0·025

One-way ANOVA. Means with different letters along the same row indicate significant ($P < 0{\cdot}05$) differences; Tukey's HSD.

Table IV. Soil parameters (mean ± SD in parentheses; $n = 9$) in Tiamamut and Kijabe group ranch zones

Parameter		Tiamamut		Kijabe		$df_{1,2} = 3, 32$	
		Grazing zone	Conservation zone	Grazing zone	Conservation zone	*F*	*P*
pH H_2O		6·62 (0·14)	6·71 (0·29)	6·57 (0·13)	6·71 (0·34)	0·68	0·57
N_t	$g\,kg^{-1}$	0·67 (0·21)a	1·05 (0·42)ab	0·76 (0·23)a	1·28 (0·39)b	6724	0·001
TOC	$g\,kg^{-1}$	7·5 (1·6)a	11·8 (4·9)ab	9·4 (3·1)a	14·6 (5·1)b	5·44	0·004
P	$g\,kg^{-1}$	0·55 (0·01)a	0·49 (0·01)b	0·50 (0·00)c	0·52 (0·01)d	279·83	0·001
Ca	$cmol_c/kg$	3·37 (1·19)a	4·30 (1·13)ab	4·04 (0·92)ab	5·29 (1·55)b	3·84	0·019
K	$cmol_c/kg$	0·99 (0·37)	1·04 (0·27)	0·97 (0·24)	1·14 (0·35)	0·052	0·672
Mg	$cmol_c/kg$	1·81 (0·56)	1·65 (0·41)	1·78 (0·25)	1·87 (0·62)	0·32	0·814
Na	$cmol_c/kg$	0·03 (0·03)	0·25 (0·65)	0·02 (0·01)	0·03 (0·11)	1·11	0·361
Cation exchange capacity	$cmol_c/kg$	11·78 (3·12)	13·17 (6·50)	10·64 (1·16)	11·57 (3·04)	0·63	0·601

One-way ANOVA. Means with different letters along the same row indicate significant ($P < 0{\cdot}05$) differences; Tukey's HSD.

Tiamamut conservation zone. The soil pH value in the sampled sites ranged from 6·57 to 6·71 indicating neutral soils.

DISCUSSION

The savannahs, home of African rangelands, are dynamic systems where spatio-temporal variability of abiotic factors shapes the biotic life (Westoby *et al*., 1989; Sankaran *et al*., 2005). While grazing alone does not determine the overall vegetation structure in semi-arid rangelands, its effects can be adverse when rangelands are not well planned or managed. The dominance of Increaser II grass species (Tables I and II) indicates that the rangeland has been under long-term stress from grazing. Tiamamut grazing zone had significantly lower species diversity compared with the conservation zone (Table III), indicating a change from the original status before land zoning and successive conservation management since 1999. Continuous grazing in Tiamamut grazing zone resulted in significantly lower frequencies and counts of perennial grasses and the high proportion of bare ground. The conservation zones in both Tiamamut and Kijabe had only 3–4% Decreaser grass species, mainly *Cenchrus ciliaris*, *Enteropogon macrostachyus* and *Themeda triandra*, indicating that the rangeland is yet to fully recover despite the 10 years exclusion of livestock grazing since 1999. However, the species richness was significantly higher in conservation than grazing zones of both ranches. Exclusion from grazing by livestock has been reported to improve the condition of overgrazed and degraded rangelands. For instance, Allen *et al*. (1995) and Wasonga *et al*. (2011) reported an increase in frequencies of perennial species after 6 years of grazing exclusion in passively restored semi-arid rangelands of Central Otago New Zealand and in Baringo Kenya, respectively. In contrast, Martínez *et al*. (2013) reported an improvement of the grasses and rangeland condition by grazing goats to restore pastures invaded by shrubs in the Spanish Cantabrian Mountains. The presence of key indicator species in the conservation zones indicates the potential of NRM programmes in restoring the rangeland productivity and biodiversity. In both Tiamamut and Kijabe grazing zones, the species that are less resistant to grazing have diminished, leaving more adaptable species that are less palatable to grazers. The dominant grass species in Tiamamut grazing zone, *Cynodon dactylon* and *Cynodon plectostachyus*, are associated with disturbed areas and are able to withstand heavy grazing through propagation by means of rhizomes and stolons (Boonman, 1993). According to Young *et al*. (1995), the two species mostly colonise fertile soils in abandoned livestock *bomas* and under *Acacia tortilis* canopies forming glades.

Following the exclusion of livestock grazing, the conservation zones in both Tiamamut and Kijabe had a higher grass and forbs cover, and total herbage (Tables I), showing an improving rangeland condition despite being utilised continuously by wildlife. McIntosh and Allen (1998) reported a doubling of the amount of standing aboveground biomass in the steep seasonally dry pastoral lands of Southern Island, New Zealand after 16 years of exclusion from grazing. The results from Beeskow *et al*. (1995) and Verdoodt *et al*. (2009) also showed that plant composition, standing biomass and vegetation cover improved in the enclosure sites, compared with adjacent open rangeland. In contrast, the grazing zones in Tiamamut and Kijabe had a lower grass and forbs cover, total herbage and higher bare ground. With an increased grazing intensity and without a regular destocking plan, the rangeland condition in the grazing zones is likely to further deteriorate leading to a stable state with a poor cover of annual grasses, absence of perennial grasses and a high proportion of bare soil (Roques *et al*., 2001).

The grazing zones in Tiamamut and Kijabe had the highest bare ground and the lowest grasses and forbs cover, respectively (Table I). The percentage of bare ground on a site and hence the soil erosion potential increase with grazing pressure (Milton *et al*., 1994; Robertson, 1996). Overgrazing within the Mukogodo Maasai rangelands in Laikipia has led to loss of vegetation leaving bare soils and rangeland condition in a poor steady state as seen in Wikimapia.org (2013a) imagery. According to Skarpe (1991), a reduction in basal cover and total standing biomass was observed in East African savannahs because of intensive communal grazing. As grazing pressure increased, the Decreaser grass species declined, leaving Increaser II species of low forage potential. Most of Increaser I and II grasses, such as *Penisetum sp*. and *Digitaria sp*., respectively, are relatively palatable during the wet season but progressively become hard and fibrous during the dry season and are thus likely to be avoided by grazers. These species may become more abundant with time. *Pennisetum mezianum* dominates the *lagga*, forming glades that serve as important dry season grazing reserves in the degraded community ranches (Wikimapia.org, 2013b). Intensive livestock grazing has frequently resulted in a large species turnover, with a reduction in palatability of the sward under heavy grazing in African savannahs (Sarmiento, 1992). Also in South America, the dominant grasses are often unpalatable and grazing resistant and are usually confined to disturbed, grazed habitats (Sarmiento, 1992). In the CWCs in northern Kenya, this situation may pose a management dilemma in the mid-tem to long term, following severe depletion of grazing resources on one part of the ranch, while the other part is lush with pasture.

Soil properties varied across the different treatments (Table IV). The increased concentrations of total *N* in the conservation areas is most likely due to the higher standing biomass, increased litter deposition and reduced soil erosion (McIntosh & Allen, 1998). Kijabe conservation zone had the highest levels of plant nutrients, pH, exchangeable basic cations, total carbon and total nitrogen. Grazing affects the flux of nutrients in grazing lands through trampling, consumption, excreta deposition and redistribution and export (Lavado *et al*., 1996). Changes in soil properties might also arise from the indirect effects of grazing, such as nutrient accumulation through livestock dung and urine in areas settled by pastoralists (Augustine, 2003) and soil enrichment by litter accumulation and subsequent decomposition (Tessema *et al*., 2011). The lack of significant differences among soil properties between sites could be due to the slow rates of change in soil properties over time (Marrs *et al*., 1989). The conservation zones may have gained nutrients from leaf decomposition, as there was minimal removal except through wild herbivore defoliation and reduced soil loss following increase in vegetation cover. Similar studies showed that extremely degraded lands in Eastern Cape, South Africa had less organic carbon than moderately degraded areas (Oluwole & Sikhalazo, 2008). Under heavy grazing, rangelands showed decline in soil carbon and nitrogen (He *et al*., 2011).

Exchangeable calcium was higher but not significant in both Tiamamut and Kijabe conservation zone soils probably because of the high calcium content in the plant organic matter that decomposed during the 10 years of exclusion from grazing. According to Whalen *et al*. (2003), the type of vegetation and hence the chemical composition and rate of decomposition of plant residues are important determinants of nitrogen and calcium accumulation in the soil. Calcium is also found in elevated levels in abandoned pastoralist settlements in the East African rangelands, because of ash deposits from cooking fires and manure from livestock *bomas* (cattle corrals) used within the settlements. Thus, the traditional shifting of livestock *bomas* within the landscape play an important role in restructuring vegetation structure and herbivory through nutrient concentration (Augustine *et al*., 2003; Muchiru *et al*., 2008). In the NRM programme implemented in Tiamamut and Kijabe group ranches and the entire Naibung'a Wildlife Conservancy, pastoral settlements can only be installed in the high-intensity use (settlement) zone. This is likely to also affect nutrient cycling and rangeland dynamics in the long term and result in distinct land degradation zones within the landscape, posing a great challenge to the conservation management in place.

This study showed that Kijabe conservation area had a more positive response in terms of soil parameters, grasses cover, herbage, species diversity and richness compared with Tiamamut conservation area after 10 years of conservation. This was attributed to the current management plans and governance structures in Kijabe group ranch that has a stricter adherence to the existing grazing by-laws leading to low incidences of illegal grazing in the conservation area than in Tiamamut. Similar conditions are observed along fence lines of most of Laikipia's private ranches that exist in good rangeland condition compared with the adjacent communal ranches (Wikimapia.org, 2014). This illustrates the importance of rational management, particularly controlling stocking density in maintaining the integrity of the rangelands.

CONCLUSION

Excluding livestock grazing in the conservation zones for 10 years significantly increased the grass cover and biomass relative to the continuously grazed zones. The decrease in bare ground, the increase in grass biomass, forage potential and soil nutrients in conservation zones indicate the potential of grazing withdrawal in the passive restoration of degraded community rangelands in northern Kenya. It is likely that most of the areas have an adequate soil seed bank and would gradually recover under minimal or no grazing pressure. On the other hand, increased grazing pressure in the grazing zones has led to reduced herbaceous cover, species diversity and biomass production. These findings emphasise the role of regulated grazing in maintaining productivity of semi-arid rangelands. Long-term implementation of NRM programme in CWCs seems to drive the semi-arid savannahs to exist in two steady states and transitions under the influence of grazing. One state in conservation zones is typical for sites with a low grazing pressure, characterised by ample herbaceous cover (basal cover), perennial grasses and with scattered trees and good soil conditions. The second state in grazing zones can be found at sites with heavy grazing, with annual grasses of low forage value, absence of perennial grasses and a high proportion of bare crusted soil. If the *status quo* is maintained, the grazing and settlement zones will degrade further within a short time, unless stocking rates are controlled. The rehabilitation of such a degraded state is unlikely to be achieved spontaneously with simple reduction of heavy grazing pressure because these areas may develop feedback loops that inhibit restoration because of changes in vegetation structure and composition and changes in soil properties associated with heavy grazing. We recommend shifting livestock *bomas* across the grazing zones, aggressive rehabilitation of severely degraded patches through reseeding and random grass seed broadcast along stock routes in order to restore grasses. Such measures, in addition to regular destocking through livestock marketing, can significantly mitigate accelerated rangeland degradation.

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