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Impacts of management and enclosure age on recovery of the herbaceous rangeland vegetation in semi-arid Kenya

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ABSTRACT

Establishment of seasonal grazing enclosures has become an important rangeland rehabilitation strategy in semi-arid regions. This study assessed the impact of enclosure age and enclosure management on the vegetation composition in the Njemps Flats range unit, Lake Baringo Basin (Kenya). Six communal enclosures (13–23 years since establishment) and six private enclosures (3–17 years since establishment) were selected. Point-line transect and quadrat-based measurements were made of herbaceous cover, functional group relative abundance and standing crop inside the enclosures and in the adjacent open rangeland. Unpalatable forbs and sedges dominated the herbaceous vegetation of the degraded open rangeland. Informal semi-private land ownership reduced open rangeland degradation as shown by a higher cover of surviving annual grasses. Rangeland enclosure fostered regeneration of annual and perennial grasses, and significantly increased grass cover and standing crop. Private and communal enclosure management were equally successful in rehabilitating grass cover. Standing crop in the communal enclosures was fully recovered, but it was sub-optimal in all private enclosures reflecting recent grazing or grass cutting activities. The variability in rehabilitation success highlights the high potential of individual herders' incentives to promote rangeland rehabilitation but also stresses the importance of more detailed characterisation and monitoring of the enclosure management decisions.

1. Introduction

Establishment of exclosures, denoting areas closed off from grazing for a specific period of time, is a well-known management tool to restore degraded rangeland ecosystems. Regeneration of the vegetation has positive effects on biodiversity (Asefa et al., 2002; Abebe et al., 2006) and soil fertility (McIntosh et al., 1997; Mekuria et al., 2007; Su et al., 2005); it reduces soil erosion (Descheemaecker et al., 2006) and increases water availability (Hongo et al., 1995). The rehabilitation generally starts from relict vegetation or from the seed bank (Whisenant et al., 1995; Tefera et al., 2007). In severely degraded areas, autogenic recovery is hampered by inadequate supply of seed, absence of suitable micro-sites for germination, and reduced soil functioning (Abebe et al., 2006; Beukes and Cowling, 2003; van den Berg and Kellner, 2005). In those cases, ecosystem rehabilitation needs to be fostered through tilling, if necessary combined with planting and reseeding (Visser et al., 2004) of indigenous and exotic plant species.

Enclosures demonstrate the direct economic benefit of controlled use of these fenced-off rangelands for rotational or seasonal grazing, as well as for other income generating activities such as grass cutting, seed harvesting and bee keeping. According to Beyene (2009), rangeland enclosure by pastoralists is mainly driven by ecological, institutional and socio-economical incentives. A growing body of literature indicates that enclosing, and thus privatizing formerly communal rangelands, may result in social conflicts and foster rangeland degradation rather than contribute to rehabilitation and productivity increases (Beyene, 2010). Understanding the dynamics of these semi-arid rangelands is therefore a prerequisite for their proper management (Retzer, 2006). Long-term experiments are an important tool to investigate rangeland rehabilitation and grazing impact. Sinclair (2005) lists some of the longest-running rangeland monitoring projects in the world, with a maximum time frame up to 75 years. Yet, according to Ruiz-Jaen and Aide (2005), the monitoring phase of most rehabilitation projects rarely lasts for more than 5 years. Consequently, most rangeland rehabilitation studies measure the process or variable of interest in exclosures of increasing age since establishment and apply so-called chronosequence analyses (Asefa et al., 2002; Abebe

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et al., 2006; Descheemaecker et al., 2006; Mekuria et al., 2007; Su et al., 2005; Yayneshet et al., 2009).

The semi-arid rangelands of Lake Baringo Basin in the Kenyan Rift Valley are occupied by pastoral communities employing a communal resource system for livestock production. In the last few decades, human and livestock populations have increased, while the wildlife population has continued to diminish due to habitat destruction. Increasing population pressure, land use changes, overgrazing, and droughts induced severe land degradation (Hickley et al., 2004; Homewood and Lewis, 1987; Pratt, 1963; Rosenschein et al., 1999; Snelder and Bryan, 1995; Sutherland et al., 1991; Thom and Martin, 1983). The degraded rangelands are characterised by a lack of vegetation cover, increased soil erosion, invasion of alien plant species and bush encroachment, primarily by *Prosopis juliflora* (Mwangi and Swallow, 2008).

Rangeland rehabilitation in the Baringo Basin is fostered through the establishment of communally and privately managed enclosures. In the Njemps Flats range unit, six communal and six private 3- to 23-year old enclosures and unfenced control plots in the open rangeland were subjected to a chronosequence analysis. Herbaceous cover, functional group abundance and standing crop are the biotic indicators of rangeland rehabilitation success that were measured. We tested the impact of the emerging informal land ownership on open rangeland degradation, and the effectiveness of the enclosure strategy in rangeland rehabilitation. In addition, we verified whether communal and private enclosure management is equally successful, and we assessed the relationship between rangeland rehabilitation and enclosure age.

2. Materials and methods

2.1. Study area

The Njemps Flats (1°45′- 0°15′ N latitude; 35°45′–36°30′ E longitude) is one of the range units of the Lake Baringo District and covers approximately 30 500 ha. This flat to slightly undulating plain, located west and south of Lake Baringo, has an average altitude of 900 m a.s.l. (Herlocker et al., 1994) and receives a total annual rainfall varying between 300 and 700 mm (de Groot et al., 1992; Meyerhoff, 1991). The rainfall pattern is bimodal, with peaks in April–May and July–August (Snelder and Bryan, 1995). Ekaya et al. (2001) described the rainfall as low, erratic and unreliable. Analysis of a time series of rainfall records by Kipkorir (2002) revealed an increase of the rainfall intensity on the rainy days, separated by longer periods of drought. The temperature shows little variation throughout the year with mean monthly values ranging from 24 to 26 °C (Ekaya et al., 2001; Kipkorir, 2002). According to the reconnaissance soil survey (USDA-SCS/GoK, 1978), the dominant soils of the Njemps Flats are well drained, silt loam to clay loam, Eutric and Calcaric Fluvisols (FAO-UNESCO, 1974) that are located in an occasionally flooded, ancient lake bed. The natural vegetation is dominated by ephemerals, regenerating after the rains. *Acacia* woodland (80%), permanent swamp and seasonally flooded grassland (15%), and shrub grassland (5%) are the main vegetation types. The dominant land use has always been grazing and livestock herding by the “Il Chamus” semi-pastoralist community.

2.2. Communal and private enclosure management

Communal enclosures have been established by the Rehabilitation of Arid Environments (RAE) Trust Project. They vary in size from 6 to 400 ha and have been fenced using solar-powered electric fences (de Groot et al., 1992; Meyerhoff, 1991; Rosenschein et al., 1999). After removing most of the unpalatable shrubs and trees, the land was prepared by ripping along the contours using a tractor fixed with a disc ripper and chisel points, producing parallel micro-catchments. These furrow-like micro-catchments were closed alternately by hand using a hoe to avoid development of gullies. A mixture of drought-resistant trees, such as the fast-growing exotic *Prosopis* (later discovered to be aggressively invasive) and *Leucaena* species, as well as grasses, including the indigenous species *Cenchrus ciliaris* and *Eragrostis superba,* was reseeded. The seed mixture was hand broadcast and incorporated into the soil using a tractor drawn harrow. After the third year of full protection, initial harvesting of grass seeds and fodder to supplement livestock feed, as well as occasional dry season grazing, was allowed. All harvesting, cutting and grazing activities were strictly controlled by a Field Management Committee which is normally chaired by a respectable elder. Stocking rates of the ruminant livestock (cattle, sheep, goats and camels) vary from very high grazing intensities for very short periods to light intensities for prolonged periods. The common practice is to open the communal enclosures for grazing at most twice a year, resulting in high grazing intensities within short periods. In general, about 100 milking cows or steers for fattening can graze for 1 month in an equivalent area of approximately 20 ha. Other uses comprise fuel wood resale and bee keeping.

Individual pastoralists established small (<1 ha) private enclosures by closing off parts of their semi-private land with cut thorn bushes (*Acacia* and *Prosopis* sp.) and/or planted thorn cactus (*Opuntia* sp.), and removing the undesirable woody vegetation. The construction of water harvesting structures along with the quality of seedbed preparation and seed mixtures applied, varied with the financial and technical means at their disposal. Each herder is responsible for the management of his private enclosure. After the third year of full protection, use by livestock starts after flowering and seeding to ensure that there is enough grass seed for subsequent forage recruitment. The grass is harvested to be used as fodder or for thatching houses. All private enclosures also act as reserve pastures that are occasionally grazed during the dry season by the young stock, sick animals and milking cows, a practice that is also known in Ethiopia (Angassa and Oba, 2008) and Tanzania (Mwilawa et al., 2008). The herders commonly use cover, grass height and percentage of flowered grass to take decisions on stocking densities. Stocking densities for the private enclosures are highly variable, and depend on the enclosure size, the level of regeneration and grass establishment, and the household herd size. Herd size still matters as it is the traditional pastoralist's measure of wealth. Yet, more and more herders prefer to keep fewer but healthier and more productive animals, and are slowly gaining skills in determining the stocking rates to avoid overgrazing inside their enclosures. Compared to the management of the communal enclosures, ruminant grazing in the private enclosures is characterised by lower grazing intensities for longer periods of time.

2.3. Study design and sampling strategy

Six communal and six private enclosures (Table 1) were systematically selected for sampling across the Njemps Flats. The selection criteria – similarity of terrain, soil, and land use – aimed at minimising variability in the abiotic determinants of rangeland vegetation composition and functioning. The enclosure ages ranged from 3 to 17 years and from 13 to 23 years for the private and communal enclosures, respectively. In the absence of undisturbed reference sites (Ruiz-Jaen and Aide, 2005), open rangeland was chosen as a benchmark against which the rehabilitation success was compared.

Herbaceous vegetation cover and relative abundance of ephemeral and perennial grasses were estimated using the point – line transect technique (Brady et al., 1995). Three 50 m long transect lines

Table 1
General characterisation of the selected enclosures.

ID[a]	Local ID	Management	Area (ha)	Age (yr)
P3	LOKOR	Private	13.0	3
P6	CHEM	Private	2.0	6
P8	CHEROP	Private	0.7	8
P11	CHEPKO	Private	1.0	11
P15	KOE	Private	2.5	15
P17	CHEBU	Private	1.6	17
C13	F13	Communal	140.0	13
C16	F4A	Communal	102.3	16
C18	F1B	Communal	16.7	18
C20	F4	Communal	22.4	20
C22	F1A	Communal	6.6	22
C23	F1	Communal	9.3	23

[a] In the ID, the number represents the enclosure age, the letter refers to private (P) or communal (C) management.

were placed in a Z-shaped orientation within each enclosure. The height and vigour of the grasses growing near the enclosure fences clearly showed edge effects. Thorn bushes surrounding the private enclosures provided shading and litter, and positively influenced the microclimate, soil characteristics and forage productivity near the fence. Higher herbage production nearby these thorny fences can also be attributed to protection from grazing animals. The community maintained an area of about 15 m adjacent to the communal fences, in which grass and other plants were mowed to a low height, and which acted as a fire-break or provided access to and around the enclosure. To avoid any edge effects, the transect lines were laid 5 and 30 m away from the boundaries of the private and communal enclosures, respectively. One transect line was placed outside each enclosure, parallel to and 30 or 5 m away from communal or private enclosure fencing, respectively. The point data, collected systematically at each meter along all transect lines, recorded the species hit, the nearest plant to the hit, or whether the hit was on bare ground, litter, dung, or rock. All plant species were categorised into four major life forms – grasses, forbs, sedges and vascular plant seedlings. Percent cover by each of the life forms and relative abundance of the ephemeral and perennial grasses were computed by Equations (1) and (2), respectively.

$$\text{cover of life} - \text{form A}(\%) = (n^\circ \text{ hits of life} - \text{form A}/\text{total } n^\circ \text{ hits}) \times 100 \qquad (1)$$

$$\text{relative abundance of functional group A } (\%) = (n^\circ \text{ hits of functional group A}/n^\circ \text{ hits of all species}) \times 100 \qquad (2)$$

Five 0.25 m^2 quadrats were laid at 10 m intervals along each transect line. All herbaceous standing material rooted within the quadrats was clipped at 2 cm above the ground level and oven-dried to a constant weight at 70 °C for 48 h. Standing crop was expressed in kg ha^{-1} on dry matter basis. The sampling was organised during the month of July, within the long rainy season.

2.4. Statistical analysis

Before subjecting the data to a statistical analysis, the uniformity of the physical and chemical topsoil characteristics was checked (Verdoodt et al., 2009). Significant differences in the exchangeable sodium percentage (ESP) were identified. The ESP is generally 1% and maximally 4% at all sampled sites, except for the topsoil of private enclosure P15 and its adjacent rangeland where it amounted to 29 and 11%, respectively. Soil alkalinity, corresponding to ESP values exceeding 15%, influences plant growth directly through toxicity of the sodium ion, and gives rise to a massive or coarse columnar soil structure and low soil permeability, with indirect impacts on plant growth. In view of minimising the variability in the abiotic soil factors among the different sites, enclosure P15 and the adjacent rangeland were omitted from the statistical analysis.

Mann–Whitney *U*-tests were run to identify significant differences in herbaceous cover, functional group abundance and standing crop of the open rangeland as influenced by land ownership (continuous grazing near semi-private land versus communal land). Comparisons of the enclosures with the adjacent controls in the open rangeland under both management types were done using pair-wise Wilcoxon signed ranks tests. To avoid pseudoreplication, average site values were used. Data distributions were sometimes non-symmetrical and not all log-transformations proved successful, justifying the use of the non-parametric tests.

In view of assessing the impact of enclosure age and management, the transect lines and quadrats were used as replicates, reflecting the variability in herbaceous composition and standing crop within each enclosure. After confirming the near-normality of the data distribution in each of the cells, robust one-way ANOVA (Welch test) and post hoc tests (Tukey and Tamhane T2 for equal and unequal error variances, respectively) were used to identify differences in herbaceous cover, functional group abundance and standing crop between all individual enclosures. A General Linear Model (GLM) univariate analysis was run with management type as the fixed-effect factor. Some of the dependents were logarithmically, rather than linearly, correlated with enclosure age. The base-10 logarithm of enclosure age was therefore inserted as covariate. Homogeneity of variances was tested as well. The model evaluated the impact of the enclosure management, enclosure age, as well as the management × $\log_{10}$(age) interaction. Results need to be interpreted with care because of the non-orthogonal experimental design.

3. Results

3.1. Impact of land ownership on open rangeland degradation

On average, 63–67% of the continuously grazed, open rangeland was devoid of vegetation cover (Table 2). In the communal rangeland, unpalatable forbs (*Tribulus terrestris*) and sedges (*Cyperus rotundus*) were the dominant life forms. In the semi-private rangeland, the surviving herbaceous vegetation was dominated by both palatable and unpalatable forbs. The Mann–Whitney *U*-test revealed significant differences in herbaceous vegetation between the communal and semi-private rangelands. Open range adjacent to the private enclosures was characterised by a significantly lower sedges cover ($U = 0.0$, $P = 0.006$), higher grass cover ($U = 3.5$, $P = 0.022$), and higher relative abundance of ephemerals ($U = 3.5$, $P = 0.022$) than the communal rangeland. There was a non-significant ($U = 12.0$, $P = 0.584$) trend for a higher standing crop in the semi-private rangeland than in the communal rangeland.

3.2. Impact of the enclosure strategy on rangeland rehabilitation

Pair-wise comparison of the enclosures and adjacent open rangeland (Table 2) proved that the private and communal enclosure strategies successfully reduced the bare ground cover from 63 to 25% ($Z = -2.21$, $P = 0.039$) and from 67% to 7% ($Z = -2.06$, $P = 0.027$), respectively. The dominant life form observed in the enclosures is grass. Grass cover, comprising annual and perennial species, significantly increased from 9 to 34% in the private enclosures ($Z = -2.02$, $P = 0.043$) and from 0 to 51% in the communal enclosures ($Z = -2.21$, $P = 0.027$). The most abundant perennial grasses were *C. ciliaris*, *E. superba*, *Cynodon dactylon*, *Eriochloa meyerianum* and *Dactylonium aegyptium* in the communal

Table 2
Herbaceous vegetation (Mean ± SD) of the private and communal open range and enclosures, and results of the pair-wise comparison of enclosures with the adjacent open range.

Herbaceous vegetation	Private management ($n = 5$)			Communal management ($n = 6$)		
	Open range	Enclosure	*P*	Open range	Enclosure	*P*
Cover (%)						
Bare ground	63 ± 11	25 ± 11	0.039	67 ± 9	7 ± 6	0.027
Grass	9 ± 9	34 ± 9	0.043	0 ± 1	51 ± 4	0.027
Forbs	13 ± 3	15 ± 3	0.068	12 ± 6	16 ± 1	0.173
Sedges	3 ± 2	6 ± 5	0.109	11 ± 2	7 ± 4	0.115
Vascular seedlings	7 ± 3	10 ± 5	0.197	6 ± 3	9 ± 3	0.089
Litter	0 ± 0	6 ± 7	0.066	0 ± 0	10 ± 4	0.027
Dung	3 ± 1	3 ± 1	0.317	4 ± 3	0 ± 0	0.027
Relative abundance (%)						
Perennial grasses	0 ± 0	34 ± 14	0.042	0 ± 0	38 ± 14	0.027
Annual grasses	9 ± 9	22 ± 10	0.138	0 ± 1	19 ± 11	0.027
Standing crop (kg DM ha^{-1})	562 ± 213	1602 ± 383	0.043	428 ± 231	4405 ± 1217	0.028

SD = standard deviation. *P*, probability (Wilcoxon Signed Ranking Test).

enclosures, and *C. ciliaris* and *C. dactylon* in the private enclosures. The other life forms did not benefit from the enclosure strategy. During the field visits, the occurrence of some bare patches, patches of unpalatable forbs, and glades of a single grass species (often the perennial grass *C. dactylon)* were reported, but in general, the variability in vegetation composition was relatively low.

The open rangeland was devoid of litter. However, the private and communal enclosures were characterised by a highly variable litter cover. Only in the communal enclosures was the increase statistically significant ($Z = -2.21$, $P = 0.027$). The private enclosure strategy didn't alter dung cover ($Z = -1.00$, $P = 0.317$), reflecting the frequent access of livestock or wild herbivores to these enclosures during the rainy season. No dung was reported inside the communal enclosures ($Z = -2.21$, $P = 0.027$).

The enclosures also showed variability in terms of standing crop, increasing from 562 kg DM ha^{-1} in the semi-private open range to 1602 kg DM ha^{-1} inside the private enclosures ($Z = -2.02$, $P = 0.043$) and from 428 kg DM ha^{-1} in the communal open range to 4405 kg DM ha^{-1} inside the communal enclosures ($Z = -2.20$, $P = 0.028$).

3.3. Evolution of rangeland rehabilitation with enclosure age and management

The ANOVA analysis (Table 3) identified significant differences between individual enclosures with respect to standing crop ($F_{Welch,10,61} = 1398.34$, $P < 0.001$) and cover by bare ground ($F_{Welch,10,22} = 26.12$, $P < 0.001$), grass ($F_{Welch,10,9} = 20.29$, $P < 0.001$), sedges ($F_{Welch,10,22} = 8.07$, $P < 0.001$), and vascular seedlings ($F_{Welch,10,9} = 4.57$, $P = 0.017$). Also the relative abundance of annual ($F_{Welch,10,9} = 13.33$, $P < 0.001$) and perennial ($F_{Welch,10,8} = 93.69$, $P < 0.001$) grasses differed significantly (Fig. 1).

The bare ground and grass cover showed logarithmic trends with enclosure age (Fig. 2a, b). GLM analysis (Table 4) confirmed that bare ground ($F = 21.6$, $P < 0.001$) and grass cover ($F = 17.5$, $P < 0.001$) varied significantly with $\log_{10}$(age), but no significant impact of the enclosure management or the interaction management × $\log_{10}$(age) was shown. The grass cover of the private enclosures significantly increased between 3 and 6 years of establishment and then stabilised around 39% in the enclosures P6, P8 and P11. Grass cover in the communal enclosures further increased slowly from 48% (C13) to 58% (C23). By contrast, the bare ground cover decreased from 36% in private enclosure P3–17% in private enclosure P8, and stabilised at values ranging between 0 and 13% beyond this age. However, in private enclosure P17, characterised by a grass and bare ground cover of 32% and 34% respectively, the rehabilitation strategy clearly proved less successful.

The observed variation in cover by sedges (0–13%) and vascular seedlings (3–18%) could not be explained by differences in enclosure management or $\log_{10}$(age).

In general, the relative abundance of perennial grasses increased logarithmically with enclosure age (Fig. 2d), at the expense of the relative abundance of annual grasses (Fig. 2c). In enclosures P8, C18, C22 and C23, the relative abundance of the perennial grasses (51% on average) clearly surpassed the annual grasses (9%).

Table 3
Herbaceous cover ($n = 3$), relative abundance ($n = 3$) and standing crop ($n = 15$) of the private and communal enclosures (Mean ± SD). Within columns, means with different subscript letters indicate significant ($P < 0.05$) differences.

Enclosure	Cover (%)					Relative abundance (%)		Standing crop (kg DM ha^{-1})
	Bare	Grass	Forbs	Sedges	Vascular	Annuals	Perennials	
P3	36 ± 3^{a}	18 ± 3^{a}	12 ± 3	6 ± 3^{abcd}	18 ± 4^{d}	30 ± 2^{c}	26 ± 2^{a}	1000 ± 100^{a}
P6	33 ± 4^{a}	39 ± 6^{bc}	11 ± 3	10 ± 3^{cd}	5 ± 2^{ab}	26 ± 3^{bc}	21 ± 3^{a}	1830 ± 135^{cd}
P8	17 ± 5^{b}	40 ± 5^{bc}	14 ± 4	2 ± 2^{ab}	9 ± 4^{abc}	9 ± 2^{a}	55 ± 3^{d}	1680 ± 147^{c}
P11	12 ± 5^{bcde}	39 ± 3^{bc}	17 ± 5	10 ± 3^{cd}	9 ± 5^{abc}	32 ± 3^{c}	26 ± 2^{a}	2000 ± 169^{d}
C13	13 ± 3^{bcd}	48 ± 5^{cde}	15 ± 2	9 ± 3^{bcd}	9 ± 2^{bc}	30 ± 2^{c}	26 ± 2^{a}	3430 ± 145^{f}
C16	10 ± 5^{bcde}	49 ± 4^{cde}	15 ± 4	10 ± 2^{cd}	9 ± 2^{abc}	23 ± 2^{bc}	23 ± 0^{a}	4830 ± 172^{h}
P17	34 ± 7^{a}	32 ± 3^{b}	19 ± 6	0 ± 0^{a}	9 ± 3^{bc}	14 ± 2^{ab}	42 ± 2^{b}	1500 ± 79^{b}
C18	2 ± 0^{de}	52 ± 4^{de}	18 ± 2	3 ± 3^{abc}	11 ± 5^{bc}	9 ± 1^{a}	56 ± 6^{d}	5250 ± 316^{i}
C20	13 ± 7^{bcd}	49 ± 3^{cde}	16 ± 1	13 ± 5^{d}	3 ± 2^{a}	32 ± 3^{c}	26 ± 2^{a}	2597 ± 366^{e}
C22	4 ± 1^{cde}	50 ± 4^{cde}	14 ± 2	4 ± 2^{abc}	13 ± 4^{cd}	9 ± 3^{a}	47 ± 1^{bc}	4400 ± 233^{g}
C23	0 ± 0^{e}	58 ± 5^{e}	17 ± 4	2 ± 2^{ab}	11 ± 6^{c}	8 ± 1^{a}	47 ± 1^{bc}	5920 ± 219^{j}

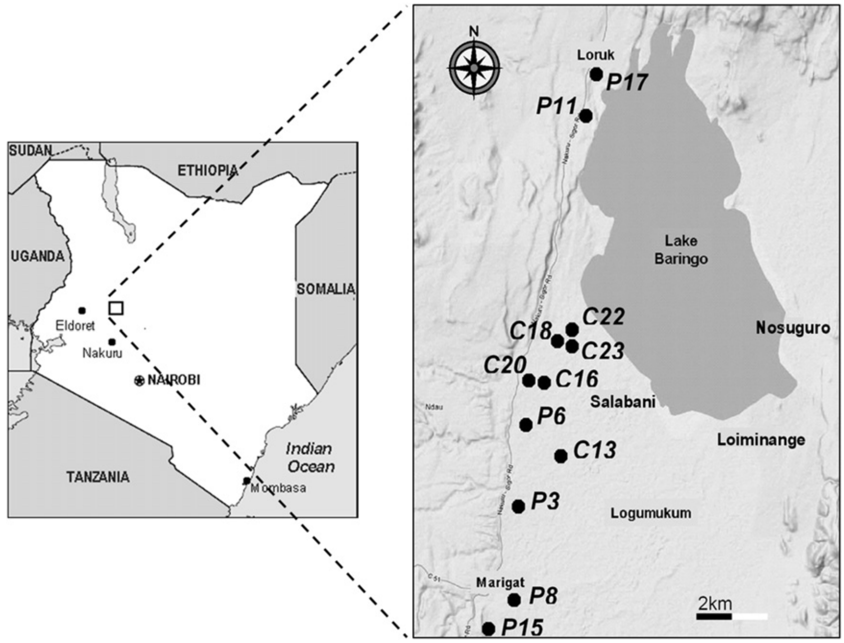

Fig. 1. Location of the Njemps Flats and study sites.

However, large site to site variations in annual and perennial grass abundance, affecting both private and communal enclosures, reduced the strength of the logarithmic trends shown in Fig. 2c and d. Large differences were seen in the functional group composition of enclosures P8 and C18, both characterised by a relatively high abundance of perennial grasses. Large differences were also seen in enclosures P11 and C20, both characterised by a relatively high abundance of annual grasses. Nevertheless, the GLM identified significant contributions from enclosure management ($F = 4.89$, $P = 0.035$), $\log_{10}$(age) ($F = 10.45$, $P = 0.003$) and their interaction ($F = 4.34$, $P = 0.046$) to explain the recorded variation in the relative abundance of annual grasses. The relative abundance of perennial grasses was significantly ($F = 8.30$, $P = 0.007$) affected by $\log_{10}$(age) only, though there is a non-significant trend towards an impact of management ($F = 3.67$, $P = 0.065$). For annual grasses, the reported changes in relative abundance were much more apparent in the communal than in the private enclosures. In view of the large variation reported in functional group composition across the management strategies, more observations are needed to confirm the results revealed by the GLM procedure.

In contrast to the other herbaceous parameters, standing crop was strongly affected by enclosure management, with significantly higher values reported in the communal enclosures than in the private ones (Table 3) and a different behaviour with enclosure age (Fig. 2e). Private enclosures were characterised by a standing crop ranging from 1000 to 2000 kg DM ha^{-1}, and significant but small changes with time. In contrast, the standing crop of the communal enclosures increased considerably with enclosure age from 3430 to 5920 kg DM ha^{-1}, except for the standing crop of enclosure C20. Consequently, the GLM detected a significant impact of $\log_{10}$(age) ($F = 23.08$, $P < 0.001$), as well as a significant contribution of the interaction management $\times$ $\log_{10}$(age) ($F = 11.49$, $P = 0.001$). The impact of enclosure management ($F = 2.62$, $P = 0.108$) became significant after removing enclosure C20 from the analysis ($F = 5.75$, $P = 0.024$, data not shown). In enclosure C20, the significantly lower standing crop, the relatively higher abundance of annual grasses compared to perennial ones, and the higher bare ground cover compared to other communal enclosures in the same age category, reflect the negative impact of management decisions on enclosure C20's rehabilitation success.

4. Discussion

4.1. Rangeland degradation affected by informal land ownership

Compared to the open rangelands of northern Kenya, accumulating 846–2531 kg ha^{-1} (Oba et al., 2001), the standing crop of the Njemps Flats (498 ± 212 kg ha^{-1}) is limited and reflects the poor rangeland condition. The dominance of forbs and sedges in the surviving vegetated patches reflects year-round grazing. Sedges thrive well in the overgrazed areas. They germinate in response to moisture availability, rapidly disappear in the dry season, and have a very low grazing value. Most of the natural vegetation is dominated by undesirable woody species such as *Acacia reficiens*, *A. nilotica* and *A. nubica*, suppressing grasses and herbaceous ground cover. Over-browsed shrubs, evidences of sheet, rill, gully and wind erosion, soil sealing and crusting, hard setting, and invading unpalatable forbs and woody species, especially *P. juliflora* (data not shown), are other indicators of the rangeland degradation that were reported during the field work. With the topsoil seed banks depleted through erosion, rehabilitation of the rangelands is largely dependent on reseeding and tree planting rather than on natural regeneration.

The significantly lower sedges cover and higher grass cover in the semi-private rangeland compared to the communal rangeland suggest a lower degree of rangeland degradation under semi-private ownership. Based on a study addressing changing socio-economic factors and perceptions of the Lake Baringo basin community in relation to land rehabilitation efforts (Meyerhoff, 1991), this can be attributed to an increasing trend towards respect for individual land tenure (ownership). Though the land is owned and managed communally, the society respects the fact that a household has lived in one place for a long time, and thus considers it as private land. Other herd owners will not graze the open rangeland adjacent to private enclosures, except in times of drought.

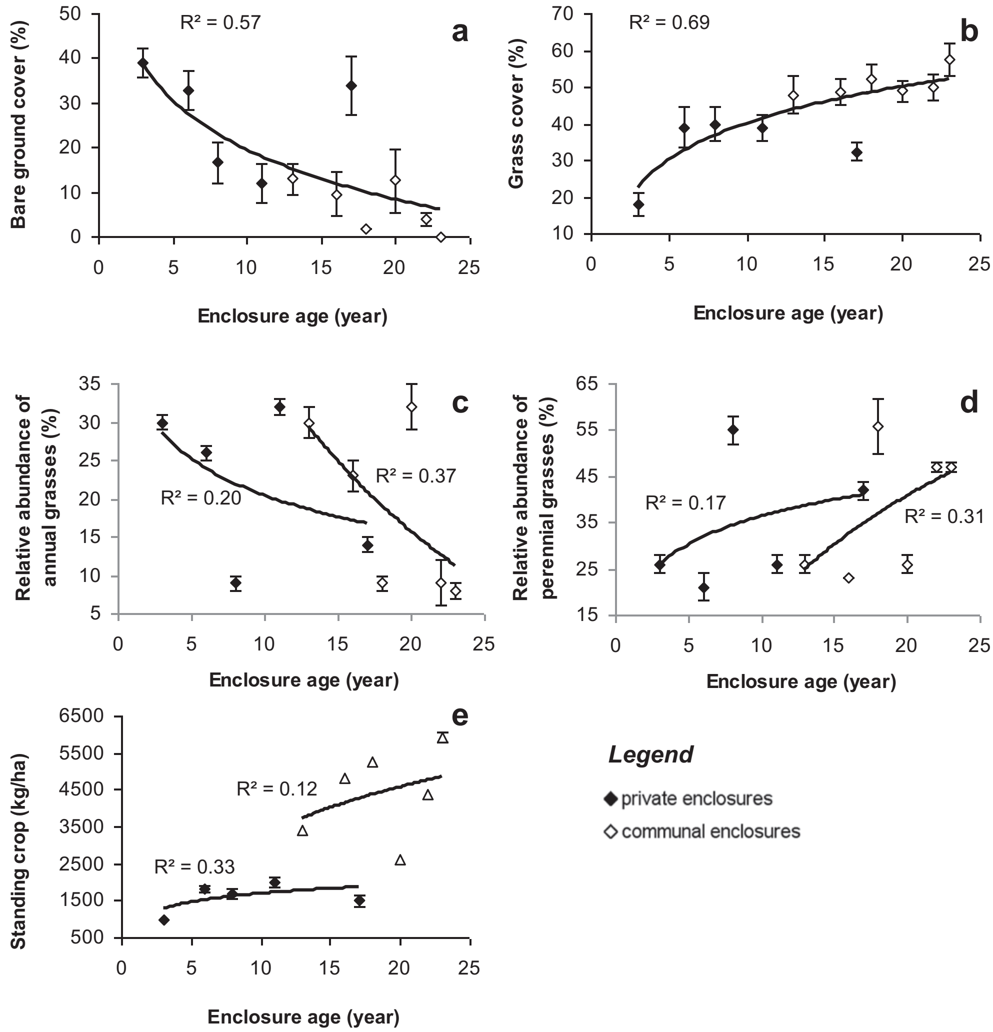

Fig. 2. Logarithmic trends with enclosure age in bare ground (a) and grass (b) cover, relative abundance of annual (c) and perennial (d) grasses, and herbaceous standing crop (e) (Mean ± SD).

4.2. Impact of the enclosure strategy on rehabilitation of the herbaceous vegetation

The variation in plant life forms between enclosures and open rangeland was particularly pronounced for grasses. Grasses dominate the vegetation cover in all enclosures and profit most from the enclosure strategy. Their significant response to the active enclosure management contrasts sharply to the very slow rehabilitation obtained by passive restoration efforts in very severely degraded arid regions. Time lags of at least 20 years before any significant recovery of the perennial grasses following removal of grazing livestock have been reported (Valone et al., 2002). The relative abundance of perennial and annual grass species, irrespective of enclosure management or age, provided an indirect indication of increased ecosystem resilience (Peterson et al., 1998) and highlighted the importance of perennial species in providing sustained forage production throughout the year. In some of the enclosures, active management favoured the regeneration of perennial grasses at the expense of the ephemerals. *C. ciliaris*, one of the species most abundantly found in communal enclosures and also present in half of the private enclosures, and *E. superba*, abundant only in communal enclosures, constitute the basis of the seed mixtures used for the rangeland rehabilitation. They were selected because of their drought resistance, high reseeding capacities or quick vegetative spread, and forage value. The patches dominated by *C. dactylon* are probably former cattle corrals or old settlement sites of traditional pastoralists. Several authors have reported that good perennial grasses establish easily and fast on these islands of fertile soils, forming glades which become hotspots of grazing intensity that persist for decades after corral abandonment (Augustine, 2003; Stelfox, 1986; Young et al., 1995). However, the resilience of these corrals may be compromised by soil compaction through hoof action in case of high grazing intensities and prolonged grazing periods (Mureithi, 2006).

The enclosure strategy did not significantly affect the cover by forbs, sedges and vascular seedlings of woody shrubs and trees. Difficulties in establishing subdominant forbs in grassland restorations have been reported in many other studies (Baer et al., 2002). The large variation in sedges and vascular seedlings cover is related to the micro-topography of the Baringo plain and the seed bank composition. Furthermore, the 23-year long restoration trajectory in the Njemps Flats does not confirm the progressive shift towards the woody species reported by other researchers (Angassa and Oba, 2008; Sinclair, 2005). This might be explained by the active enclosure management removing unpalatable shrubs and trees, and by the controlled use of wood for fuel and poles. A detailed analysis of the woody vegetation is required to provide a decisive answer.

Table 4
Results of the general linear model procedure, analyzing the effects of enclosure management and log10(age) on herbaceous vegetation.

Variable	Source	df	*F*	*P*
Cover (%)				
Bare	Management	1	0.43	0.520
	Log_{10}(age)	1	6.18	0.019
	Management × $\log_{10}$(age)	1	1.08	0.307
Grass	Management	1	0.02	0.889
	Log_{10}(age)	1	5.84	0.022
	Management × $\log_{10}$(age)	1	0.08	0.775
Sedges	Management	1	1.72	0.200
	Log_{10}(age)	1	4.05	0.053
	Management × $\log_{10}$(age)	1	1.18	0.287
Forbs	Management	1	0.36	0.552
	Log_{10}(age)	1	1.61	0.214
	Management × $\log_{10}$(age)	1	0.58	0.452
Vascular seedlings	Management	1	1.15	0.293
	Log_{10}(age)	1	0.01	0.916
	Management × $\log_{10}$(age)	1	1.47	0.236
Relative abundance (%)				
Perennial grasses	Management	1	3.67	0.065
	Log_{10}(age)	1	8.30	0.007
	Management × $\log_{10}$(age)	1	3.17	0.085
Annual grasses	Management	1	4.89	0.035
	Log_{10}(age)	1	10.45	0.003
	Management × $\log_{10}$(age)	1	4.34	0.046
Standing crop	Management	1	2.62	0.108
(kg DM ha^{-1})	Log_{10}(age)	1	23.08	< 0.001
	Management × $\log_{10}$(age)	1	11.49	0.001

The increase of fresh or partly decomposed plant litter within the enclosures is a positive indicator of range recovery as it contributes to organic matter input, enhances biological activity and thus promotes nutrient cycling and the formation of good soil structure. Occasional grazing is predominantly a good range management practice as it opens up the grass tufts, disperses the seeds and enriches the soil seed bank. It also increases litter fall, while hooves break up the surface crust in the bare patches forming micro-catchments that trap water in subsequent rainfall events. The compounded result is improved regeneration in the next season, thereby increasing cover and abundance of the most prolific grass species, such as *C. ciliaris*, *Enteropogon macrostachyus*, and *E. superba*.

Rehabilitation of the standing crop in the communal enclosures proved successful in comparison with values (2100–3900 kg DM ha^{-1}) reported in the Kenyan national parks and research stations with similar bimodal rainfall patterns (de Leeuw and Nyambaka, 1988) and in 12–18 year old rangeland enclosures (4200 kg ha^{-1}, 500 mm annual rainfall, dry season grazing) of northern Kenya (Oba et al., 2001). Because standing crop is the result of the combined effects of productivity and herbivory (Retzer, 2006), the significantly lower standing crop that characterises the private enclosures reflects – least partly – the higher grass cutting and grazing activities adopted in private enclosure management. No evidence for a difference in biomass productivity between private and communal enclosures can be given based on the available data.

4.3. Implications for enclosure management

Vegetation composition and functioning in semi-arid rangelands are known to be strongly controlled by both environmental and management determinants such as rainfall, geology, soil, tree density and canopy cover, animal numbers, feeding classes and fire. Especially stocking density, fire, selective grazers, mixed feeders and tree canopy cover have an important influence on herbaceous composition and cover (Peel et al., 2005). The site selection strategy adopted in this study was oriented towards revealing the impact of enclosure age and management. Grass cover in particular was clearly responsive to enclosure age. Its initially fast rehabilitation after enclosure establishment is in accordance with other studies (Mekuria et al., 2007; Ruiz-Jaen and Aide, 2005; Su et al., 2005). Differences in capital invested in initial enclosure preparation (fencing, seedbed preparation, water harvesting structures, seeding rate) and management decisions related to grass cutting and grazing activities did not significantly affect rehabilitation of the herbaceous cover. However, an orthogonal sampling design comprising private and communal enclosures representative for the entire time span of the chronosequence is necessary to confirm the elaborated trends with enclosure age. Rehabilitation of the standing crop with time inside the private enclosures is predominantly realised during the first 6 years of private enclosure management, following the reduced grazing and grass cutting activities immediately after enclosure establishment. In contrast, the standing crop of the communal tends to increase with enclosure age. The significantly smaller standing crop characterising the private enclosures highlighted the large impact of enclosure management as an important driver of vegetation rehabilitation. Private enclosure owners tend to open their fields for their herds more often. Since the fencing of the private enclosures is not secure, grazing by wildlife such as zebras and ostriches could also occur. A low standing crop and litter cover might impede restoration of the bio-physico-chemical topsoil quality (Verdoodt et al., 2009) and compromise the long-term resilience of the private enclosures to external stresses such as drought. In view of the different grazing intensities inside private and communal enclosures, biomass productivity would be a more unbiased indicator of rehabilitation success.

Though enclosure management most strongly influenced standing crop, the cutting and grazing activities didn't seem to induce a significant decrease in herbaceous cover and regeneration with time in most of the enclosures. In the oldest private enclosure P17, however, the relatively low standing crop is related to a significantly lower grass and litter cover, resulting in a doubling of the bare ground cover, and suggesting some constraints to its rehabilitation. Also the vegetation composition of communal enclosure C20, characterised by a relatively low standing crop, vascular seedlings and litter cover, but a relatively high sedges and bare ground cover, reflects less successful rangeland rehabilitation. More detailed monitoring of the grass cutting and grazing activities, including information on stocking densities applied in the individual enclosures, is therefore recommended and would enable the formulation of more specific animal stocking density guidelines.

5. Conclusion

The communal rangelands in the semi-arid Njemps Flats continue to be eroded and denuded, partly due to poor management as an open access resource. Nevertheless, semi-private land ownership indirectly reduces the grazing densities, resulting in less pronounced rangeland degradation. Active enclosure management, by removing undesirable species, installing water harvesting structures, preparing seedbeds and reseeding the rangeland, fostered a fast recovery of the grass cover and standing crop, and promoted the regeneration of annual as well as perennial grasses. Within the given time frame, both private and communal enclosure management strategies were equally successful in rehabilitating the herbaceous cover, but the standing crop was significantly lower in the private enclosures. The results highlight the capacity of the individual herders' incentives to effectively promote rangeland rehabilitation. Yet, the analysis also demarcates a rather difficult vegetation restoration in some of the private and communal enclosures and therefore stresses the importance of a more detailed characterisation of the enclosure management strategies with careful monitoring of the adopted grazing and grass cutting frequencies. Future treatment designs should focus on revealing the impact of the individual management actions, i.e. inclusions of water harvesting structures, soil seedbed preparation, seed/planting densities, grass cutting and grazing intensities on rangeland rehabilitation, in order to identify the most cost-effective management strategy.

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