FULL TITLE:

VEGETATION, WILDLIFE AND LIVESTOCK RESPONSES TO PLANNED GRAZING MANAGEMENT IN AN AFRICAN PASTORAL LANDSCAPE

SHORT TITLE:

PLANNED GRAZING ENHANCES PASTORAL RANGELAND PRODUCTIVITY

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ABSTRACT

Rangelands are vital for wildlife conservation and socio-economic well-being, but many face widespread degradation due in part to poor grazing management practices. Planned grazing management, typically involving time-controlled rotational livestock grazing, is widely touted as a tool for promoting sustainable rangelands. However, real-world assessments of its efficacy have been lacking in communal pastoral landscapes globally, and especially in Africa. We performed landscape-scale assessment of the effects of planned grazing on selected vegetation, wildlife and cattle attributes across wide-ranging communally managed pastoral rangelands in northern Kenya. We found that planned grazing enhanced vegetation condition through a 17% increase in normalized difference vegetation index (NDVI), 45-234% increases in herbaceous vegetation foliar cover, species richness and diversity, and a 70% reduction in plant basal gap. In addition, planned grazing increased the presence (44%) and species richness (53%) of wild ungulates, and improved cattle weight gain (> 71%) during dry periods when cattle were in relatively poor condition. These changes occurred relatively rapidly (within 5 years) and despite grazing incursion incidents and higher livestock stocking rates in planned grazing areas. These results demonstrate, for the first time in Africa, the positive effects of planned grazing implementation in communal pastoral rangelands. These improvements can have broad implications for biodiversity conservation and pastoral livelihoods.

Keywords: Grazing management; Pastoral livelihoods; Biodiversity conservation; Rangeland productivity; Livestock production.

INTRODUCTION

Rangelands are important for biodiversity conservation and livestock production, and support the livelihoods of millions of people - many of them among the world‟s poor (Campos *et al*., 2016; Nadal-Romero *et al*., 2016). However, many rangelands are severely degraded due to anthropogenic and climatic factors, with grave consequences for people and wildlife (Lu *et al*., 2015; Zhang *et al*., 2016). Poor grazing management is often cited as a major contributor to rangeland degradation (Lesoli, 2011; Kiage *et al*., 2013; Carter *et al*., 2014; Nadal-Romero *et al*., 2016; Tóth *et al*., 2016) and can seriously impair rangeland sustainability (Ibáñez *et al*., 2014). Therefore, there is need for sustainable grazing management practices that enhance ecological and socio-economic values of rangeland systems. This need is particularly great in communal pastoral rangelands, such as those in Africa, which harbour some of the most severely degraded rangeland ecosystems in the world (Niamir-Fuller, 2000; AU-IBAR, 2012).

In the past, livestock grazing in pastoral rangelands in Africa was carried out in a semi-nomadic manner, with frequent changes in pasture allowing regeneration. Today, however, this livestock mobility has declined tremendously, due in part to government policies that encourage sedentarization of pastoralist communities. In Kenya, for example, establishment of group ranches where pastoralist groups are issued land titles has contributed to reduced mobility of pastoralists and their livestock (Ngethe, 1993). Reduced livestock mobility results in relatively permanent grazing, leading to overgrazing and land degradation (Niamir-Fuller, 2000; AU-IBAR, 2012; Groom & Western, 2013). This degradation negatively affects livestock productivity and pastoral livelihoods. Moreover, because these are unfenced rangelands that are commonly used by wildlife, their degradation affects biodiversity conservation (Georgiadis *et al*., 2007; Groom & Western, 2013).

One proposed solution to rangeland degradation is planned grazing management, typically involving establishing multiple paddocks among which livestock are rotated with variable grazing periods based on forage growth rate; grazing periods are shorter during rapid forage growth and vice versa (Savory, 1983; Angell, 1986). This approach is in many respects analogous to Voisin‟s rational grazing method (Voisin & Lacompte, 1962), but additionally incorporates other aspects including planning for drought, allocating forage to wildlife, using animals as a tool for land regeneration, and incorporating forage condition into grazing plans (Savory, 1999). The planned grazing management approach contrasts with the current scenario across many communal pastoral lands in Africa where livestock grazing is relatively continuous throughout the growing season, with no deliberate attempt to routinely rest the range or reserve some forage for wildlife.

Planned grazing has been heralded as a tool for improving rangeland condition for both wildlife and livestock (Savory, 1999; Neely & Hatfield, 2007). Its proponents argue that concentrated herds 1) break up compacted soil thereby increasing water infiltration and plant growth, 2) enhance seed burial, laying of litter, and dunging effects, and 3) graze less selectively thereby enhancing growth of palatable species; and that 4) time-controlled grazing rotations, with adequate rest periods, enhance plant recovery from defoliation. Despite these claims, however, there has been persistent debate on the value of this grazing management approach (Holecheck *et al*., 1999; Briske *et al*., 2008; 2014). This has been partly attributed to lack of large-scale, real-world scientific assessments that incorporate human variables such as goal setting, experiential knowledge and decision making (Briske *et al*., 2011). Moreover, such assessments have been lacking across communally managed pastoral rangelands, and especially those in Africa. Such evaluation is particularly critical because there has been growing interest in expanding the planned grazing approach across these rangelands (Skinner, 2010).

In this study, we assessed the effects of planned grazing management on selected attributes of vegetation, wildlife and livestock across wide-ranging communal rangelands in northern Kenya. In these rangelands, communal planned grazing implementation generally involves establishing multiple unfenced grazing blocks, and herding pooled community cattle rotationally among these blocks. Cattle are usually bunched (concentrated) using traditional herd control techniques to maximize animal impact (hoof action, dunging and urination) and reduce selective grazing. Grazing block residence time is usually a function of herd size, forage conditions (growth, quality and quantity; assessed visually), and the desired level of forage utilization (typically 50% to accommodate wild grazers). Cattle use of grazing blocks is usually tracked using livestock movement maps (see Figure S1 for example). Planned grazing implementation is usually spearheaded by a grazing committee comprised of community members. Further details on communal planned grazing implementation are presented in Appendix S1.

MATERIALS AND METHODS

Study area

The study was conducted across communal pastoral properties (group ranches) forming part of the Northern Rangelands Trust (NRT) in northern Kenya, namely, Il Motiok, Koija, Il Ngwesi, Leparua and West Gate (Figure 1). Rainfall in the study area is generally low (annual mean 189-430 mm; Figure S2). Generally, rainfall occurs bi-modally, with peaks in

April-June (long rains) and October-November (short rains); January, February and September are usually the driest months (Figure S2). The area is generally hot (mean annual temperature 16-33°C). The dominant vegetation is savanna grassland with varying densities of woody vegetation, primarily comprised by a mixture of several species of *Acacia*, *Commiphora*, *Balanites*, *Boscia* and *Grewia*. The study area is underlain by a mosaic of soil types including Regosols, Calcisols, Cambisols, Luvisols and Alisols (Figure S3; Batjes & Gicheru, 2004).

Pastoralism is the major land use system in the area, with cattle (*Bos indicus*), sheep (*Ovis aries*) and goats (*Capra aegagrus hircus*) dominant among livestock species. The area is also important for wildlife conservation, and supports a range of wild mammalian herbivores including elephants (*Loxodonta africana*), gerenuks (*Litocranius walleri*), plains zebras (*Equus burchelli*), Grevy"s zebras (*E. grevyi*), warthogs (*Phacochoerus aethiopicus*), reticulated giraffes (*Giraffa camelopardis*) and dik-diks (*Madoqua kirkii*).

Study design

To study vegetation and wildlife responses to planned grazing, we compared normalized difference vegetation index (NDVI), herbage foliar cover, herbaceous species richness and diversity and plant basal gap, and wild ungulate presence and species richness between sites where planned grazing had been ongoing for approximately 5 years and adjacent control sites where unplanned, relatively continuous grazing was proceeding. The planned grazing sites were located in Il Motiok, Il Ngwesi and a section of West Gate, while their corresponding adjacent unplanned grazing sites were in Koija, Leparua and the remaining section of West Gate, respectively (Figure 1). Hereafter, we refer to these site-pairs (also called „localities") as Il Motiok-Koija, Il Ngwesi-Leparua and West Gate. Notably, the planned and unplanned grazing areas in Il Motiok-Koija and Il Ngwesi-Leparua were managed by different pastoral communities, whereas those in West Gate were managed by the same community.

For each grazing treatment (planned vs. unplanned) site within each locality, we established five (50 m x 50 m) plots for basal plant gap and NDVI measurements, and 25 (20 m x 20 m) plots for all other vegetation and wildlife measurements. At each site, the 20 m x 20 m plots were arranged systematically along five transects (five plots per transect), with an interval of approximately 50 m between successive plot centers. The middle plot along each transect was nested within the larger (50 m x 50 m) plot. The minimum inter-transect distance was approximately 150 m. Transects were oriented approximately north-south. Plots were opportunistically placed in areas easily accessible by road, but were at least 50 m from road margins. For each locality, all plots were located within approximately 5 km from the common border separating the planned and unplanned grazing sites (Figure 1).

Within each locality, experimental plots were established on areas with similar soil and topographical characteristics. Using a soil map for the area (Figure S3), we confirmed whether plots met these conditions; two plots in Il Ngwesi-Leparua did not, and were consequently excluded from the study. Notably, some communities occasionally carry out rangeland restoration activities, including mechanical control of invasive plants, gully healing and reseeding within designated areas. We identified all such areas and excluded them from sampling.

To assess cattle response, we monitored cattle performance (weight gains) in planned and unplanned properties in Il Ngwesi-Leparua (Il Ngwesi [planned] vs. Leparua [unplanned]) and Il Motiok-Koija (Il Motiok [planned] vs. Koija [unplanned]). For each Il Ngwesi-Leparua property, we randomly selected 20 test heifers owned by three to six different families. For each Il-Motiok-Koija property, we randomly selected five test heifers from each of five herds owned by different families. All test heifers were *Bos indicus* aged approximately 2 years.

We estimated stocking rates using information on livestock numbers and grazing periods across the sampled properties obtained from group ranch chairmen (for unplanned properties) and grazing coordinators (for planned properties; see Appendix S1 for further details). On average, small stock (sheep and goats) and cattle stocking rates were 113% and 23%, respectively, higher in planned than unplanned grazing areas (Table 1). Notably, stocking rates for the planned grazing areas could even be higher if grazing incursions are considered.

It is noteworthy that planned grazing implementation is usually challenging in these communal rangelands due to unwanted access to planned grazing areas by livestock from within or outside the implementing properties. Such grazing incursions are usually exacerbated during periods of adverse weather conditions and forage shortage. These incidents were relatively common during 2014-2015 due to adverse weather conditions. It was not possible to eliminate grazing incursions during this study.

Vegetation and wildlife surveys

Using the centres of the 50 m x 50 m plots as reference points, we extracted NDVI values for the periods before (June 2007-February 2010) and after (June 2010-February 2015) planned grazing inception (see Methods S1 for further details). We measured plant basal gap once during August-September 2014 in Il Motiok-Koija and Il Ngwesi-Leparua, and during January 2015 in West Gate. The weather was generally dry during these periods, and cattle were absent from the sampled sites. Basal gap was measured along four line transects placed within each 50 m x 50 m plot. All the transects originated approximately 2 m from the plot center and terminated at the mid-point of either the northern, eastern, southern or western plot margin. Along each transect, we measured the gap between the bases of successive individual herbaceous plants that occurred within 1 cm of the transect line, ignoring gaps less than 20 cm.

Herbage foliar cover and species richness and diversity were estimated during two sampling periods; February-March 2015 (dry period) and June 2015 (wet period). Cattle had utilized and were absent from all sampling sites in February-March. During sampling in June 2015, cattle had just started returning and had access to both planned and unplanned sampling sites. Foliar cover was measured using the point-step method along four line transects systematically located within each 20 m x 20 m plot. All transects originated approximately 1m from the center and terminated at the corner of the plot. The sampling procedure involved pacing and vertically placing a 1-m pin perpendicularly to the ground after every one step 10 times along each transect, and recording the first pin hits with herbaceous vegetation by species. Pins not intercepted by vegetation were recorded as bare hits. For each plot, we calculated foliar cover for individual herbage species as percentage of pins that hit the respective species. We used these data to calculate foliar cover for grasses (including sedges), forbs and total herbage. We calculated total herbage, grass and forb species richness as the total number of species hit by the pin. In addition, we used the pin hit data to calculate Shannon"s diversity indices for total herbage, grasses and forbs.

Concurrent with vegetation sampling in February-March 2015, we conducted wildlife dung surveys in each of the 20 m x 20 m plots (five plots per transect, five transects per site). Each plot was visually inspected and the presence of droppings of different wild ungulate species recorded. Wild ungulate species richness was estimated for each transect as the total number of species whose droppings were encountered within plots associated with that transect.

Cattle performance measurement

Using a portable weighing scale, we measured live weights of the test heifers at the start and end of April-June 2014 (wet period) and July-September 2014 (dry period) in Il Ngwesi-Leparua, and June-July 2015 (wet period) and July-August 2015 (dry period) in Il Motiok-Koija. Test heifers were maintained within their respective herds throughout sampling. The sampled cattle herds grazed within their respective properties throughout sampling, except Leparua herds which migrated in search of better forage elsewhere. Sampling in Il Ngwesi was performed when cattle were actively involved in planned grazing. In Il Motiok, however, we sampled before planned grazing resumed, but cattle had access to the planned grazing area.

We calculated daily weight gain for each test heifer per sampling period by dividing live weight change by the total number of days corresponding to that change. Several test heifers were unavailable for weighing (12 in Il Ngwesi-Leparua [five in wet period, seven in dry period] and eight in Il Motiok-Koija [three in wet period, five in dry period,]) and were therefore excluded from the study.

Data analysis

For each continuous dependent variable, we pooled data per sampling unit (plot, transect or test heifer) per sampling period, and performed a linear mixed-effects model with grazing system (unplanned vs. planned) as a fixed factor. Additional fixed factors were month (February vs. June), time period (before vs. after planned grazing initiation) for NDVI; and season (wet vs. dry) for all other vegetation attributes and cattle performance. Where applicable, interactions between fixed factors were included in the model. For vegetation and wildlife attributes, random factors were localities (Il Motiok-Koija, Il Ngwesi-Leparua and West Gate) and plots or transects (nested within localities). For cattle performance, we analysed each locality separately, specifying individual test heifers (nested within families) as random factors. For wildlife presence or absence (dichotomous) data, we first categorized wildlife species based on body size; mesoherbivores (warthogs, dik-diks, gerenuks, lesser kudu, zebras and impalas) and megaherbivores (elephants and giraffes). We then performed a generalized linear mixed-effects logistic regression model to test for the effects planned grazing on the presence of each herbivore guild, specifying localities, transects and plots as random factors.

We used the packages *nlme* (Pinheiro *et al*., 2016) and *lme4* (Bates *et al*. 2015) in the R environment (R 3.2.3; R Core Team, 2015) for linear mixed-effects and generalized linear mixed-effects models, respectively. Models for cattle performance and all vegetation characteristics (excluding basal gap) included an autoregressive AR(1) covariance structure to address the non-independence of repeated measures on the same subjects (transects, plots or test heifers). We checked normality and homoscedasticity of linear mixed-effects model residuals using graphical tools (histograms and QQ plots), and transformed data when necessary to meet model assumptions. Obvious violation of homoscedasticity even after transformation necessitated incorporation of the variance structure *varIdent* into the model to allow unequal variances between groups. Significant differences were accepted at $P < 0.05$. Tukey"s post-hoc test was used to separate means for significant interaction terms. We report all data as untransformed estimates. R scripts, full statistical models and outputs are presented in Appendix S2.

RESULTS

Vegetation characteristics

Normalized difference vegetation index (NDVI) did not differ ($P = 0.320$) between sites before inception of planned grazing, but was 17% higher ($P < 0.001$) in planned than unplanned grazing sites after planned grazing initiation (grazing system x time period interaction $F_{1,369} = 4.9$, $P = 0.034$; Figure 2). In addition, NDVI was significantly greater after than before planned grazing commencement for sites managed under planned grazing ($P = 0.018$) but not for unplanned grazing sites ($P = 0.996$).

Overall, we encountered 79 herbaceous plant species; 45 forbs, 32 grasses and two sedges across the sampled sites (Table S1). Herbaceous plant basal gap was 70% smaller in planned than unplanned grazing sites (44.4 cm ± 3.1 [SE] vs. 146.5 cm ± 28.1; $F_{1.26} = 11.3$, $P = 0.002$). Conversely, total herbage and grass attributes were 45-234% higher in planned than unplanned grazing sites (all $P < 0.001$; Figure 3 & Table 2). However, forb attributes did not differ significantly between these sites (Figure 3 & Table 2).

Wildlife and cattle responses

Grazing system significantly influenced wild ungulate presence, with both guilds occurring more frequently in planned than unplanned grazing sites (mesoherbivores $b = 1.3$, SE = 0.5, z = 2.9, $P = 0.004$; megaherbivores $b = 1.7$, SE = 0.6, z = 3.0, $P = 0.003$; Figure 4). Overall wild ungulate species richness was 53% higher in planned than unplanned grazing sites ($F_{1,24}$ = 16.3, $P < 0.001$; Figure 4).

Cattle performance was influenced by an interaction between grazing system and season (Il Ngwesi-Leparua $F_{1,27}$ = 8.4, $P = 0.007$; Il Motiok-Koija $F_{1,39}$ = 12.0, $P = 0.001$; Figure 5). Specifically, during dry (but not during wet) period, cattle performed significantly better under planned grazing. Notably, in Il Ngwesi-Leparua, both treatment groups lost weight during the dry period, but this loss was 71% less for cattle under planned grazing. In Il Motiok-Koija, cattle in planned grazing areas gained weight while those in unplanned grazing areas lost weight during dry period.

DISCUSSION

In this first real-world assessment of planned grazing management in African communal pastoral rangelands, we found enhanced vegetation, wildlife and cattle conditions following its implementation. These improvements were seen across wide-ranging actively managed pastoralist areas. To our knowledge, these are the first findings to show positive outcomes from large-scale communal implementation of planned grazing. These results are even more striking considering that planned grazing had been in place for as few as 5 years on the sampled communal properties, while unplanned grazing had preceded it for several decades (Grandin, 1987; Ngethe, 1993). These relatively rapid responses suggest that these communal pastoral rangelands are fairly resilient and can quickly recover when subjected to appropriate grazing management practices.

Moreover, these improvements were evident despite higher livestock stocking rates in planned grazing areas. This is significant because increased stocking would normally be expected to have negative effects on vegetation, cattle and wildlife (Fynn & O'Connor, 2000; Mishra *et al*., 2004; Clark *et al*., 2013). These improvements suggest that the benefits of planned grazing practices can outweigh any undesirable effects of increased stocking rate. Further, these improvements were evident despite incidents of incursion grazing in planned grazing areas. However, it is notable that NDVI increase was smallest in 2014-2015, possibly due to increased incidents of incursion grazing following a prolonged drought. This suggests that such incidents may retard the progress of rangeland regeneration under planned grazing management.

Because forb attributes did not differ significantly between planned and unplanned grazing sites, the observed improvements in the overall herb-layer vegetation attributes primarily resulted from changes in grass attributes. The non-responsiveness of forbs could possibly be attributed to the more than twice higher small stock (sheep and goats) stocking levels in planned than unplanned grazing areas (see Table 1). In these rangelands, sheep and goats (unlike cattle) have been shown to have strong preference for forbs (Lusigi *et al*., 1984; Coppock *et al*., 1986). Consequently, their increased stocking in planned grazing areas may have hindered the recovery of forbs. Therefore, controlling the stocking levels of these small ruminants may be necessary for meaningful response of forbs to planned grazing in these communal rangelands.

The demonstrated improvements in vegetation attributes appear to have been large enough to benefit both livestock and wildlife. This is evidenced by the observed concomitant large increases in the presence and species richness of wild ungulates, and improved dry season performance of cattle in planned grazing areas. Consistent with these findings, comparable vegetation improvements have been shown to trigger positive responses by wild and domestic herbivores in other Kenyan rangeland systems (Young *et al*., 2005; Odadi *et al*., 2011a; 2011b; Groom & Western, 2013).

Pooling community cattle into one large herd (for planned grazing) may suppress cattle performance through increased intraspecific competition (Odadi & Rubenstein, 2015). In the present study, however, cattle performed better under planned grazing even when pooled (in Il Ngwesi), indicating that the benefits of improved forage conditions under planned grazing outweighed the effects of increased herd size. Moreover, in Il Ngwesi-Leparua, planned grazing cattle performed better than their unplanned grazing counterparts during the dry season despite the latter group having migrated in search of better forage elsewhere. This indicates that planned grazing management better cushions cattle against excessive dry season weight loss, and may therefore reduce the need for frequent cattle migrations during such periods.

Beyond the direct effects on vegetation attributes that we observed, additional benefits may be accruing to the communal rangelands due to planned grazing. The reduced plant basal gap and increased herbage foliar cover (and thus lower percentage bare soil) in planned grazing areas may reduce soil erosion, thereby lessening land degradation. Additionally, we propose that the higher foliar cover in planned grazing areas is likely to be associated with increased soil water infiltration, which could lead to further positive feedback on herb-layer vegetation structure and composition (Weber & Gokhale, 2011).

The non-significant NDVI difference between sites before planned grazing initiation suggests that the sites were in similar initial condition and therefore the vegetation improvements reported here are primarily attributable to planned grazing management. Planned grazing as practiced in our study region involves time-controlled grazing and frequent rotation of concentrated communal cattle herds. While the actual mechanisms underlying the observed vegetation improvements are unclear, we propose that they resulted from adequate rest periods and ensuing enhanced plant recovery from defoliation. Specifically, frequent rotations and rests under planned grazing appear to be critical in enhancing herbage production in these pastoral lands. In unplanned grazing areas, herbaceous plants are permanently subjected to defoliation which may lower primary productivity. Additionally, the higher herbaceous plant diversity in areas under planned grazing could be partly attributed to more even distribution of grazing pressure and reduced forage selectivity by concentrated cattle herds.

We further posit that the observed vegetation improvements may have been driven by enhanced soil condition in planned grazing areas. Although soil properties were not directly measured in the present study, an assessment in Il Motiok-Koija shows improved soil conditions under planned grazing (Lutta Alphayo, unpublished data). Similarly, previous studies elsewhere have reported improved soil attributes under the planned grazing management approach (Sanjari *et al*., 2008; Sanjari *et al*., 2009; Weber & Gokhale, 2011).

We propose that the improvements demonstrated here were reinforced by increased involvement of the pastoralists in managing their land. In particular, pastoralists practicing planned grazing are routinely involved in forage condition assessment and making key decisions regarding when, and for how long, to graze or rest different portions of their land. These actions appear to be vital in ensuring successful implementation of planned grazing, which is key to achieving positive results. We suggest that the success of planned grazing management hinges on pastoralist communities being able to make critical decisions that lead to controlled timing of livestock grazing and resting of the land for enhanced vegetation recovery.

CONCLUSIONS

Planned grazing management as practiced in our study system enhanced vegetation conditions, thereby triggering positive wildlife and livestock responses. Notably, planned grazing implementation in these communal rangelands often faces disruptions due to adverse weather conditions and incursion grazing. Despite these challenges, we still see its positive benefits, suggesting that even non-continuous or interrupted communal planned grazing has measurable benefits. However, we suggest that these benefits could be amplified by strengthening community governance systems to minimize grazing incursions. Our findings demonstrate that planned grazing management can improve forage, wildlife and livestock conditions in communally managed pastoral rangelands. These enhancements can have broad positive implications for wildlife conservation and pastoral livelihoods. We recommend further long-term investigations to ascertain the sustainability of these improvements, and the key mechanisms underlying these changes.

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REFERENCES

Angell, RF. 1986. Short duration grazing. In Proceedings of the Short Duration Grazing and Current Issues in Grazing Management Shortcourse held January 21-23, 1986 at Kennewick, Washington, Tiedeman JA (ed). Washington State University, Pullman, Washington, USA; 151-157.

AU-IBAR (African Union-Interafrican Bureau for Animal Resources). 2012. Rational Use of Rangelands and Fodder Crop Development in Africa, AU-IBAR Monographic Series No. 1, AU-IBAR, Nairobi, Kenya.

Bates D, Maechler M, Bolker B, Walker S. 2015. Fitting Linear Mixed-Effects Models Using lme4. *Journal of Statistical Software* **67**: 1-48. DOI:10.18637/jss.v067.i01

Batjes NH, Gicheru, P, 2004. Soil data derived from SOTER for studies of carbon stocks and change in Kenya (ver. 1.0; GEFSOC Project). Report 2004/01, ISRIC - World Soil Information, Wageningen.

Briske DD, Derner JD, Brown JR, Fuhlendorf SD, Teague WR, Havstad KM, Gillen RL, Ash AJ, Willms WD. 2008. Rotational grazing on rangelands: reconciliation of perception and experimental evidence. *Rangeland Ecology & Management* **61**: 3–17. DOI:10.2111/06-159R.1.

Briske DD, Sayre NF, Huntsinger, L, Fernandez-Gimenez M, Budd B, Derner JD. 2011. Origin, persistence, and resolution of the rotational grazing debate: integrating human dimensions into rangeland research. *Rangeland Ecology and Management* **64**: 325–334. DOI:10.2111/REM-D-10-00084.1.

Briske DD, Ash AJ, Derner JD, Huntsinger L. 2014. Commentary: A critical assessment of the policy endorsement for holistic management. *Agricultural Systems* **125**: 50–53. DOI:10.1016/j.agsy.2013.12.001.

Campos P, Ovando P, Mesa B, Oviedo JL. 2016. Environmental income of livestock grazing on privately-owned silvopastoral farms in Andalusia, Spain. *Land Degradation & Development*. DOI:10.1002/ldr.2529.

Carter J, Jones A, O‟Brien M, Ratner J, Wuerthner G. 2014. Holistic management: misinformation on the science of grazed ecosystems. *International Journal of Biodiversity*. DOI:10.1155/2014/163431.

Clark A, DelCurto T, Vavra M, Dick BL. 2013. Stocking rate and fuels reduction effects on beef cattle diet composition and quality. *Rangeland Ecology & Management* **66**: 714–720. DOI: 10.2111/REM-D-12-00122.1.

Coppock DL, Ellis JE, Swift DM. 1986. Livestock feeding ecology and resource Utilization in a nomadic pastoral ecosystem. *Journal of Applied Ecology* **23**: 573-583.

Fynn RWS, O‟Connor TG. 2000. Effect of stocking rate and rainfall on rangeland dynamics and cattle performance in a semi-arid savanna, South Africa. *Journal of Applied Ecology* **37**: 491-507. DOI: 10.1046/j.1365-2664.2000.00513.x.

Georgiadis NJ, Olwero JGN, Ojwang G, Romanach SS. 2007. Savanna herbivore dynamics in a livestock-dominated landscape: I. Dependence on land use, rainfall, density, and time. *Biological Conservation* 137: 461–472. DOI:10.1016/j.biocon.2007.03.005.

Grandin BE. 1987. Pastoral Culture and Range Management: Recent Lessons from Maasailand. *ILCA Bulletin*, No. 28, September, 1987. ILCA, Addis Ababa, Ethiopia.

Groom RJ, Western D. 2013. Impact of land subdivision and sedentarization on wildlife in Kenya's southern rangelands. *Rangeland Ecology & Management* **66**: 1-9. DOI: 10.2111/REM-D-11-00021.1.

Holecheck JL, Gomez H, Molinar F, Galt D. 1999. Grazing studies: what we‟ve learned. *Rangelands* **21**: 12–16.

Ibáñez J, Lavado Contador JF, Schnabel S, Pulido Fernández M, Martínez Valderrama J. 2014. A model-based integrated assessment of long-term soil degradation by water erosion in a valuable Spanish rangeland. *Environmental Modelling and Software* **55**: 201–213. DOI: 10.1016/j.envsoft.2014.01.026.

Kiage LM. 2013. Perspectives on the assumed causes of land degradation in the rangelands of Sub-Saharan Africa. *Progress in Physical Geography* **37**: 664–684. DOI: 10.1177/0309133313492543.

Lesoli MS. 2011. Characterisation of Communal Rangeland Degradation and Evaluation of Vegetation Restoration Techniques in the Eastern Cape, South Africa (Ph.D Thesis), University of Fort Hare. Eastern Cape, South Africa.

Lu X, Yan Y, Sun J, Zhang X, Chen Y, Wang X, Cheng G. 2015. Short-term grazing exclusion has no impact on soil properties and nutrients of degraded alpine grassland in Tibet, China. *Solid Earth*, **6**: 1195-1205. DOI: 10.5194/se-6-1195-2015.

Lusigi WJ, Nkurunzinza ER, Masheti S. 1984. Forage preferences of livestock in the arid lands of northern Kenya. *Journal of Range Management* **37**: 542-548.

Mishra C, Van Wieren SE, Ketner P, Heitkönig IMA, Prins HHT. 2004. Competition between domestic livestock and wild bharal *Pseudois nayaur* in the Indian Trans-Himalaya. *Journal of Applied Ecology* 41: 344-354. DOI: 10.1111/j.0021-8901.2004.00885.x.

Nadal-Romero E, Lasanta T, Cerdà A. 2016. Integrating extensive livestock and soil conservation policies in Mediterranean mountain areas for recovery of abandoned lands in the central Spanish Pyrenees. A long-term research assessment. *Land Degradation & Development*. DOI:10.1002/ldr.2542.

Neely CL, Hatfield R. 2007. Livestock systems, in Scherr SJ, McNeely JA (Eds.), Farming with Nature: the Science and Practice of Ecoagriculture. Island Press, Washington, DC, pp 121–142.

Ngethe JC. 1993. Group ranch concept and practice in Kenya with special emphasis on Kajiado District, in Kategile JA, Mubi S (Eds.), Future of Livestock Industries in East and Southern Africa. Proceedings of the Workshop held at Kadoma Ranch Hotel, Zimbabwe 20-23 July 1992. ILCA, Addis Ababa, Ethiopia. pp 187-200.

Niamir-Fuller M. 2000. Managing mobility in African rangelands, in McCarthy N, Swallow B, Kirk M, Hazell P (Eds.), Property Rights, Risk, and Livestock Development in Africa. International Food Policy Research Institute, Washington, DC, pp 102–131.

Odadi WO, Karachi MK, Abdulrazak SA, Young TP. 2011a. African wild ungulates compete with or facilitate cattle depending on season. *Science* **333**: 1753–1755. DOI:10.1126/science.334.6056.594-d.

Odadi WO, Jain M, Van Wieren SE, Prins HHT, Rubenstein DI 2011b. Facilitation between bovids and equids on an African savanna. *Evolutionary Ecology Research* **13**: 237–252.

Odadi WO, Rubenstein DI. 2015. Herd size-dependent effects of restricted foraging time allowance on cattle behavior, nutrition, and performance. Rangeland Ecology & Management **68**: 341–348. DOI:10.1016/j.rama.2015.05.009.

Pinheiro J, Bates D, DebRoy S, Sarkar D., R Core Team. 2016. *nlme: Linear and Nonlinear Mixed Effects Models*. R package version 3.1–128, http://CRAN.R-project.org/package=nlme.

R Core Team. 2015. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

Sanjari G, Ghadiri H, Ciesiolka CAA, Yu B. 2008. Comparing the effects of continuous and time-controlled grazing systems on soil characteristics in Southeast Queensland. *Soil Research* **46**: 348–358. DOI:10.1071/SR07220.

Sanjari G, Yu B, Ghadiri H, Ciesiolka CAA, Rose CW. 2009. Effects of time-controlled grazing on runoff and sediment loss. Soil Research **47**: 796–808. DOI:10.1071/SR09032.

Savory A. 1983. The Savory Grazing Method or Holistic Resource Management. *Rangelands* 5: 155-159.

Savory A. 1999. Holistic Management: A New Framework for Decision Making, Island Press, Washington, DC.

Skinner D. 2010. Rangeland Management for Improved Pastoralist Livelihoods: The Borana of Southern Ethiopia (MA thesis), Oxford Brookes University, Oxford, UK.

Tóth E, Deák B., Valkó O., Kelemen A., Miglécz T., Tóthmérész B., Török P. 2016. Livestock type is more crucial than grazing intensity: traditional cattle and sheep grazing in short-grass steppes. *Land Degradation & Development*. DOI:10.1002/ldr.2514.

Voisin A., Lecomte A. 1962. Rational grazing, the meeting of cow and grass: a manual of grass productivity. C. Lockwood LTD, London, UK.

Weber KT, Gokhale, BS. 2011. Effect of grazing on soil-water content in semiarid rangelands of southeast Idaho. *Journal of Arid Environments* **75**: 464–470. DOI:10.1016/j.jaridenv.2010.12.009.

Young TP, Palmer TM, Gadd ME. 2005. Competition and compensation among cattle, zebras, and elephants in a semi-arid savanna in Laikipia, Kenya. *Biological Conservation* **122**: 351–359.

Zhang M, Wu J, Tang Y. 2016. The effects of grazing on the spatial pattern of elm (*Ulmus pumila* L.) in the sparse woodland steppe of Horqin Sandy Land in northeastern China. *Solid Earth*, **7**: 631-637. DOI:10.5194/se-7-631-2016.

Table 1. Livestock stocking rates and planned grazing commencement dates for the sampled properties.

	Koija Unplanned	Il Motiok Planned	Leparua Unplanned	Il Ngwesi Planned	West Gate Unplanned	West Gate Planned
Total area (ha)	7,605	3,651	34,551	2,695	39,006	1,014
Planned area (ha)	0	2,000	0	2,128	0	1,014
Number of blocks		4		7		5
Planned grazing start date		April 2010		April 2010		June 2010
TLUs						
Cattle	1,656	497	4,968	331	5,796	254
Sheep and goats	608	228	912	304	1,710	456
Grazing duration (days $year^{-1}$)						
Cattle	180	128	240	365	150	105
Sheep and goats	365	365	365	365	300	60
TLU ha^{-1}						
Cattle	0.11	0.09	0.09	0.16	0.06	0.07
Sheep and goats	0.08	0.11	0.03	0.14	0.04	0.07
Combined	0.19	0.20	0.12	0.30	0.10	0.14

TLU = Tropical Livestock Unit (1 TLU = 250kg live weight).
Livestock numbers were converted to live biomass using 207 kg (cattle) and 19 kg (sheep and goats) (see Georgiadis *et al*., 2007).

Table 2. Results of linear mixed-effects models of herbage characteristics in response to grazing system (planned vs. unplanned) and sampling periods (dry vs. wet). Degrees of freedom: system 1,26; period and system x period 1,28.

	Overall		Grasses		Forbs	
	F	*P*	*F*	*P*	*F*	*P*
Foliar cover						
System	70.5	< 0.001	57.8	< 0.001	< 0.1	0.923
Period	18.5	< 0.001	14.3	< 0.001	12.4	0.002
System* Period	< 0.1	0.982	0.3	0.577	0.2	0.655
Species richness						
System	86.4	< 0.001	40.7	< 0.001	2.5	0.126
Period	12.4	0.002	9.4	0.005	6.2	0.019
System* Period	0.2	0.622	0.3	0.616	0.1	0.730
Species diversity						
System	82.5	< 0.001	62.3	< 0.001	0.2	0.662
Period	8.1	0.008	6.8	0.014	3.4	0.074
System* Period	< 0.1	0.909	0.2	0.639	0.4	0.536

Figure Captions

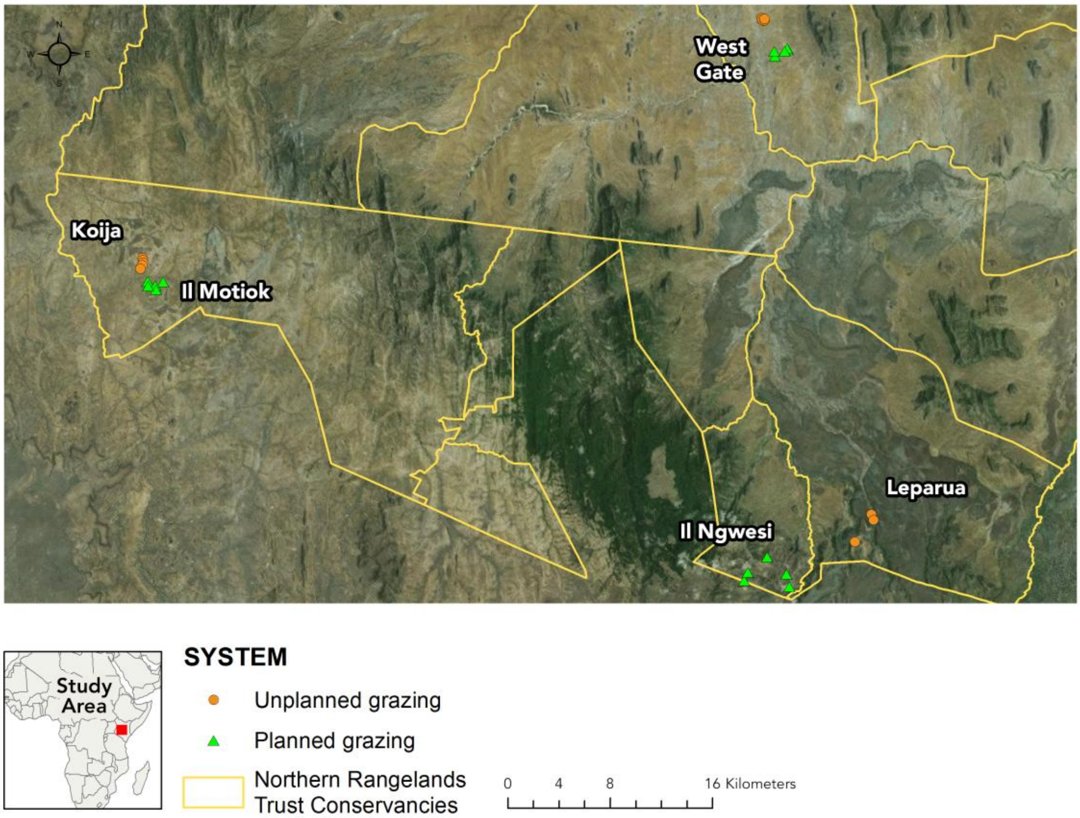

Figure 1. Location of sampled properties and associated study plots and grazing treatments. Points represent the centers of the 50 m x 50 m plots.

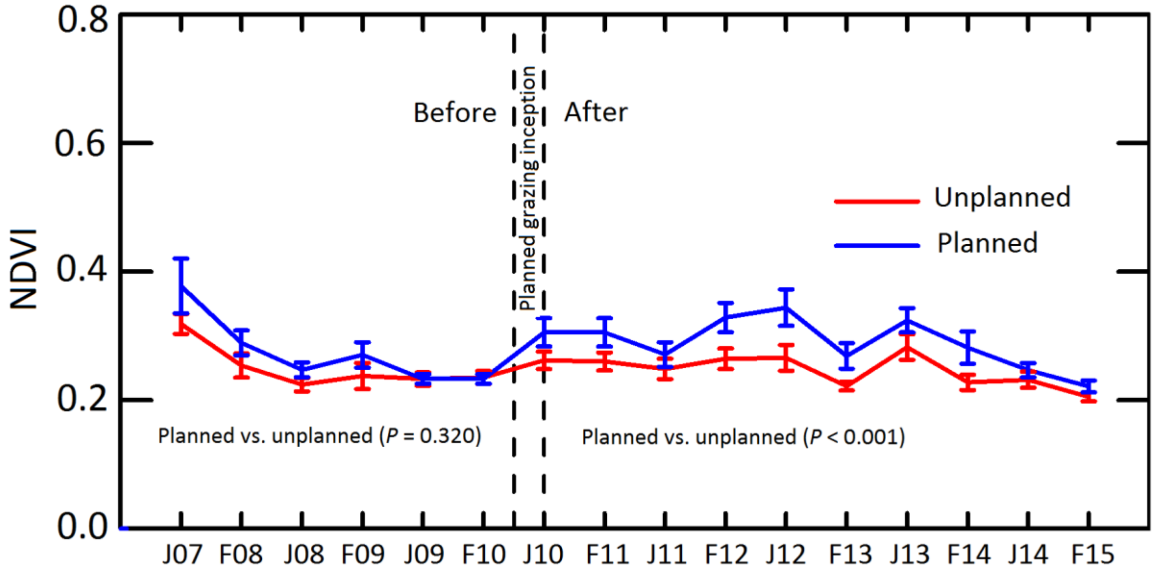

Figure 2. Normalized difference vegetation index (NDVI; mean ± standard error) across study sites before and after planned grazing initiation. On the x-axis, letters "J" and "F" represent June and February, respectively while digits represent years (e.g. "07" = 2007).

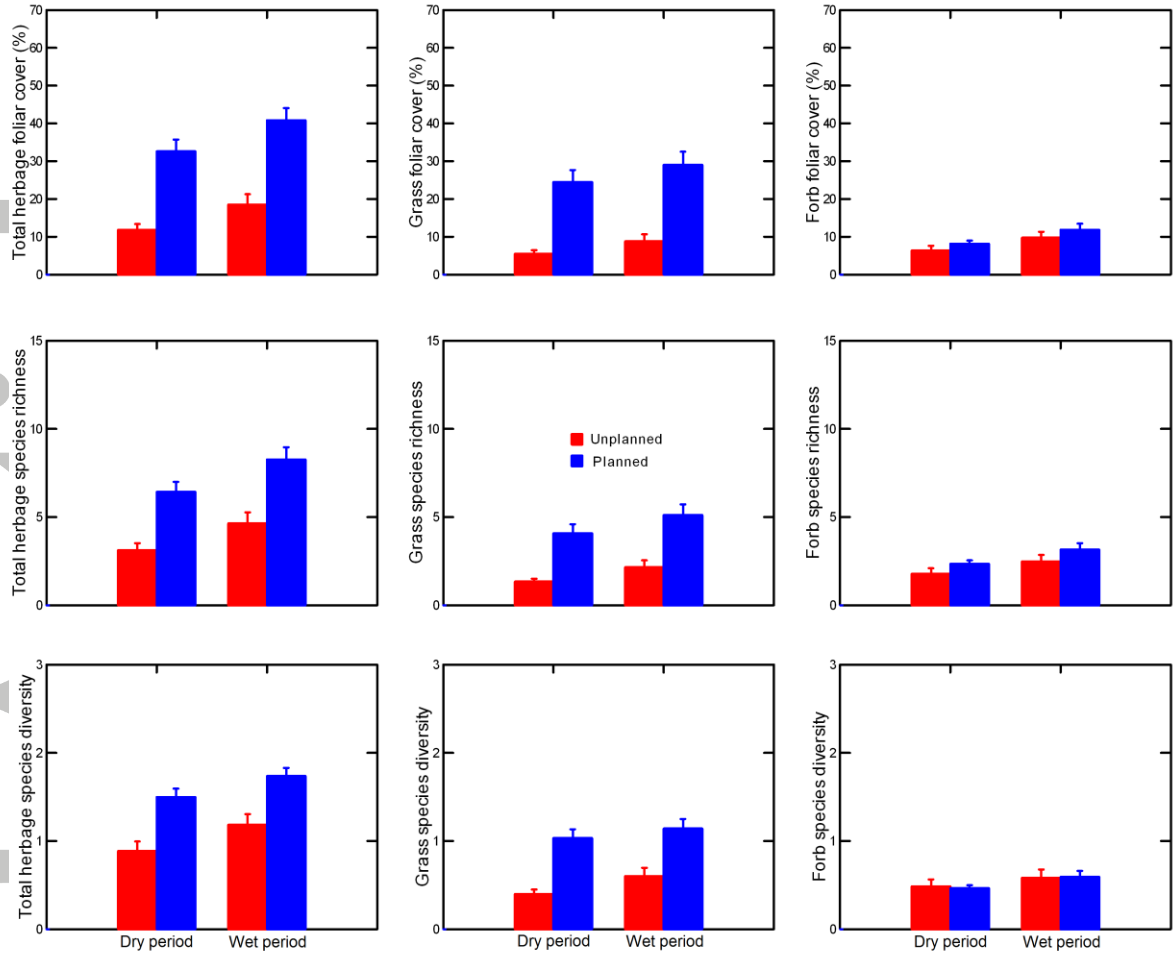

Figure 3. Herbaceous vegetation foliar cover, species richness and Shannon‟s diversity indices (means ± standard error) across planned and unplanned grazing sites. Associated statistical results are presented in Table 2.

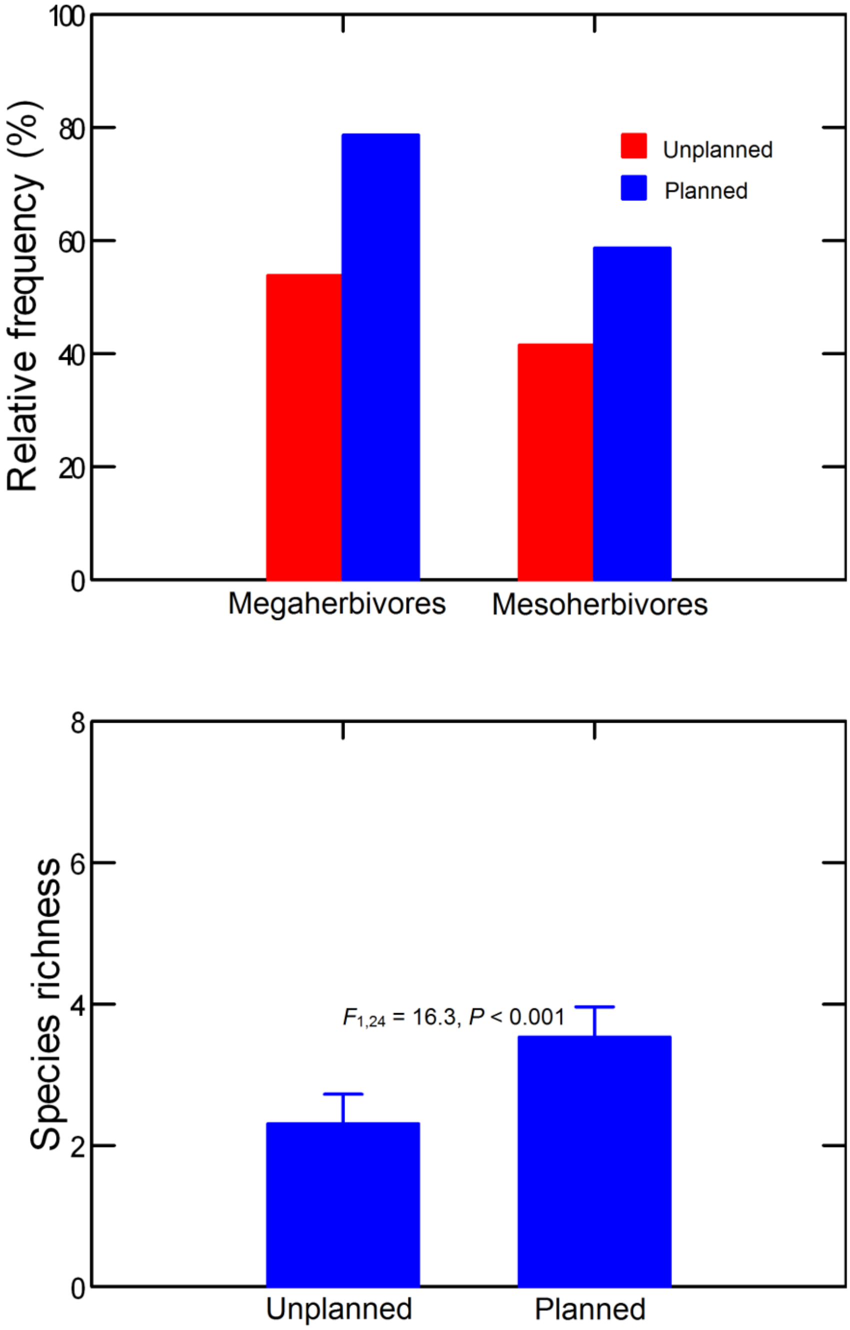

Figure 4. Relative frequency and species richness (mean ± standard error) of wild herbivores across planned and unplanned grazing sites.

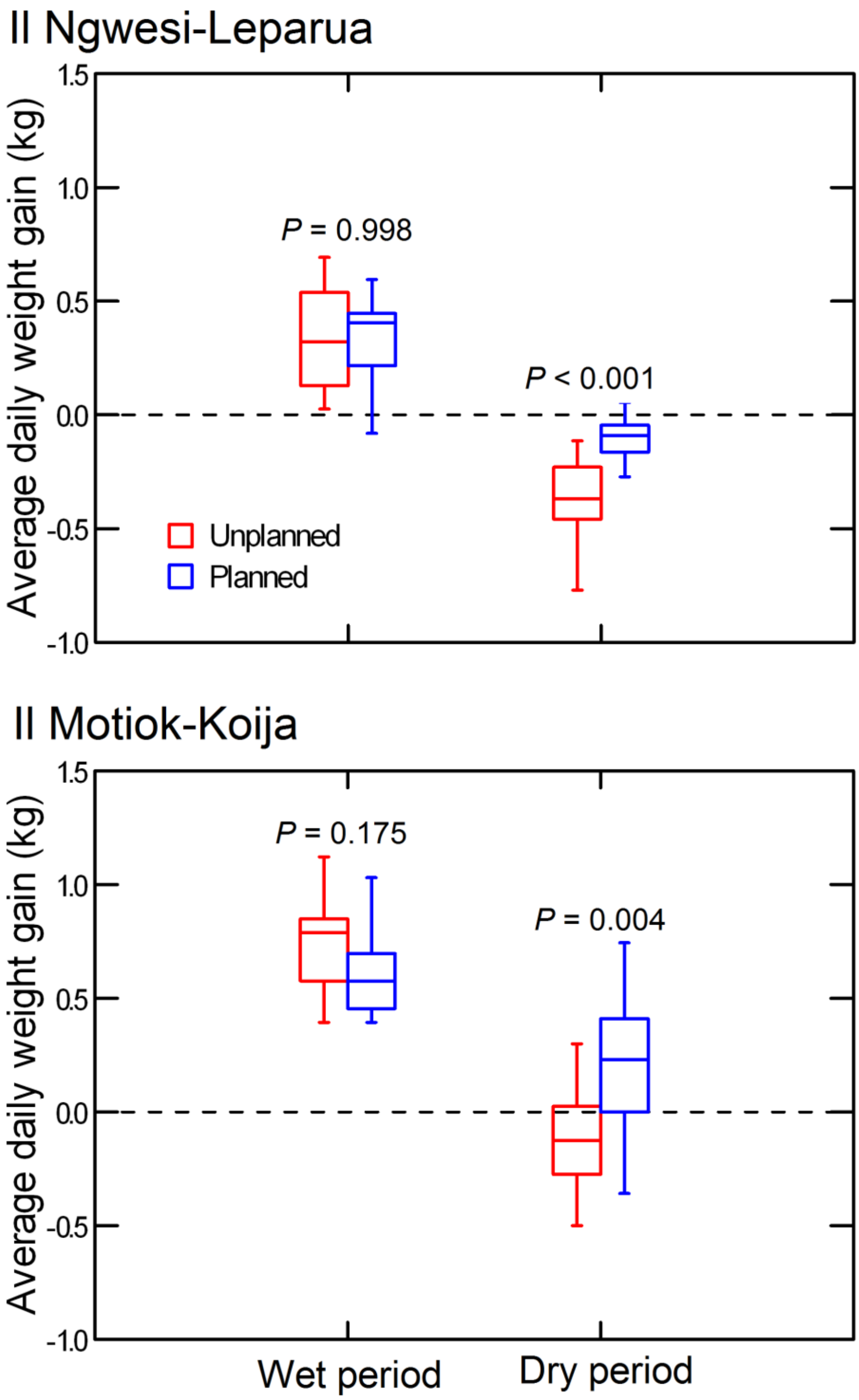

Figure 5. Performance of pastoral cattle under planned and unplanned grazing management. The figures show median weight gains (lines), 25% to 75% quartiles (boxes), and ranges (whiskers).