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Review

A meta-analysis of the effects of communal livestock grazing on vegetation and soils in sub-Saharan Africa

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ABSTRACT

Extensive livestock grazing is one of the most common and widespread forms of land uses in sub Saharan Africa (SSA). Studies assessing the effects of extensive livestock grazing on vegetation and soils in SSA are inconsistent in the direction and magnitude of study outcomes. We applied meta-analysis to identify whether studies so far conducted in the rangeland systems of SSA have detected significant rangeland degradation as approximated by changes in vegetation attributes (reduction in species diversity and richness; decreased biomass and ground cover; increased woody species density and canopy cover) and soil properties (Decreased soil OC, N and P). We quantified results of the included studies using the response ratio, which is the log proportional change in the means of a treatment and a control group. Four moderator variables (elevation (<1500 and ≥1500 m above sea level); plant life form (herbaceous and woody), rainfall amount (<600 mm and ≥600 mm), rainfall modality (mono and bimodal), and soil texture (Loam, sandy, sandy loam)) appeared to affect the response of species diversity and richness patterns to different grazing regimes, i.e., communal grazing systems, exclosures, livestock ranches and game reserves. Species diversity and richness values were generally lower in the communal grazing systems compared to the other grazing regimes. Only three moderator variables (rainfall amount and modality, and soil texture) affected the herbaceous basal cover response. Differences in soil OC were highest between communal and exclosure areas, visible at high elevations and under high rainfall. Soil N was influenced by rainfall modality and soil texture. We conclude that the effects of grazing regimes onto the environment cannot be generalized but are specific across vegetation and soil variables and differ considerably with rainfall and elevation.

1. Introduction

Extensive livestock grazing is one of the most common and widespread forms of land uses in sub Saharan Africa (SSA). The effect of grazing by livestock on the vegetation and soils of rangelands is highly variable and has been debated in both technical and development policy dimensions (Ellis and Swift, 1988; Milton et al., 1994). Despite their large area coverage and recognized importance to the local pastoral economy, there has been various reports that associate extensive grazing with degradation (Lamprey, 1983; Dodd, 1994; Milton et al., 1994; Kraaija and Milton, 2006; Rutherford and Powrie, 2011). Although debatable, the following major factors are perceived to threaten the sustainability of most communal grazing systems: desertification, woody encroachment and deforestation (Asner et al., 2004; Ward, 2005; Biggs et al., 2008). Studies assessing the effects of extensive livestock grazing on vegetation and soils in SSA are inconsistent in the direction and magnitude of study outcomes (Anderson and Hoffman, 2007).

The presence of highly variable effect sizes has led to heightened debates about the effectiveness of traditional grazing systems (Illius and O'Connor, 1999; Sullivan and Rohde, 2002). The lack or insufficiency of general quantitative syntheses highlights the need for a comprehensive analysis, which is particularly imperative for SSA where a significant part of the land is used for grazing livestock (Todd and Hoffman, 2009).

Meta-analysis has emerged as a powerful quantitative approach to address many ecological issues shadowed by inconsistency in the direction and effect of study outcomes (Adams et al., 1997; Brett, 1997; Osenberg et al., 1999). Most studies employed meta-analysis to establish the consistency of studies on herbivory (e.g.,

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Milchunas and Lauenroth, 1993; Hawkes and Sullivan, 2001; Díaz et al., 2007) from the perspective of temperate grazing systems, with little attention given to the SSA region where extensive livestock grazing is widely practiced.

We applied meta-analysis to identify whether studies so far conducted in the communal grazing systems of SSA have detected significant livestock induced rangeland degradation as approximated by changes in species diversity (Milchunas et al., 1998; Ruiz-Jaen and Aide, 2005) and richness (McLachlan and Knispel, 2005), loss of biomass (Huntly, 1991), reduction in basal cover (Harrison and Shackleton, 1999), increases in woody species density (Ward, 2005) and soil properties (Smet and Ward, 2006). We used the following benchmarks as reference points for our comparison: Exclosures (Scholes, 2009; Rutherford et al., 2011) and livestock ranches (Abel and Blaikie, 1989; Abel, 1997; Vetter, 2013). Exclosures are protected land units excluded from the activities of grazing animals using various deterrants (Young, 1958). The term "exclosure" is often interchangeably used with "enclosure" (Aerts et al., 2009), and in our meta analysis we treated these two terms as synonymous.

Grazing systems in SSA have diverse socio-economic and ecological importance (Oba et al., 2000). In view of their diverse roles, measuring the sustainability of grazing systems using a set of vegetation and soil indicators is essential. We included a broad set of frequently measured vegetation and soil variables to compare traditional communal grazing systems with livestock ranches and game reserves. The inclusion of different vegetation attributes serves as a proxy for evaluating the sustainability of grazing systems (Fernandez-Gimenez and Allen-Diaz, 1999; Shackleton, 2000). For instance, measuring species diversity and vegetation structure can provide important clues about the capacity of grazing systems to sustain themselves over time (Ruiz-Jaen and Aide, 2005).

In this review we addressed the following research questions: (1) what is the combined effect of grazing by livestock on communal land vegetation (diversity, richness, biomass, cover, density) and soils (organic carbon concentration, total nitrogen and available phosphorus) in SSA? (2) Is this magnitude similar for different grazing regimes (communal grazing land, exclosures, livestock ranches, and game reserves)? (3) Which moderator variables influence the magnitude of the combined effect sizes on vegetation and soil parameters?

2. Materials and methods

2.1. Study selection

We carried out a thorough literature search of articles appearing in the Scopus and ISI Web of Knowledge databases (1970 through October 2012) using the following search terms either alone or in various combinations. We started our search with the broad search string 'communal grazing AND sub-Sahara* Africa OR sub Sahara* Africa'. The wildcard '*'was used to capture the various forms of a particular term such as range or rangeland. This was then expanded using the Boolean 'OR' followed by the name of each country included in sub Saharan Africa as used by Otte and Chilonda (2002). To be more inclusive, we added the following descriptive search string terms: rangeland OR grassland OR savanna OR savannah OR grazing land OR enclosure OR exclosure OR veld as well as the names of the countries included in sub Saharan Africa. In order to be able to identify references relevant to this review, we further included specific vegetation and soil terms: *mass OR richness OR *diversity OR density OR cover as well as soil organic carbon OR soil total nitrogen OR soil available phosphorus. We also manually searched all references appearing in the reference lists of the retrieved papers. In total, our research resulted in 328 papers (Supplement 1).

Because meta-analysis is affected by the use of a particular inclusion criteria (Hedges et al., 1999; Osenberg et al., 1999), while selecting studies we adhered to the following cumulative criteria: the study (1) must be carried out in SSA, must have passed peer review and be published in a regularly appearing online international journal in the period from 1970 to 2012; (2) addresses communal grazing land issues in relation to effects of livestock on either soils or vegetation or both (3) was methodologically designed to compare at least freely grazed communal grazing land with an adjacent land that is either exclosure, livestock ranches, or game reserves), and (4) must provide statistics in a form useable for meta-analysis.

We treated studies that included multiple comparisons along gradients of grazing intensities as independent for each comparison, although this is likely to introduce non-independence of effect-size estimates (Gurevitch and Hedges, 1999). In cases where the same data have been presented by the same author/s in two or more different publications, only the most recent publication was included in the analysis.

Results reported in the form of graphs were digitalized with Enguage digitizer version 4.1 (Mitchell, 2002). We created nine databases corresponding to six vegetation and three soil attributes commonly used in the literature to measure differences between communal grazing and exclosures/livestock ranches/game reserves.

2.2. Effect sizes and their variances

Effect sizes expressed on the response ratio (RR) have been shown to be more accurate than those expressed on the standardized mean difference (Hedges et al., 1999). Expressing effect sizes using the RR transformed by the natural log scale has a number of advantages including this ratio's independence from the actual unit of measurement used by the different studies and its symmetrical properties, which give equal weight to negative and positive effects (Hedges et al., 1999).

We calculated the response ratio in the natural logarithm scale (Ln RR) as:

$$\ln\,(\mathrm{RR}) = \ln(\overline{X}_{ip}) - \ln(\overline{X}_{io})$$

Where ln (RR) = natural log response ratio

$\overline{X}_{ip}$ = average response for vegetation attribute type i from exclosure/livestock ranch/game reserve areas, where i can be species diversity, species richness, herbaceous basal cover, woody density, woody canopy cover, soil carbon, total nitrogen or available phosphorus.
$\overline{X}_{io}$ = average response for vegetation attribute type i from the communal grazed sites, where i can be species diversity, species richness, herbaceous basal cover, woody density, woody canopy cover, soil carbon, total nitrogen or available phosphorus.

The ln (RR) from each study was weighted by the inverse of the within-study variance plus the common between-studies variance (Borenstein et al., 2010).

The variance (V) of ln (RR) was calculated as:

$$\mathrm{V} = \frac{(SD_{ip})^2}{n_{ip}\overline{X}_{ip}^2} + \frac{(SD_{io})^2}{ni_o\overline{X}_{io}^2}$$

Where,

SD_{ip} = the standard deviation for vegetation attribute type i from the exclosures/livestock ranch/game reserves, where i can be species diversity, species richness, herbaceous basal cover, woody density, woody canopy cover, soil carbon, total nitrogen or available phosphorus.
SD_{io} = the standard deviation for vegetation attribute type i from the communal grazed areas, where i can be species diversity, species richness, herbaceous basal cover, woody density, woody canopy cover, soil carbon, total nitrogen or available phosphorus.
n_{ip} = the number of observations for vegetation attribute type i from the exclosures/livestock ranches/game reserves, where i can be species diversity, species richness, herbaceous basal cover, woody density, woody canopy cover, soil carbon, total nitrogen or available phosphorus.;
n_{io} = the number of observations for vegetation attribute type i from the communal grazed areas, where i can be species diversity, species richness, herbaceous basal cover, woody density, woody canopy cover, soil carbon, total nitrogen or available phosphorus.;
$\overline{X}_{ip}$ and $\overline{X}_{io}$ are as defined above.

From each published study, we classified the reported long term average rainfall as either <600 or ≥600 mm/year, rainfall modality as mono or bimodal, elevation as <1500 or ≥1500 m above sea level (masl), soil texture as sandy, sandy/loam, or vertisol, and the particular form of land use considered as exclosure, livestock ranch or game reserve. These variables were then used as categorical moderator variables in our meta-analytical model.

The random-effects model was applied to detect differences in mean effect sizes among studies and groups. This model takes into account both sampling error and differences among studies (Gurevitch and Hedges, 1999). If the 95% confidence interval did not overlap with zero, then the overall and group effect sizes were declared significant at $P < 0.05$. Positive ln (RR) values represented increased vegetation and soil attributes under the exclosure/livestock ranch/game reserves, negative values implied increased levels of vegetation and soil variables under the communal grazing system, and zero values indicated neutral (absence of strong evidence) effects.

2.3. Publication bias

Publication bias is a potential threat to the validity of all meta-analysis studies (Duval and Tweedie, 2000; Møller and Jennions, 2001; Gates, 2002; Nakagawa and Santos, 2012). We evaluated the presence of possible publication bias using funnel plots of effect sizes and Spearman's rho rank correlation. Bias towards publication of larger effects was indicated by the presence of a significant correlation between effect size and sample size (Gurevitch and Hedges, 1999). We also ran sensitivity and cumulative analyses, which show the overall effect without that particular study and the effect size trend over time, respectively (Borenstein et al., 2010).

Sensitivity analyses were done by repeatedly running the analysis while removing one study for each iteration. These were used to control for dependence between data and confirm that the trends detected were not affected by a few large studies (Gates, 2002; Lortie and Callaway, 2006). Cumulative analysis, which reveals a shift in evidence over time, was conducted by running the analysis repeatedly while adding an additional study with each iteration.

We quantified heterogeneity using either Cochran's Q test (Higgins and Thompson, 2002; Nakagawa and Santos, 2012). Heterogeneity in the overall average effect size evaluated using the test statistic Q is a weighted sum of squares comparable to the total sum of squares in ANOVA (Adams et al., 1997; Osenberg et al., 1999; Rosenberg et al., 2000).

3. Results

3.1. Species diversity and richness

There were 25 studies retrieved for plant species diversity analysis (Supplement 1). When all studies were combined, herbaceous and woody species diversity was significantly lower under the communal grazing than under the other forms of land uses (Fig. 1). However, the overall pattern changed when the six moderators were considered separately. Exclosures resulted in a significant increase in species diversity compared to the communal grazing systems while the livestock ranching and game reserve areas were similar in their diversity. Elevation affected the pattern of variation in species diversity, with studies carried out in higher elevation (≥1500 masl) areas reported lower species diversity in communal grazing systems whereas studies carried out in the lowlands (<1500 masl) failed to provide evidence of variation in species diversity between communal grazing and the other forms of land uses. Studies conducted in areas with bimodal rainfall and receiving <600 mm annual rainfall reported a reduction in species diversity in the communal grazing systems.

There were 82 studies included in the analysis of plant species richness (Supplement 1). Herbaceous and woody species richness followed a pattern similar to species diversity, except that game reserves were more species rich than communal grazing areas (Fig. 1). The difference in species richness between communal grazing and the other land uses was higher at higher elevations, and was more pronounced for woody species than for herbaceous species. Species richness significantly declined in the communal grazing areas receiving an average annual rainfall of <600 mm compared to areas that received ≥600 mm annual rainfall. Both herbaceous and woody species richness were also higher in the exclosures/livestock ranches/game reserves where the soil texture was sandy or sandy loam.

3.2. Herbaceous biomass and basal cover

We were able to retrieve 41 studies on herbaceous biomass (Supplement 1) all of which provided a uniform and strong evidence of the effects of communal grazing on herbaceous biomass (Fig. 2). Herbaceous biomass was lower in the communal grazing systems than in the exclosures. However, herbaceous biomass in the livestock ranches and game reserve was similar to the communal grazing areas.

There were 34 studies included in our cover analysis (Supplement 1). The overall effect size showed that herbaceous basal cover was lower under the communal than under the exclosure and livestock ranches (Fig. 2). Herbaceous basal cover responded differently to the five moderators. Studies carried out in the lowlands (<1500 masl) revealed lower basal cover under the communal grazing systems while the effects of rainfall and its modality were significant only in locations with less than 600 mm/year and bimodal rainfall pattern.

3.3. Woody canopy cover and density

Thirty three studies were included in the analysis of woody species canopy cover (Supplement 1). When all studies were combined the overall effect size did not differ between the communal grazing lands and livestock ranches/game reserves (Fig. 3). Studies carried out in high-elevation (≥1500 masl) detected significant woody canopy cover differences among the four land

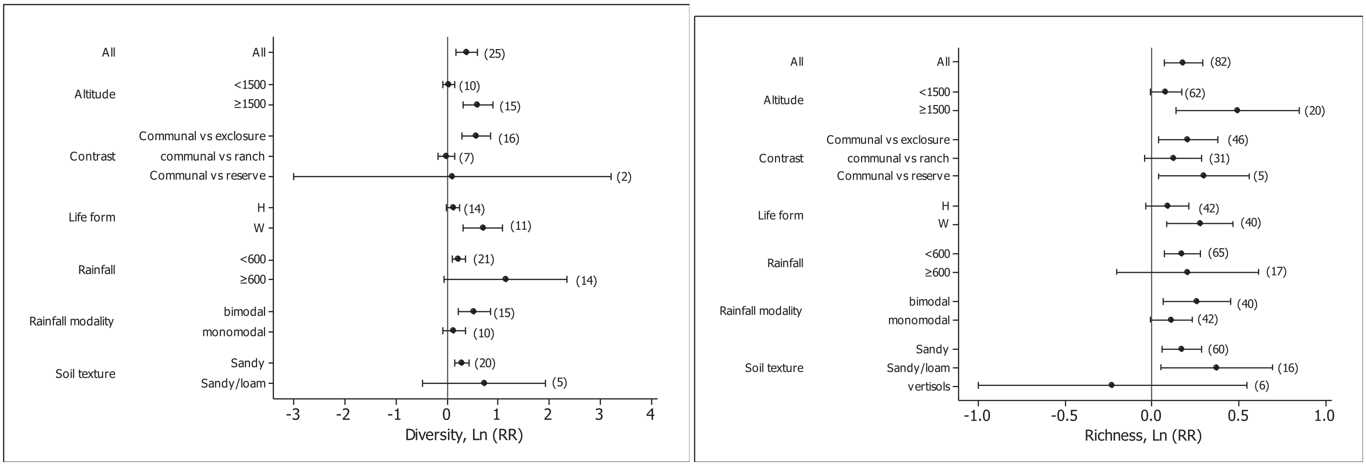

Fig. 1. Average species diversity and richness effect sizes categorized under six moderators. Numbers in parenthesis represent the number of studies included in the analysis.

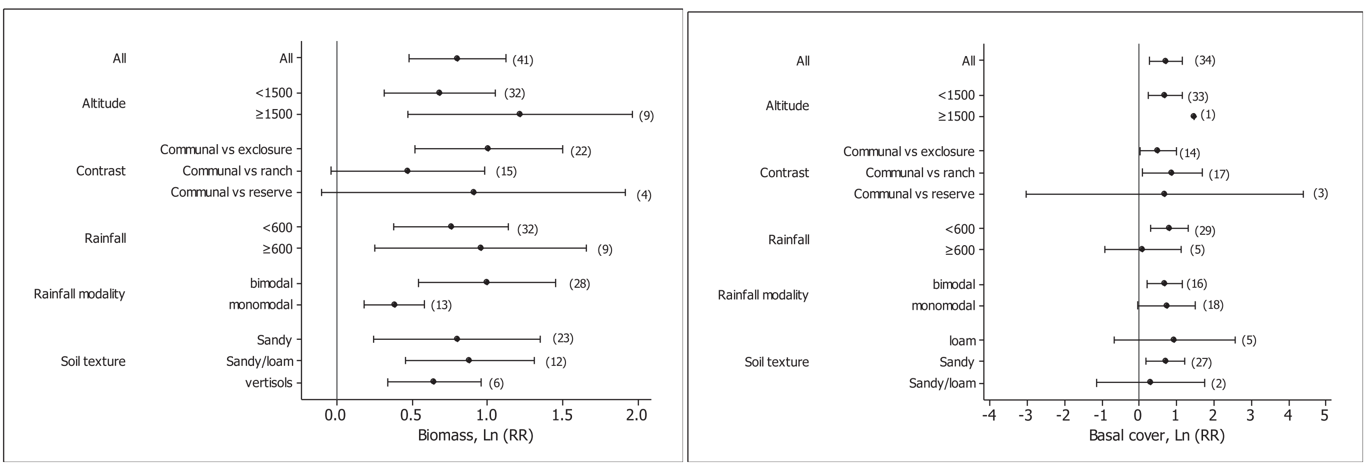

Fig. 2. Average herbaceous biomass and basal cover effect sizes categorized under five moderators. Numbers in parenthesis represent the number of studies included in the analysis.

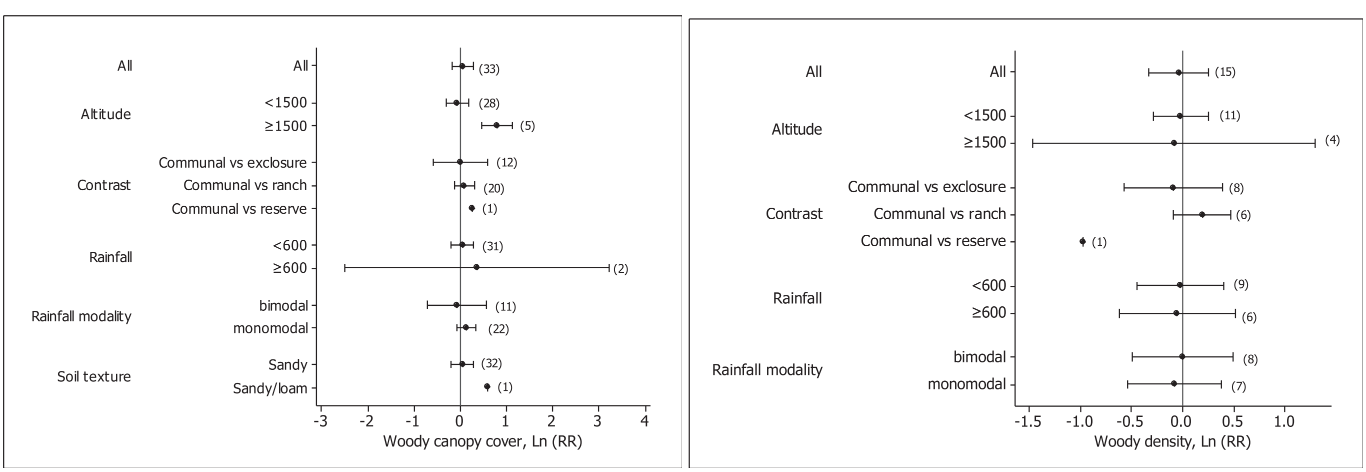

Fig. 3. Average woody canopy cover and density effect sizes categorized under five moderators. Numbers in parenthesis represent the number of studies included in the analysis.

uses compared with those studies carried out in low elevation (<1500 masl) areas. Communal grazing systems located in the high elevation areas supported less woody cover than the other land uses. Despite the lack of significant effect size differences in the lowlands, woody canopy cover tended to be higher in the livestock ranches/game reserves than in the communal grazing systems.

There were 15 studies included in the analysis of woody density (Supplement 1), and the overall density pattern was not different for the communal grazing lands, livestock ranches and game reserves (Fig. 3). Woody density tended to be higher in the communal grazing systems than in the livestock ranches (n = 6) and game reserves (n = 1).

3.4. Soil OC, available P and total N

Thirty four studies were retrieved for soil OC analysis (Supplement 1). The combined effect size on soil OC did not differ between the communal grazing lands and livestock ranches/game reserves (Fig. 4). Studies carried out in high elevation (≥1500 masl) and receiving ≥600 mm annual rainfall detected higher soil OC concentration in the exclosures than in the communal grazing systems.

There were 29 studies for available soil P analysis (Supplement 1). The combined effect size on soil available P did not significantly vary between the communal grazing lands and livestock ranches/game reserves (Fig. 4). Available soil P concentration was significantly higher on the communal grazing systems located in areas with an elevation of <1500 masl. Despite the lack of significant differences, available soil P tended to be higher in the communal grazing than in the other land uses under most of the moderators.

There were 28 studies included in the total soil N analysis (Supplement 1). The combined effect size on total soil N was significantly lower in the communal grazing systems compared to the livestock ranches/game reserves (Fig. 4). Total soil N was significantly increased under complete exclusion of livestock in high elevation (≥1500 masl) areas, but not in the lowlands. This significant effect size was observed in areas that received bimodal rainfall. Land use form affected total soil N in relation to sandy textured soils but not loam and sandy loam soils.

3.5. Between study heterogeneity

The heterogeneity for diversity was significant for all moderators except rainfall amount and soil texture (Table 1).

Studies used for soil OC analysis were homogeneous except when grouped by elevation and form of grazing regime (Table 2). The heterogeneity for total N was not significant under rainfall and soil texture while the heterogeneity for available P was significant when the studies were grouped by rainfall modality and elevation.

4. Discussion

Our meta-analysis synthesized livestock management effect sizes and their direction under different environmental factors. We used six vegetation and three soil attributes to measure differences between communal grazing and exclosures/livestock ranches/

Table 1
Summary Q-statistics for between study heterogeneity of vegetation parameters using the random-effects model.

Parameter	Life form	Rainfall	Rainfall modality	Altitude	Soil texture	Land use
Diversity						
Q-value	9.40	7.48	2.78	8.61	0.39	7.26
P	0.00	0.01	0.09	0.00	0.53	0.03
Richness						
Q-value	1.63	5.26	1.09	3.55	11.19	7.26
P	0.21	0.02	0.30	0.06	0.00	0.03
Biomass						
Q-value	–	0.16	5.98	3.40	6.87	12.09
P	–	0.69	0.01	0.07	0.03	0.00
Basal cover						
Q-value	–	5.68	1.04	2.63	0.75	6.43
P	–	0.02	0.31	0.11	0.69	0.04
Canopy cover						
Q-value	–	1.71	0.83	24.62	2.36	0.19
P	–	0.19	0.36	0.00	0.13	0.91
Density						
Q-value	–	0.00	0.01	0.11	–	1.95
P	–	0.99	0.92	0.74	–	0.34

Table 2
Summary Q-statistics for between study heterogeneity of soil parameters using the random-effects model.

Parameter	Rainfall	Rainfall modality	Altitude	Soil texture	Land use
Organic C					
Q-value	1.52	2.92	18.78	0.66	10.05
P	0.23	0.09	0.00	0.72	0.01
Total N					
Q-value	1.29	5.35	9.74	4.51	21.19
P	0.26	0.02	0.00	0.11	0.00
Available P					
Q-value	0.1	6.24	24.59	0.99	4.36
P	0.75	0.01	0.00	0.32	0.11

game reserves. Four moderatorators (elevation; plant life form; rainfall amount; rainfall modality; and soil texture) were used to group studies.

4.1. Strength and direction of effect sizes

4.1.1. Species diversity and richness

The overall effect size on herbaceous and woody species diversity and richness exhibited a clear reduction in the communal grazing systems compared to the exclosures, livestock ranches, and game reserves. When the modulators were considered separately, studies carried out in high elevation areas consistently detected a reduction in species diversity and richness on communal grazing compared to other forms of land uses. It is acknowledged that in the

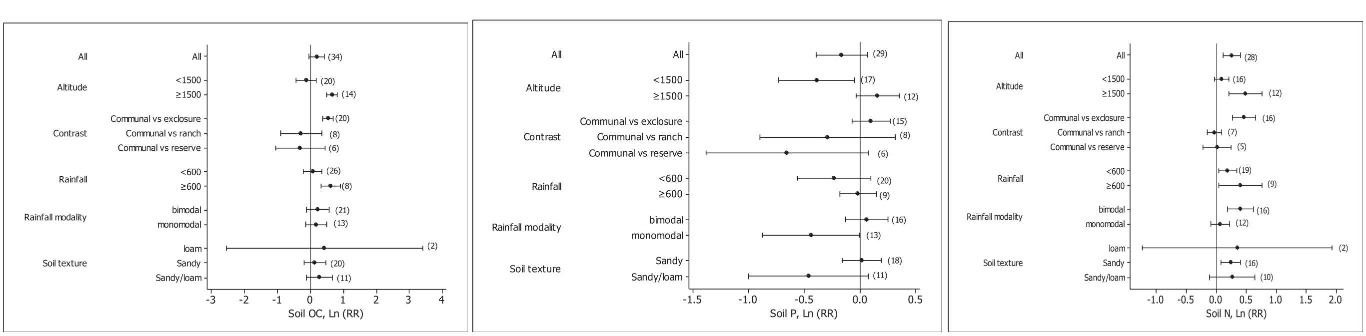

Fig. 4. Average soil organic matter, total nitrogen and available soil phosphorus effect sizes categorized under five moderators. Numbers in parenthesis represent the number of studies included in the analysis.

arid and semi-arid areas where pastoral livestock density is reportedly below the carrying capacity of the rangelands, the probability of grazer induced reduction in species diversity and richness is generally low (Ellis and Swift, 1988; Abel, 1993; Behnke and Scoones, 1993; Scoones, 1993). Rainfall modality rather than amount strongly influenced the pattern of species diversity and richness in the communal grazing systems.

4.1.2. Herbaceous aboveground biomass and cover

One immediate impact of protection from grazing is increased biomass and cover (Harrison and Shackleton, 1999; Verdoodt et al., 2009). Our moderator variables appeared to play little role in revealing patterns of variations in the impact of communal grazing on aboveground herbaceous biomass, suggesting that a reduction in aboveground biomass after grazing is the first early sign observed under all climatic and environmental situations. Except in exclosures, significant differences in aboveground herbaceous biomass were not detected between the communal grazing and the other forms of land uses (livestock ranching and game reserves). This is probably attributed to the presence of seasonal heavy grazing in those land uses frequently accessed by domestic and wild animals (Metzger et al., 2005).

4.1.3. Woody cover and density

Mean annual precipitation plays significant role in determining woody cover closure in African arid and semi-arid savanna systems, and in areas that receive less than 650 mm annual rainfall cover is controlled by the availability of moisture (Sankaran et al., 2005). Woody cover between the communal grazing and other land uses showed significant differences when the moderator variable is elevation. Studies carried out in the highlands ($\geq$1500 masl) detected clear increase in woody cover. The increased woody cover in the highlands is probably attributed to the establishment of exclosures (Aerts et al., 2006; Verdoodt et al., 2009). None of the categorical modulators produced significant changes in the pattern of woody density. This is despite the presence of repeated claims of widespread woody species encroachment in the communal grazing systems (Roques et al., 2001; Ward, 2005; Wigley et al., 2009; Gil-Romera et al., 2010; Eldridge et al., 2011; Angassa et al., 2012).

4.1.4. Soil texture

Soil OC was increased under protection when the specific study was carried out in the highlands and rainfall amount contributed to differences in soil OC across the different grazing regimes. Grazing management effects on soil N varied with rainfall and sandy soils. Soil parameters varied in relation to a specific moderator variable, and this may suggest that climatic conditions play significant role in the process (Harrison and Shackleton, 1999). This is also consistent with the general trend that woody species tended to increase soil C and N concentrations (Eldridge et al., 2011), and that areas subjected to intense grazing resulted in decreased soil C and N concentrations (Hiernaux et al., 1999).

4.2. Publication bias

Publication bias is a common problem in almost all studies that involve meta-analysis of published articles (Arnqvist and Wooster, 1995; Gurevitch and Hedges, 1999). We detected some publication bias using the funnel shape approach (Duval and Tweedie, 2000), which might have been caused by the strict inclusion criteria we applied and the failure of authors to report basic statistical parameters essential for meta analysis. Nevertheless, a simple visual inspection of such plots may not necessarily mean the presence of missing studies in the analysis (Terrin et al., 2005). Given such a limitation, the current status of communal grazing systems in SSA is likely to be influenced as much by the choice of particular vegetation and soil attributes as the inclusion of suitably chosen moderator variables.

5. Conclusions

Significant changes in selected vegetation attributes and soil properties was related to the inclusion of moderator variables (elevation, land use, plant life form, rainfall amount, rainfall modality, and soil texture). The response of plant species diversity and richness to the grazing regimes was strongly related to environmental factors. Herbaceous biomass was consistently lower in the communal grazing systems than in the exclosures. Despite many studies on bush encroachment as a response to overgrazing, woody species density and canopy cover were not uniformly higher under extensive livestock grazing compared to other grazing regimes in our study. Rainfall and sometimes elevation influenced soil organic carbon (OC) and soil N status in relation to the grazing regimes considered in this study. We conclude that the current status of communal grazing systems in SSA is difficult to generalize and strongly related to the sites chosen, which exhibit underlying variations in environmental factors and soil types.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.jaridenv.2015.01.015.

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