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Ecological, biophysical and production effects of incorporating rest into grazing regimes: A global meta-analysis

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Abstract

1. Grazing can have considerable ecological impacts when managed inappropriately, however livestock production is a significant contributor to global food security and the removal of land from production is not always a viable option. Grazing management practices that incorporate periods of planned rest (i.e. strategic-rest grazing) may be an alternative to grazing exclusion or continuous grazing that could achieve ecological and animal production outcomes simultaneously.
2. We conducted a meta-analysis of global literature to investigate how strategic-rest grazing mediates ecological (i.e., plant richness and diversity), biophysical (plant biomass and ground cover) and production response variables (animal weight gain and animal production per hectare) compared to continuously grazed or ungrazed areas.
3. Overall, total ground cover and animal production per hectare were significantly greater under strategic-rest grazing than continuous grazing management, but biomass, plant richness, plant diversity and animal weight gain did not differ between grazing treatments. Increasing the length of rest relative to graze time under strategic-rest grazing was associated with an increase in plant biomass, ground cover, animal weight gain and animal production per hectare when compared to continuous grazing.
4. *Synthesis and applications*. Understanding both the ecological and animal production trade-offs associated with different grazing management strategies is essential to make informed decisions about best-management practices for the world's grazing lands. We show that incorporating periods of rest into grazing regimes improves ground cover and animal production per hectare and that these benefits are more pronounced with increases in the length of time land is rested for. This extended rest also improves biomass production and weight gain compared to continuous grazing systems. Based on these meta-analyses, we recommend that future research considers the duration of rest compared to graze time in comparisons of grazing systems.

KEYWORDS
biodiversity, biomass, continuous grazing, grazing exclusion, grazing management, ground cover, rotational grazing, weight gain

1 | INTRODUCTION

Livestock grazing is the single most extensive use of land on the planet, occupying ~25% of global land area and 66% of the world's agricultural land (Asner, Elmore, Olander, Martin, & Harris, 2004; FAOSTAT, 2016). The livestock industry employs over 1.3 billion people, is worth $1.4 trillion to the economy and provides about 33% of human protein intake (Thornton, 2010). However, the livestock sector is also a key driver of land-use change and can lead to degradation of ecosystem structure and function (Dorrough et al., 2004; Eldridge, Poore, Ruiz-Colmenero, Letnic, & Soliveres, 2016), biodiversity loss (MA, 2005; Steinfeld et al., 2006) and soil degradation (Greenwood & McKenzie, 2001; MA, 2005; Steinfeld et al., 2006; Yates, Norton, & Hobbs, 2000) when poorly managed. With projected increases in human global population and corresponding demands for food production, pressures on grazing lands are likely to increase (FAO, 2011; Steinfeld et al., 2006; Tilman et al., 2001). Therefore, the sustainable management of livestock to address food production needs whilst balancing environmental impacts is a major challenge to address.

Excluding livestock is often seen as a solution to conserve biodiversity and improve ecological condition (Eldridge et al., 2016; Pettit, Froend, & Ladd, 1995; Prober & Thiele, 1995; Spooner, Lunt, & Robinson, 2002), though this strategy inevitably comes with a loss of food and fibre production and can be expensive and difficult to achieve across large scales (Neilly, Vanderwal, & Schwarzkopf, 2016). However, livestock grazing may be compatible with maintaining ecological outcomes, if managed appropriately (Dorrough et al., 2004; Wallis De Vries, Bakker, Bakker, & Wieren, 1998; Watkinson & Ormerod, 2001). In many parts of the world, large herbivores coevolved with vegetation communities, whereby many plant species have adapted to grazing pressure and developed mechanisms to tolerate herbivory (Coughenour, 1985; Milchunas, Sala, & Lauenroth, 1988). In some circumstances, livestock can also increase plant diversity by reducing the dominance of competitive plants (Elias & Tischew, 2016; Grime, 1973), providing opportunities for plant regeneration (Belsky, 1992; Grubb, 1977), facilitating seed dispersal (Albert et al., 2015; Olff & Ritchie, 1998) and increasing plant community heterogeneity (Limb, Hovick, Norland, & Volk, 2018).

In contemporary grazing systems, land is commonly grazed continuously (year-long or throughout the entire grazing season) without periods of planned rest (Earl & Jones, 1996; Shakhane et al., 2013). Continuous grazing can result in uneven grazing patterns, that is, patch grazing (Adler, Raff, & Lauenroth, 2001; Fuhlendorf & Engle, 2001), which can result in overgrazing of palatable and grazing-sensitive species (Briske et al., 2008; Norton, Barnes, & Teague, 2013; Teague & Dowhower, 2003; Teague et al., 2011). Severe overgrazing of large patches can also lead to land degradation processes, such as soil erosion (Blackburn, 1984). Incorporating periods of planned rest into grazing regimes, hereafter called strategic-rest grazing, is an alternative to continuous grazing management that is thought to reduce environmental degradation while maintaining or improving productivity (Hart, Clapp, & Test, 1993; Norton, 1998; Teague et al., 2008). Previous reviews have concluded that there are few benefits for animal production and landscape sustainability from strategic–rest grazing systems, yet significant knowledge gaps remain (Briske et al., 2008; Hawkins, 2017; Holechek, Gomes, Molinar, Galt, & Valdez, 2000; Nordborg, 2016; Teague, Provenza, Kreuter, Steffens, & Barnes, 2013). Climate type, the length of time land is rested relative to time grazed and differences in stocking rates between treatments compared have been shown to affect responses to grazing (Briske et al., 2008; Eldridge et al., 2016; Teague, Grant, & Wang, 2015). However, previous reviews into strategic-rest grazing have not assessed the importance of the length of rest periods and climate zone or compared both biodiversity and production metrics simultaneously, across multiple biomes or types of grazing systems that incorporate rest periods. In addition, there have been no reviews comparing effects of grazing with periods of rest with ungrazed areas on ecological or biophysical variables.

Here, we conduct the first quantitative, global meta-analysis to investigate the extent to which strategic-rest grazing (SRG) and varying length of rest periods influence ecological, biophysical and production outcomes across climate zones, compared to continuously grazed (CG) and ungrazed (UG) systems. Understanding the impacts of strategically managed livestock on both ecological and production objectives will increase the potential of land-sharing options for livestock grazing that are an alternative to grazing exclusion, which in many circumstances can have negative socio-economic consequences.

Specifically, we ask the following research questions:

1. How do differences in grazing management systems affect ecological outcomes (plant richness and diversity)?
2. How do differences in grazing management systems affect biophysical outcomes (biomass and ground cover)?
3. How do differences in grazing management systems affect animal production outcomes (weight gain and animal production per hectare)?
4. To what extent do climate, differences in stocking rate and the length of the graze and rest periods mediate ecological, biophysical and livestock production responses?

2 | MATERIALS AND METHODS

A systematic review of worldwide literature was conducted using Scopus, returning articles from 1950 until November 2017 to examine the effect of SRG on plant species richness, plant species diversity, ground cover, plant biomass, weight gain per animal and animal production per hectare. We searched for studies that compared SRG systems with either CG or UG areas. Search terms were identified to address the scope of the study and retrieve as many relevant studies as possible. Title, keywords and abstracts were searched for the following terms: (graz*) AND (*divers* OR biomass OR “carrying capacity” OR “weight gain” OR conserv* OR richness or product* OR “ground cover” OR “groundcover” OR “bare ground”) AND (rotation*

OR cell OR tactical OR holistic OR adaptive OR "short duration" OR planned OR continuous OR "set stocked" OR "set stocking" OR shepherd* OR "high intensity" OR "low frequency" OR "time controlled" OR "time control" OR "multi paddock" OR multipaddock OR "restorative" OR "grazing management" OR rest OR regenerat* OR "grazing system" OR "grazing regime" OR "grazing strategy" OR nomadic OR herding OR herder OR seasonal OR "active grazing"). Studies were only included in the analyses if grazing animals were domesticated ruminants (e.g. cattle, sheep, goats, deer), the studies were published in English, and they reported above-ground biotic or animal production variables. Studies based on models or simulations were not included.

2.1 | Meta-analyses

We compiled a dataset for each of the six response variables on which corresponding meta-analyses were conducted. In each dataset, we collated the mean, standard deviation and sample size, along with the explanatory variables stocking rate difference, climate zone and the rest:graze ratio for each independent grazing contrast (comparing an SRG treatment with a CG or UG treatment). Stocking rate difference referred to the difference in stocking rate (animal units ha^{-1} $year^{-1}$) between SRG and CG treatments in a contrast, where lower means the stocking rate of the SRG treatment was lower than the CG treatment, and higher means the stocking rate of SRG was greater than the CG treatment compared. Climate zone referred to the Koppen–Geiger climate classification where the study was undertaken (tropical, arid/semi-arid, temperate or cold/continental). The rest:graze ratio referred to the length of time pasture was rested relative to the length of the graze period. For example, a pasture that is rested for 5 weeks and grazed for 1 week will have a rest:graze ratio of 5:1. Information on geographic region, stock type, method of calculation of richness, diversity and ground cover, the type of diversity index and unit of animal production per hectare was also recorded (see Table S1 for definitions). Where this information was not provided either in the text or as supplementary information, the studies were not included in meta-analyses. Where the same data were reported in multiple papers, data from only one paper was included.

A total of 220 articles were retained from the results of our literature search, however only 176 of these articles contained data suitable for the meta-analyses (Table S2). Of these, we analysed 76 studies relating to biomass, 79 for individual animal weight gain, 38 for ground cover, 36 for animal production per hectare, 28 for plant richness and 18 for diversity (across both the SRG–CG and SRG–UG datasets). Overall the majority of contrasts between SRG and CG treatments were compared at equal stocking rates for each response variable except plant richness (Table S3).

We undertook meta-analyses using the *metafor* (v.1.9-6) and *metagear* (v.0.4) packages (Lajeunesse, 2016; Viechtbauer, 2010) within the R open-source software environment (Version 3.4.0; R Core Team, 2017). We calculated the effect sizes of each comparison as the log response ratio (lnRR; Hedges & Olkin, 1985):

$$\ln\left(\frac{X_T}{X_R}\right), \tag{1}$$

where X_T was the mean value of the response variable (in either the UG or CG system) and X_R is the mean value for the SRG system. The lnRR quantified the log proportional change between means of each grazing system. If the >lnRR0 (positive), the response was greater for CG or UG systems, whereas if <lnRR0 (negative), the response outcome was greater under SRG. The lnRR has been widely used in the ecological literature and in comparable recent meta-analyses on grazing practices (e.g. Eldridge et al., 2016; Piñeiro, Maestre, Bartolomé, & Valdecantos, 2013). The statistical properties of the lnRR allow complex data structures to be modelled appropriately (Lajeunesse, 2016). Although unweighted analyses are common in the ecological literature, such an approach can bias overall effects by giving equal weight to studies of differing precision (Koricheva, Gurevitch, & Mengersen, 2013). We undertook a weighted analysis to account for the heterogeneity in sample size and variance among studies. The sampling variance of lnRR was calculated as follows:

$$\mathrm{var}(RR) = \frac{\mathrm{SD}_T^2}{N_T X_T^2} + \frac{\mathrm{SD}_{TC}^2}{N_C X_C^2}. \tag{2}$$

This variance helped to limit the influence of studies with low statistical power, that is, those with a low sample size or large standard deviations (Hedges & Olkin, 1985). Analyses that included studies with multiple contrasts and common treatments were weighted with a variance–covariance matrix that accounted for this dependency (Lajeunesse, 2011, 2016). See Appendix S1 for information on variance computation for studies with missing variance data.

Multi-level random-effect (MLRE) models were fitted for the effect sizes of each response variable for SRG–CG and SRG–UG comparisons separately. These model types are appropriate for ecological meta-analyses as they account for the non-independence among effect sizes through the inclusion of random effects and variance–covariance matrices (Koricheva et al., 2013; Lajeunesse, 2011; Nakagawa & Santos, 2012; Viechtbauer, 2010). We included a nested random term region/study/livestock type in all models. In the models of plant species richness, diversity and ground cover, the random effect was further nested to account for calculation method of how species richness and diversity were estimated in each study. In models of the effect size of plant diversity, the random term was further nested to include the diversity index (Table S1). In the animal production per hectare models, we added an additional nested level for the type of unit (Table S1).

MLRE models were initially fitted without explanatory variables, to assess if the overall effect size differed significantly from zero (i.e. a null model). Null models included all studies of the response variable of interest. To explain variability in effect size, we fitted MLRE models with the explanatory variables of climate zone, stocking rate difference and rest:graze ratio as fixed effects, using only the studies where these data was available. It was not possible to calculate a rest:graze ratio for every study due to a lack of information provided in studies (Table S4). Due to the higher proportion of missing rest:graze information in datasets of plant richness, diversity, biomass and ground cover, the effect of rest:graze ratios were tested in separate models for these variables. Stocking rate difference was not tested for animal production per hectare studies, as this was confounded with the response. We tested the significance of individual factor levels by calculating their marginal means for each response variable. Effect-size heterogeneity in each model was assessed using the least squares extension of Cochran's Q-test (Q_E; Hedges & Olkin, 1985; Viechtbauer, 2010). A significant Q_E-value indicated that effect size differed more than expected due to sampling variability (Hedges & Olkin, 1985).

MLRE models were fitted using maximum likelihood. We assessed the significance of the fixed effects using two tests: an omnibus test (Q_M) and likelihood-ratio tests (χ^2; Table S5; Viechtbauer, 2010). Model selection was guided by assessment of the Akaike Information Criterion (AIC) and its small sample size correction (AIC_c). In selecting models for plant species richness and diversity, we focussed on AIC_c, given the small sample sizes. A difference in AIC or AIC_c value of >2 was considered better than the null model. We report only the best fitting models in the results. Homogeneity of variance was assessed by visualizing model residuals against fitted values. Model over-parameterization was assessed by visualizing likelihood-profile plots. Over-parameterization was defined by the presence of 'flat' profile plots or gaps in likelihood profile due to lack of convergence (Viechtbauer, 2010). Parameterization was improved by either changing optimization settings and re-checking profile plots or reducing the number of parameters. All models had a significant amount of residual heterogeneity, despite inclusion of explanatory variables. Publication bias was assessed using Egger's regression test (Egger, Smith, Schneider, & Minder, 1997; Sterne & Egger, 2005), which is appropriate for use with MLRE models (Habeck & Schultz, 2015). See Appendix S1 for further information on publication bias.

3 | RESULTS

3.1 | Biomass and ground cover

Overall, biomass and ground cover were significantly higher under SRG compared to CG management (biomass: $z = -4.17$, $p < .001$; ground cover: $z = -2.67$, $p = .008$; Figure 1). However, differences in stocking rate affected the biomass result (Figure S1), with biomass being significantly greater under SRG when the stocking rate of SRG was lower than that of CG ($z = -3.38$, $p \leq .001$), but there was no difference in biomass between SRG and CG when the stocking rate of SRG was equal to ($z = -1.83$, $p = .067$) or greater than CG ($z = -0.71$; $p = .473$). Biomass and ground cover were significantly lower under SRG than UG (biomass: $z = 2.39$, $p = .017$; ground cover: $z = 3.04$, $p = .002$; Figure 1).

Biomass increased under SRG relative to CG as the rest:graze ratio increased ($z = -16.31$, $p < .001$; Figure 2a). When stocking rates of SRG were equal to CG there was no difference in biomass between SRG and CG at low rest:graze ratios, but biomass was greater under SRG when rest:graze ratios were higher than 6:1. Biomass decreased in SRG relative to UG systems as the rest:graze ratio increased ($z = 7.46$, $p < .001$; Figure 2b), becoming greater under UG than SRG above a rest:graze ratio of 4:1.

Ground cover under SRG relative to CG increased as the rest:graze ratio increased ($z = -29.52$, $p < .001$). When the SRG stocking rate was equal to CG, ground cover was always greater under SRG (Figure 2c). Ground cover increased under SRG relative to UG as the rest:graze ratio increased but was always greater under UG than SRG ($z = -4.92$, $p < .001$; Figure 2d).

3.2 | Animal weight gain and animal production per hectare

Overall, there was no difference in weight gain between SRG and CG systems ($z = 0.30$, $p = .765$) but animal production per hectare was significantly greater under SRG than CG ($z = -2.09$, $p = .036$; Figure 1). Results did not differ when the stocking rate difference or climate zone were considered.

As the rest:graze ratio increased, there was greater weight gain and animal production per hectare under SRG compared to CG (weight gain: $z = -8.51$, $p < .001$; Figure 2e; animal production per hectare: $z = -18.77$; $p < .001$; Figure 2f). Significantly greater animal production per hectare under SRG was found at rest:graze ratios greater than 3:1, but at small rest:graze ratios (below 0.4:1) production per hectare was greater in CG systems. No significant difference was found for weight gain between the SRG and CG systems within the range of rest:graze ratios tested in our analysis.

3.3 | Plant species richness and diversity

There was no significant difference overall between the grazing treatments for either plant species richness (SRG–CG: $z = -0.64$, $p = .524$; SRG–UG: $z = 0.77$, $p = .443$) or plant diversity (SRG–CG: $z = -1.05$, $p = .296$; SRG–UG: $z = 0.67$, $p = .500$, Figure 1). There were also no significant differences in richness and diversity between SRG and CG when considered with the stocking rate difference. Richness decreased under SRG compared to CG as the rest:graze ratio increased ($z = 4.25$, $p < .001$; Figure 2g). Despite this, there was no significant difference in richness between SRG and CG within the range of rest:graze ratios tested in our analyses.

In arid and semi-arid climates, species richness under SRG was lower than in UG areas ($z = 2.20$, $p = .028$), but there were no differences between SRG and UG in other climate zones. Richness decreased under SRG compared to UG as rest:graze ratio in SRG systems increased ($z = 2.41$, $p = .016$; Figure 2h). Species richness was always significantly greater for UG than SRG areas above rest:graze ratios of 44:1. There were no differences associated with explanatory variables in comparisons of plant diversity between SRG and UG systems.

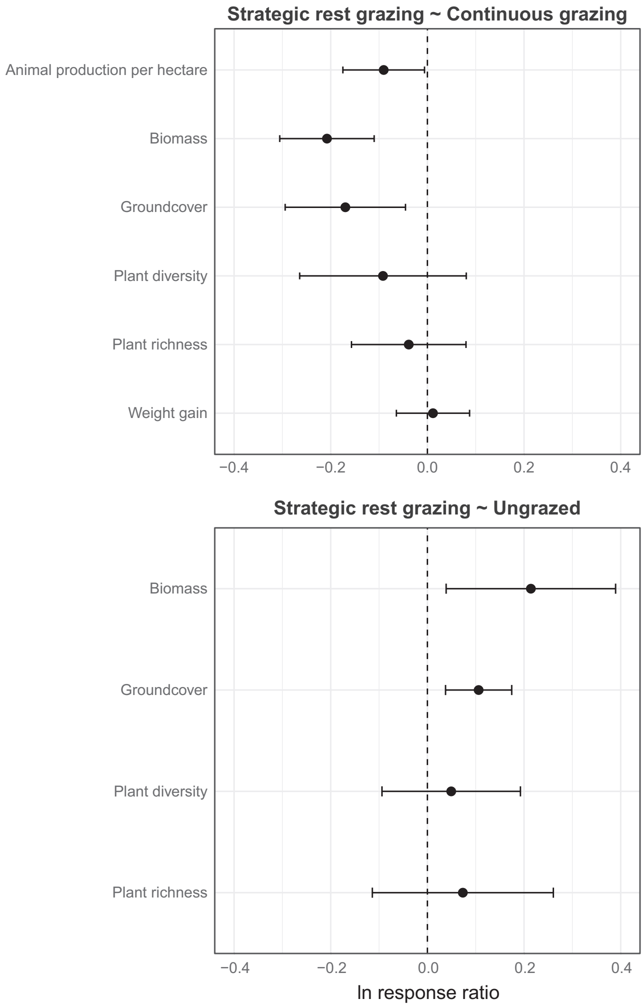

FIGURE 1 Effect size ±95% confidence intervals of null (overall) models for SRG–CG and SRG–UG datasets

4 | DISCUSSION

Identifying the global and regional patterns of grazing management that drive plant diversity and production metrics across continents and biomes is critical if we are to understand the likelihood of achieving production and biodiversity outcomes simultaneously. This study has addressed significant literature gaps related to better understanding ecological, biophysical and production effects of grazing systems that incorporate periods of rest compared with continuously grazed or ungrazed systems. We synthesized the current literature to demonstrate that strategic grazing incorporating periods of rest is associated with increased ground cover and animal production per hectare relative to continuous grazing practices. Importantly, the benefits to biophysical and livestock production variables increased as the length of rest relative to grazing time increased.

Biomass and ground cover are two important indicators of ecosystem functioning as they are known to stabilize soil, provide a buffer from extreme temperatures, reduce soil erosion, improve infiltration and contribute to nutrient cycling through the decomposition and mineralization of plant material (Clarholm, 1985; Gardiner & Reid, 2010; Yates et al., 2000). Standing biomass and ground litter also provide habitat for small animals including invertebrates, birds, reptiles and small mammals (King & Hutchinson, 2007). While ground cover was greater under SRG than CG, the response of biomass was confounded by differences in stocking rates of the treatments compared. When compared at equal stocking rates there was no significant difference in biomass between SRG and CG. Despite this, biomass became greater under SRG than CG when a rest:graze time greater than 6:1 was applied. The lower biomass and ground cover found under SRG than UG was unsurprising as livestock consume plant materials, trample plant and litter and disturb the soil surface. These results indicate that although SRG increases biomass and ground cover compared to more traditional CG practices, overall grazing impacts still override any effect of management system for these attributes, regardless of climate zone. This is consistent with previous conclusions (Ash & Stafford Smith, 1996; O'Reagain & Turner, 1992).

Continuous grazing is often considered to lead to greater weight gain as livestock are able to selectively graze preferred plants (Briske et al., 2008; Ellison, 1960; Joseph, Molinar, Galt, Valdez, & Holechek, 2002). In contrast, smaller grazing units under SRG can lead to greater and more uniform herbage production and utilization with consequently greater animal production per hectare (Joseph et al., 2002; Norton et al., 2013; Williamson, Aiken, Flynn, & Barrett, 2016). Our meta-analyses partially support these findings, as we found no significant difference in animal weight gain between SRG and CG and greater animal production per hectare under SRG than CG. Importantly, our study revealed that both animal production metrics increased in SRG systems as the rest:graze ratio increased. This is consistent with Teague et al. (2015) who demonstrated a positive relationship between the number of paddocks (and therefore longer rest periods) in rotational grazing systems and ecological condition and profitability. Previous studies have rarely considered the influence rest:graze ratios on response to grazing management, and few studies have investigated outcomes under rest:graze ratios larger than 10:1, which may account for the often contrasting findings and contribute to the ongoing debate surrounding the benefits of SRG strategies such as rotational grazing (Briske et al., 2008; Teague et al., 2013). The rest:graze ratio is likely an important component in achieving the goal of balancing productivity and ecological sustainability in grazing systems.

Livestock grazing is often considered to have negative impacts upon species richness and diversity (Lunt, Eldridge, Morgan, & Witt, 2007; MA, 2005; Steinfeld et al., 2006). However, previous research has typically compared continuously grazed with ungrazed areas rather than grazing systems that incorporate periods of rest. The lack of difference in species richness and diversity between SRG and UG treatments in this study may be a result of periods of rest allowing plants to recover and regenerate from grazing events. Lower species richness under SRG compared to UG treatments in semi-arid environments likely reflects the greater susceptibility of these environments to land degradation and biodiversity loss (Eldridge et al.,

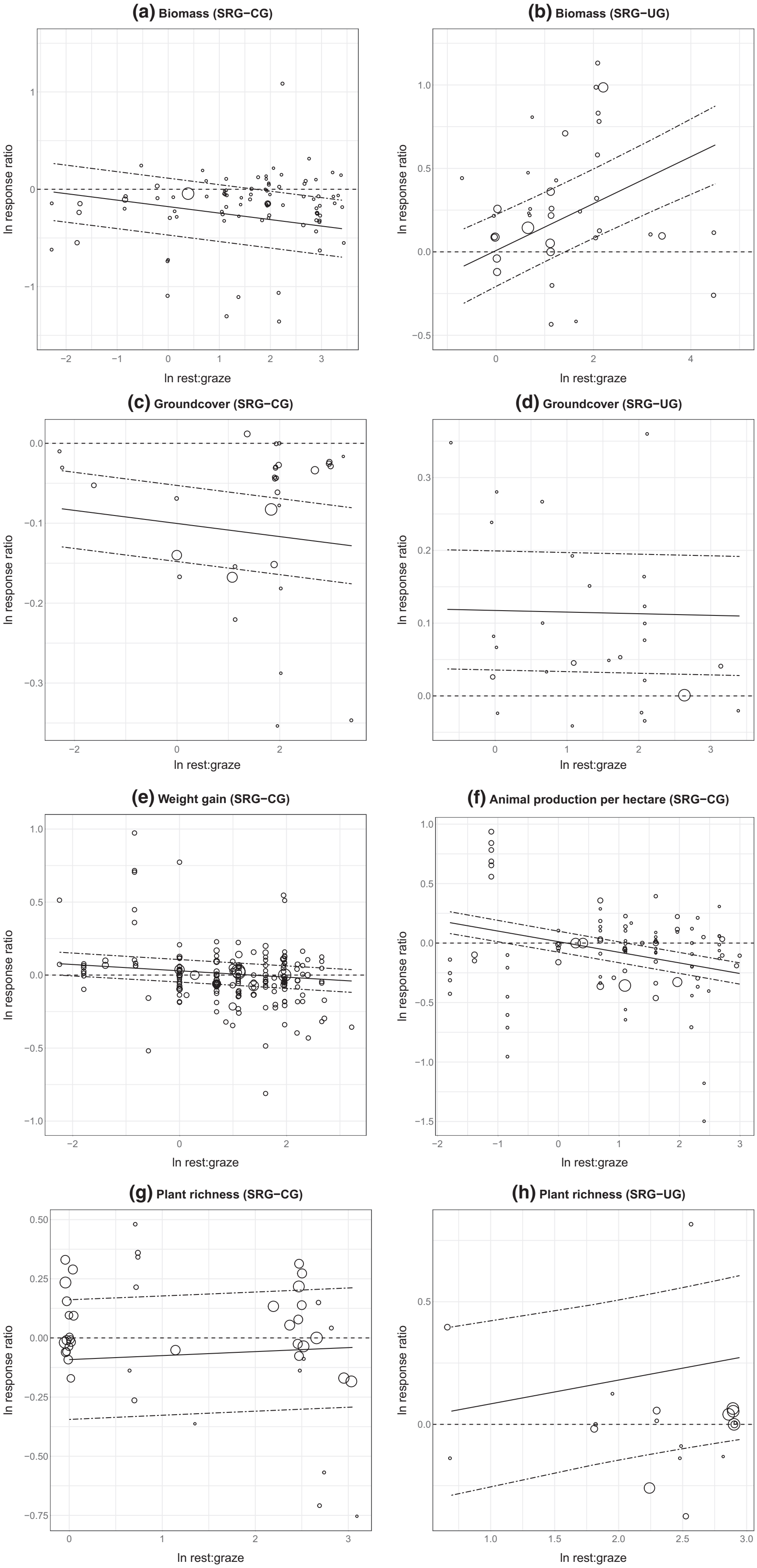

FIGURE 2 Rest:graze ratio relationship with effect size for: (a) plant biomass SRG–CG contrast (at equal stocking rates only); (b) plant biomass SRG–UG contrast; (c) ground cover SRG–CG contrast (at equal stocking rates only); (d) ground cover SRG–UG contrast; (e) weight gain per animal SRG–CG contrast; (f) animal production per hectare SRG–CG contrast; (g) plant richness SRG–CG contrast; and (h) plant richness SRG–UG contrast. Dotted lines represent the ±95% confidence interval. The observed effect sizes are drawn proportional to the inverse of the corresponding standard errors (i.e. larger circles reflect a smaller standard error, and were given greater weighting in the analysis)

2016; Holechek, Gomez, Molinar, & Galt, 1999). Further, the lack of difference in plant species richness and diversity between SRG and CG areas is likely because stocking rate and overgrazing are more influential drivers of floristic richness and diversity than grazing management system (Ash & Stafford Smith, 1996; O'Reagain & Turner, 1992; Provenza, Villalba, Dziba, Atwood, & Banner, 2003). Reduced richness under SRG as the length of rest increased may be a reflection of more uniform grazing patterns under SRG. Although we did not observe differences in species richness and diversity between grazing treatments, it is possible that compositional changes occurred that were not captured with the metrics we used in this study. Grazing affects species differently, with some responding positively (increasers) and others negatively (decreasers), thereby cancelling out the effects (Eldridge et al., 2018). Species composition and functional trait information may therefore be more informative measures (Cadotte, Carscadden, & Mirotchnick, 2011; Winfree, Bartomeus, & Cariveau, 2011).

4.1 | Directions for future research

A large proportion of studies included in our meta-analyses did not compare grazing regimes at equivalent stocking rates or reported stocking rate differences poorly. This was particularly true of studies that focused on ecological outcomes. Only a small proportion of studies included in our meta-analyses examined the effects of SRG management with rest:graze ratios greater than ten, thus further research into SRG systems with larger rest:graze ratios is needed. The significance of the stocking rate difference and the rest:graze ratio in many of the models highlights the need for greater consideration of these factors in future studies. Future studies would also benefit from greater attention to other important factors such as the types of rest–grazing systems, the timing of rest periods relative to periods of key pasture growth (Jones, 1933; Lodge & Whalley, 1985), management cues, sampling methods, the length of time that the grazing treatment was imposed prior to research being undertaken and the dominant vegetation type in the pasture. The large amount of residual heterogeneity in the meta-analyses indicate that these and other unexplained factors were likely influencing outcomes. Similar issues were encountered by Hawkins (2017). Unfortunately, much of this unexplained variation is challenging to overcome in the context of complex agro–ecological systems influenced by environmental, social and economic factors that are difficult to replicate or control for in field experiments (Briske et al., 2008; Heady, 1961; Provenza et al., 2003; Teague et al., 2013). These differences may have masked potential benefits or disadvantages of particular grazing management practices and confounded results (Briske et al., 2008). While no differences in species richness or diversity between SRG and CG or SRG and UG systems were found, we caution that the small sample sizes for these analyses alongside variability in the way data was reported may be influencing this result and suggest that greater research for these ecological attributes is needed. Importantly, ecological and animal production outcomes were rarely considered simultaneously in the studies investigated, suggesting that there is a limited understanding of trade-offs between ecological and animal production objectives.

5 | CONCLUSIONS

We show that rest periods are important to grazing sustainability and productivity. Quantifying both biodiversity and production outcomes associated with different grazing practices is urgently needed to make informed decisions about best-management practices for sustainable management of the world's grazing lands for joint production and ecological outcomes. However, our meta-analysis revealed that the predominant focus of existing studies comparing strategic-rest with continuous grazing has been on biophysical (e.g. plant biomass and ground cover) and animal production measures (e.g. livestock weight gain or animal production per area) with relatively few studies focused on biodiversity measures (e.g. species richness and diversity). If we are to further our understanding of the effects of, and the trade-offs between different grazing strategies it is important to consider effects on ecological as well as biophysical and animal production variables.

AUTHORS' CONTRIBUTIONS

S.E.M., R.L. and R.R. conceived the ideas of this paper. S.E.M. and R.L. undertook the literature search and data compilation. L.K. and S.E.M. undertook the statistical analyses and L.K. prepared the figures. All authors (S.E.M., R.L., L.K. and R.R.) contributed to the writing and critical editing of this manuscript and gave their approval for publication.

DATA AVAILABILITY STATEMENT

Data available via the Dryad Digital Repository https://doi.org/10.5061/dryad.kf160cj (McDonald, Lawrence, Kendall, & Rader, 2019).

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