A global meta-analyses of the response of multi-taxa diversity to grazing intensity in grasslands

Chao Wang and Yujia Tang

1 Beijing Research & Development Center for Grasses and Environment, Beijing Academy of Agriculture and Forestry Sciences (BAAFS), Shuguan Garden Middle Road No. 9, Haidian District, Beijing 100097, People’s Republic of China
2 School of Life Sciences, Capital Normal University, Beijing 100048, People’s Republic of China
E-mail: c_wang@pku.edu.cn

Keywords: grazing intensity, multi-taxa, biodiversity, plant, arthropod, microbe

Supplementary material for this article is available online

Abstract
Livestock grazing is an important component and driver of biodiversity in grassland ecosystems. While numerous studies and a few meta-analyses had been conducted on the response of single taxon diversity to grazing in grasslands, a synthesis of how multi-taxa diversity is affected has been largely missing, especially reflecting its changes along a grazing intensity gradient. We performed a comprehensive meta-analyses of 116 published studies on the species richness (SR) and Shannon–Wiener index (H′) of plants, arthropods, and microbes to examine the response of biodiversity to grazing intensity in temperate grasslands globally. This quantitative assessment showed that the response of SR and H′ to grazing intensity agreed with the intermediate disturbance hypothesis in grasslands; SR and H′ increased with light and moderate grazing intensities, while they decreased at heavy intensity. In addition, plant SR increased markedly with light and moderate grazing and declined with heavy grazing intensity; however, H′ increased at light intensity and declined at moderate and heavy intensities. Moreover, the SR and H′ of microbes were enhanced at light and moderate grazing and were significantly reduced with heavy intensity. The SR and H′ of arthropods monotonously declined with increasing grazing intensity. Importantly, structural equation modeling showed that grazing resulted in enhanced plant SR mainly through its negative effects on plant biomass. Grazing had negative effects on plant coverage and arthropod abundance so that arthropod SR declined with increased grazing intensity. Moreover, increased grazing intensity caused an increase in soil pH, decrease in soil moisture, and then a decrease in microbe SR. Our findings confirm that different taxa exhibit diverse responses to changes in grazing intensity, and the way that grazing intensity affects diversity also varied with different taxa. We strongly recommend considering the requirements of multi-taxa diversity when applying grazing management and including arthropods and microbes in monitoring schemes.

Introduction
Grassland is one of the most widespread vegetation types worldwide, covering approximately 40% of the terrestrial surface, while providing important ecosystem services including biodiversity conservation and carbon sequestration (LeCain et al 2002, Lal 2004, Suttie et al 2005). Grazing is well known as one of the major factors controlling the species composition and diversity in grasslands (Borer et al 2014, Allan et al 2015, Gossner et al 2016). Classical ecological theory shows that species diversity is assumed to follow a unimodal response along gradients of grazing intensity, and peaks with intermediate grazing intensity (McNaughton 1983, Milchunas et al 1988, Milchunas and Lauenroth 1993). Currently, a majority of the world’s grasslands are experiencing overgrazing (Salvati and Carlucci 2015), which threatens the biodiversity of grassland ecosystems (Smith 1940, Borer et al 2014, Huang et al 2018). Therefore, a better understanding of the effects of grazing on the biodiversity of grasslands at the global scale through the
quantitative comparison of enclosures and openly grazed situations is important for predicting future grassland biodiversity.

Over the past 40 years, a large number of studies have been conducted to examine the responses of plant diversity to grazing in grasslands (Oliva et al 1998, Campbell et al 2010, Cheng et al 2011, Dong et al 2011, Meyers et al 2014). These studies have considerably improved our knowledge of the mechanisms underlying the possible effects of grazing. For example, grazing has a variety of effects on plant diversity, with the literature supporting both positive and negative effects (Bakker et al 2006, Oesterheld and Semmartin 2011, Zhu et al 2012, Borer et al 2014). Moderate grazing may contribute to increasing plant species diversity and ecosystem stability (Milchunas et al 1988), while no grazing may decrease diversity in a community at equilibrium (i.e. intermediate disturbance hypothesis, Connell 1978, Sasaki et al 2009).

However, the kind of plant species present in a community is only one component of biodiversity in grasslands. Recent studies have shown that grazing not only influences plant diversity, but also affects the diversity of arthropods and microbes through altering their habitats and food sources (Hobbs et al 1996, Olff et al 2002). For instance, arthropod diversity is often more strongly affected by grazing than plant diversity (van Klink et al 2015). Intermediate grazing intensity increases soil bacteria diversity (Zhou et al 2010), but low grazing intensity increases the diversity of arbuscular mycorrhizal fungi (Ba et al 2011). It is well known that different taxa in an ecosystem are linked and will interact closely; that is, a small change in one taxon may significantly affect other taxa (de Vries and Bardgett 2012, Staudacher et al 2013, van Klink et al 2015). However, most previous studies have focused on the response of the diversity of a single taxon to grazing (Winfree et al 2009, van Klink et al 2015, Herrero-Jáuregui and Oesterheld 2018), making it imperative to understand the effects of grazing on the biodiversity of various taxa in grasslands.

The contradictory responses of biodiversity to grazing in different studies and areas may be associated with differences in grazing intensity and regime, or in environmental conditions (Bakker et al 2006, Allan and Crawley 2011, Yan et al 2015). Grazing intensity may be the major driving factor affecting biodiversity because grazing intensity alters the diversity of plants, arthropods, and soil microbes (Mcnaughton 1985, Cagnolo et al 2002, Deng et al 2014, Qu et al 2016, Porensky et al 2017). For example, Campbell et al (2010) found that light, moderate, and heavy grazing resulting in a significant decrease in plant diversity. In contrast, Dong et al (2011) and Oliva et al (1998) found that plant diversity significantly increased along a gradient of increasing grazing intensity. In addition, Cheng et al (2011) showed that plant diversity increased with a light grazing intensity, but decreased at moderate and heavy grazing intensities. Moreover, Boschi and Baur (2007) found that land snail species richness (SR) significantly decreased, while Gou et al (2015) found soil bacteria diversity increased along a gradient of increasing grazing intensity. Therefore, all available data in grasslands need to be compiled to reveal the patterns and mechanisms of biodiversity of the responses of different taxa to different grazing intensities.

The objective of this study was to quantitatively evaluate grazing-induced changes in biodiversity and elucidate the potential mechanisms involved. We compiled a large dataset of changes in biodiversity related to 575 paired comparisons from 116 experimental studies and conducted a comprehensive meta-analyses. The objectives of this study were to (1) quantify the effect of grazing on SR and the Shannon–Wiener index (H') of different taxa in grasslands; (2) assess the effects of grazing intensity on the SR and H' of plants, arthropods, and microbes; (3) and identify the underlying mechanisms for the effects of grazing intensity on the diversity of plants, arthropods, and microbes.

**Materials and methods**

**Data collection**

Using Google Scholar (www.scholar.google.com), ISI Web of Science (isiknowledge.com), and China National Knowledge Infrastructure (CNKI, www.cnki.net) we searched for journal articles that reported plant, arthropod, and microbial diversity in response to grazing intensity during 1900–2018, the following search term combinations: (graz OR grazing OR grazed OR fence* OR enclosed OR enclosure OR enclos) AND (plant OR arthropod* OR microbe* OR diversity* OR richness* OR insects* OR microbial* OR biodiversity) AND (effect* OR respon* OR affect* OR impact* OR increas* OR decreases OR alter*) NOT (medic* OR chemist*). To avoid bias in publication selection, the studies were selected based on the following considerations. (1) Experiments were conducted in the field using both enclosed and grazing treatments at the same temporal and spatial scales; experiments also included an analyses of SR and H'; (2) grazing intensity was clearly described in the paper, such as light, moderate, and heavy; (3) the means, standard deviations/errors, and samples sizes of variables in the enclosed and grazing treatments could be extracted directly from the text, tables or digitized graphs. In total, 116 published studies related to the effects of grazing intensity on biodiversity in grassland were selected (figure 1, appendix 1 provides a list of the data sources, Wang and Tang 2019).

Meanwhile, we also collected other site-specific information, including the source of the data, location (latitude and longitude), arthropod species and abundance, microbe types, plant biomass and coverage, total soil carbon and nitrogen, soil pH, soil moisture, mean annual temperature, and mean annual
precipitation (Data S1–3). The classification of grazing intensity was documented based on the local conditions in the author’s description. Arthropod species were divided into pollinators and carabids. Microbes were divided into bacteria and fungi; all the data for microbes originated from the same soil layer (0–10 cm).

In most cases, data were either obtained from tables or extracted from figures using the GetData Graph Digitizer (version 2.24, http://getdata-graph-digitizer.com/). When not on GetData, the data were extracted from the Worldclim database at http://worldclim.org/ using the location information (e.g. latitude and longitude).

**Data analyses**

We followed the methods of Hedges *et al* (1999) and Gurevitch *et al* (2018) to evaluate the effects of grazing on the diversity indices of plants, arthropods, and microbes. A metric commonly used in meta-analyses, the response ratio (RR, natural log of the ratio of the mean value of grazing treatment plots to that in enclosed plots) and its variance (v) were calculated using equations (1) and (2):

\[
RR = \ln \left( \frac{\bar{x}_g}{\bar{x}_e} \right) = \ln (\bar{x}_g) - \ln (\bar{x}_e),
\]

\[
v = \frac{s_g^2}{n_g \bar{x}_g^2} + \frac{s_e^2}{n_e \bar{x}_e^2},
\]

where \(\bar{x}_g\) and \(\bar{x}_e\) are means of variable being analyzed in grazing and enclosed treatments, respectively; \(n_g\) and \(n_e\) are the sample sizes of grazing and enclosed treatment, respectively; \(s_g\) and \(s_e\) are the standard deviations for the grazing and enclosed treatment, respectively. The reciprocal of the variance of RR \((w = \frac{1}{v})\) was considered as the weight of each RR, which was consistent with the weighting estimates in Zhou *et al* (2016). The mean response ratio (RR\(_{++,}\)) was calculated from the RRs of individual pairwise comparison between grazing and enclosed treatments. Here, \(m\) is the number of groups (e.g. different grazing intensities), \(k\) is the number of comparisons in the \(i\)th group, and \(RR_i (i = 1, 2, \ldots, m; j = 1, 2, \ldots, k)\) is the response ratio of each samples

\[
RR_{++} = \frac{\sum_{i=1}^{m} \sum_{j=1}^{k} W_{ij} RR_{ij}}{\sum_{i=1}^{m} \sum_{j=1}^{k} W_{ij}}.
\]

The standard error of \(RR_{++,}\) was estimated by

\[
S(\text{RR}_{++}) = \frac{1}{\sqrt{\sum_{i=1}^{m} \sum_{j=1}^{k} W_{ij}}}.
\]

We further evaluated to see if \(RR_{++}\) was affected by grazing intensity, the total heterogeneity among group \((Q_b)\) was partitioned into within-group \((Q_w)\) and between-group \((Q_a)\) heterogeneity. According to Hedges *et al* (1999), significance of \(Q_a\) indicates that the response ratios are different among different subgroups (table S1 is available online at stacks.iop.org/EnvironResLett/14/114003/mmedia); therefore, a separate mean RR\(_{++}\) and 95% confidence intervals (1.96 \(\times\) S (RR\(_{++}\))) was calculated for each category group based on the equations (3) and (4). The percentage changes of variables were calculated based on \((e^{\text{RR}_{++} - 1}) \times 100\%\). Structural equation modeling was employed to evaluate the hypothesized underlying factors that influence biodiversity along a grazing intensity gradient (Wang *et al* 2017) using the package ‘piecewiseSEM’ in R software. The model was assessed by Fisher’s C statistic, Akaike information criterion (AIC), and P-values. Due to the lack of data for the H′ of arthropods and microbes, we focused on reporting the results based on SR.

All data were analyzed using Metawin 2.4 and R 3.5.1 (R Core Team 2018); the statistical results were considered to be statistically significant at \(P \leq 0.05\).
The graphs were drawn with the ggplot2 package in R 3.5.1 (R Core Team 2018).

**Results**

**Effects of grazing on biodiversity**

Grazing significantly affected the biodiversity in grasslands, but the effects varied with different taxa and grazing intensities (figure 2). Across all studied taxa, grazing resulted in enhanced SR, while $H'$ significantly decreased after grazing (figure 2). Among different taxa, SR of plant significantly increased, but $H'$ decreased after grazing. Both of SR and $H'$ of arthropods significantly decreased, while the two indexes for microbe increased after grazing (figure 2). Along the gradient of increasing grazing intensity, plant SR markedly increased with light and moderate grazing and decreased with heavy grazing (figure 2(a)), however, $H'$ was enhanced with light intensity and declined with moderate and heavy intensity grazing (figure 2(b)). Both SR and $H'$ of arthropods significantly decreased along the gradients of increasing intensity.
grazing intensity (figure 2), including pollinators and carabids (figure 6). The SR and H’ of microbes increased with light and moderate intensity grazing, but significantly decreased with heavy grazing (figure 2). In addition, bacterial SR increased with light and moderate intensity and decreased with heavy intensity grazing, while fungal SR increased with light intensity and declined with moderate and heavy intensity grazing (figure 6).

**Factors influencing the response of diversity**

Grazing intensity affected the diversity of plants, arthropods, and microbes through creating changes in diverse factors (figures 3–5). Structural equation modeling showed that mean annual temperature and the response of plant biomass jointly explained 51% of the variation in the response of plant SR to changes in grazing intensity (figure 3(a)); the response of plant biomass and coverage jointly explained 23% of the variation in the response of H’ (figure 3(b)). The positive effects of grazing intensity on plant SR mainly occurred through its negative effect on plant biomass (figures 3(a) and S1(a)). The response of plant coverage and arthropod abundance jointly explained 61% of the variation in the response of arthropod SR to grazing intensity (figure 4). The negative effects of grazing intensity on arthropod SR occurred through the negative effect of grazing on plant coverage and arthropod abundance (figures 4, S1(b) and (c)). In addition, the response of soil pH and moisture jointly explained 48% of the variation in the response of bacterial SR (figure 5(a)). The decrease of SR of bacteria along with a gradient of increasing grazing intensity was mainly caused by the positive effect of grazing intensity on soil pH and negative effect on soil moisture (figures 5(a), S1(d) and (e)). Similar to bacteria, 71% of the variation in the response of fungal SR was jointly explained by the response of soil total carbon and moisture (figure 5(b)). The decrease of SR...

---

**Figure 3.** A structural equation modeling of grazing effects on (a) plant species richness and (b) Shannon–Wiener diversity (H’). Red and black arrows represent significant positive and negative pathways, respectively, and gray arrows indicate insignificant pathways. Numbers indicate the standard path coefficients. Arrow width is proportional to the strength of the relationship. $R^2$ represents the proportion of variance explained for each dependent variable. Parameters for model (a): akaike information criteria (AIC) = 36.1, $P = 0.42$, Fisher’s C = 24.1, df = 52; for model (b): akaike information criteria (AIC) = 38.6, $P = 0.15$, Fisher’s C = 6.86, df = 92. Note: MAP, mean annual precipitation; MAT, mean annual temperature; RR, response ratio.

**Figure 4.** A structural equation modeling of grazing effects on arthropod species richness. Red and black arrows represent significant positive and negative pathways, respectively, and gray arrows indicate insignificant pathways. Numbers indicate the standard path coefficients. Arrow width is proportional to the strength of the relationship. $R^2$ represent the proportion of variance explained for each dependent variable. Parameters for model: akaike information criteria (AIC) = 33.1, $P = 0.9$, Fisher’s C = 10.17, df = 20. Note: MAP, mean annual precipitation; MAT, mean annual temperature; RR, response ratio.
Grazing by livestock is a major human activity that significantly affects biodiversity of grasslands, but the response of diversity varies among different taxa (Winfree et al 2009, Liu et al 2015, van Klink et al 2015, Andriuzzi and Wall 2017, Davidson et al 2017, Herrero-Jáuregui and Oesterheld 2018). Our meta-analyses showed that plant diversity significantly increased after grazing, which agrees with the results from the meta-analyses of Davidson et al (2017) and Herrero-Jáuregui and Oesterheld (2018); the increase in plant diversity may be attributed to the direct ingestion of plants by livestock (Tahmasebi Kohyani et al 2008). Our meta-analyses are among the first to find microbial diversity significantly increased after grazing, which may closely related to the changes of plant diversity and soil properties (Fierer and Jackson 2006, Jing et al 2015). However, the response of arthropod diversity to grazing in our study was opposed to the effects of grazing on plants and microbes. We found that grazing resulted in a significant reduction in arthropod diversity, which was consistent with the results from meta-analyses of Winfree et al (2009) and van Klink et al (2015). It has been proved that a reduction in arthropod diversity after grazing was mainly induced by the ingestion of plants by livestock and by habitat modification (Cumming and Cumming 2003, van Noordwijk et al 2012). Therefore, the different factors influencing the effects of grazing could lead to diverse responses in biodiversity for different taxa.

Factors regulating the response of diversity to grazing intensity
Grazing intensity affected biodiversity with different magnitudes or even directions in a large number of individual studies (Cagnolo et al 2002, Dumont et al 2009, Zhou et al 2010, Ba et al 2011, Deng et al 2014). Using a meta-analyses method, we found that the response of plant and microbial diversity along a gradient of increasing grazing intensity is in accordance with the intermediate disturbance hypothesis, which was similar to the results from Zhou et al (2010) and Deng et al (2014) in desert and typical steppes, respectively. However, arthropod diversity monotonously decreased along a gradient of increasing grazing intensity (figure 2), which was similar to the results from van Klink et al (2015). Importantly, the most important drivers for the change of diversity in plants, arthropods, and microbes were diverse along the grazing intensity gradient.

Grazing intensity affected plant diversity mainly through decreasing plant biomass. At the initial stage, grazing decreased plant biomass (figure S1(a)), which weakened the competitive advantage of dominant fungi along an increasing grazing intensity gradient was mainly caused by a decrease in soil moisture (figures 5(b) and S1(e)).

Discussion
Many studies have explored the response of biodiversity to grazing. Three aspects of our study, however, distinguish it from these previous studies. First, while a few studies of grazing on biodiversity have considered plants, arthropods, and microbes separately, our study examines the effects of grazing on the diversity of three different groups of taxa in a single meta-analyses. Second, our study explores the different effect of grazing intensity on biodiversity. Third and most importantly, our study demonstrated that grazing intensity altered biodiversity through its effects on both and abiotic factors, while the factors causing these effects varied in their effects on the diversity of plants, arthropods, and microbes as distinct groups.

Inconsistent effects of grazing on diversity among taxa
Grazing by livestock is a major human activity that significantly affects the biodiversity of grasslands, but the response of diversity varies among different taxa (Winfree et al 2009, Liu et al 2015, van Klink et al 2015, Andriuzzi and Wall 2017, Davidson et al 2017, Herrero-Jáuregui and Oesterheld 2018). Our meta-analyses showed that plant diversity significantly increased after grazing, which agrees with the results from the meta-analyses of Davidson et al (2017) and Herrero-Jáuregui and Oesterheld (2018); the increase in plant diversity may be attributed to the direct ingestion of plants by livestock (Tahmasebi Kohyani et al 2008). Our meta-analyses are among the first to find microbial diversity significantly increased after grazing, which may closely related to the changes of plant diversity and soil properties (Fierer and Jackson 2006, Jing et al 2015). However, the response of arthropod diversity to grazing in our study was opposed to the effects of grazing on plants and microbes. We found that grazing resulted in a significant reduction in arthropod diversity, which was consistent with the results from meta-analyses of Winfree et al (2009) and van Klink et al (2015). It has been proved that a reduction in arthropod diversity after grazing was mainly induced by the ingestion of plants by livestock and by habitat modification (Cumming and Cumming 2003, van Noordwijk et al 2012). Therefore, the different factors influencing the effects of grazing could lead to diverse responses in biodiversity for different taxa.
species for light and nutrient resources, offered an better opportunity for the invasion of other species, especially locally distributed species (Connell 1978, Yan et al 2015). Hence, new species with lower powers of dispersal and slower growth can now reach maturity, and thus lead to an increase in plant diversity with the light and moderately intense grazing. However, with an increase in grazing intensity, soil nutrients and moisture availability became more limited (Savadogo et al 2007, Davidson et al 2017; figure S1) due to the rapid reduction in plant biomass (figures 3(a) and S1), which may eliminate the habitat of most species. Therefore, the plant community will consist of only those few species capable of quickly reaching maturity (Connell 1978, Marion et al 2015), and consequently lead to a reduction in plant diversity under heavy grazing intensity.

Arthropod diversity monotonously decreased along the gradient of increasing grazing intensity, this was mainly caused by the decline in arthropod abundance and plant coverage. First, many studies have shown that large herbivores directly ingested arthropods unintentionally as a by-product of their forage intake (Bonal and Munoz 2007, Gómez and González-Megías 2007, van Noordwijk et al 2012), including pollinators and carabids (figure 6). This could lead to a reduction in population sizes of arthropods (figure S1(c)), and then cause a decrease in arthropod diversity along the grazing intensity gradient (figure 4). Secondly, grazing indirectly decreased arthropod diversity through habitat modification. Plant coverage declined because plants were ingested by livestock, which may leave a smaller amount of space for arthropods to reproduce and increase the risk to arthropods of being preyed upon by their natural enemies (Hobbs et al 1996, Cumming and Cumming 2003). Thus, the decline in shelter along a grazing intensity gradient may be another reason for the reduction in arthropod diversity.

The effect of grazing intensity on the diversity of soil bacteria and fungi transferred into an increase in soil pH and decrease in soil moisture along the grazing intensity gradient. It has been clearly indicated that the response of the soil microbial community to grazing is closely related to the change in soil properties (Fierer and Jackson 2006, Steffens et al 2008, Dimitriu and Grayston 2010, Qu et al 2016), such as soil pH and moisture. Previous studies reported that microbial diversity declined as the soil pH increased from neutral to alkaline (Fierer and Jackson 2006) and as soil moisture decreased (Qu et al 2016, Davidson et al 2017) after grazing. With the light intensity grazing, bacterial and fungal diversity increased with the increase of soil moisture and the decrease of soil pH (figures S1(d) and (e)). As grazing intensity increased, soil pH significantly increased but soil moisture decreased (figures S1(d) and (e)), which may be followed by a reduction in bacterial and fungal
diversity (figure 6). Therefore, grazing-induced changes in microbial diversity may be ascribed to the changes in soil pH and moisture with the gradient of increasing grazing intensity.

Conclusions

Our meta-analyses were helpful in elucidating the effects of grazing intensity on multi-taxa diversity in grasslands at the global scale. Grazing resulted in a significant enhancement of biodiversity, with increases in plant and microbial diversity, while arthropod diversity significantly decreased. This suggests that the diversity of multiple taxa should be considered in monitoring schemes designed to evaluate the effects of grazing on biodiversity. The divergent responses of different taxa to the increase in grazing intensity revealed that changes in the diversity of a single group of species were a poor predictor for the alteration of biodiversity in grasslands. Moreover, the key drivers for the response of diversity to grazing intensity were varied among taxa, which indicated that comprehensive factors, including multi-taxa diversity and multi-functionality, should be considered when applying grazing management in grasslands.

Acknowledgments

This study was supported by Beijing Academy of Agriculture and Forestry Sciences (BAAFS) Special Project on Hi-Tech Innovation Capacity (Grant No. KJCX20180707 and KJCX20180405) and National Natural Science Foundation of China (Grant No. 31901173). We would like to acknowledge the work carried out by the researchers whose published data was used for this meta-analyses. We also thank LetPub (www.letpub.com) for its linguistic assistance during the preparation of this manuscript.

Data availability statements

The data that support the findings of this study are openly available at https://doi.org/10.5061/dryad.2lz612k0.

ORCID iDs

Chao Wang @ https://orcid.org/0000-0002-8916-4735

References

Allan E and Crawley M J 2011 Contrasting effects of insect and molluscan herbivores on plant diversity in a long-term field experiment Ecol. Lett. 14 1246–53
Allan E et al 2015 Land use intensification alters ecosystem multifunctionality via loss of biodiversity and changes to functional composition Ecol. Lett. 18 854–43
Andriuzzi W S and Wall D H 2017 Responses of belowground communities to large aboveground herbivores: meta-analysis reveals biome-dependent patterns and critical research gaps Glob. Change Biol. 23 3857–68
Bakker E S, Ritchie M E, Olf H, Milchunas D G and Knox J M 2006 Herbivore impact on grassland plant diversity depends on habitat productivity and herbivore size Ecol. Lett. 9 780–8
Ba L, Ning J, Wang D, Facelli E, Facelli J M, Yang Y and Zhang L 2011 The relationship between the diversity of arbuscular mycorrhizal fungi and grazing in a meadow steppe Plant Soil 352 143–56
Bonal R and Munoz A 2007 Multi-trophic effects of ungulate intraguild predation on acorn weevils Oecologia 152 533–40
Borer E T et al 2014 Herbivores and nutrients control grassland plant diversity via light limitation Nature 508 517–20
Bosch C and Baur B 2007 The effect of horse, cattle and sheep grazing on the diversity and abundance of land snails in nutrient-poor calcareous grasslands Basic Appl. Ecol. 8 55–65
Cagnolo L, Molina S I and Valladares G R 2002 Diversity and guild structure of insect assemblages under grazing and exclusion regimes in a montane grassland from Central Argentina Biodivers. Conserv. 11 407–20
Campbell W B, Freeman D C, Emlen J M and Ortiz S L 2010 Correlations between plant phylogenetic and functional diversity in a high altitude cold desert depend on sheep grazing season: implications for range recovery Ecol. Indicators 10 676–86
Cheng Y, Tsubo M, Ito T, Nishihara E and Shinoda M 2011 Impact of rainfall variability and grazing pressure on plant diversity in Mongolian grasslands J. Arid Environ. 75 471–6
Connell J H 1978 Diversity in tropical rain forest and coral reefs Science 199 1302–10
Cumming D H and Cumming G S 2003 Ungulate community structure and ecological processes: body size, hoof area and trampling in African savannas Oecologia 134 560–8
Davidson K E, Fowler M S, Skov M W, Doerr S H, Beaumont N, Griffin J N and Bennett J 2017 Livestock grazing alters multiple ecosystem properties and services in salt Marshes: a meta-analysis J. Appl. Ecol. 54 395–405
de Vries F T and Bardgett R D 2012 Plant–microbial linkages and ecosystem nitrogen retention: lessons for sustainable agriculture Front. Ecol. Environ. 10 425–32
Deng L, Sweeney S and Peng S 2014 Grassland responses to grazing disturbance: plant diversity changes with grazing intensity in a desert steppe Grass Forage Sci. 69 524–33
Dimitriu P A and Grayston S J 2010 Relationship between soil properties and patterns of bacterial beta-diversity across reclaimed and natural boreal forest soils Microb. Ecol. 59 563–73
Dong Q, Zhao X, Ma Y, Shi J, Wang Y, Li S and Sheng L 2011 Effects of yak grazing intensity on quantitative characteristics of plant community in a two-seasonal rotation pasture in Kobresia parva meadow Chin. J. Plant Ecol. 35 2233–9
Dumont B, Farruggia A, Garel J P, Bachelard P, Boitier E and Frain M 2009 How does grazing intensity influence the diversity of plants and insects in a species-rich upland grassland on basalt soils Grass Forage Sci. 64 92–105
Fierer N and Jackson B R 2006 The diversity and biogeography of soil bacterial communities Proc. Natl Acad. Sci. USA 103 626–31
Gómez J M and González–Megías A 2007 Long-term effects of ungulates on phytophagous insects Ecol. Entomol. 32 229–34
Gou Y, Nan Z and Hou F 2015 Diversity and structure of a bacterial community in grassland soils disturbed by sheep grazing, in the Loess Plateau of northwestern China Genet. Mol. Res. 14 16987–99
Gurevitch J, Koricheva J, Nakagawa S and Stewart G 2018 Meta-analysis and the science of research synthesis Nature 555 175–82
Gossner M M et al 2016 Land–use intensification causes multitrophic homogenization of grassland communities Nature 540 266
Hedges L, Gurevitch J and Curtis P 1999 The meta-analysis of response ratios in experimental ecology Ecology 80 1150–6
