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Characteristics and trends of grassland degradation research

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Abstract
Purpose Grasslands are the largest type of terrestrial ecosystem on the earth, providing rich and unique ecosystem services. However, climate change and human activities have triggered a global degradation of grasslands, which has become a major ecological crisis. In this study, a scientometric analysis was performed to explore the hotspots and frontiers of global grassland degradation research.
Materials and methods Two methods involving visualization were used to analyze these data: document co-citation analysis and burst analysis based on the papers indexed in the Web of Science (WOS) during 1970–2020.
Results and discussion A total of 3580 research papers related to grassland degradation research and 54,666 references were included. The results showed that Harris's paper in 2010 had the strongest burst value of 26.2, far larger than any other, which shows that this paper was a turning point in the research process. The document co-citation network was divided into 14 main theme clusters. The most influential and emerging research theme clusters were including alpine meadow, grazing exclusion, alpine region, and human activities. Alpine meadow was the largest cluster lasting from 2010 to 2020, indicating that this topic is still active in grassland degradation research. Furthermore, research focus has transferred toward grasslands in Qinghai-Tibetan Plateau. The topic of grazing exclusion is both classic and currently active as it lasted as a research hotspot for 15 years (2004–2018). However, the extent and state of grazing effects research are unclear.
Conclusions As the first scientometric review on grassland degradation research, our study identified the research hotspots and their shifts over the past 50 years, pointing to some potential research frontiers in the future. The scientometric analysis is a useful tool for a quantitative evaluation of research hotspots and trends of global grassland degradation.

Keywords Grassland degradation · CiteSpace · Scientometric analysis · Visualization · Frontiers

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1 Introduction

Grasslands, composed of natural, seminatural, and improved grasslands (Bengtsson et al. 2019), represent the largest type of terrestrial ecosystem on the earth, accounting for 40% of the land surface (Milchunas 1993; Cingolani 2005). They provide essential and unique ecosystem services such as raw materials, products, and other economic values for human beings (Blair et al. 2014; Bengtsson et al. 2019) and contribute to the livelihoods of over 800 million people including many smallholders (da Silveira Pontes et al. 2015; Hadidi 2018). All these functions of grasslands not only are economically crucial in many parts of the world but also play an irreplaceable role in socio-ecological systems (Chen et al. 2018). Some people argue that grassland conservation would hinder socio-economic development due to continuous financial investment (Leisher et al. 2011). However, from a sustainable development perspective, once the grassland is threatened, substantial ecological functions will be weakened, resulting in an unpredictable ecological structure disorder (Zhang et al. 2020b). Close to 50% of the world's grassland has experienced different degrees of degradation, with nearly 5% of the grassland reaching severe degradation (Gang et al. 2014). Asia takes the largest share of degraded grasslands in the world (Gang et al. 2014). Grassland degradation represents a major global threat to ecosystem functions and regional ecological security (Harris 2010; Wu et al. 2014; Lu et al. 2015) and seriously restricts global socioeconomic development and the effective realization of the 2030 sustainable development goals.

Grassland degradation is a complicated social-ecological problem (Fig. 1), which will lead to a decrease in the degree of coupling between the structure and function of the grasslands (Dong et al. 2020; Zhang et al. 2020b), an unsteady state in the ecosystem (Cao et al. 2019), changes in community composition and structure (Dong et al. 2012; Wang et al. 2020), disorder in terrestrial biogeochemical cycles, and decline in ecosystem services and functions (Zhang et al. 2020b). Numerous studies in the past have demonstrated that grassland degradation results from the joint driving force of climate change and human activities, which mainly refer to overgrazing of grasslands (Han et al. 2018a; Dong et al. 2012). Some researchers have shown that global climate change and increasing human activities have led to the severe degradation of Eurasian grassland (Harris 2010; Zhou et al. 2014; Zhang et al. 2020a; Bardgett et al. 2021), particularly the alpine grassland in Qinghai–Tibetan Plateau and the temperate grassland in Mongolian Plateau (Cao et al. 2011; Dong et al. 2012; Dong et al. 2020; Zhang et al. 2020a). Therefore, quantitative assessments of effects and relative contribution of climate change and human activities are necessary to understand grassland degradation (Gang et al. 2014; Han et al. 2018b). Clarifying the impacts of climate change on grassland degradation will further improve our understanding of the degradation mechanism and promote the consensus around grassland degradation standards. Grazing, as one of the dominant types of human activities, is also a critical control of grassland degradation. There are vast differences in grazing regime around the world. Many scholars have systematically discussed different grazing methods, such as exclusive grazing, fenced grazing, seasonal grazing, multi-household grazing have different impacts to grassland ecosystem (Chen et al. 2018; Otte et al. 2019; Azevedo et al. 2020). However, once overgrazing will lead the degradation of grassland (Li et al. 2018).

The problem of grassland degradation has attracted the attention of scholars. Therefore, it is important to have a comprehensive understanding of grassland degradation research. To obtain this, we need to review the grassland degradation knowledge structure systematically, and discuss its current research status, research trends. Analysis of hotspots dynamics and trends of global grassland research can facilitate the understanding of grassland degradation and restoration deeply (Tiscornia et al. 2019; Xie et al. 2020),

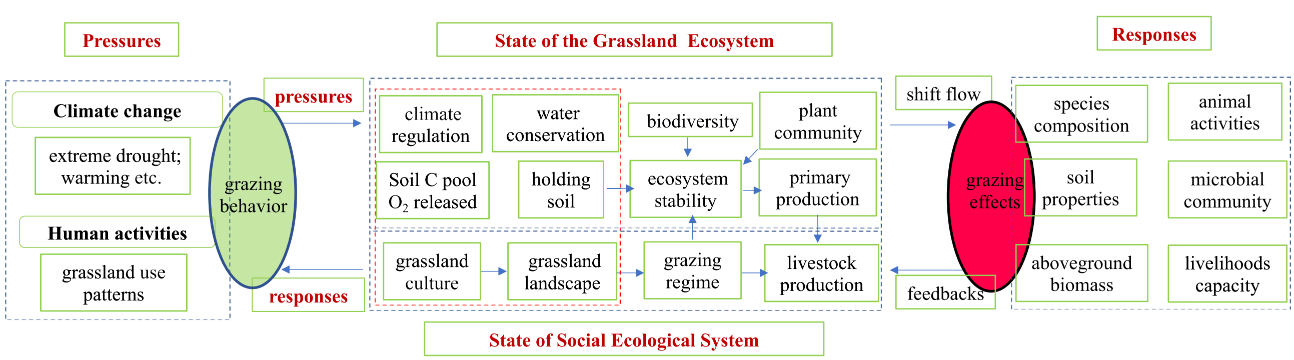

Fig. 1 Concept graph of grassland degradation studies into climate and human pressure and the feedback model (Chen et al. 2018; Otte et al. 2019; Azevedo et al. 2020) Adapted from the pressure response model)

which can provide hints for grassland restoration research in the future.

Bibliometric and scientometric methods have been widely used on forest degradation, land degradation, sustainable development, ecosystem services evaluation. Bibliometrics and its subfield scientometrics are both important quantitative tools for analyzing the progress of a certain research topic from the macro (e.g., dual map overlays) to the micro (e.g., influential articles, influential authors) level, based on many scientific peer-reviewed published studies. Compared with bibliometrics, the advantage of scientometrics lies in keyword analysis, analysis of research topic evolution, frontier dynamic analysis (such as document co-citation analysis, which can help the researcher to establish the research basis as knowledge base), and other aspects with strong analysis efficiency. It provides in-depth qualitative outputs in the form of a knowledge map and quantitative analysis of citations or cited references. Both methods of bibliometrics and scientometrics have become useful tools to track the core contents of research. Based on the WOS database, Aleixandre-Benavent et al. (2018) analyzed the scientific production, cooperation between countries, and the most cited papers on deforestation through bibliometric and social network research. Xie et al. (2020) described the present situation, development, and future of land degradation using bibliometrics, and studied the land ecological service function by scientometrics. Though both studies were conducted from the perspective of bibliometric analysis, they lacked an in-depth analysis of the results of co-citation network clustering. Escadafal et al. (2015) analyzed land and soil degradation by bibliometric analysis of publications on desertification. Zhang et al. (2020a, b) used bibliometric analysis and network view to explore the ecology and sustainability of Inner Mongolia grassland from 1998 to 2019. Other researchers have used bibliometric methods to analyze plant species diversity, and soil chemical and physical properties (McSherry and Ritchie 2013). All these literature reviews have highlighted the practicality and reliability of this method.

Although the scientometric method of literature review in the field of degradation has become an important means of interpretation, its implementation was generally limited to certain regions, and the literature analysis lacked comprehensive systematic study and subject refinement. In addition, there was no clear distinction between the usage of scientometrics and bibliometrics in the published studies (Hafner et al. 2012; Shi et al. 2013; Li et al. 2018). To our knowledge, there is no comprehensive review of studies on global grassland degradation using scientometrics and visual knowledge maps published in peer-reviewed journals. To address this issue, we combined the main tools of bibliometric analysis and the scientometric method. In this study, we reviewed the overall picture and analyzed the development trends of grassland degradation studies. We searched for all relevant documents on global grassland degradation research from 1970 to 2020 and used the software CiteSpace to analyze these data systematically and draw a map of scientific knowledge on grassland degradation. Several important methods of network identification involving visualization and text mining were used to analyze these data: burst analysis, document co-citation analysis. In this way, the major research fields on global grassland degradation were tracked, evaluated, and interpreted. In this review, we explore two key research questions: 1. What are the impactful publications (burst references) in grassland degradation research studies? 2. What are the major research trends of global grassland degradation research studies?

2 Materials and methods

2.1 Literature search

We used an online search application to retrieve grassland degradation studies from the WOS core collection. We used the advanced search method to find the related documents under the topic of grassland degradation research studies, with the key words covering different names of grassland and degradation (Li et al. 2021). The details of key-word combinations and other search settings were shown in the supplementary information (Online Resource 1). After elimination and cleaning of irrelevant results, this process finally yielded a total of 3580 publications and 51,566 unique references from the WOS database between 1970 and 2020. The file containing the list of publications was downloaded and imported into the CiteSpace software for further scientometric analysis (Chen et al. 2010; Chen 2017; Aryadoust and Ang 2019).

2.2 Data visualization and analysis

We visualized and analyzed the dataset with a new version of CiteSpace (Version 5.7R2). CiteSpace is a visual software based on Java language developed by Professor Chen Chaomei of Drexel University (Chen et al. 2010; Chen 2017), which is used to analyze and review scientific research literature. The software is based on citation analysis and co-occurrence word analysis to conduct statistics, research, and mining of literature in a specific field, to find the evolution trend of the discipline.

2.2.1 Impactful publications: burst analysis

One of the important functions of CiteSpace is citation burst analysis. As the number of citations of an article increases sharply in the period after the cited reference, this function is a useful method for exploring the development of research trends (Chen 2017). The function uses the mutation detection algorithm designed by Kleinberg (Zhang and Chen 2020) to extract explosive nodes from large data quantities and identify bursts, which can represent the research hotspots (Zhang and Chen 2020). The burst detection refers to a certain time range. The identified burst literature does not necessarily have the absolute highest number of citations but a high rate of change in citations, indicating that in a certain time range, the literature was able to attract the attention of peers. The higher the burst strength, the higher the publication's importance in the short term, which is often the turning point of a research direction or attracts the attention of peers. A burst analysis plays an important role in helping researchers find landmark documents in relevant research areas and assess the key or core research (Chen et al. 2010; Chen 2017).

2.2.2 Research trends: document co-citation analysis

CiteSpace performs document co-citation analysis through the cited reference function and the function modules timeline view. The timeline view focuses on describing the evolution trend and interaction of various research fields over time, which is important to grasp the past and present of the discipline and predicting the research hotspots. The unique feature of the timeline view is that it can sketch the relationship between clusters and the historical span of documents in a cluster. The color curves represent the co-citation links, and the curve thickness represents the co-citation strength in timeline view (Chen and Song 2019). Large nodes or nodes with red tree rings are particularly worth exploring because they are either highly cited, burst, or both. At the nodes of each timeline, up to three references and at least one reference cited in a particular year are displayed. The most cited reference label is placed at the lowest position, and the least cited reference is placed at the left side (Chen 2017). Based on their size, the clusters are identified with Arabic numerals, with cluster #0 being the largest cluster placed at the top of the graph.

3 Results

3.1 Impactful publications from burst analysis

Table 1 shows the main 10 references burst ranked by their strength. The top-ranked item is Harris (2010), a notable publication showing a high document strength value of 26.2 since 2012. This suggests that Harris's paper was highly influential and contributed to the development of grassland degradation studies, especially during 2012–2015. The results show that the citation span of all top 10 references with the strongest citation bursts under 5 years (Table 2).

Currently, the documents with high burst values and citations ending in 2020 are Liu (2020a) with a burst value of 13.16, Chen et al. (2014) with a burst value of 12.01, Zhou et al. (2017b) with a burst value of 8.3, Wang et al. (2017) with burst value of 7.87. The most important research reference hotspots with citations ending in 2019 were Chen et al. (2013) with a burst value of 8.01 and Wang et al. (2016) (with a burst value of 7.97 in 2019. The research hotspots with citation ending in 2018 were Li et al. (2013), McSherry and Ricthie (2013), and Wu et al. (2010) with burst values of 13.69, 10.42, 8.96, respectively (Table 1).

3.2 Research trends from document co-citation analysis

Figure 2 shows the timeline view of each research hotspot identified by document co-citation analysis. As the timeline view shows, the persistence of research content clusters is different. Some clusters last more than 20 years,

Table 1 Top 10 references with the strongest citation bursts

References	Publication year	Burst strength	Citation begin	Citation end	Citation span
Harris (2010), Journal of Arid Environments, V74, P1	2010	26.20	2012	2015	4
Li et al. (2013), Land Degradation and Development, V24, P72	2013	13.69	2015	2018	4
Liu et al. (2018), Agriculture Ecosystems & Environment, V252, P93	2018	13.16	2019	2020	2
Chen et al. (2014), Agricultural and Forest Meteorology, V189, P11	2014	12.01	2016	2020	5
McSherry and Ritchie (2013), Global Change Biology, V19, P1347	2013	10.42	2014	2018	5
Wu et al. (2010), Plant and Soil, V332, P331	2010	8.96	2014	2018	5
Gang et al. (2014), Environmental Earth Sciences, V72, P4273	2014	8.36	2016	2017	2
Zhou et al. (2017b), Ecological Indicators, V83, P303	2017	8.30	2018	2020	3
Chen et al. (2013), Global Change Biology, V19, P2940	2013	8.01	2016	2019	4
Wang et al. (2016), Ecological Informatics, V33, P32	2016	7.97	2017	2019	3

Table 2 Temporal properties of the 14 main clusters identified by document co-citation analysis on grassland degradation research

ID	Cluster size (no. of references)	Silhouette	From year	To year	Cluster duration (year)	Mean year	Persistence	Activeness	Theme
0	175	0.71	2010	2020	11	2014	+++++	+	Alpine meadow
1	132	0.87	2004	2018	15	2007	++++++	+	Grazing exclusion
2	113	0.89	2006	2017	12	2010	+++++	+	Alpine region
3	56	0.93	1998	2006	9	2003	+++	–	Soil aggregate stability
4	55	0.99	2000	2008	9	2004	+++	–	*Leymus chinensis* grassland
5	42	0.97	2012	2019	8	2015		+	Human activities
6	42	0.92	2014	2019	6	2016		+	Qinghai–Tibetan alpine steppe
7	34	0.96	2010	2017	8	2013		+	Mapping change
8	31	0.98	2011	2019	9	2014	+++	+	Subtropical grassland
11	24	0.99	2007	2014	8	2009		–	Southern edge
13	18	0.99	2006	2012	7	2008		–	Southern edge
16	13	0.99	2002	2007	6	2003		–	Middle Awash valley
38	6	1.00	2014	2019	6	2017		+	Wood cover
48	5	0.99	2010	2013	4	2011		–	Linking range management

while others have a relatively short life span. Some clusters remained active until 2020, the latest year for which references are cited in this study. Clusters were numbered from 0, i.e., Cluster #0 was the largest cluster and Cluster #1 was the second largest one. As shown in the timeline overview, the persistence (continuous active periods) of a cluster varied.

Table 2 presents a summary of the fourteen main clusters identified by document co-citation analysis. The four largest and active research hotspots were clusters 0–2 and 5. The largest cluster #0, labeled as "alpine meadow," had 175 references (23.7% of all clusters) from 2010 to 2020, with a silhouette value of 0.713, showing a relatively low level of homogeneity. The mean year of all references in this cluster

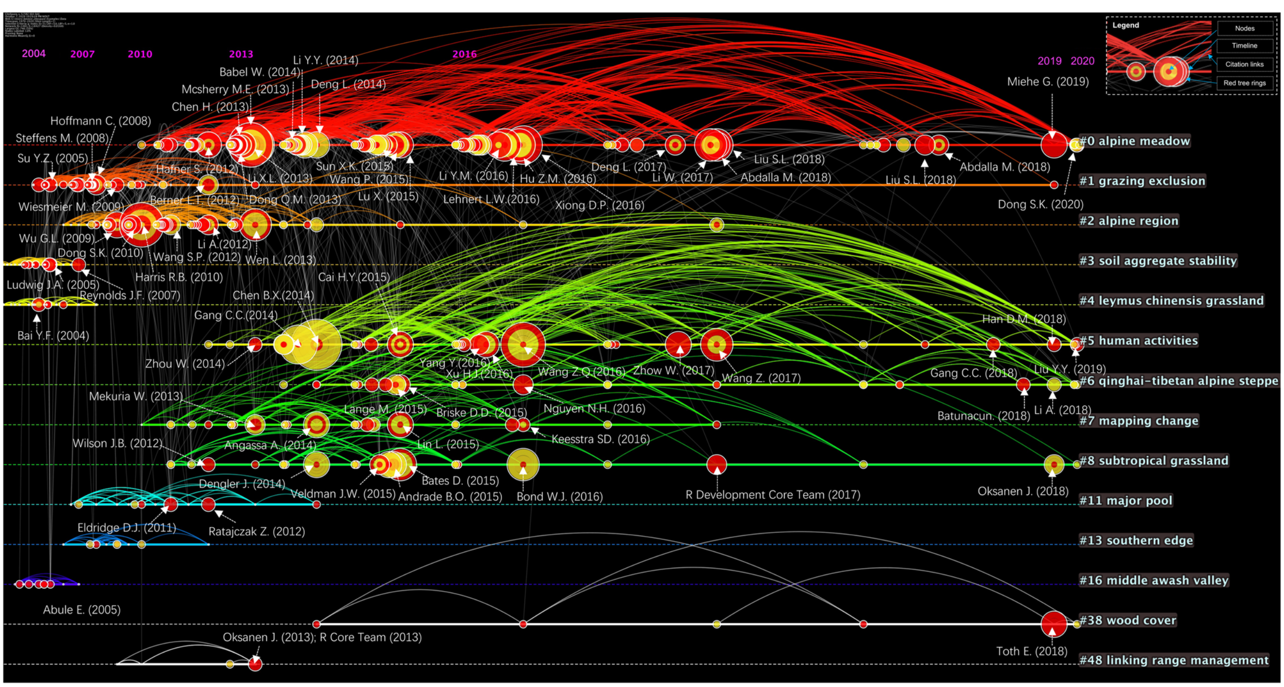

Fig. 2 A timeline visualization of main clusters of the total on grassland degradation research from 1970 to 2020 (LRF = 3.0, LBY = 5, e = 1.0)

was 2014 (Table 2), but the 20 most representative cited articles in the cluster had a mean year of 2017. The cluster showed research activity from 2010 until the present. The continuity of time was excellent, and it will probably continue to be active in the future.

Cluster #1 "grazing exclusion" was the second-largest cluster, containing 132 references (17.7% of all clusters) that sustained a 15-year duration from 2004 to 2018. In the grassland degradation studies database, it was the most extended over time and was still active in the last 2 years. Cluster #2 labeled as "alpine region" was the third largest cluster with 113 cited references (15.1% of all clusters). The silhouette value was 0.89, which was slightly higher than the previous clusters #0 and #1, suggesting a higher homogeneity. From 2006 to 2017, this cluster was active for 12 years. Seen from another perspective, this research is more extensive than the one previously established, which showed the highest sustainability, was a continuing focus and hotspots for researchers. The maximum burst reference, Harris (2010), appeared in this cluster.

The period from 2012 to 2019 was a highly active period for cluster #5, labeled as "human activities". The most active citer in this cluster was Shen et al. (2011). The most notable contributions in this cluster included the original article with the hypothesis that "The extent and magnitude of grassland degradation remain largely unknown and the causes of degradation still are uncertain" on the Qinghai–Tibetan Plateau (Chen et al. 2014).

4 Discussion

In this study, various methods of co-citation analysis were used to unravel the internal relationship among published papers on grassland degradation over the past few decades. This section discusses the main findings.

4.1 Impactful publication from burst analysis

The publication year of a citation burst can help researchers trace back to the early stages of the research field, highlight the strength of the literature, illustrate the key findings in the specific period, and discover research directions and hotspots at different stages. These references are of high burst value in the publication year. The citation span of all the main citation bursts was under 5 years, indicating that research hotspots migrate over time and do not last long. Table 3 describes research hotspots topics from burst literature during 2018–2020.

Table 3 suggested that the hotspots of research on global grassland degradation are concentrated in the alpine grasslands of the Qinghai–Tibetan Plateau. This hotspot literature generally analyzed the contribution of human activities and climate change to grassland degradation, through different assessment methods (remote sensing, models, field experiments.). The main results of this research were that climate change and human activities are the two main factors accelerating grassland degradation and affecting the structure, function, and process of grasslands, and that human activities play a greater role in the process of grassland restoration.

Burst analysis demonstrated that the most influential paper was "Rangeland degradation on the Qinghai–Tibetan Plateau: A review of the evidence of its magnitude and causes" published in the Journal of Arid Environments, by Harris (2010, vol 74, p1–12). However, many of the top 15 cited documents are still being cited, and further data may be needed for a more exact evaluation.

4.2 Detailed discussion of the major clusters

Despite a higher rank based on both documents and activity, #3 and #4 clusters are less active than #5 cluster (see column activeness in Table 2). Therefore, we describe #5 instead of #3 and 4#. The following discussion will particularly focus on the four largest and most active research hotspots (Table 3).

4.2.1 Cluster #0 "alpine meadow"

This cluster mainly focused on grazing effects on grassland degradation and restoration in the alpine meadows of the Qinghai–Tibetan Plateau. Alpine grassland is the main ecosystem in the Qinghai–Tibetan Plateau (Cao et al. 2019). It plays an important role in climate regulation and water resource security, not only in Asia but also in the world, and contributes to the global biogeochemical cycle and biodiversity conservation (Chen et al. 2013). These functions are reported to be threatened by meadow degradation on the Qinghai–Tibetan Plateau (Lehnert et al. 2016). The degradation of alpine grassland is characterized by the gradual shifting of the plant community structure from perennial species (grasses and sedges) to annual grasses along the degradation gradient. After severe grassland degradation, plant diversity and productivity also change. Therefore, plant species diversity and productivity are essential predictors of different stages of alpine meadow degradation (Deng et al. 2014; Jing et al. 2014; Wu et al. 2014). Some research results indicated that grazing was beneficial to the maintenance of plant diversity in alpine grassland. However, grazing exclusion was beneficial to increase aboveground biomass (Lu et al. 2015; Hu et al. 2016).

The cluster #0 results show that grazing behavior has been studied in many kinds of research on alpine grassland degradation and restoration mechanisms. Grazing is one of the typical grassland disturbances. It can impact ecosystem structure or function, and also affects the grasslands' health

Table 3 Research hotspots in the past 3 years based on burst analysis

Year	Hotspot	Research region	Grassland type	Objectives	Main conclusions
2018	Liu et al. (2020a)	Qinghai–Tibetan Plateau	Alpine grassland (*Kobresia* pastures)	Seeking the consequences for carbon and nutrient cycles of grassland degradation	"42% of SOC stocks were lost, relative to non-degraded pastures"
	Chen et al. (2014)	Qinghai–Tibetan Plateau	Alpine grassland	Evaluating the effects of climate change and anthropogenic activities	"The negative effect caused by climate change to ecosystem could have been relatively mitigated or offset"
	Zhou et al. (2017a)	China	Grasslands	Calculating the contribution of climate and human factors to grassland degradation	The contribution of climate change and human activities to grassland degradation was almost in equilibrium. However, for grassland restoration, human activities were the dominant factors
	Wang et al. (2017)	Inner Mongolia	Temperate grassland	Analyzing the changes in indicators of ecosystem services and functions	Climatic variation has negative impacts on grassland ecosystem services. Uncertain climatic variation mainly causes grassland degradation
2019	Chen et al. (2013)	Qinghai–Tibetan Plateau	Alpine grassland and swamp meadow	Evaluating the contribution of climate change and human activities on biogeochemical cycles	Human activities (e.g., grazing and land cover changes) further modified the biogeochemical cycles and amplified such uncertainties on the plateau
	Wang and Wesche (2016)	Qinghai–Tibetan Plateau	Alpine grassland	Quantitatively assessing the driving forces of grassland degradation	Climate was the principal driving force of grassland degradation, whereas human activities were the dominant factor in grassland restoration
2020	Li et al. (2013)	Qinghai–Tibetan Plateau	Alpine grassland	Evaluating the extent and underlying causes of grassland degradation	It is very difficult or even impossible to rehabilitate new assemblages of species, which appear as a result of climate change
	McSherry and Ritchie (2013)	Global scale	Global grassland	Analyzing the effects of grazing on grassland soil carbon	Grazer effects on SOC are highly context-specific and imply that grazers in different regions might be managed differently to help mitigate greenhouse gas emissions
	Wu et al. (2014)	Qinghai–Tibetan Plateau	Alpine swamp meadow	Evaluating the effects of fencing	Long-term fencing improved soil properties and soil organic carbon storage in western China

Table 4 Effects of grazing behavior on grassland structure and function resulting from the research on the theme cluster #0, "alpine meadow"

Grazing behavior	Indicator	Effect	Reference
Grazing exclusion	Aboveground biomass	+	(Lu et al. 2015; Hu et al. 2016)
	Underground biomass	−	(Yan and Lu 2015; Hu et al. 2016; Wang and Wesche 2016)
Increasing grazing intensity (from moderate to heavy grazing)	C (carbon) and N (nitrogen) losses	+	(Li et al. 2014; Wang et al. 2014)
	Soil total N content	−	(Steffens et al. 2008; Wang and Wesche 2016)
	Ecosystem services and functions	−	(Wen et al. 2012)
	Soil organic C content	−	(McSherry and Ritchie 2013)
	The pH or C/N ratio	no	(Steffens et al. 2008)
	Total P (phosphorus) content	−	(Wang and Wesche 2016)
Establishing artificial grassland as restoration measure	Aboveground and underground biomass	+	(Wang and Wesche 2016)
	Richness, diversity, and evenness index	−	(Wang and Wesche 2016)
Moderate grazing	Soil C input and C absorption	+	(Hafner et al. 2012)

and sustainability directly (Lu et al. 2015) (Table 4). Grazing intensity and grazing regime play an important role in the process of control and restoration in degraded grasslands (Hafner et al. 2012; Shi et al. 2013; Li et al. 2018). Field control experiments and meta-analysis were mostly used to assess grazing effects, and relevant progress was made in understanding plant community structure, soil physical and chemical properties, and the biogeochemical cycle in grazed grasslands. However, significant controversies exist on the grazing contribution to large-scale grassland degradation (Lehnert et al. 2016; Dong et al. 2020; Fayiah et al. 2020; Manuelian et al. 2020). For example, Lehnert argued that climate change is the leading cause of vegetation cover change in the Tibetan Plateau since the new millennium, rather than the grazing effect (Lehnert et al. 2016).

Soil nutrient content is an important predictor of the alpine grassland degradation stage (Wang et al. 2014). Although many studies have shown that grazing exclusion is an effective way to restore vegetation and soil carbon sequestration in degraded grassland (McSherry and Ritchie 2013; Hu et al. 2016; Xiong et al. 2016), the soil C content is affected by annual average precipitation (Wang and Wesche 2016), soil N change rate (Su et al. 2015), and grazing intensity (Hu et al. 2016; Zhou et al. 2017a). Some research, however, has revealed that grazing exclusion is not conducive to the absorption of organic carbon in the soil in the northeast of Qinghai–Tibetan Plateau (Shi et al. 2013; Yuan et al. 2020). This topic needs, therefore, to be further verified by long-term experiments (Liu et al. 2020a; Wang et al. 2020).

The results from some research show that the degradation of alpine grassland changed the surface energy exchanges and the grasslands functions (Babel et al. 2014; Miehe et al. 2019). With the increase in degradation degree of the alpine grassland, ecosystem services and functions decrease (Wen et al. 2012), but the slightly degraded grassland had a positive effect on carbon maintenance and nutrient uptake (Wu et al. 2008; Li et al. 2018; Liu et al. 2020a). Grazing intensity alters ecosystem C and N cycles in grasslands (Zhou et al. 2017a). Moderate grazing had positive effects on soil C input and C absorption (Hafner et al. 2012). Aside from grazing intensity, many other grassland traits and research characteristics were found to influence the degree of grassland degradation, such as soil type, grass type, study duration, soil sampling depth (McSherry and Ritchie 2013).

4.2.2 Cluster #1 "grazing exclusion"

Cluster #1 mainly focused on the research into the grazing regime's impact on the process of restoration of the degraded semi-steppe ecosystem (Table 5). To some extent, grazing exclusion itself can be regarded as a form of grazing, which is an important approach to restore vegetation in degraded grassland. Some influential papers paid attention to the grazing effects as one of the most important human activities changing the aboveground and underground productivity in the steppe.

Dust emission (wind erosion and sandstorm) is another typical disturbance process in a semiarid grassland (Hoffmann et al. 2008). Dust deposition plays an extremely vital role to regulate the C and N balance in semiarid grasslands (Hoffmann et al. 2008), which has a significant effect on increasing C/N content. Dust emission and deposition dynamics are determined by grazing intensity (Hoffmann et al. 2008). Grazing in some areas causes dust emission, whereas the dust deposition in the non-grazed areas is higher than that in grazing areas. The soils of long non-grazed areas are N sink, mainly due to dust deposition (Gao et al. 2008, 2013a, 2013b). Dust deposition and dust emission are in balance during moderate grazing. Overgrazing and N loss (Gao et al. 2008, 2013a, 2013b) compromise the N fixation turnover of plants and microorganisms (Gao et al. 2013b). However, the dust deposition rate (Hoffmann et al. 2008) and dust emission (Tong et al. 2004) are influenced by topography,

Table 5 Effects of grazing behavior on grassland structure and function resulting from the research on the theme cluster #1, "grazing exclusion"

Factor	Indicator	Effect	Source
Grazing intensity from low to high degree	Soil organic C	−	(Su et al. 2005; Li et al. 2008; Steffens et al. 2008; Wiesmeier et al. 2009)
	Total N	−	(Su et al. 2005; Li et al. 2008; Steffens et al. 2008; Wiesmeier et al. 2009)
	Total S (sulfur)	−	(Steffens et al. 2008; Wiesmeier et al. 2009)
	Total P	−	(Li et al. 2008)
	Soil biological characteristics (including some enzyme activities) and soil respiration	−	(Su et al. 2005)
	Soil bulk density	+	(Li et al. 2008; Steffens et al. 2008; Wiesmeier et al. 2009)
	Soil available P, available N (NO_3^- and NH_4^+)	No	(Li et al. 2008; Lin et al. 2010a, 2010b)
	Electrical conductivity, pH value or concentration of soluble ions (Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^- and SO_4^{2-})	No	(Li et al. 2008)
	Aboveground plant biomass	−	(Li et al. 2008; Wiesmeier et al. 2009)
	Living root biomass and belowground net primary productivity	−	(Gao et al. 2008)
Continuous VS rotational grazing	Plant production	≥	(Briske et al. 2008)
Exclusion of livestock grazing	Vegetation restoration, litter accumulation and the growth of annual and perennial grasses	+	(Su et al. 2005)

the deposition rate of the leeward slope being 29–33% higher than that of the windward slope, crest, and plane positions.

4.2.3 Cluster #2 "alpine region"

Cluster #2 was the third largest cluster. This cluster gathered the emergent and high-frequency references with Harris (2010) as the core. Harris (2010) systematically reviewed the scope, scale, and causes of grassland degradation and concluded that, due to the subjective nature of monitoring methods and incomplete records as well as the extent and scope of grassland degradation research, the future circumference of grassland is uncertain (Harris 2010). At the same time, he proposed that the cause of alpine grassland degradation was still undetermined, mainly because the hypotheses of the published research were too vague to be tested. There is no explicit demonstration for any cause of grassland degradation (Harris 2010). These doubts about the most basic information on grassland degradation have attracted the attention of ecologists all over the world, and more attention has been paid to grassland areas sensitive to climate change in the Qinghai–Tibetan Plateau.

Due to its particular geographical location, alpine grassland is characterized by specific factors such as high altitude, sensitivity to climate change (Chen et al. 2013), fragile habitat, distinctive structure of husbandry, and limited livelihood of local people. In addition, the alpine grasslands have been subject to an overall "warm and humid" climatic trend in the Qinghai–Tibetan Plateau (Xu et al. 2008; Chen et al. 2013; Liu et al. 2020b). These single or complex factors, directly and indirectly, lead to the spatial and temporal differences of degradation forms, degradation intensity, and restoration methods of alpine grassland (Chen et al. 2013; Li et al. 2013; McSherry and Ritchie 2013; Yan and Lu 2015; Cao et al. 2019; Dong et al. 2020; Fayiah et al. 2020; Wang et al. 2020).

4.2.4 Cluster #5 "human activities"

Cluster #5 was the third active research cluster. This cluster's studies showed how to distinguish between the contribution of the two factors. This issue is a challenging research topic (Chen et al. 2014; Gang et al. 2014; Wang et al. 2016; Zhou et al. 2017b). Quantitative assessment of grassland degradation caused by climate change and human activities can help to understand grassland degradation mechanisms and to effectively curb grassland degradation (He et al. 2015; Zhou et al. 2017b),which is of great significance to support the sustainable utilization of global grassland (Cai et al. 2015; He et al. 2015). Most quantitative research adopted simulation models (He et al. 2015), combined with remote sensing data (such as NDVI, LAI, Near-Infrared, and Mid Infrared Bands) and meteorological data (precipitation, temperature, and radiation) (Wang et al. 2016). As comprehensive evaluation variables, net primary productivity (NPP) is one of the key indicators (Gang et al. 2014; Yang et al. 2016; Zhou et al. 2017b) to assess the grasslands status. There are also other indicators, such as grassland species composition, grassland desertification, and aboveground biomass (AGB) (Wang et al. 2017; Han et al. 2018a) in grassland evaluation. The variation of the grassland degradation spatial scale from a typical local scale (Chen et al. 2014; Cai et al. 2015; Wang et al. 2017) to national (Zhou et al. 2014, 2017b), regional (Yang et al. 2016) and global scale (Gang et al. 2014) was also considered.

The research results showed that climate change and human activities were the two fundamental causes of global grassland degradation, and 49.2% of grasslands had experienced degradation on the global scale, with the largest area of degradation and recovery occurred in Asia (Gang et al. 2014). In China, some 61.5% of the grassland was once under degradation (Chen et al. 2014; Zhou et al. 2017b). The contribution of human activities to grassland degradation is greater than that of climate change (Zhou et al. 2017b). However, human activities are also the dominant factor in the restoration of degraded grasslands, while the contribution of climate change is comparatively small. Many different driving factors lead to obvious spatial heterogeneity (Hilker et al. 2014; He et al. 2015; Zhou et al. 2017b) and temporal differences in landscape degradation.

5 Conclusions

The scientometric approach used in this study has revealed systematically the relationships between grassland degradation research and other disciplines, dynamics of the research hotspots as well as near future trends. The active cluster with the highest number of papers was "alpine meadow," which had 175 references from 2010 to 2020. Other important clusters were "grazing exclusion," "alpine region," and "human activity." Important research topics included anthropogenic activities, especially grazing effects. In particular, the effects of grazing management on plant and soil and the responses of alpine grassland degradation are important topics both currently and in the near future. In summary, this first scientometric review of grassland degradation research showed that the alpine grassland in Qinghai–Tibetan Plateau was a hotspot and focal area with extensive international research. Grassland management (grazing management) is an important tool that can be adopted by humans to guide the direction of grassland degradation. Specific thresholds and models need to be further explored to formulate grassland management strategies. The key research directions include assessing the ecological effects of climate change and human activities, especially on the biogeochemical cycle as well as on structure and function of plant communities, quantitatively separating the contributions of main driving factors of grassland degradation and highlighting the potential trends of alpine grassland degradation.

These findings can play an important disciplinary reference role for an in-depth understanding of the past and present of grassland degradation research. This could also accurately grasp the current and future focus, especially for scientists, governments, and international organizations to provide important guidance and reference for faster and better responses to land degradation issues.

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Declarations

Conflict of interest The authors declare no competing interests.

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