Journal of Arid Environments 196 (2022) 104654

Contents lists available at ScienceDirect

Journal of Arid Environments

journal homepage: www.elsevier.com/locate/jaridenv

Rangeland degradation in Mongolia: A systematic review of the evidence

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ARTICLE INFO

Keywords:
Land degradation
Overgrazing
Sustainable land management

ABSTRACT

Rangeland degradation compromises the functioning of extensive natural ecosystems and threatens pastoral livelihoods worldwide. Yet, defining rangeland degradation and its underlying causes remains controversial. In this study we review rangeland studies to identify different approaches used to assess rangeland degradation in Mongolia, where the prevalence of degradation is frequently referenced in media and policy documents. We compiled studies addressing rangeland degradation, with a special emphasis on the grey literature, to assess: 1) how different studies defined and quantified rangeland degradation; 2) whether a theoretical background was explicitly mentioned; 3) which drivers of degradation were identified and whether their effects were quantified; and 4) the distribution of the studies across relevant environmental gradients. We found 114 studies published between 1950 and 2021. Degradation was frequently assessed as a change in vegetation or land cover, but there was no standard definition of rangeland degradation and only a few studies explicitly defined contrasting degradation levels (19 studies). Less than one third of studies (27) referred to a theoretical framework. Grazing and climate (precipitation and temperature), alone or in combination, were most frequently mentioned as drivers of degradation but the impact of different drivers differed across ecological zones. The majority of studies were conducted in the steppe, forest steppe and desert steppe zones of central Mongolia. Future studies should consider the differences in ecological potential of each rangeland and quantify the relative importance of different drivers in each ecological zone. Emerging initiatives for rangeland assessment and monitoring that use long-term data collection following standardized methodologies based on robust theoretical frameworks hold promise for the design of policies and strategies for sustainable land use in Mongolia.

1. Introduction

Rangelands are the most dominant land cover type, covering about half of Earth's terrestrial surface (ILRI, IUCN, FAO, WWF, UNEP and ILC, 2021). They provide valuable ecosystem services, harbor high biodiversity, and sustain the livelihoods of millions of people worldwide (Bengtsson et al., 2019; Sala et al., 2017). Rangeland degradation is a global concern because it signals a loss of ecosystem services and threatens livelihoods that depend on rangelands (White et al., 2000). Currently, many rangelands are at risk of continued declines in productivity and increased year-to-year climatic variability and unpredictability in forage resources (Godde et al., 2020). However, a clear understanding of the nature of rangeland degradation, the drivers responsible for degradation in specific areas, and how to respond to these drivers, has been elusive (Herrick et al., 2019).

In this study we use Mongolia as a case to identify different approaches to assess and measure rangeland degradation. Mongolia has among the world's last intact grasslands, that represent about 2.5% of the world's total grassland area (White et al., 2000). Mongolian rangelands support the traditional livelihoods of nomadic pastoralists and other sectors of society (Addison et al., 2012). As in other Central Asian countries, overgrazing and rangeland degradation have become primary environmental concerns in Mongolia in recent decades (Hilker et al., 2014). The total number of livestock, especially the number of goats, has increased dramatically since the early 1990s because of socio-economic changes that led to the privatization of livestock. As a result, livestock numbers currently exceed the

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https://doi.org/10.1016/j.jaridenv.2021.104654
Received 3 June 2021; Received in revised form 29 September 2021; Accepted 11 October 2021
Available online 20 October 2021
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carrying capacity in many Mongolian rangelands (Densambuu et al., 2018; Gao et al., 2015). Traditionally overgrazing has been considered the main driver of rangeland degradation (Li et al., 2013), but an increasing number of studies has challenged this view (Addison et al., 2012; Harris, 2010). In any case, the increase in livestock numbers is compounded by ongoing changes in climatic conditions. For instance, the mean annual temperature in Mongolia increased by 1.7 °C between 1940 and 2001 (Batima et al., 2005), and extreme weather events like extremely harsh winter conditions (*dzud* in Mongolian) have become more frequent (Fernandez-Gimenez et al., 2012; Sternberg, 2018). Consequently, the intensity and urgency of rangeland degradation has become a recurring theme in international policy documents and media coverage (Hilker et al., 2014; Liu et al., 2013; UNEP, 2002).

Mongolia has an extensive territory that covers six broad ecological zones, with distinct climate and vegetation: high mountain, mountain taiga, forest steppe, steppe, desert steppe and desert. These ecological zones, given their contrasting ecological conditions, are expected to respond differently to environmental pressures, including grazing (Ahlborn et al., 2020). For instance, in arid regions such as the desert steppe, where rainfall varies considerably between years, changes in vegetation are dominated by precipitation and seem to be relatively insensitive to grazing. In contrast, in the forest steppe, grazing pressure drives changes in plant biomass and total vegetation cover (Fernandez-Gimenez and Allen-Diaz, 1999). In addition, different parts of Mongolia are experiencing different pressures. For example, the forest steppe and steppe zones are the most suitable areas for agriculture and human habitation (Densambuu et al., 2018). Therefore, these areas are more densely populated, more intensively used, and are estimated to be more degraded than other zones (Densambuu et al., 2018; Jamiyansharav et al., 2018; Venable et al., 2015). Similarly, ongoing warming trends are more pronounced in the high mountain areas and their valleys, and less so in the Gobi desert (Batima et al., 2005). Disentangling these complexities is critical to developing sustainable management practices adapted to local conditions.

To better understand how degradation occurs and how it can be managed, process-based degradation frameworks can provide a useful tool. Conceptual frameworks are a fundamental part of successful adaptive monitoring and long-term research programs worldwide (Lindenmayer and Likens, 2009). Conceptual frameworks to describe rangeland degradation include the traditional range succession model (Dyksterhuis, 1949), state and transition models (STM) (Westoby et al., 1989), and several degradation frameworks, like Milton's stepwise model (Milton et al., 1994) and Whisenant's model (Whisenant, 1999). These frameworks differ in the way they represent ecosystem changes and their reversibility. According to the traditional range succession model, changes in vegetation are linear and temporary, meaning that these changes can be reversed through modifications in management. In contrast, STMs and similar degradation frameworks allow for non-linear and irreversible transitions. These models usually recognize degradation as a stepwise process from biotic to abiotic changes. Degradation is usually reversible in the early stages but can become irreversible in more severe stages. However, the extent to which these frameworks have been applied to the study of degradation in Mongolian rangelands remains unknown.

Here, we systematically review studies on rangeland degradation in Mongolia to synthesize information on the use of different study designs, the theoretical background of the studies, the main drivers of degradation identified in the studies and their geographical distribution. While we include scientific literature published in international journals, a special effort is made to include grey literature. A large proportion of the research on rangeland condition in Mongolia has been published as internal reports, generally in Mongolian or Russian, so it is not accessible to the wider research community. The few available reviews and papers published in international journals provide mainly descriptive summaries of these sources (Addison et al., 2012; Jamsranjav et al., 2018), so many important details are buried in the grey literature. Compiling and synthesizing the current knowledge on rangeland condition in Mongolia is critical if we want to understand the state of knowledge on rangeland degradation.

Specifically, we address the following questions: 1) How do different studies define and quantify rangeland degradation? 2) Do studies explicitly relate to a theoretical framework to assess degradation in Mongolian rangelands? 3) What are the main drivers of rangeland degradation identified by the studies and how are they quantified? 4) Is there a bias in the distribution of studies on rangeland degradation in Mongolia in terms of the ecological zones and environmental conditions being studied?

2. Methods

To synthesize data on the approaches to assess rangeland degradation in Mongolia, we compiled a list of relevant documents by searching international and national databases (Fig. 1). In March 2020 we searched in international online databases (Web of Knowledge, Scopus and Google Scholar) using the search string: "(((range* OR pasture* OR steppe OR grazing) AND (degrad* OR desert* OR erosion OR (rangeland AND health) OR (*land AND (condition OR quality)) OR (vegetati* AND change) OR recover*) AND (Mongolia* NOT Inner Mongolia))". This search was updated in April 2021. Since the focus of the review is on Mongolian rangelands, we explicitly excluded studies conducted in the Chinese region of Inner Mongolia. We included the term vegetation change to be able to capture earlier studies that described similar processes but did not specifically use the term degradation (but see inclusion criteria below). We placed no restriction in the publication year of our search. Following Haddaway et al. (2015), we only included the first 300 search results from Google Scholar.

We also searched for publications in local databases and online journals in Mongolia and Russia, using a simplified search string: ((range* OR pasture* OR steppe OR grazing) OR (degradation* OR desertification* OR erosion) in English, Mongolian and Russian. These sources included the Russian Science Citation Index (https://elibrary.ru), the online repository of the Mongolian Academy of Sciences (https://biology.ac.mn/), the Mongolian Journal of Biological Sciences (https://www.biotaxa.org), and two Mongolian online journals (https://www.mongoliajol.info): the Proceedings of the Mongolian Academy of Sciences and the Mongolian Journal of Agricultural Sciences.

We expanded this search by including relevant references found within the original documents. To further increase the coverage of the grey literature and documents not included in online databases, we consulted the catalogues of national libraries at the Mongolian University of Life Sciences, the Research Institute of Animal Husbandry and the Institute of Biology of the Mongolian Academy of Sciences, and consulted national experts in the field (Dr. Chultemjamts, Research Institute of Animal Husbandry, and Dr. Indree, Mongolian Academy of Sciences).

Duplicate documents were excluded after combining all publications into a single database (Fig. 1). The documents were screened for relevance first based on the title, then on the contents of the abstract, and finally on the full text. Non-relevant studies (i.e. those not considering aspects of rangeland ecology, or not specifically addressing rangeland degradation or vegetation change) were filtered out. Screening was conducted by a single person (SS). To avoid duplicating information we excluded documents not presenting original primary data, for example those reviewing other published studies like many book chapters or review papers. Similarly, chapters of dissertation theses were excluded if they had been published separately and were already included in our search. From each of the documents we extracted bibliographic information (i.e., type of document, language and year of publication) and information on the approach used to measure degradation, the types of degradation drivers identified by the studies, if and how these drivers were quantified, the type of study design, where the studies were conducted and the use of theoretical frameworks to describe the degradation process. We extracted geographical coordinates for each study,

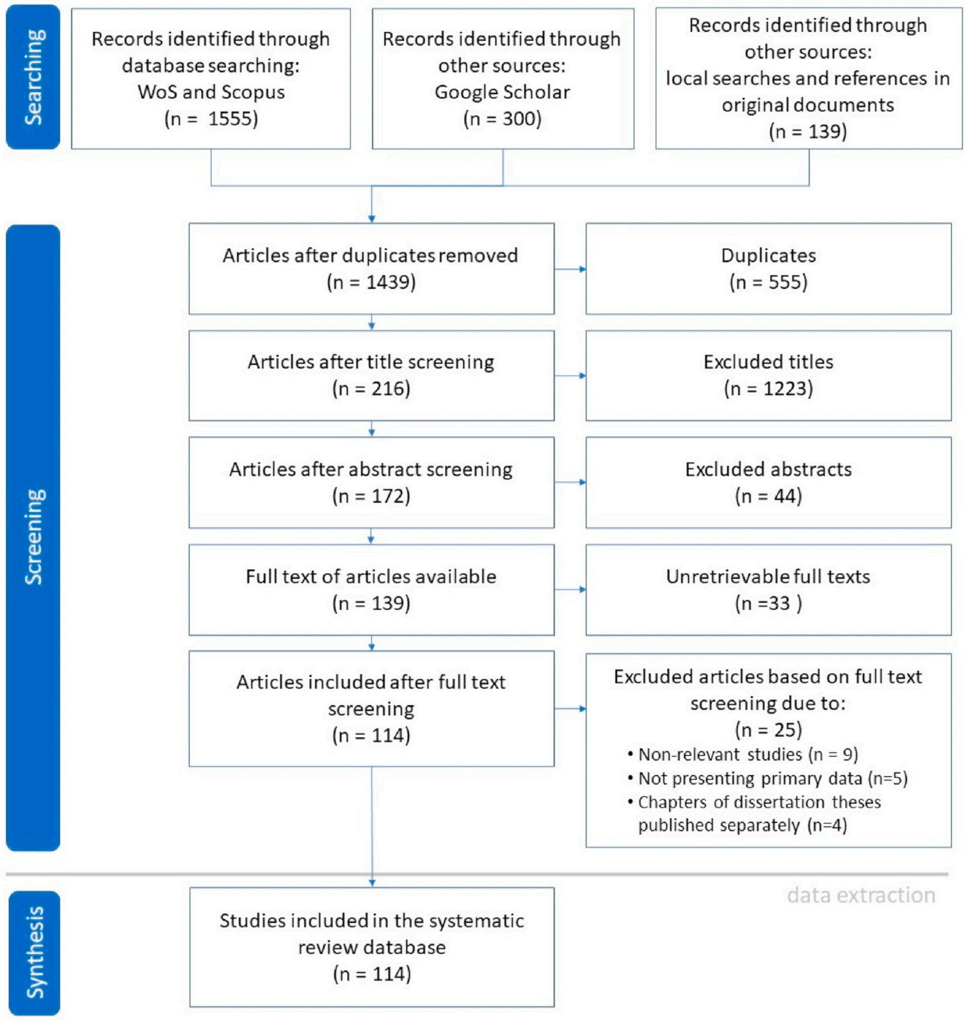

Fig. 1. Reporting standards for Systematic Evidence Syntheses (ROSES) diagram indicating the review process, including the number of studies identified and the number of studies excluded at each stage.

except for studies conducted for the whole country. The location of studies with large study areas (e.g. whole province) were defined at the center of the corresponding province. To assess if there was a bias in the distribution of studies across ecological zones, we compared the observed number of studies in each zone to the expected number based on the area covered by each zone in Mongolia with a Chi square test. To assess the climatic space covered by our studies, in terms of mean annual temperature and mean annual precipitation, relative to the whole country, we extracted climate data from WorldClim (Fick and Hijmans 2017) from the geographical coordinates of our studies and a random selection of 500 points across Mongolia.

Data summaries were conducted in R 4.0.1 (R Core Team 2020).

3. Results

The literature search in international databases retrieved 717 documents in Web of Knowledge, 838 documents in Scopus and the first 300 results from Google Scholar (Fig. 1). The search in local sources retrieved 119 documents, complemented with 20 documents from additional searches through reference lists, visiting libraries and consulting experts. Once duplicates were removed, the database included 1439 studies. After screening for relevance at title, abstract and full text stage, the list included 114 documents addressing rangeland degradation (Table S1), published between 1950 and 2021. Seventy-seven documents were found in international and 37 in local databases. Only six documents were published before 1999, when documents published in international databases started to appear (Fig. 2). Earlier studies did not highlight rangeland degradation as a common concern, but rather mentioned vegetation change. In contrast, specific mentions of rangeland degradation increased after 1990. Most documents were written in English (84 documents), followed by Mongolian (18) and Russian (12). Most of the documents were scientific articles (86), but other document types such as book chapters (12), conference papers (9), reports (5), one atlas and one doctoral dissertation were also found.

3.1. How do different studies quantify and define degradation?

Most rangeland studies quantified changes that were attributed to rangeland degradation based on field data (80) or using remote sensing techniques alone (21), while a few studies used a combination of remote sensing data validated with field measurements (8). Two studies used questionnaires to herders to assess changes in rangeland condition, one of them in combination with field measurements of vegetation change. Three studies used models parameterized using field data on plant and soil parameters, climate and grazing pressure, to estimate the amount of degraded rangeland.

By far the greatest number of studies assessed changes in rangeland condition based on changes in plants and plant communities alone (Fig. 3). Other studies assessing rangeland degradation based on a single

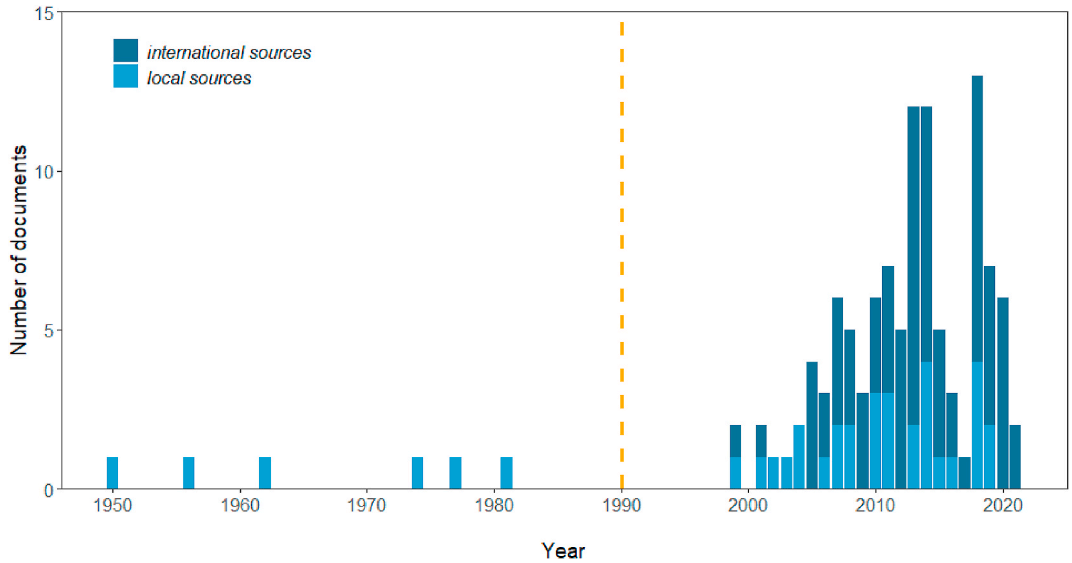

Fig. 2. Number of relevant documents published over time on rangeland degradation in Mongolia. Different colors indicate publication source, either international online databases (Web of Knowledge, Scopus and Google Scholar) or local sources (online journals, libraries and expert knowledge). The vertical dashed line indicates the collapse of the USSR when important socio-economic changes take place in Mongolia. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

response variable focused on changes in land cover types (including remotely sensed indices, field measurements or a combination), soil properties, animal communities, soil microorganisms or human aspects, like poverty and herders' perceptions. Twenty-seven studies based their assessment on several variables, most commonly involving plant measurements together with soils (14) and with land cover (7). Plant responses were the most frequently measured in the forest steppe, steppe and desert steppe, followed by land cover and soils, while land cover was the most frequently measured response variable in the high mountain, mountain taiga and desert, followed by plants and soils (Fig. S1).

Generally, studies measuring plant responses associated increased rangeland degradation with reductions in plant cover, biomass, productivity, diversity and reproduction/recruitment. Studies measuring soil variables included physical and chemical properties such as organic carbon, soil pH, available P and K, soil total C and N, coarse fragments, and bulk density, and associated rangeland degradation with reduced soil humus and organic carbon content, soil pH and bulk density.

Although all the studies included in this review mentioned rangeland degradation, only 19 studies explicitly identified contrasting stages of degradation based on objective criteria (Table S2). In 17 of these studies, the assignment of an area to a particular degradation level was based on plant species composition, depending on the relative abundance of grazing tolerant and unpalatable plants, with reductions in valuable forage species indicating initial stages of degradation. The studies that identified contrasting stages of degradation classified areas into three to six levels of degradation, from slightly degraded to moderately and heavily degraded, with some studies including non-degraded areas and others including very heavily degraded areas. Twelve of these studies followed the degradation categories proposed by Chognii (2001), which link vegetation cover and structure to different grazing pressures. Thus, in this classification degradation levels are inherently linked to different grazing pressures. In this sense, lightly grazed areas are considered less

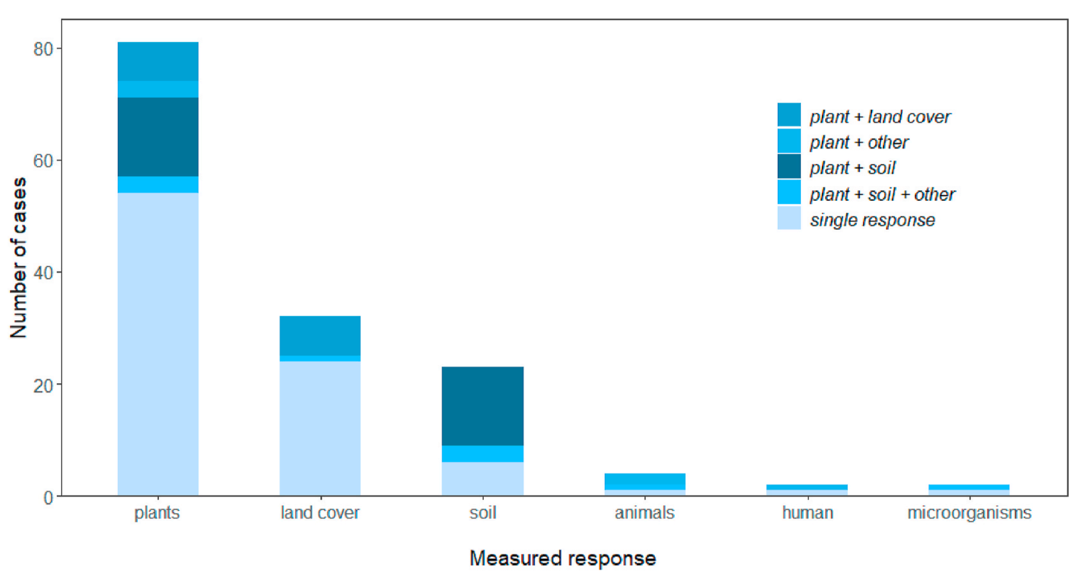

Fig. 3. Types of responses measured by studies to assess degradation of Mongolian rangelands. Some studies (27) assessed rangeland degradation based on several responses, so the total number of cases (144) presented in the figure exceeds the number of studies (114) included in the literature review.

degraded, and are dominated by palatable grass species like *Festuca* spp. and *Stipa* spp. In moderately grazed areas, grass cover declines and is replaced by grazing resistant, mostly rhizomatous plants like *Carex* spp. and *Elymus chinensis*. In heavily grazed areas, which are considered degraded, grasses become very scarce and unpalatable plants like *Artemisia adamsii* and other degradation indicator species become dominant.

Often, the definition of different degradation levels also included soil parameters (Table S2). Four studies included soil loss, chemical or hydrological changes together with vegetation assessments in their definition of the most degraded levels. These studies measured soil surface indicators, such as resource retention class or soil redistribution class, physical properties like bulk density, soil texture or humus content, and chemical properties like pH and $CaCO_3$. The higher levels of degradation were associated with permanent soil loss, changes in soil chemistry or hydrology, and decreased humus content.

Among the studies classifying land into degradation stages, six studies provided nationwide estimates of the extent and severity of rangeland degradation in Mongolia (Table 1); in addition, one report also provided an estimate of rangeland degradation in Mongolia but did not clearly identify degradation stages (UNEP, 2002). These nationwide estimates of rangeland degradation were obtained using different methodologies, based on field assessments or remote sensing approaches, and were conducted over the whole territory or within a subset of provinces.

Three of these studies provided estimates of the extent of degradation in the different ecological zones separately (ALACGC, 2011; Densambuu et al., 2018; Jamsranjav et al., 2018; NAMEM and MEGDT, 2015). Estimates of degradation in each ecological zone varied widely, with the most degraded zones being the forest steppe (25–77%), steppe (26–49%) and the desert steppe (11–47%). High mountain (18–20%) and desert zones (0–29%) were less often considered to be degraded. No estimates were provided for the mountain taiga.

3.2. Do studies refer to a theoretical framework to assess degradation in Mongolian rangelands?

Less than one third (27) of the studies assessing rangeland degradation and vegetation change in Mongolia explicitly mentioned a theoretical framework. The most frequently mentioned framework was the traditional successional model; state and transition models and an integrated degradation framework were mentioned less frequently (Table 2). Earlier studies referred to the traditional successional model, while other frameworks became more common after 2008, first with the implementation of state and transition models, and more recently (2015) with integrated degradation frameworks.

All studies mentioned at least one driver of degradation, and the majority of studies (87) tried to quantify these drivers. Sixty-six studies (57.9%) identified grazing as the only driver of degradation. About one fifth of the studies (19) identified more than one driver of degradation acting simultaneously (Table S4). In 17 cases, grazing was among the several drivers considered, usually together with precipitation and temperature (11); only one study considered precipitation and temperature as the only drivers of degradation. Among the studies identifying several drivers of degradation, 12 tried to rank the relative importance of the drivers. This ranking, however, often depended on the ecological zone or precipitation (Table S4).

When looking at the ecological zones separately, grazing was the most commonly identified driver of rangeland degradation in the steppe, forest steppe and desert steppe zones (Fig. 4), followed by precipitation and temperature. However, the relative importance of these drivers differed between ecological zones (Table S4). Other drivers of degradation mentioned were human influence, including mining and other infrastructure, soil erosion and fire.

With regard to how studies assessed the effects of different drivers, over one fourth (21) of the studies that identified grazing as a driver of rangeland degradation used exclosures (i.e. areas where access of grazing animals was prevented). Most of these studies reported differences in plant cover, biomass, species composition, richness, diversity and growth forms when comparing plots inside and outside the fenced areas, but these differences depended on the ecological zone and vegetation type (Table S5). Only four studies manipulating grazing pressure used enclosures (i.e. areas with a known number of grazing animals). Most studies (61) used spatial gradients from herder camps, water points or settlements as proxies for grazing intensity. In general, these studies reported differences in the strength of these gradients that depended on the ecological zone and climatic conditions. The studies that identified precipitation and temperature as drivers of degradation used observational approaches based on data from meteorological stations and interpolated climate data.

Is there a bias in where and under which environmental conditions rangeland degradation in Mongolia is studied?

Rangeland degradation studies included in this paper were conducted in all six ecological zones of Mongolia (Fig. 5). Some studies (21) spanned the whole country and included all ecological zones, but most studies focused on one (47) or several ecological zones (46). The vast majority of studies included steppe (78), forest steppe (71) and desert steppe (67), while fewer studies included desert (29), high mountain (27) and mountain taiga (19; Table S6). Based on the area covered by each ecological zone, there was a significant difference between the observed and the expected number of studies in each ecological zone (Chi square = 23.9, df = 5, $p < 0.001$; Table S6), with more studies than expected in the high mountain and mountain taiga, and less than

Table 1
Nationwide assessments of rangeland degradation in Mongolia. Most studies classified degradation into four or five degradation classes (or their closely related concept of "recovery classes", indicated by an asterisk). Total percent degraded represents the sum across all degradation classes, from slightly degraded to heavy or very heavily degraded. **One study provided estimates of degradation based on resource retention classes and soil redistribution classes separately.

Reference	Methodology	Percent degradation					
		None	Slight	Moderate	Heavy	Very heavy	Percent degraded
UNEP (2002)	Field assessments based on plants; different levels of degradation not identified						70
Avaadorj and Badrakh, 2007	Field measurements in 4 soums of 2 aimags; estimates of degradation based on literature review						30
ALACGC (2011)	Visual areal estimates of plant cover and soil in four-season pastures	77.4	8.1	11.2	3.3	NA	22
Bulgan et al. (2013)	Remote sensing of four-season pastures	22	35	26	7	10	78
NAMEM and MEGDT, 2015*	Plot-level assessments using plant and soil indicators (LPI) in four-seasonal pastures	52	25	15	7	0	48
Densambuu et al., 2018*	Plot-level assessments using plant and soil indicators (LPI) in four-seasonal pastures	43	29	16	12	0	57
Jamsranjav et al., 2018**	Plot-level assessments based on resource retention classes (plant connectivity) in winter pastures in some provinces only	18	33	29	18	1	81
Jamsranjav et al., 2018**	Plot-level assessments based on soil redistribution classes (severity and extent of erosion) in winter pastures in some provinces only	5	53	40	2	0	95

Table 2
Conceptual frameworks of rangeland degradation applied by rangeland studies in Mongolia.

Theoretical framework	Number of studies	Measured variables	Characteristics	Year of first application to Mongolia	Relevant references
Traditional successional model	17	Mainly based on plant responses, sometimes include soil indicators as well	Different levels of degradation are recognized. Transition or restoration pathways are not identified	1950	Chognii (2001)
State and transition models	8	Plant/soil	Levels of degradation, drivers and reversibility are described	2008	(Densambuu et al., 2018; Jamiyansharav et al., 2018)
Integrated degradation framework	2	Plant/soil	Different levels of degradation and reversibility are described but transition or restoration pathways are not identified	2015	(Jamsranjav et al., 2018; Khishigbayar et al., 2015)

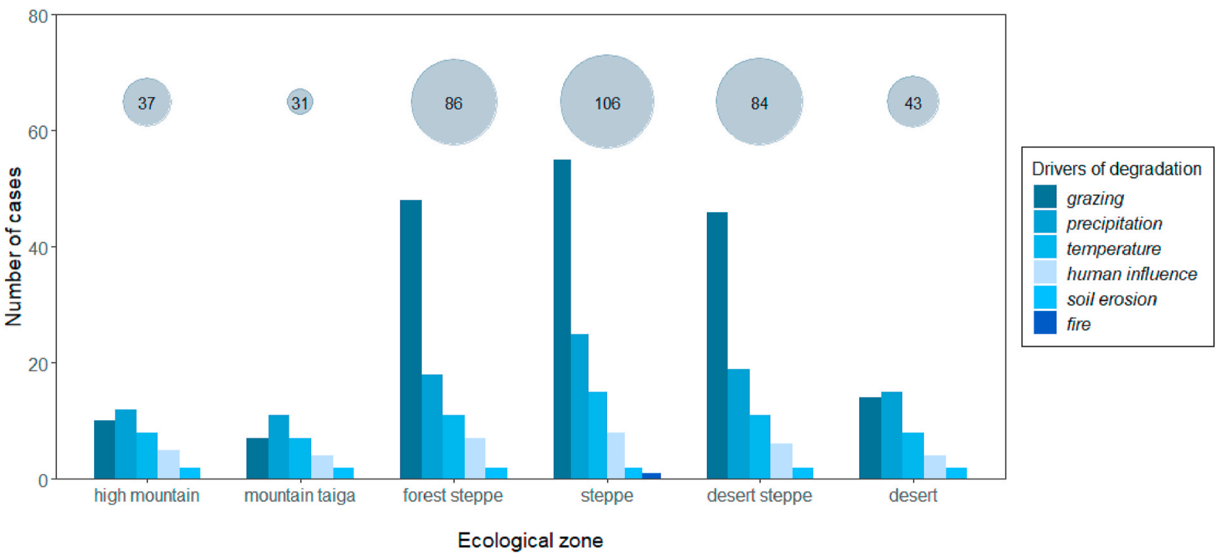

Fig. 4. Main drivers of degradation of Mongolian rangelands identified in the literature review in each of the ecological zones. Some studies (46) were conducted across several ecological zones and/or identified several drivers of degradation (20), so the total number of cases presented in figure (387) exceeds the number of studies included in the literature review that quantified degradation drivers (87 studies). The number of cases in each ecological zone are included in the grey circles, with size of the circle proportional to the number of cases.

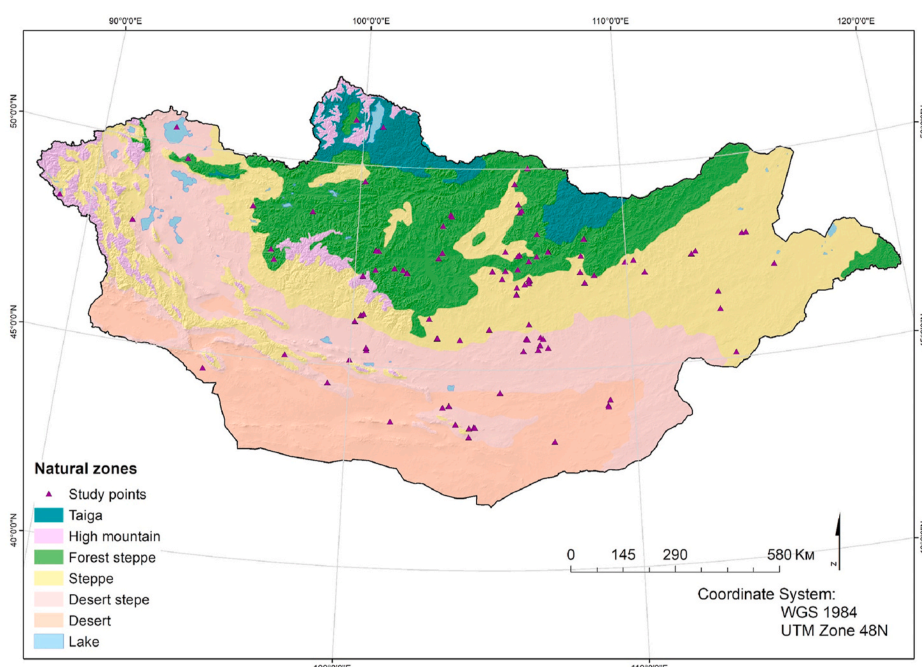

Fig. 5. Location of the studies and the ecological zones in Mongolia. Studies covering the whole country (21 studies) are not included here.

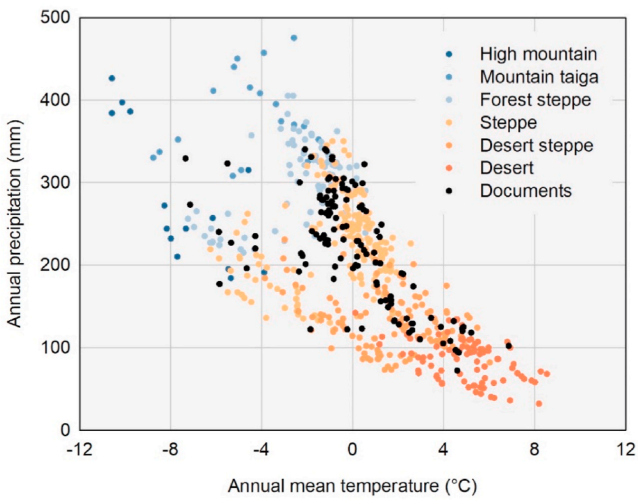

Fig. 6. Locations of studies included in the literature review (black dots) in the climate space, as defined by mean annual temperature (°C) and mean annual precipitation (mm), as extracted from WorldClim (Fick and Hijmans 2017). The colored dots show 500 locations randomly distributed throughout Mongolia; colors indicate different ecological zones. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

expected in the desert. All other ecological zones had a similar number of studies than would be expected based on their area.

Studies were conducted across all the twenty-one provinces of Mongolia (Fig. S2). The provinces most frequently studied were located in central Mongolia: Tuv, Umnugobi, Dundgobi, Bayankhongor and Arkhangai. The least studied provinces were those in western Mongolia: Bayan-Ulgii, Uvs, Khovd and Gobi-Altai (Fig. S2). With regard to the climate space covered by the studies, the majority of studies were conducted in areas with mean annual temperature between −5 and 5 °C, and between 100 and 300 mm mean annual precipitation (Fig. 6). This covers most of the average temperature and precipitation range, but excludes the driest and wettest parts of Mongolia, and most of the coldest and warmest regions.

4. Discussion

Our systematic search of national and international literature spans 70 years. While the rate of publication of new studies in Mongolia has increased dramatically since 2000, we also detected differences in author interpretations of rangeland degradation studies over time. In the earlier studies, broad-scale rangeland degradation was not reported as a common concern, despite the high numbers of wild and domestic herbivores present in Mongolia. The perceived lack of negative effect of grazing on rangelands at that time was attributed to the traditional grazing practices and the slow growth rates of vegetation associated with the dry conditions. The number of studies on rangeland degradation in Mongolia increased since the mid-1990s, especially in documents published in English and in international databases. The 1990s represent a turning point in the socio-economic conditions of Mongolia, with the collapse of the Soviet Union and the transition to a market based-economy, with the subsequent increase in livestock numbers (Lkhagvadorj et al., 2013) and an increasing concern about rangeland degradation issues.

How is rangeland degradation defined and measured in Mongolia?

All studies included in this review mentioned rangeland degradation but only nineteen studies explicitly defined contrasting stages of degradation, based on pre-defined criteria. The vast majority of studies quantified changes in some ecosystem property, mostly plant-related indicators, that were associated with rangeland degradation, but did not explicitly state whether an area was degraded or not or to which extent. This lack of a clear definition of degradation has been pointed out by previous studies (Jamsranjav et al., 2018; Khishigbayar et al., 2015), and prevents meaningful comparisons across studies within Mongolia and worldwide (Li et al., 2013). Defining and measuring rangeland degradation is challenging, especially in systems with high inter-annual variability in climatic conditions (Godde et al., 2020). This is further complicated in Mongolian rangelands because a long evolutionary history of nomadic grazing has likely shaped the composition and traits of present-day vegetation (Milchunas and Lauenroth, 1993).

Many studies defined rangeland degradation based on changes in vegetation or land cover alone, without considering changes in other ecosystem processes or in soil function. Considering only changes in vegetation as a measure of degradation can be misleading, because seasonal and yearly fluctuations in vegetation associated with changes in precipitation and seasonal use of livestock may not necessarily represent a persistent change in ecosystem functioning (Liu et al., 2013). Rangelands are complex systems that include many interrelated components, so when defining degradation, it is important to include as many parts of the ecosystem as possible and their functioning (Milton et al., 1994; Whisenant, 1999). Ideally, rangeland assessments should consider indicators that measure fundamental changes in key socio-economic and biophysical indicators of pastoral systems (Reynolds et al., 2011).

Similarly, changes in land use based on remote sensing data alone may lead to different interpretations without adequate ground-truthing data. For instance, two remote sensing studies interpreted changes in the Normalized Difference Vegetation Index (NDVI) differently and reached opposite conclusions. Hilker et al. (2014) interpreted the widespread decline in NDVI across Mongolia as evidence for extensive rangeland degradation, whereas Gao et al. (2015) interpreted the reduction in NDVI as a proxy for grazing pressure and, since changes were not very pronounced, they concluded that overgrazing was not widespread. The discrepancies between these studies could be resolved by combining remote sensing data with long-term monitoring data in the field and the simultaneous use of several indicators of degradation (Jamsranjav et al., 2018). Recent developments have shown that remote sensing datasets, when used in combination with local data and knowledge are a powerful tool to inform decision-making but should not be used in isolation (Allred et al., 2020). Machine learning algorithms can help combine on-the-ground data to create continuous, long-term cover estimates that can be applied to compare trends among different landscapes (Bestelmeyer et al., 2021).

The differences in methodology in the assessment of rangeland degradation makes comparisons across studies difficult (Jamsranjav et al., 2018). The seven assessments of rangeland degradation that provided national-level estimates for degradation in Mongolia used different criteria for site selection and different methods for assessing degradation. These assessments reached different conclusions, reporting estimates of the extent of degradation ranging between 22 and 95% of the country. For the assessments that distinguished several stages of degradation, the study reporting the highest amount of slightly degraded rangelands 33–53% (Jamsranjav et al., 2018); focused on winter rangelands, which are rested during the growing season and tend to be less degraded than adjacent summer and spring/fall pastures (Densambuu et al., 2018). In contrast, the report from (ALACGC, 2011), while also using a field assessment but spanning the whole country and covering both winter and seasonal rangelands, provided a lower estimate of slightly degraded rangelands (8%). Another national-level assessment of rangeland degradation relied on remote sensing data rather than field data, and estimated among the highest extent of rangeland degradation country-wide (Bulgan et al., 2013). This apparent inconsistency in the results of different studies makes it difficult to provide a clear message to inform the public and policy makers (Addison et al., 2012). As a result, in 2011 the Green Gold Animal Health project of the Swiss Agency for Development and Cooperation, in collaboration with the National Agency for Meteorology and Environmental Monitoring (NAMEM) developed a nationally standardized methodology for rangeland assessment and monitoring. This methodology proposes long-term, multi-year assessment of degradation using a combination of core monitoring methods (Herrick et al., 2019), coupled to a quantitative conceptual framework that provides a consistent evaluation of the status of Mongolian rangelands. This standardized methodology has been applied annually since 2011 to record data on over 1500 plots across Mongolia. Primary data of rangeland monitoring is entered into a database by engineers at the aimag level (first administrative units of Mongolia, above soums and bags). After careful quality control, the data is analyzed centrally. Key products such as the national reports, produced every 3 years, and the recovery class maps, produced annually, are provided to Government agencies at all administrative levels. Decision-makers use these products for national and regional level planning in land management and restoration programs. Although there are still gaps in communication and application at local levels (Jamsranjav et al., 2019), some initiatives like the certification of livestock raw materials and products as "responsible products" following a positive assessment of rangeland monitoring data have improved the participation and communication of herders and local governments. Such efforts represent an important step forward in developing a robust system for the assessment and monitoring of rangeland condition in Mongolia that needs to be sustained.

4.1. Use of conceptual frameworks to understand rangeland degradation in Mongolia

Given their importance for successful adaptive monitoring, it was surprising that less than one fourth of the studies on vegetation change and rangeland degradation in Mongolia referred specifically to a conceptual framework. The conceptual frameworks mentioned by Mongolian studies belonged to one of the three main paradigms in rangeland ecology and ecological restoration: the traditional range succession model (Dyksterhuis, 1949), state and transition models (Westoby et al., 1989) and an integrated degradation framework (Jamsranjav et al., 2018).

The range succession model has been widely used to interpret vegetation condition in the US (Dyksterhuis, 1949) and in Mongolia (Chognii, 2001; Tuvshintogtokh, 2014). Early rangeland studies in Mongolia adhere to this paradigm, which is still being used by some (Tuvshintogtokh, 2014). However, this model does not allow for non-linear and irreversible transitions that are observed in many rangeland systems (Briske et al., 2005), including many Mongolian rangelands (Densambuu et al., 2018). A more flexible approach is provided by the STM framework (Westoby et al., 1989), where plant community changes can be reversible, exhibit hysteresis (e.g., a relatively rapid vegetation change followed by slow recovery), or be irreversible. Recent nation-wide rangeland health assessments in Mongolia (Densambuu et al., 2018; NAMEM and MEGDT, 2015) are based on STMs, which are becoming a primary tool for interpreting long term rangeland monitoring data and short term grazing impact assessments in Mongolia. These assessments include plant and soil indicators to assess rangeland degradation. More recently, two studies have applied an integrated degradation framework, including soil and vegetation changes to assess rangeland degradation in the forest steppe, steppe and desert steppe zones of Mongolia (Jamsranjav et al., 2018; Khishigbayar et al., 2015). This framework identifies distinct degradation steps, but does not explicitly include drivers or triggers of degradation and recovery pathways. One of these studies compared their results to those of other assessments and since there was some alignment, the authors concluded that this framework could be widely applied to Mongolian rangelands (Jamsranjav et al., 2018). STMs and the integrated degradation framework present many advantages over the classic range succession model, in that they allow assessing the reversibility of degraded states and the role of restoration in recovering rangeland ecosystems (Suding et al., 2004). In addition, these frameworks can be used to help focus conservation resources on areas at highest risk of degradation or with the greatest potential for recovery (Bestelmeyer et al., 2017). However, robust implementation of these theoretical frameworks requires validation with empirical field data collected, if possible, over several years to account for year-to-year variation.

4.2. What are the main drivers of rangeland degradation identified by the studies and how are they quantified?

Understanding what drives rangeland degradation is a key step to designing policies and strategies for sustainable land use (Harris, 2010). Climate change and overgrazing have been considered the main drivers of rangeland degradation in Mongolia over the past thirty years (Liu et al., 2013). Consistent with this common belief, the drivers of degradation most commonly mentioned in our review were grazing, followed by precipitation and temperature. This pattern was consistent across ecological zones, except in the mountain taiga, where precipitation was mentioned more frequently than grazing. However, the frequency of studies mentioning a particular driver does not necessarily reflect the importance of that driver relative to others. In fact, some studies aimed at comparing the relative importance of different drivers concluded that either climate (Liu et al., 2013) or grazing (Hilker et al., 2014) played a more prominent role, but this varied regionally and differed between ecological zones (Liu et al., 2013). For instance, Narantsetseg et al. (2015) concluded that rangeland health in Mongolia is controlled by regional variations in climate and vegetation productivity but is locally modified by intensive livestock grazing pressure with different grazing sensitivity for different steppe types. Other studies concluded that grazing might not be the leading driver of degradation in non-equilibrium systems like the desert steppe and desert, where precipitation has a more prominent role in causing vegetation change (Fernandez-Gimenez and Allen-Diaz, 1999; Wesche and Retzer, 2005). Management strategies should thus consider these differences across the ecological zones.

Most studies that assessed the relationship between a hypothesized driver and the level of degradation or vegetation change were observational, and only a few used experimental manipulations of the driver. Experimental approaches were limited to studies addressing the effects of grazing and used exclosures or enclosures (Bat-Oyun et al., 2016; Wesche et al., 2010). Studies comparing non-grazed exclosures to grazed areas outside the exclosures often disregard the levels of grazing intensity (or utilization). As well, removal of grazing may not represent a reference condition in systems that evolved over millennia with grazing by wild and domestic herbivores. Most of these studies found an effect of excluding grazing, but the magnitude of these effects depended on the ecological zone where the effects were studied. For example, exclosure and enclosure studies in non-equilibrium systems, like the desert steppe or desert zones, found that the effects of grazing were overridden by precipitation (Wesche et al., 2010).

A more common approach to infer the effects of grazing was based on spatial gradients, where the distance to places where livestock concentrate, such as winter camps or wells, was used as a proxy for grazing intensity (Ahlborn et al., 2020; Narantsetseg et al., 2015). In some cases, the gradients in grazing intensity were confirmed using dung counts in the same areas (Sasaki et al., 2018), but dung counts may not work well for all species and may differ between ecological zones (Jamsranjav et al., 2018). Spatial gradients, compared to exclosure experiments, have the advantage of allowing comparisons of multiple levels of grazing and the ability to cover larger spatial scales. However, spatial gradients have some disadvantages as well. For instance, localized spatial gradients may not reflect the prevalence of grazing pressure across entire landscapes. Being observational approaches, spatial gradients can suffer from confounding effects because the allocation of grazing treatments is not randomized. In contrast, experimental studies can provide a mechanistic understanding of the effects of grazing, but may lack realism, because they are generally conducted at relatively small spatial scales, involve a low number of replicate plots and in most cases cannot address the effects of multiple levels of grazing. Importantly, well designed experiments that are able to separate the effects of grazing and climate are fundamental to disentangle to role of different drivers (Harris, 2010). We therefore recommend that future studies on rangeland degradation in Mongolia use a combined approach, including experimental manipulations of grazing and other hypothesized drivers of degradation and large-scale observations to tease apart the causes of degradation. Experimental studies should include adequate replication and randomization of grazing treatments, ideally incorporating multiple levels of grazing.

4.3. Distribution of studies across ecological zones and climatic gradients

Rangelands in Mongolia occur over a wide range of environmental conditions, from deserts to forest steppe and high mountains. Depending on their ecological potential, rangelands will respond differently to disturbance (Densambuu et al., 2018; NAMEM and MEGDT, 2015). The recovery of rangelands needs to be evaluated with respect to the ecological potential of the rangeland. Therefore, the assessment of rangeland degradation and its relationship to restoration strategies should be based on characteristics of the ecological zones that reflect their ecological potential.

Most of the studies found in our literature review were conducted in three main ecological zones: steppe, forest steppe and desert steppe. Fortunately, the number of studies in these areas was proportional to the area that these zones represent in Mongolia (about 70%). These ecological zones are the most heavily utilized and are often considered to be the most degraded (Densambuu et al., 2018; Hilker et al., 2014; Jamsranjav et al., 2018; Sheehy and Damiran, 2012). In contrast, fewer studies were conducted in the desert, which in turn was reported as the ecological zone experiencing the least degradation (NAMEM and MEGDT, 2015). Most studies on rangeland degradation were conducted in the central provinces of Mongolia, where most of the population is concentrated and grazing pressure is higher. Rangeland degradation has been less of a concern in the eastern provinces, where grazing pressure is lower (Gao et al., 2015) and rangelands are assumed to be in better condition, including by the Mongolian public. As a consequence, many herder families and thousands of animals have moved to eastern Mongolia and their impacts on wildlife habitat have increased in the last years (Ito et al., 2018). Rangeland degradation is not "yet" considered to be a significant problem there, but current trends suggest that degradation may increase in the near future.

Most studies were conducted under intermediate conditions of annual temperature and precipitation. Sites with more extreme conditions were underrepresented. Studies in drier and warmer conditions may help understand better the responses of Mongolian rangelands to the projected increases in temperature and increased aridity (Batima et al., 2005). Climate change is predicted to negatively impact vegetation in most rangelands worldwide by decreasing biomass production and increasing inter-annual variability, and Mongolian rangelands have been identified among the most sensitive (Godde et al., 2020). Climatic trends are concerning because they threaten the livelihoods of peoples that depend on rangelands for goods and services. Rangeland socio-ecological systems are complex, and their resilience and ability to adapt is increasingly threatened by political, economic and climatic stresses (Reid et al., 2014).

5. Conclusions

Our review of rangeland degradation literature in Mongolia shows that (1) through time, there is lack of consensus on how to define and measure rangeland degradation. The different approaches used in the literature are likely to be responsible for the contrasting estimates of rangeland degradation in Mongolia reported by different studies, which in turn confuses the message that is conveyed to the public. Standardized methods, like those implemented recently in the Green Gold and NAMEM assessments should be used to assess rangeland degradation in a way that is comparable across studies. (2) The use of conceptual models in rangeland monitoring and assessment could improve the adaptive management of these systems, by providing a theoretical framework to assess changes in ecosystems and guide management strategies. In particular, the recent use of STMs and the integrated degradation framework shows promise to help design sustainable management strategies for Mongolian rangelands. These models are based on both plant and soil parameters and include contrasting degradation and recovery stages, allowing for reversible and irreversible processes, that characterize the dynamics of Mongolian rangelands better than the traditional rangeland succession model. (3) Grazing is frequently mentioned as a driver of rangeland degradation, followed by precipitation and temperature, but the impact of different drivers is likely to differ across different ecological zones. Grazing is seldom identified as the main driver of degradation in the desert steppe and desert zone where precipitation is viewed as more important, while grazing is considered the main driver in less variable environments like the forest steppe. Future studies should consider differences in the ecological potential of rangelands occurring in different climates and soils, using an interpretive framework such as ecological sites that have been developed by government agencies (Densambuu et al., 2018). Ecological sites establish localized benchmarks against which assessment and monitoring data can be compared, such that natural variations due to soils and climate are not confused with degradation (Bestelmeyer et al., 2017). Furthermore, it will be important to quantify the relative importance of different drivers in each ecological zone in order to evaluate where specific interventions, especially changes to grazing management or restoration actions, will produce the most beneficial outcomes. Finally, (4) most studies were concentrated in central Mongolian rangelands in the steppe, forest steppe and desert steppe, likely because these areas are exposed to higher land use pressures. However, climate change, land use change, and shifts in herder populations are occurring across Mongolia, so monitoring efforts should be distributed across ecoregions and ecological sites in order to manage adaptively the effects of global change and target interventions to sustain rangeland ecosystem services into an uncertain future.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

Funding for this project was provided by GRÓ Land Restoration Training programme. We thank Jebediah Williamson for his contribution extracting WorldClim data and creating the climate figure. We thank Budbaatar Ulambayar for assistance in creating the map presented in Fig. 5.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jaridenv.2021.104654.

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