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Environmental Evidence

SYSTEMATIC MAP PROTOCOL

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What evidence is available on the drivers of grassland ecosystem stability across a range of outcome measurements: a systematic map protocol

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Abstract

Background: Recently there has been considerable focus on the ecosystem services concept which has resulted in important advancements in biodiversity conservation across land management scales. Many have, however, cautioned against the ecosystem services approach because of its focus only on certain aspects of the ecosystem which may be unsustainable in the long term. This has encouraged calls for deeper study into ecosystem functioning using an holistic ecosystem multifunctionality framework. Here greater biodiversity is thought to facilitate greater functioning leading to more sustainable ecosystems. Although ecosystem multifunctionality is a relatively recent development, the general premise is based on the hypothesis that diversity begets stability. However, several key review syntheses have consistently called for ecosystem stability driver-outcome relationship studies to extend beyond traditional measurements. Understanding these relationships requires holistic approaches which are often challenging to investigate experimentally due to resource constraints. Systematically mapping out the relationships between various stability drivers and outcomes could provide a more empirical basis on which both the ecosystem multifunctionality and services land management frameworks could be based. This work outlines the protocol for the first systematic map which will identify and catalogue diversity–stability related studies within the grassland biome. The outcomes of this study will produce a searchable database of the body of literature relevant to the debate and suggest future research directions in both empirical and applied ecology fields.

Methods: Relevant studies will be sourced from online databases. Inclusion criteria will be applied to the returned articles to identify studies relevant to the primary question; what evidence is available on the drivers of grassland ecosystem stability across a range of outcome measurements. These inclusion criteria will be based on (1) subject population—the grassland biome; (2) possible ecosystem stability drivers and comparators (i.e. measures of diversity, functioning, food web connectedness, and disturbances); and (3) stability outcomes considering all measures of ecosystem stability (i.e. coefficients of variation, changes in ecosystem functionality, resistance to disturbances and invasions, return rates following disturbance). Studies will be screened for relevance and included articles will be critically appraised for meta-analysis and systematic review potential. A narrative synthesis, together with a searchable and expandable database, will be compiled to catalogue the relevant studies. Descriptive summary statistics and bibliometric network analyses will also be presented.

Keywords: Ecosystem services, Ecosystem functions, Ecosystem sustainability, Ecological processes, Land management practices, Ecosystem change

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Background

Ecosystem services

Ecosystems biology has seen the explosion of the ecosystem services concept over recent decades where ecosystems are studied principally to understand their socio-economic contribution to human societies [1, 2]. This discipline has largely formed out of the growing awareness of the anthropically-driven demand for natural resources which is driving the biodiversity crisis affecting both humans and the environment [3–7]. The ecosystem services concept has rapidly spread from academic arenas and is now influencing governmental policies resulting in numerous important conservation projects aimed at ensuring that the supply of these services is maintained or restored [8–10].

Ecosystem services are, however, somewhat subjectively defined and quantified, as they are based on the needs or desires of a particular human population at a given space and time and are therefore anthropogenically biased [11]. Whilst this is useful for policy development [1, 12–14], it is not useful when objectively defining or describing ecosystems and their functioning in their natural state. The danger here is that humans may be shifting their management focuses of largely undisturbed ecosystems towards those which promote only a few key beneficial or profitable services whilst other services are ignored [11]. There do exist important ethical debates surrounding anthropocentric perspectives towards environmental management [15, 16]; however, an anthropocentric approach is often key to mitigating poverty and suffering in under-resourced communities. In these scenarios Fisher et al. [17] argued that there must be a strong focus on maintaining ecosystem services use to ensure both human and ecological community sustainability. Successful examples of this approach include alien plant clearing programmes in South Africa [18, 19], protected areas in Madagascar which aim to alleviate poverty, improve natural resource sustainability as well as conservation [20], forest restoration in Vietnam [21], and conventional (monocropped) versus traditional (three species intercropped) farming methodology in Costa Rica [22].

There have indeed been impressive positive advancements and applications of the ecosystem services concept. However, whilst highlighting the breadth of knowledge across several key scientific disciplines Abson et al. [23] also identified a low occurrence of key sustainability terminology (< 40% of 265 key terms identified during their systematic mapping) in nine key research clusters. Mace et al. [24] have identified difficulties in handling terminology surrounding the complex relationships which exist between biodiversity and ecosystem services which has negatively impacted the way humans manage land as many interactions between biodiversity and ecosystem processes are poorly understood. This raises some issues concerning the ecosystem service approach's to sustainability when managing land. Although acknowledging the ecosystem services concept's importance in solving many important problems, Norgaard [25] similarly argued that the ecosystem services concept's rapid proliferation may blind us to the underlying complexity. This is relevant particularly from a pure ecology perspective which lacks universal or generic models that can be easily imported into economic models [26]. Therefore, calls for further investigations to understand the complex feedback and trade-off mechanisms involved when sustainably managing land for multiple ecosystem services to meet basic human needs seem valid [27, 28]. In a sense these authors recognised the limitations of applying reductionist approaches to ecosystems studies.

Ecosystem multifunctionality—the bridge between applied and theoretical ecology

Manning et al. [11] recognised this problem of somewhat ambiguous ideas and definitions. Their proposed solution is an important distinction between ecosystem services and ecosystem functioning. They suggested that ecosystem services be quantified in situations where human gain and wellbeing is a primary concern, but ecosystem multifunctionality (the positive relationship between species diversity and number of functions; [29]) be studied in more general scenarios where an objective measure of the ecosystem's overall performance is useful. Knowledge on ecosystem functioning is thus logically an important prerequisite for productive and sustainable ecosystem management.

Superficially, ecosystem functions (generally measures of vegetation production and removal, nutrient cycling, and soil microbe and plant pathogen activities; [11, 29–31]) do not appear to be important ecosystem services. However, investigations of land use change's effect on ecosystem multifunctionality revealed a marked reduction in species diversity whilst grass biomass production increased dramatically as agricultural land uses shifted from a natural state towards functionality focussed on biomass production [32, 33]. Thus, communities become more similar across trophic levels as one function becomes dominant—an example of biotic homogenisation [33].

Whilst the ecosystem multifunctionality topic is a relatively recent development [34], it only considers the relationship between diversity and functioning. An agricultural setting may strive for biotic homogenisation to boost productivity in intensive agriculture. However, the danger of biotic homogenisation is more easily understood when considering the diversity–stability hypothesis which underpins the multifunctionality thesis. More diverse systems have been hypothesised to be more stable for several decades (reviewed by [35]). Larger species pools lead to more complex species interactions which may help mitigate ecological shifts during environmental perturbations [36]. Tilman and Downing's [37] drought resistance assessment showed that higher grass species diversity results in proportionately less change in biomass production during droughts. The similarities between ecosystem stability and engineering principles was then realised by Naeem and Li [38]. This idea suggests that each species (or each part in a machine) carries out a particular function which contributes to the overall system's functioning. The more unique species present in the community, the greater the number of functions within the community. Greater species number can also result in an insurance effect where multiple species performing one function will allow the function to persist in the ecosystem even if some species become lost from the ecosystem [39]. Isbell et al. [40] conducted a global analysis of how the number of species promoting ecosystem functioning changes across space and time. They concluded that most plant species (approximately 84%) occurring in grasslands provide ecosystem services. Thus, losing only a few species could severely affect the ecosystem's sustainability and stability thereby reducing the area's ability to consistently and effectively supply ecosystem services.

Diversity and stability—its current relevance

The studies highlighted in the previous section suggest a strong link between species diversity and ecosystem stability which have direct or indirect effects on sustainable land management to promote for ecosystem services. However, Donohue et al. [41] showed how ecologists and environmental policymakers and practitioners differed widely in their usage of stability-related terms. This has made ecosystem stability a confusing term to grasp [42] and makes measuring policy implementation success difficult to quantify and monitor. Donohue et al. [41] proposed several solutions which could address this, an important one being developing methods to quantify the stability of whole ecological networks through time and space. Several metricise have been developed to address this (Rapid Ecosystem Function Assessment [43], Landscape Function Analysis [44]). These methods are based largely on biodiversity–ecosystem functioning which, like the ecosystem multifunctionality thesis, provide a more holistic understanding of the ecosystem [24]. Whilst this is an important step forward these metricise do not actively identify the underlying mechanisms driving and sustaining biodiversity and ecosystem functioning remain unknown. Combination studies addressing ecosystem stability and functioning do exist. However, these tend to study the effect of diversity on biomass production stability (for examples see [45–47]). Even fewer studies have addressed multiple stability and disturbance components in one experiment [41]. This likely results from methodological challenges in measuring multiple variables across an entire ecosystem. Given that the ecosystem services concept encompasses functions derived from almost all levels of an ecosystem, the current empirical framework on which stability-promoting policies can be based on seems insufficient. What Donohue et al. [41] may be alluding to then in order to better answer the question is the harmonisation of the ecosystem multifunctionality and stability paradigms. This harmonisation could exist in the intersection of biodiversity, ecosystem multifunctionality [48–50] and stability, an area that has recently gained important traction [51, 52].

Although the diversity–stability debate remains, at present, unanswered, both classical and recent reviews have consistently called for increased field-based data to be collected from across trophic levels and beyond species richness assessments [35, 41, 53, 54]. McCann [39] critically assessed the diversity–stability topic concluding that stability likely originates from the high level of interconnectedness between trophic levels whereas instability on the other hand results from species loss which reduces interconnectedness (for further developments of this idea see [55–57]). Large scale experiments have also revealed that environmental conditions and grassland diversity may not be the most important contributor to multifunctionality and aboveground vegetation biomass production may not be the most important measure of functionality but that individual trophic levels may contribute more than others to particular functions [30]. It appears then inter-trophic relationships contribute importantly to stability. This is consistent with theses highlighting that ecosystem functions are mediated by complex aboveground and belowground biota linkages [33, 58]. However, the magnitudes, directions, and mechanisms involved in promoting ecosystem connectedness and, by extension, stability and sustainability remain unknown.

The rate at which multifunctionality is lost varies geographically, between ecosystem types, across trophic levels [59], and land-use intensities [32, 33]. However, many of these ecosystem stability and multifunctionality studies have been conducted in grassland ecosystems [41, 59] which are both economically and socially important and globally threatened principally through land transformation and degradation such as by eutrophication, overgrazing, herbivore or fire exclusion [47, 60–63]. If ecosystem functioning is a key component to ecosystem sustainability, then the underlying mechanisms maintaining and promoting functionality should be studied in greater detail and incorporated into the ecosystem services discipline. In little over a decade there has been substantial development in the volume of literature addressing the diversity–stability debate (354 studies identified in 2016—[41], 52 studies identified in 2007—[64]). We believe that a systematic map identifying the drivers of the various measures of ecosystem stability in grassland ecosystems from across the globe could help identify solutions to a somewhat broad and challenging topic. A systematic map to capitalise on this rapid growth and identify future research trajectories for the ecological stability literature will make important contributions to both pure and applied ecologists and land managers working to maintain reliable ecosystem functioning through space and time.

This systematic map could also be incorporated into current ecosystem assessment protocols by encouraging increased focus towards relevant drivers of ecosystem stability—a potentially valuable tool for assessing policy effectiveness, implementation success, and ecosystem management sustainability [24]. Areas needing deeper research and areas where systematic reviews and meta-analyses can be carried out will also be highlighted through this systematic map.

Stakeholder engagement

The scope and focus of the systematic map were broadly established by the review team and then refined following stakeholder input. Stakeholders were engaged via an online Google Forms survey. Approximately 60 invitations were sent out via email to potential stakeholders with 22 responses received. Majority of the respondents identified as academics (68.2%) with the next biggest identifying as directly influencing local or national policy and governance (18.2%). Most stakeholders were South Africans (41.01%), North Americans (31.81%), and Europeans (18.18%) with one Brazilian respondent. Stakeholders provided key input into search string development and contributed key articles which were incorporated into the test list. Helpful suggestions on the systematic map presentation were also provided (see Additional file 1 for the individual and summarised responses).

Objectives of the systematic map

The primary objective of this systematic map is to identify the body of evidence related to the biotic and abiotic drivers of grassland ecosystem stability from across trophic levels. Data for this map will be sourced from experimental, quasi-experimental and observational studies conducted in natural, conserved, and agricultural grassland settings from across the globe. The outputs of this systematic map will consist of a narrative synthesis summarising the evidence pertaining to the different driver and outcome measures of ecosystem stability. This will be presented together with suggestions on how these data can be used by theoretical, pure, and applied ecologists and the ecosystem services discipline. The narrative synthesis will be accompanied by a searchable and expandable database documenting the driver-outcome relationships of grassland ecosystem stability research.

There have also been recent calls that solutions to the problem of ecosystem sustainability should be based on ideas synthesised from the pure ecology discipline and then implemented into society at large [11, 41]. This study thus, secondarily aims to identify areas where ecologists and stakeholders may enter into relationships to identify and develop future questions and solutions which can be applied to policy revisions and development.

Primary question

What evidence is available on the drivers of grassland ecosystem stability across a range of outcome measurements?

Components of the primary question

Population/subject Experimentally manipulated, undisturbed, conserved, or extensively managed grasslands. Depending on the focus of the article, studies within the savanna biome may also be included. Studies where the grassland has been structurally altered anthropogenically into a monocrop or has experienced dramatic urbanisation will not be included.

Intervention/exposure Potential drivers of grassland ecosystem stability largely acknowledged in the ecological literature. These could include positive drivers such as diversity and connectedness but also negative drivers such as invasions or climatic instabilities.

Comparator Absence or lack of a driver or alternatively a treatment application gradient. This treatment gradient could be different levels or frequency of a disturbance or different numbers of species within a plant community.

Outcome Measures of grassland ecosystem stability largely acknowledged in the ecological literature. Commonly used measurements include temporal coefficients of variation or return times to a pre-disturbance state.

Methods

Searches

Search terms

The search term consists of three parts each pertaining to the three aspects of the primary question; population, driver (which includes both intervention and comparator terms), and outcome. The population search consists of synonyms referring to 'grassland' from across the globe. This list was generated by extracting commonly occurring terms in the International Vegetation Classification divisions used to describe grassland regions [65] together with stakeholder input. Drivers of ecosystem stability comprising the intervention component of the primary question were selected from terms suggested as important from key diversity–stability debate reviews [39, 41, 64] together with articles and suggestions from the stakeholder community. The terms comprising the outcome search string component were selected from a thematic review [64] and a terminology inventory article [42] together with articles and suggestions from the stakeholder community.

The search is based on three groups of search terms, the grassland synonyms (population), the contributors to stability (driver), and the stability measurements (outcome). Search terms within each question component will be combined using the Boolean "OR" operator. Each question component will then be combined using the "AND" operator. A wildcard (*/$) will be used where accepted by a database or search engine to return multiple prefixes and suffixes.

Population *grass* OR prairie* OR meadow* OR rangeland* OR steppe OR veld* OR pasture* OR pampa* OR heath* OR tagia* OR campo* OR llano* OR tundra OR lawn

Driver richness OR *synchron* OR turnover OR divers* OR *function* OR process* OR product* OR bef OR complexit* OR interact* OR *connect* OR web OR network OR trophic OR invasion* graz* OR *herbivor* OR fire OR drought OR precipitation OR rain* OR fertili* OR land use OR perturb* OR disturb* OR spatial varia* OR temporal varia* OR spatio-temporal varia* OR pulse*

Outcome stabl* OR unstabl* OR *stabilit* OR *sustain* OR chao* OR invasibilit* OR coefficient of varia* OR resist* OR return* OR Holling* OR resili* OR alternat* OR recover* OR collapse* OR *equilibrium OR transition

Where databases do not allow wildcards, the simplest root word will be included in the search string. If complex search terms are not accepted the search term will be modified according to suggestions in the search platform's help documentation. If the search term is restricted to length a simplified phrase will be used. No time or document type restrictions will be applied to database searches. Only the English language will be used to search within the databases. Should the systematic map process take longer than 18 months, these database searches will be updated.

Publication databases

All key journals which were suggested by the stakeholder community are included in the following databases and so no targeted e-journal searches will be conducted. The search will include the following online databases:

- Agricola
- CAB Direct
- EBSCO Academic Search Complete
- EBSCO GreenFILE
- PubAg
- PubMed
- Scopus
- ISI Web of Science Core Collection

Grey literature

We will search the following databases and websites for links or references to articles not returned using publication databases or search engines:

- arXiv (https://arxiv.org/)
- bioRvix (https://www.biorxiv.org/)
- Dissertation.com (http://dissertation.com/)
- Open Access Theses and Dissertations (https://oatd.org/)
- Open Grey (http://www.opengrey.eu/)
- OpenThesis (http://www.openthesis.org/)
- ProQuest Dissertations & Theses Open (https://pqdtopen.proquest.com/search.html)
- Regime Shifts DataBase (http://www.regimeshifts.org/)

To access governmental and non-governmental organisation literature, internet searches will be performed using the following search engines:

- Google (http://www.google.com)
- Google Scholar (http://www.scholar.google.com)
- Google Custom International Governmental Organizations (IGO) (https://cse.google.com/cse?cx=006748068166572874491:55ez0c3j3ey)
- Google Custom Non-Governmental Organizations (NGO) search (https://cse.google.com/cse?cx=012681683249965267634:q4g16p05-ao)

The first 300 records returned using each of the above Google search engines will be examined for data relevant to the primary question.

Targeted searches

Principal investigators of major long term ecological experiments (e.g. Biodiversity and Ecological Processes in Terrestrial Herbaceous Ecosystems [66], Cedar Creek Ecosystem Science Reserve [67], Inner Mongolia Grassland Ecosystem Station [68], Jena Experiment [69], Konza Prairie Long-Term Ecological Research [70], Nutrient Network [71]) and national park research teams [72–74] will be contacted for information on any publications, databases, or unpublished data related to the primary question. Online databases such as DataONE [75], DEIMS-SDR [76], Dryad [77], ESA's Ecological Archives [78] and Google's Dataset Search [79] will also be queried for any relevant studies pertaining to the primary question. Articles within reference lists of reviews identified as relevant to the primary question but not included in the final analysis will also be included in the search.

Assessing the specificity and sensitivity of the search

Comprehensiveness tests of the search terms was assessed using ISI Web of Science (results are documented in Additional file 2). Each proposed population search term was queried together with AND (*stabl* OR *stability*). The full population search string together with AND (*stabl* OR *stability*) was then queried together with each driver term. Finally, the full population and driver search strings were queried together with each stability outcome search term. Each term's specificity was assessed by recording the number of hits returned for each term and the proportion of relevant results (out of 50 citations screened at title level). To give an indication of each term's (and each full string's) sensitivity the number of test list articles returned was also recorded. The test list (also contained within Additional file 2) was developed based both on contributions from stakeholders via the survey and from the review team. All stakeholder and review team test article suggestions were then considered, and a final list was developed which covered a range of topics relating to the components of the primary question as well as being drawn from various key journals and authors. The final search term included all articles in the test list.

Article retrieval strategy

All articles obtained during this systematic map will be stored in bibliographic files. A log file recording the time and date of each database search will be kept together with these source files. All databases will then be loaded into EndNote X8, compiled into one library and duplicate references will be removed. This library will then be exported and will then be uploaded to CADIMA (https://www.cadima.info/). Inclusion/exclusion criteria will then be applied. We will exclude publications for which we cannot access the full text as it will be needed to accurately assess the study validity and accurately code and catalogue. When we do not have access to the full text we will attempt to acquire the article through inter-library loans or by contacting the authors via email.

Article screening and study eligibility criteria

Article screening

Search results will be screened by all members of the review team working independently with equal workloads over three stages: title, abstract, and full text. Before each screening stage the reviewers' study screening consistency will be assessed using Kappa statistics. These statistics will be based on the reviewers' decisions made on 10% of the total records to be screened up to a maximum of 200 records per reviewer. If there is not substantial consensus between the reviewers ($K < 0.6$) then discrepancies in the inclusion criteria will be discussed to clarify or revise the inclusion criteria to ensure consistent screening by all authors. Each title, abstract and full text article will be screened by two reviewers with any discrepancies at this level screening will be addressed by the third reviewer. If there is still uncertainty the article will be included for screening at the subsequent level. Articles included at title level will then be screened at abstract level. Articles included at the abstract level will then be screened at the full text level. If a reviewer has authored a returned article, this article will be screened by two other members of the review team or an external reviewer who has been briefed sufficiently on the screening protocol.

Conflicting inclusion/exclusion decisions at the abstract and full text screening stages will be addressed by consensus of the review team. Publications found by means other than publication database searches will enter the screening process at the abstract screening stage (if an abstract is available) or the full text stage.

Eligibility criteria

Each study will have to fulfil the following criteria to be included in the map.

Relevant subjects Grasslands across the globe. Grasslands may include any extensively managed, conserved, undisturbed or disturbed region which is primarily dominated by grasses and forbs, shrubs, crusts, and or succulents. Including studies concerning dramatic anthropogenic influence (e.g. ecological restoration, intensive agricultural practices) may provide useful insight and so we will include these studies as well as studies conducted in natural systems. However, studies where the grassland has been structurally altered anthropogenically into a monocrop or has experienced dramatic urbanisation will not be included. As this map is focussed on grasslands, studies conducted within savanna or forest habitats will not be targeted in this map. However, those which address the dynamics between grassland and wooded states will be included. Whether a study took place in a savanna biome will be determined based on the reference to tree–grass interactions in the article's study site or experimental design; article inclusion will be conservative. No studies conducted in fresh (e.g. wetlands, deltas, marshes) or marine (seagrass meadows, beaches) aquatic systems will be included. However, studies conducted in grasslands occurring along the boundaries of any of these systems will be included. Studies documenting "paleo-grasslands" will not be included.

Relevant stability drivers Drivers may be any measure of diversity (e.g. alpha, beta, gamma, richness), climate (e.g. precipitation, fire, drought, temperature), disturbance (e.g. grazing, fertilisation), trophic level complexity (number of levels, number of nodes, network asymmetry, network nestedness). Other drivers may be identified as screening progresses. These will be considered on a case by case basis.

Relevant types of comparators Either driver treatment gradients or levels (e.g. comparisons across numbers of connections within a food web or numbers of functional groups, or various intensities of experimentally imposed or naturally occurring drought) or absence of a driver treatment serving as a control.

Relevant types of outcomes There must be a measurement of stability reported in the study's results. This may include variability (or its inverse), coefficient of variation, network stability, rates of ecosystem functioning, persistence following disturbance, return time until reaching a pre-disturbance state, transitions into alternate stable states or temporal fluctuations. Studies which allude to their results being important in the diversity–stability debate without actively quantifying stability will be included in the map and will be categorised accordingly.

Relevant types of study Experimental, quasi-experimental, greenhouse, microcosm, laboratory (only those incorporating grassland taxa) or observational studies addressing the primary question will be included. Modelling, opinion, synthesis, commentary, and narrative review articles which are found to relevant will also be included in the database and will be coded accordingly for easier future reference.

Language Only studies published in English will be included during screening.

Date No date restrictions will be applied.

Bibliographic data for all articles included in the final database will be extracted and included in the final report. All articles excluded at full text level together with reasons for exclusion will be provided in a separate database table in the final systematic map.

Study validity assessment

Because of the breadth of this systematic map and the variety of methods and experimental designs study validity assessment will not be applied to this systematic map. However, basic descriptions of the experimental protocols will be recorded to assist in identifying areas of future more detailed critical appraisal and synthesis on smaller, more homogenous sub-sections of the final systematic map.

Data coding strategy

Following full-text screening included article metadata will be extracted by all members of the review team. Bibliographic information, experiment metadata and driver/outcome data will be extracted and categorised subjectively based on reviewer interpretations of the article. Bibliographic data will be extracted from the citation record. Experimental metadata will consist of the country where the experiment was conducted, the type of grassland the experiment was conducted in, the land use type of the grassland during the experiment (intensive grazing, roadside, old croplands, restored mine dump etc.), the start and end dates of the experiment, the type of experiment (laboratory, field trial, modelling etc.) the length of the experiment, and bioclimatic data. In order to standardise climatic metadata across all sites bioclimatic data will be extracted from the WorldClim database [80] based on the study site geographical coordinates. The type and measurement scale used to quantify driver and stability measurements will be also recorded. For each of these aspects four levels of data (category, sub-category, data type, and measurement scale) will be recorded. The destabilising effect (if any) will also be recorded here together with the directional response of the system to the destabilising effect following an increase in driver magnitude.

Table 1 summarises the tables and each table's associated fields which the final systematic map database file will contain. Data coding has been piloted with the first 25 records returned from a Web of Science Core Collection search using the full search query (https://stuart-demmer.shinyapps.io/grassland-ecosystem-stability-systematic-map/). Categories used for categorical fields will be continually populated as the review proceeds. The article's DOI will be employed when constructing relationships between tables for complex querying and

Table 1 Systematic map database tables (column headings) and associated fields (rows)

Bibliographic information	Inclusion/exclusion	Experimental metadata	Stability drivers and outcome measurements
Authors	DOI	DOI	DOI
Publication year	Included	Country	Driver category
Title	Excluded at title	Grassland type	Driver sub-category
Abstract	Excluded at abstract	Latitude	Driver data type
Source journal	Excluded at full text	Longitude	Driver measurement scale
DOI	Reason for exclusion	Study start date	Outcome category
Publication type	Notes relating to exclusion	Study end date	Outcome sub-category
Funding source		Experiment site name	Outcome data type
		Experiment site ID	Outcome measurement scale
		Altitude	Destabilising effect
		MAP	Effect direction
		MAT	No. of experimental units
		Soil type	Data recording spatial resolution
		Land use type	Data recording temporal scale
			Meta-analysis suitability

DOI digital object identifier, *MAT* mean annual temperature, *MAP* mean annual precipitation

filtering. As multiple drivers and outcomes may be measured for one study, there may be multiple records for each study in the drivers and outcomes tables. Each stability driver will be linked to an outcome measurement based on decisions made by the authors of the study. If this relationship is not explicitly stated by the authors, the reviewers will decide which stability outcome to associate with which driver based on the results of the article. Where there is more than one article for a study area (for example, where more than one study has been published for one experimental site), each study will be recorded independently but all these studies will be cross referenced using a shared 'Experiment site ID' field value.

To test the repeatability of the data extraction strategy before beginning data coding, each member of the review team will independently code data from a subset of 30 included articles. Where there are inconsistencies between reviewers, the data extraction process will be discussed and revised. Once inconsistencies in data coding are rectified, data coding will be conducted by all members of the review team.

Study mapping and presentation

The systematic map database will describe the current evidence pertaining to the drivers and outcome measurements of grassland ecosystem stability. Based on stakeholder requests for an easily available, online database we plan to present this map as an interactive Shiny web application [81]. This will invite easy exploration and access by both the public and scientific communities. The database will be hosted on an Amazon Web Services domain with the data queried and presented via Shiny (https://stuart-demmer.shinyapps.io/grassland-ecosystem-stability-systematic-map/). Each of the four tables as well as a personalised dataset based on the user's querying and filtering can be downloaded as a comma separated value or Microsoft Excel Workbook file from this web application. An option to include new articles to this database will be made available following the publication of the final systematic map. A note stating that these articles were not part of the original systematic map will be included for transparency. Adopting a live web-based repository to host the systematic map whilst allowing new articles to be added to the database will help ensure the continual relevance beyond the final systematic map publication.

A description of the review process, figures, tables, and bibliometric network analyses carried out using the 'nails' package (Network Analysis Interface for Literature Studies; [82]) will accompany the database. An overview of the trends in experimental design will also be presented in a summarised form. The volume and key characteristics of the evidence base (descriptions on the environmental and methodological aspects of the studies, detailed summaries of identified driver-outcome relationships) will also be presented in the final report together with narrative discussions explaining the observed trends. Knowledge gaps will be identified and highlighted as future primary research topics and knowledge clusters will be proposed as future evidence syntheses topics.

Additional files

Additional file 1. Individual and summarised stakeholder survey responses.

Additional file 2. Search term comprehensiveness assessment, test article list and the number of articles returned by proposed search databases.

Authors' contributions
SD, KK, and MT conceived the study. All authors defined the study boundaries based on the resources available. SD wrote the manuscript, designed the search strings, their quality assessment process, inclusion criteria, critical appraisal, and database coding strategy with inputs from all other authors. All authors read and approved the final manuscript.

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Competing interests
The authors declare that they have no competing interests. Should any research studies included be authored by a member of the review team, that reviewer will not be involved in any decisions regarding their own work.

Availability of data and materials
This article will be published open access, under terms of the Creative Commons Attribution 4.0 International License (https://creativecommons.org/licenses/by/4.0/). The references and their associated meta-data collected for the systematic map will similarly be made available as an expandable online Shiny web application (https://stuart-demmer.shinyapps.io/grassland-ecosystem-stability-systematic-map/).

Consent for publication
All participants in the survey provided consent to participate and have their responses published under the provision of anonymity.

Ethics approval and consent to participate
Ethics approval for this study was granted by the University of KwaZulu-Natal's Humanities & Social Sciences Research Ethics Committee (Approval Number HSS/1620/018M).

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