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Review

Edaphic arthropods as indicators of the ecological condition of temperate grassland ecosystems: A systematic review

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A B S T R A C T

Temperate grasslands are part of one of the biggest biomes on earth, sustaining high levels of biodiversity and providing multiple ecosystem services. However, the area covered by this open ecosystem is decreasing worldwide, due to several threats like land use change or climate change. Ground-dwelling arthropods are an important group of the community of grassland soil invertebrates, and they play a key role within this ecosystem, while at the same time being sensitive to the changes caused by management practices like grazing, mowing, prescribed fire, etc. Using the Web of Science database, we conducted a systematic review to identify which groups of arthropods are being used as indicators to evaluate the ecological condition of grasslands in temperate regions, and which indices are being measured. As grasslands have been traditionally managed by humans for centuries, their ecological condition is intrinsically linked to the development of different management practices like grazing, mowing or restoration strategies, which usually affect soil and vegetation structure. We found that macro-arthropods were used in a greater number of studies than micro-arthropods (91% vs 15%), and within that size group, beetles were the preferred indicator in most of the temperate grassland types (49% of the studies), followed by spiders and ants. Few studies used grasshoppers to monitor grasslands changes. The indices more frequently assessed were species richness and abundance, and we identified that the response to the different management practices was quite heterogeneous. Restoration and grazing effects were the two factors more frequently evaluated for macro-arthropods, while micro-arthropods (Acari and Collembola) were dominant to assess land use type. Overall, our findings highlight the need to increase the number of studies in some temperate regions, to explore the potential of overlooked groups of arthropods, and to include indices that measure functional diversity or community composition.

1. Introduction

Globally, human activities are directly or indirectly driving several changes that negatively affect ecosystems and biodiversity (Díaz et al., 2019; Isbell et al., 2017; Pereira et al., 2010). Direct drivers of change include pollution (Grimm et al., 2008), climate change (Sala et al., 2000), the introduction of alien species (Pyšek et al., 2017), resources overexploitation (Butchart et al., 2010), and land-use change (Ostberg et al., 2015). Overall, all these factors are limiting the available habitat (Sala et al., 2000) resulting in a decline of local richness and abundance when compared to primary ecosystems (Newbold et al., 2015; Van Der Putten et al., 2000). The conversion of vast extensions of native habitats to increase food production is one of the main causes of terrestrial biodiversity loss (Semenchuk et al., 2022) and has also led to environmental damage in the form of soil erosion (Borrelli et al., 2017), reduced fertility and loss of ecosystem services like pollination or reduced water and air quality (Foley et al., 2005; Hasan et al., 2020).

The dramatic impact of this global degradation process has also been observed and quantified in grasslands (Bardgett et al., 2021; Gang et al., 2014). According to the International Union for Conservation of Nature (IUCN), grasslands (together with savannahs) are one of the seven major terrestrial biomes on Earth. Although an unanimous definition of this ecosystem is still lacking (Bardgett et al., 2021), grasslands are characterized by the presence of a moderate to high productivity grass cover, with few or absent woody vegetation, and adapted to the seasonality of water availability (Keith et al., 2020). Grasslands are widely spread

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around the globe, covering around 40 % of the terrestrial surface (Bardgett et al., 2021; Bengtsson et al., 2019; Blair et al., 2014). Besides, they have largely been used and maintained by a gradient of different human activities, such as grazing, mowing and burning to name a few (Habel et al., 2013; Heuss et al., 2019; Oertli et al., 2005; WallisDeVries et al., 2002).

According to Bardgett et al. (2021), both temperate and tropical grasslands can be classified depending on the level of human intervention as: natural grasslands, with very low interference; semi-natural grasslands, traditionally managed for centuries; and intensively managed grasslands, which are potentially deteriorated. The importance of the different ecosystem services provided by natural and semi-natural grasslands is frequently neglected or underestimated in comparison to other ecosystems (Bengtsson et al., 2019), despite their vast services provided. Grasslands play a key role in food production (specifically providing forage for cattle), promote carbon storage and sequestration, provide habitat resources for pollination, and contribute to water regulation (Bardgett et al., 2021; Buzhdygan et al., 2020; Gang et al., 2014), among others. Grassland ecosystems also support high levels of biodiversity and are especially important for arthropod communities (Fay, 2003; Joern and Laws, 2013), which are directly impacted by management practices and influence ecosystem structure, processes and function (Whiles and Charlton, 2006). Grassland arthropods are suffering a strong decline in their abundance, biomass, and number of species (Seibold et al., 2019) and the presence of remnant natural and semi-natural grasslands is critical to enhance regional arthropod diversity, particularly in agricultural landscapes (Duelli and Obrist, 2003).

The area covered by natural and semi-natural grasslands is decreasing worldwide over time (Bengtsson et al., 2019; Joern and Laws, 2013; Schirmel et al., 2015). Among the several threats faced by these ecosystems are climate change (Gang et al., 2014) and land use intensification and conversion to croplands (Askins et al., 2007; Bardgett et al., 2021; Wimberly et al., 2018), which already affects 45 % of the temperate grasslands biome. Furthermore, afforestation is also contributing to the decline in natural and semi-natural grasslands worldwide (Buscardo et al., 2008), as well as opposite processes like abandonment and lack of management (Aune et al., 2018; Eriksson et al., 2002; Plantureux et al., 2005; Schirmel et al., 2015).

Within this context, the use of indicators may constitute a useful tool to study the current trends about the ecological status of grasslands. Biological indicators are those organisms or communities of organisms (Gerhardt, 2002) that can be used (i) to assess the ecological condition of a particular ecosystem, (ii) to monitor the impacts of specific stressors or drivers of change, and (iii) to reflect the biodiversity of a certain area (McGeoch, 2007, 1998). In particular, biological indicators can be useful to prioritize conservation areas or to assess specific restoration or management techniques (Gerlach et al., 2013). Soil invertebrates are frequently used as biological indicators because they are considered the most abundant and diverse animal group (Prather et al., 2013), being around 23 % of all the living organisms described so far (Bagyaraj et al., 2016). Soil invertebrates are also an important share of the local species pool and reflect well habitat degradation or disturbances (Lavelle et al., 2006). Their small size means that soil invertebrates are sensitive to changes and reliable to evaluate local environmental conditions (Gerlach et al., 2013).

Among the community of soil invertebrates, ground-dwelling arthropods are an important group. In terms of species richness, they comprise more than 80 % of the edaphic fauna, representing a substantial proportion of the *meso*- and macrofauna (Bagyaraj et al., 2016). Regarding their ecological function, grassland arthropods are involved in ecosystem processes and structure (Whiles and Charlton, 2006), especially in two key functions within the soil food web, such as transforming plant litter and ecosystem engineering (Bagyaraj et al., 2016) and representing an important food source for other species (Goosey et al., 2019). Herbivores and detritivores, which are among the most abundant organisms in terrestrial ecosystems, play a key role in the food web through organic matter decomposition and nutrient cycling processes (Seastedt and Crossley, 1984). These arthropods are affected by shaping forces like grazing, fire or climate change (Whiles and Charlton, 2006) and have also been used as indicators in forests (Langor and Spence, 2006; Maleque et al., 2006) or agricultural systems (Behan-Pelletier, 1999; Menta et al., 2020).

Here, we conducted a systematic literature review to summarize the existing scientific evidence regarding how the use of ground-dwelling arthropods as bioindicators allows us to assess the ecological condition of managed grassland ecosystems in temperate regions. Our aims were (i) to identify the taxonomic groups commonly used as bioindicators and their indices or descriptors estimated, and (ii) to evaluate the responses of these groups to different grassland factors like management practices, land uses or restoration strategies. Then, we identified existing knowledge gaps, discussed the importance of the different groups of arthropods within this valuable ecosystem, and suggested future challenges in temperate grasslands monitoring.

2. Material and methods

2.1. Literature search and data collection

We conducted our systematic literature review following the methodology of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) designed for indexed publications (see Appendix A in Supplementary Materials). We conducted a survey using the Web of Science™ (Clarivate Analytics, 2020) database from the year in which the first article on this subject was available (1989) up to December 2020. The survey included studies considering some of the main groups of ground-dwelling arthropods ($N = 33$ search terms), from which we selected ants, beetles, spiders, grasshoppers, mites, and springtails to be included as keywords. We acknowledge that our query might exclude publications focusing on other orders like Hemiptera or Isopoda but given the size and diversity of the arthropod phylum, and after a quick search of studies on ground-dwelling arthropod communities, we selected those groups that appeared recurrently in the literature, and which we consider allow us to achieve the objective of this review. We also searched for articles that explicitly mentioned using ground-dwelling arthropods as indicators to monitor changes or to assess the ecological condition of the ecosystem, for example after restoration strategies ($N = 7$ search terms). Finally, the survey also focused on open grassland-like ecosystems ($N = 11$ search terms) from temperate latitudes (see Appendix B in Supplementary Materials for the complete list of keywords used in the systematic review). We only included original scientific articles written in English, omitting grey literature, and excluding reviews and *meta*-analysis to avoid replication bias.

Given the vast area covered by grasslands around the globe, the scope of this review focused on those grassland ecosystems included within temperate latitudes, excluding the ones from tropical and polar regions. Temperate latitudes encompass different grassland types located in several realms, such us Nearctic, Palearctic, Neotropical and Australasian. Thus, to classify the studies according to their grassland type, we established six categories including North American prairies from both USA and Canada, Eurasian steppes with strong thermal contrasts, Mediterranean grasslands with pronounced summer droughts, South American grasslands (e.g., pampas), subtropical grasslands from temperate latitudes in Australia and New Zealand, and temperate semi-natural grasslands, which did not fall into any above-mentioned category (e.g., meadows in central Europe).

We used Web of Science's 'topic' field option to enter the keywords of the query including searching in title, abstract, author keywords, and indexed keywords fields. Overall, the literature search yielded 1,311 papers. After screening the abstracts, we excluded 1,035 and retained 276. Following the in-depth reading of the selected 276 papers, we excluded 106 because they did not fit the criteria for inclusion. Some of the reasons for exclusion were the latitudinal region and grassland type where the study took place, or the aim of the study. Thus, this review was based on 170 studies.

We analysed the content of the included studies and created two databases. The first database was used to identify the taxonomic groups of arthropods usually selected to assess specific management practices, land uses, or processes (e.g., restoration success) and the indices more frequently measured. This database included general information to characterise the study (e.g., year of publication, geographical area, grassland type, taxonomic group, monitoring method, among others). We created a second database where we registered the specific response of the arthropods chosen as ecological indicators. In this database, we incorporated as many rows per paper as taxonomic groups used and as indices evaluated for each category of assessment. Given the diversity of grassland factors being evaluated in our sample of studies, we established categories (e.g., grazing, mowing, burning, land use, restoration strategies, etc.) allowing us to better synthesise the response of the different indicators. For each case study we reported information on the specific arthropod used, the index determined and the significance of the response (significant/not significant or not specified in the study), as well as the direction of the response, when it was conclusive. Databases can be accessed at the Mendeley data repository (Solascasas et al. 2022).

2.2. Data analysis

To address the status and trends of research in this field, we performed frequency analyses (using the first database) on year of publication, country of the study area, spatial scale, grassland type, type of indicator, monitoring method and indices or descriptors determined, and we represented graphically the proportion of studies using the Excel software and the Flourish studio program (https://flourish.studio/). After analysing research trends, we focused on synthesizing the response of the different arthropod taxonomic groups as ecological indicators of the impact of anthropogenic practices like grazing, mowing, burning, or the effects of grassland restoration (using the second database). For that purpose, we first analysed whether the selected groups showed a statistically significant response to the different factors being assessed and registered if the effect on the indices being evaluated was positive or negative. We also calculated how many times the main indices identified were used to assess the different categories of grassland management practices and uses, for every taxonomic group of arthropods.

A Canonical Correspondence Analysis (CCA) was performed to explore the effect of the different factors assessed in grassland ecosystems (used as explanatory variables) on the different arthropod groups which responded significantly to these factors and on the indices determined for each group (used as dependent variables). Explanatory variables included grassland management practices like grazing, mowing, or fire, but also abandonment, disturbance or the assessment of different land uses types. Using the second database, we codified (as dummy variables) those relationships between the factors being assessed and the indices measured, for those studies that reported significant evidence. Analyses were performed using XLSTAT software.

3. Results

3.1. Status and trends in the use of arthropods as ecological indicators of temperate grasslands

According to the systematic review, the first paper explicitly addressing the use of edaphic arthropods as ecological indicators of grassland ecosystems in temperate latitudes was published more than 30 years ago (Eyre et al., 1989). Since then, the temporal trend of studies dealing with this topic revealed a steadily increasing growth rate, showing that it is an emerging research field. Overall, our selected studies encompassed up to 30 countries, and the study areas of the selected papers were mainly located in the Palearctic realm (126 studies, 73 %), followed by the Nearctic realm (33 studies, 19 %), with only 7 % of the studies conducted in the Australasian and Neotropical regions of southern temperate latitudes (9 and 4 studies respectively; Fig. 1). In terms of countries, the United States of America hold the highest number of studies ($N = 30$), followed by the United Kingdom ($N = 20$) and Germany ($N = 14$).

Most publications were conducted at a local scale (154 studies, 91 %), with only 9 % of the studies, sixteen, being conducted at subnational or national scales. Regarding the different grassland categories established, temperate semi-natural grasslands were predominant (100 studies, 59 %), followed by North American prairies (30 studies, 18 %), Mediterranean grasslands (18 studies, 11 %), Eurasian steppes (15 studies, 9 %), South American grasslands (4 studies, 2 %) and subtropical grasslands (3 studies, 2 %).

More than two thirds of the studies (114 studies, 67 %) only used arthropods as ecological indicators, while the rest (56 studies, 33 %) considered arthropods in combination with organisms from other phylum (Annelida, Nematoda, Chordata, and Mollusca) and kingdoms (plants, microorganisms, etc.). Macro-arthropods were the target of 91 % of all the papers in our sample, while only 15 % included micro-arthropods (Acari and Collembola) as ecological indicators (12 studies considered both sizes). In general terms, the Coleoptera order was the most frequently used ecological indicator in our sample (83 studies, 49 %) followed by Araneae (49 studies, 29 %) and Hymenoptera: Formicidae (47 studies, 28 %) (Fig. 2). Although there was a clear prevalence of these three groups, when we looked at each individual grassland type, Orthoptera, despite being the least monitored group of macro-arthropods (37 studies, 22 %), were more used than Formicidae in temperate semi-natural grasslands. Within the microarthropod orders, Acari were monitored in more studies (21) than Collembola (17), specially in Eurassian steppes and North American prairies. Regarding the use of other arthropods as temperate grassland indicators, we found that Hemiptera were assessed in 20 % of the studies in our sample, followed by Lepidoptera (12 %), Diptera (11 %) and bees (6 %).

The monitoring method used varied greatly among papers, depending on the target of the study. Microarthropods, such as Acari and Collembola, were mostly captured through the collection of soil cores (18 studies, 72 %; Fig. 3A). Pitfall traps were the preferred monitoring method for Araneae (26 studies, 43 %; Fig. 3B), Formicidae (28 studies, 46 %; Fig. 3D) and Coleoptera (51 studies, 52 %; Fig. 3C). Pitfall traps were also used to sample Orthoptera, but after sweep nets (18 studies, 40 %; Fig. 3E). Sweep nets were also used to capture Araneae and Coleoptera in 20 % (12 studies) and 15 % (15 studies) of the papers, respectively.

3.2. Main indices measured to assess arthropods' response to grassland changes

We recorded 22 indices used to assess the response of edaphic arthropods in temperate grasslands. Richness (130 studies) and abundance (94 studies) were the two indices most frequently evaluated (Fig. 4). The next most frequently determined measure was Shannon's diversity, followed by community composition, i.e., the assemblage of the different species comprising the studied community, which was calculated mainly for ants and beetles. Furthermore, the Indicator Species Analysis (IndVal method) developed by Dufrêne & Legendre (1997) was also used in several studies (21 %), particularly those involving spiders and beetles. Functional diversity was only measured in a small proportion of papers, 21 studies (12 %), and it mainly involved body size (12 studies), feeding niches (10 studies), dispersal ability (7 studies), sociality/behaviour (5 studies), breeding type (5 studies), or habitat affiliation (4 studies). Regarding the two most recorded functional traits, body size was mainly used for Coleoptera and Orthoptera, whereas feeding niches were determined for a wider variety of orders including Coleoptera, Orthoptera, Formicidae, Araneae and Hemiptera.

We found that species abundance and richness were the predominant

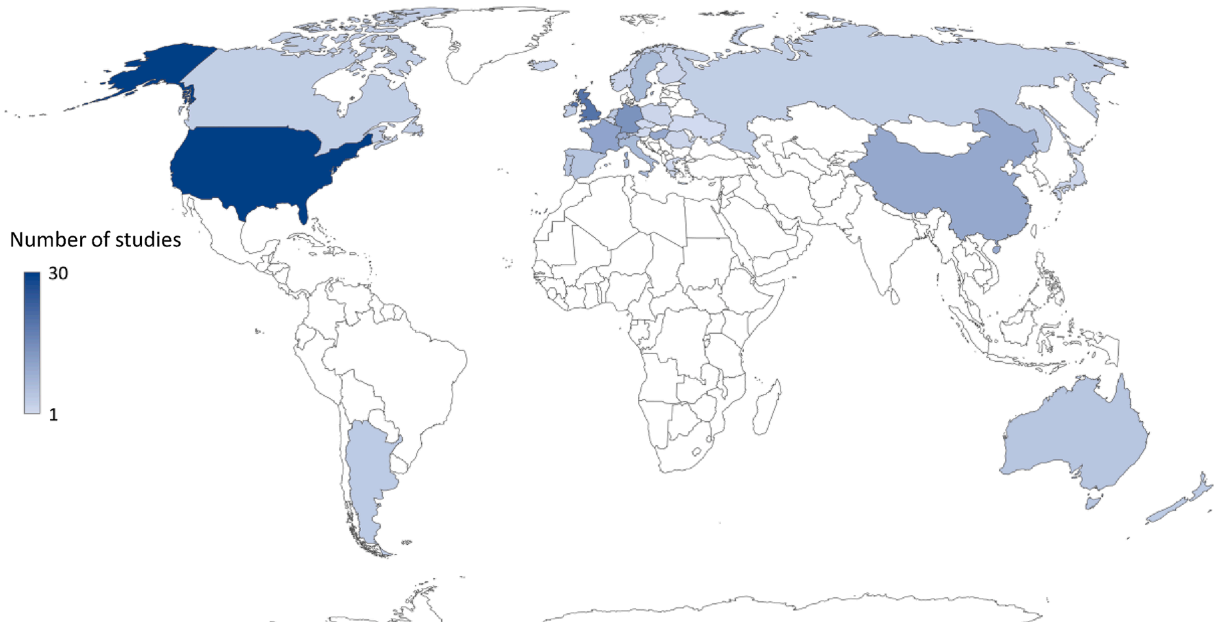

Fig. 1. Geographical distribution of the study areas of the published papers included in the review.

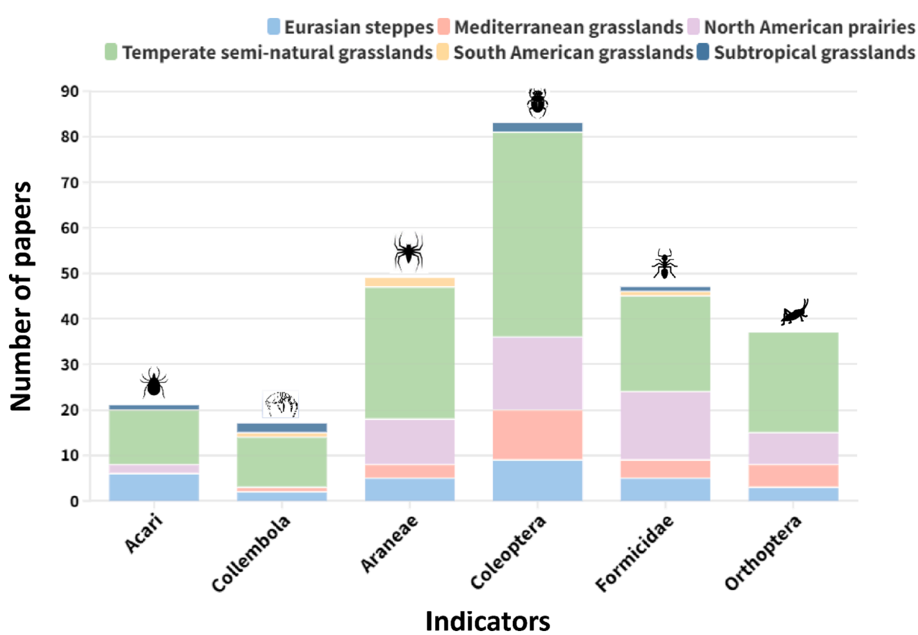

Fig. 2. Characterization of the literature sample according to the number of papers using different arthropods as monitoring indicators in relation to the six main categories of temperate grasslands.

indices when Acari and Collembola were used to assess temperate grassland ecosystems (Fig. 5A). From all the papers in our sample using these micro-arthropods as indicators (24 studies), 67 % of them used species richness and 63 % used species abundance to evaluate changes related with grazing, restoration strategies, the type of land use, or disturbances. Shannon's diversity was the third most important index to assess land use type, grazing and restoration strategies, and was determined in 42 % of the studies. Pielou's evenness, which was relevant in the assessment of land use type, was found in 17 % of the articles.

Within the macro-arthropod orders, here comprising Araneae, Coleoptera, Hymenoptera: Formicidae and Orthoptera, species richness and abundance were also predominant in most of the grassland factors identified: restoration strategies, grazing, land use type, mowing, other management, and disturbances (Fig. 5B).

From all the studies that used macro-arthropods as restoration indicators (36), 86 % of them used species richness and 61 % determined species abundance. Shannon's diversity was also a relevant index, measured in 42 % of the restoration studies.

Within the studies evaluating the effects of grazing (50), richness and abundance were employed in 80 % and 64 % respectively, followed by community composition (22 % of the studies), the third index most used for Formicidae, and Shannon's diversity (18 % of the studies), the third index most used for Coleoptera.

From the studies included in the category of land use assessment (27), species richness was the preferred index for the four groups of arthropods (spiders, beetles, ants, and grasshoppers), and it was used in 85 % of the articles. Species abundance (44 % of the studies) was mainly important for Coleoptera.

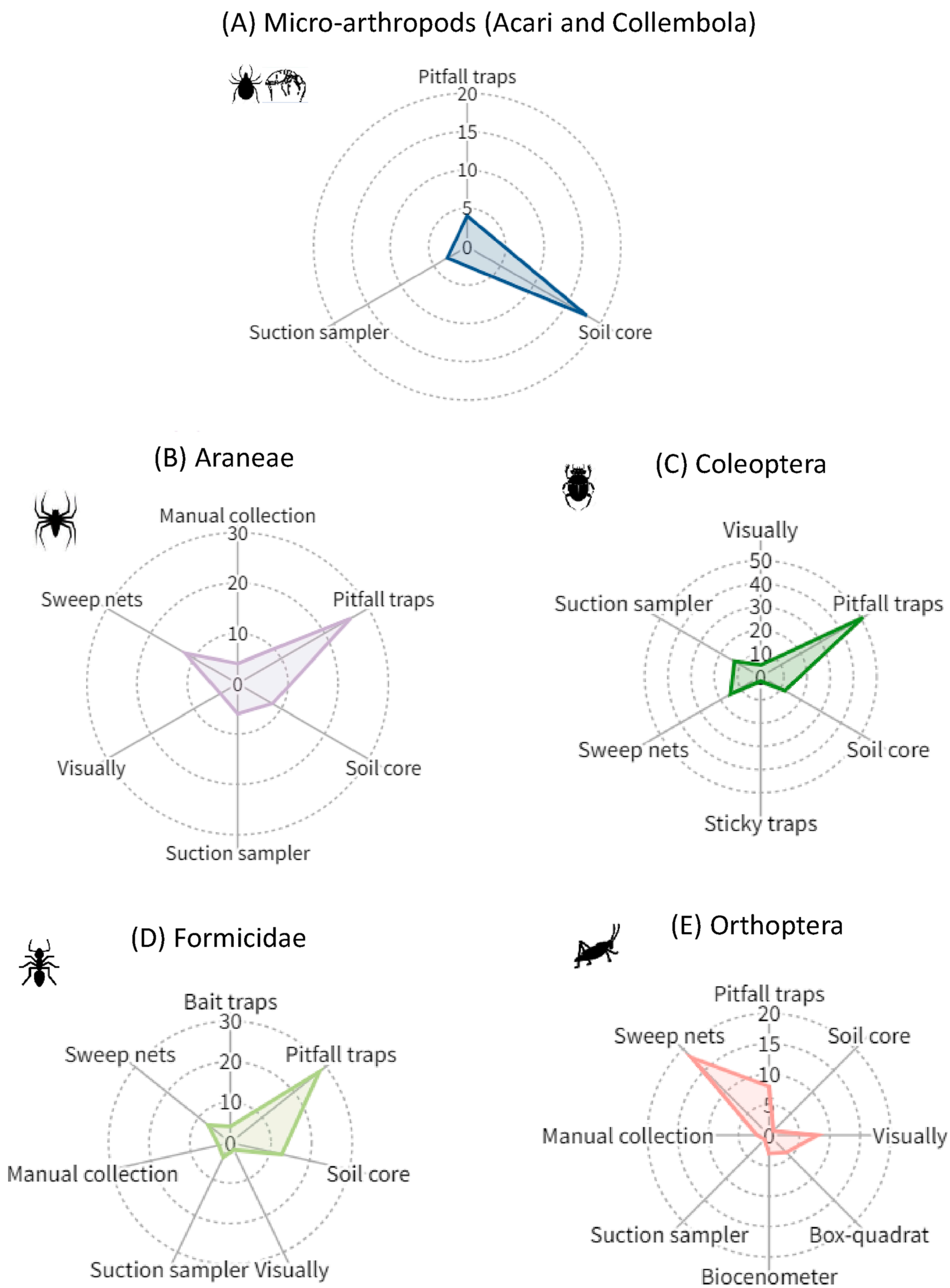

Fig. 3. Number of papers in the sample using the different collection methods to capture and monitor each of the main taxonomic groups of grassland arthropods. For visual clarity, collection methods have been omitted where they did not feature in any of the studies for that group.

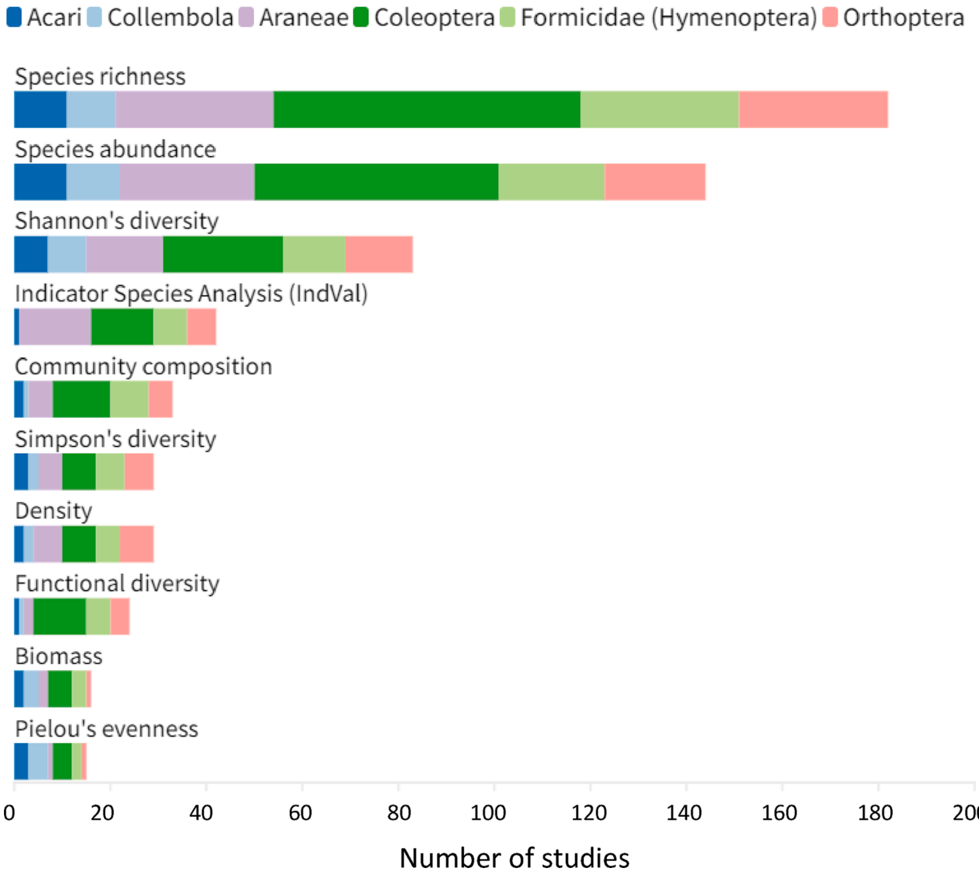

Fig. 4. Number of studies using each of the most frequently evaluated indices in the scientific literature reviewed (only those indices used in more than five papers are represented) for the main taxonomic groups of arthropods.

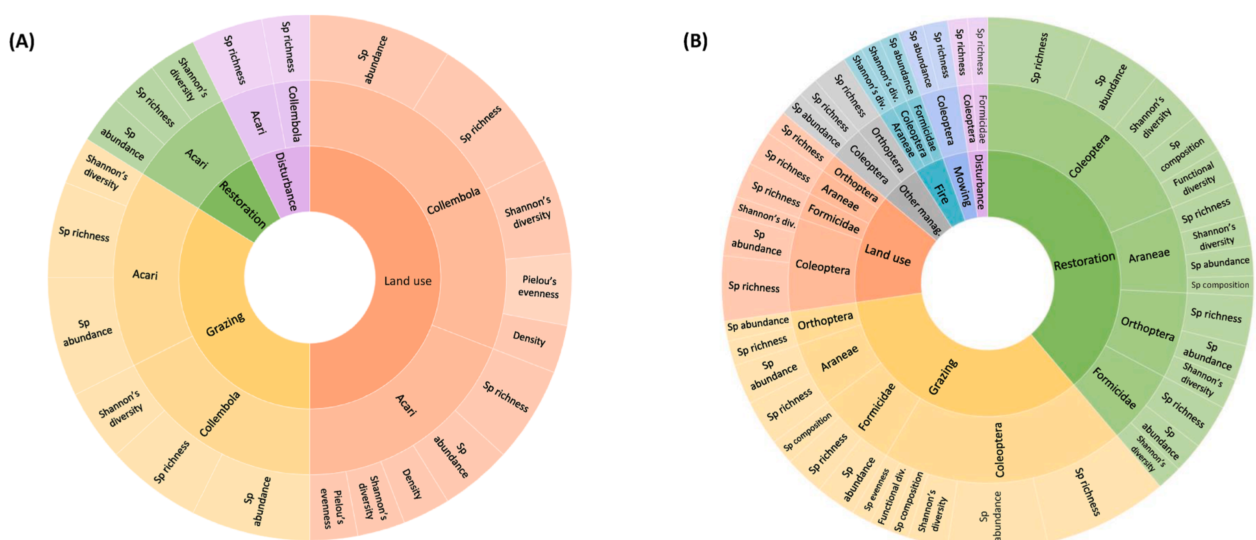

Fig. 5. Sunburst diagram showing which indices have been used to evaluate the different assessment categories for temperate grassland ecosystems, for (A) Acari and Collembola (only indices used in two or more studies are depicted) and (B) Hymenoptera (Formicidae), Coleoptera, Orthoptera, and Araneae (only indices used in more than three studies are depicted).

3.3. Response of arthropods as ecological indicators of grassland management practices and processes

The three grassland management practices, whose effects on macro-arthropods were more frequently assessed, were grazing, mowing and prescribed fire, which together accounted for 38 % of the registered responses (Fig. 6A). The effectiveness or the results of several grassland restoration strategies were evaluated using macro-arthropods as ecological indicators in 24 % of the responses (Fig. 6A). The influence of the type of land use accounted for 15 % of the registered responses, and the rest of management practices, which accounted for 13 % of the responses, were grouped under the category of "other management".

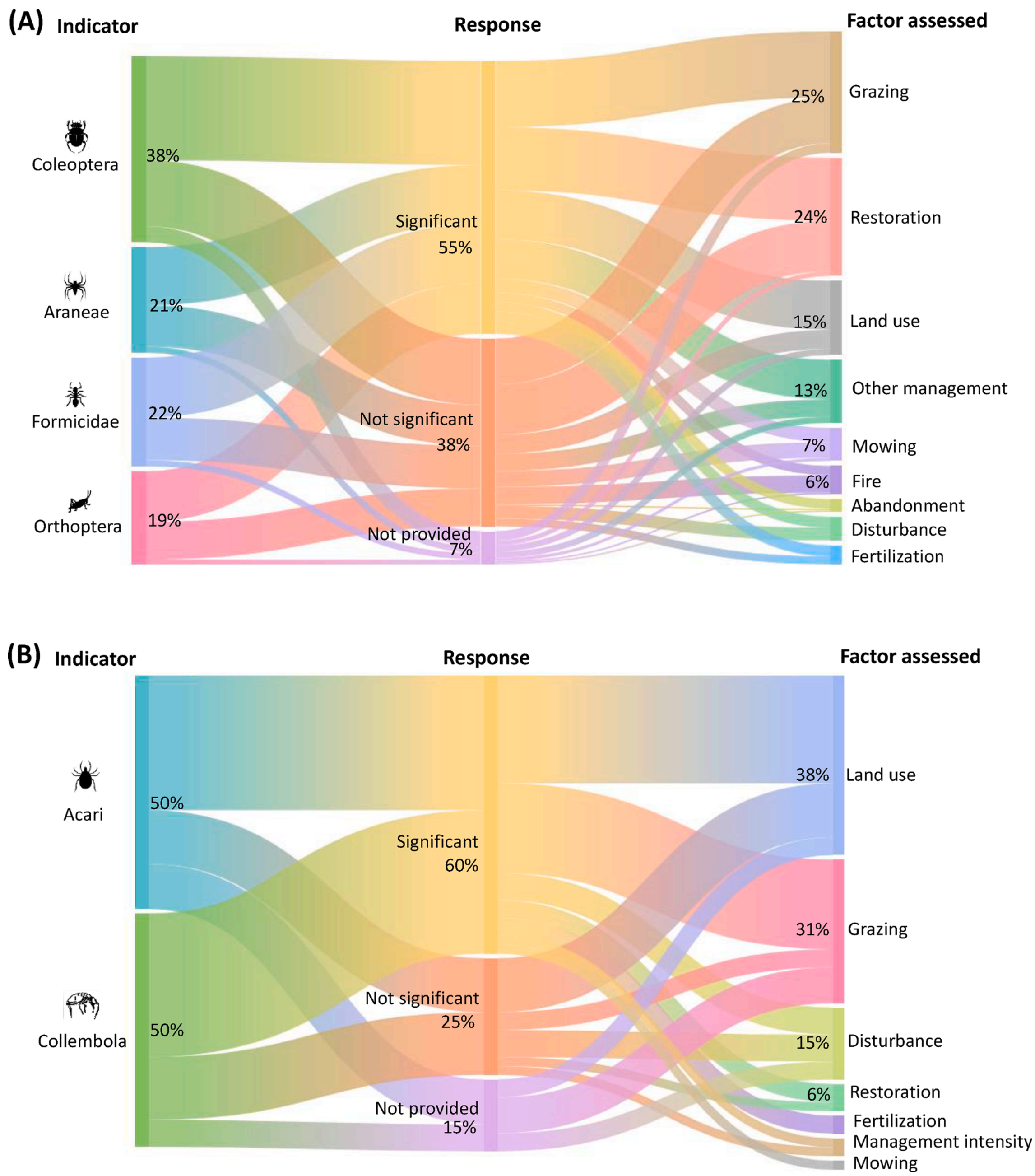

Fig. 6. Alluvial diagram depicting the links between the type of response of the different taxonomic groups of arthropods targeted in this review: (A) macro-arthropods and (B) micro-arthropods, and the categories of factors assessed in temperate grassland ecosystems.

For Araneae, Coleoptera and Formicidae, a higher number of the registered responses to grazing, restoration, and land use, were significant. However, Orthoptera responded non-significantly to grazing in a higher proportion. Regarding fire and mowing, spiders and ants registered the same proportion of significant and non-significant responses. Coleoptera and Orthoptera did not registered significant responses to fire assessment (this is coherent with the results obtained in the general Canonical Correspondence Analysis included in the Appendix C of Supplementary Materials).

Within micro-arthropod orders, the main grassland factors assessed were the different types of land uses (e.g., meadows, farmlands, or wood-pastures like *dehesas*) which accounted for 38 % of the registered responses, the effects of grazing on soil biodiversity, comprising 31 % of Acari and Collembola responses, and the third factor to which micro-arthropods responded the most (15 %) was the impact of different anthropogenic activities, like pollution or exotic species invasion, classified as “disturbance” (Fig. 6B). Both Acari and Collembola showed a higher number of significant responses to grazing and land use.

The CCA performed for each of the six main arthropod groups revealed additional information on the response of the evaluated indices to the different grassland factors. Spiders’ diversity and community composition showed significant responses to the evaluation of fire and restoration strategies, while species richness and abundance were sensitive to disturbance, mowing, grazing, and other management. Functional diversity, biomass and dominance were not associated to any of the identified factors (Fig. 7A). Coleoptera’s functional diversity and community composition were found to respond significantly to restoration strategies, while Shannon’s diversity responded to other management, and species abundance and Simpson’s diversity were associated with abandonment and mowing. Density and biomass did not

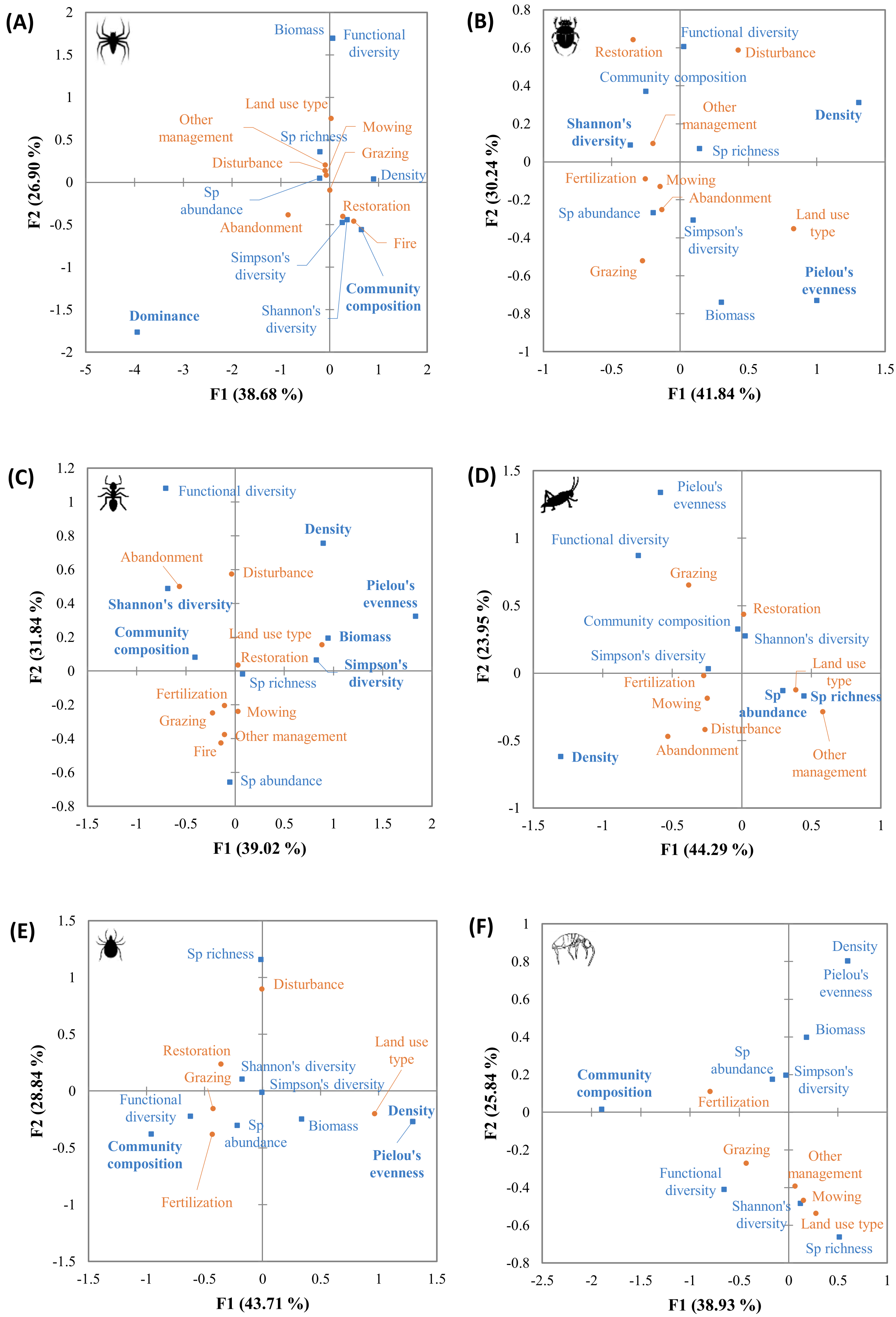

Fig. 7. Biplot of the first two CCA axes, performed for each arthropod group to uncover the relationship between the factors assessed and the significant response of the indices identified. Bold letters indicate the variables with square cosines higher than 0.35.

show a clear association to any of the factors evaluated (Fig. 7B). Formicidae's species richness responded significantly to the assessment of grassland restoration, whereas Simpson's diversity and biomass were more sensitive to land use type. Shannon's diversity showed significant responses to abandonment and functional diversity did not respond to any factor (Fig. 7C). Orthoptera's abundance and richness responded significantly to the evaluation of land use type and other management, while Shannon's diversity and community composition were more sensitive to restoration, and Simpson's diversity to fertilization and mowing. Grasshopper's functional diversity was associated with grazing (Fig. 7D).

In the case of Acari and Collembola, both micro-arthropod abundance and functional diversity were found to respond significantly to the assessment of grazing and fertilization. Regarding richness, Acari responded significantly to disturbance assessment and Collembola to land use type. Shannon's diversity was more sensitive to mowing and land use type for Collembola and to grazing and restoration for Acari (Fig. 7E, 7F).

4. Discussion

Our literature review shows that the use of edaphic arthropods as indicators of the ecological condition of temperate grasslands is an emergent topic in the research community. This is consistent with the steadily raising interest in grassland ecosystems, which are essential to delivering a wide array of ecosystem services (Bengtsson et al., 2019; O'Mara, 2012), but at the same time are considerably degraded (Gibbs and Salmon, 2015). Our review documented that, while being used to assess the effects of grazing, mowing, or restoration strategies, some taxonomic groups like Coleoptera are receiving remarkably more attention than others for all the different types of temperate grasslands identified. Furthermore, the indices used, such as species richness or abundance, do not provide as much information on the status of the communities as would be desirable.

4.1. Research gaps and biases in the use of edaphic arthropods as grassland indicators

Semi-natural grasslands and North American prairies comprise the two types of grasslands most frequently researched. Our results show that, geographically, there is a considerable dominance in the number of studies from the wealthiest northern countries, like the USA or the United Kingdom, with an important gap existing in central and eastern European countries. This contrasts with the fact that many natural and semi-natural grasslands are included as priority habitats in the EU Habitats Directive, and with studies highlighting the importance of temperate semi-natural grasslands of Europe as extremely species rich habitats, especially at small scales (Aune et al., 2018; Habel et al., 2013; WallisDeVries et al., 2002). There is also a notable lack of studies from the Eurasian steppe, which comprises one of the largest biomes on earth and represents a big share of temperate grasslands at the global scale (Wesche et al., 2016). Studies on southern temperate regions, mainly Argentina, Australia, and New Zealand, remain limited too, although the extension covered by grasslands in that latitude is remarkably lower (Dixon et al., 2014).

Furthermore, this review pinpoints that temperate grasslands monitoring research is biased toward bigger macro-arthropods, while studies using micro-arthropods (Acari and Collembola) remain scarce. This may be related to the difficulties involving taxonomic classification (Parisi et al., 2005), or it could also be explained by the fact that there is greater knowledge about macro-arthropods, which have been more frequently researched, and there could be a tendency to select them over micro-arthropods, which are underrepresented in literature (Menta and Remelli, 2020). Another reason could deal with the different responses of both groups to ecosystem changes. Micro-arthropods like Collembola and some Acari suborders, like Oribatida, may respond rapidly to abrupt environmental changes or disturbances (Chauvat et al., 2007; González-Macé and Scheu, 2018), while macro-arthropod communities can provide long term information about the consequences of changes (Campbell and Crist, 2017; Fadda et al., 2008).

Interestingly, we found that within the community of macro-arthropods used as ecological indicators, beetles were the preferred group, followed by spiders and ants. Considering that the Coleoptera order comprises 40 % of the known global insect diversity (Hammond, 1992) – their prevalence is not surprising. However, few studies monitored orthopteran communities to evaluate changes or the ecological condition of temperate grasslands, and they were underrepresented in our sample. This finding is striking since grasshoppers play important functions within grassland ecosystems, and are especially relevant as plant biomass consumers (Branson et al., 2006; Laws et al., 2018) and as a food source for other species (Belovsky and Slade, 1993). Grasshoppers also constitute a big share of the biomass of grassland arthropods and meet the criteria for being reliable indicators: they are sensitive to changes, appear in high abundances, and are relatively easy to sample and identify (Andersen et al., 2001; Báldi and Kisbenedek, 1997). Therefore, the use of Orthoptera as grassland indicators should be promoted, especially when studying practices that directly affect vegetation.

Many of the studies included in our review reflect the effects of grazing, which is one of the most used grassland management practices. This is coherent since, along with mowing, grazing is one of the most important factors shaping the structure of grassland vegetation, which is highly dependent on these practices (Hardy et al., 2020) and directly linked to arthropod communities. The use of micro- and macro-arthropods to assess the performance or success of restoration strategies was also a recurrent topic in our review, and this is consistent with the need to reverse the global grassland degradation scenario (Bardgett et al., 2021).

Furthermore, our results also showed some preferences in the use of species richness and species abundance as measures to determine the condition of grassland arthropods. Interestingly, these indices were also found to be the most frequently used in the review by Noriega et al. (2018) about the research trends in the ecosystem services provided by insects. Species richness, understood as the number of species inhabiting a given area, is one of the simplest measures of species diversity, and along with species abundance, provides useful information about the state of different communities. Another diversity measure frequently used was Shannon's index, and several case studies also included information on community composition. However, there is a significant gap in the use of functional diversity indices of arthropod communities, despite studies suggesting that species richness and abundance measures are clearly insufficient to explain how ecosystems function, and that trait-based information should also be included (Gagic et al., 2015).

4.2. Key indicator groups to evaluate grassland management practices, land uses and restoration strategies

For years, ground beetles (Coleoptera: Carabidae) have been used as indicators to monitor grassland changes caused by management practices like grazing or fertilization (Eyre et al., 1989; Rainio and Niemelä, 2003). Several studies agree on the characteristics that make carabids useful indicators. Ground beetles are ubiquitous and easy to sample, sensitive to habitat changes (Cole et al., 2006), diverse ecologically and morphologically (Lövei and Sunderland, 1996), and they have a role in the food chain as pest predators or food resource for other species (Cole et al., 2006; Menta and Remelli, 2020). This family is also known to be closely associated with open habitats (Menta and Remelli, 2020), and together with the extensive knowledge about beetles, it is not surprising that many studies in our sample used the Carabidae family over other families of beetles.

In addition to Coleoptera, spiders and ants were also frequently sampled as ecological indicators of temperate grasslands. These three groups are very dependent on edaphic and plant resources, which are directly impacted by management strategies (Andersen et al., 2004; Kwok et al., 2011). Both spiders and ants are well-studied groups, and have traits that make them valuable indicators on top of being highly diverse and playing key roles within the ecosystem function (Carvalho et al., 2020; Michalko et al., 2019; Wills and Landis, 2018).

On the one hand, spiders are the most abundant and diverse arthropods predators of grassland ecosystems (Horváth et al., 2009; Malumbres-Olarte et al., 2013b; Rushton and Eyre, 1992). Spider communities are affected by several factors like prey availability, vegetation structure, dispersal ability, and their response to management is going to be dependent upon these factors (Bell et al., 2001; Jansen et al., 2013; Prieto-Benítez and Méndez, 2011). Besides their functional significance as predators, spiders are also important prey for other species; they are easy to sample and their community composition shifts when environmental conditions change (Churchill, 1997). In addition, spiders' rapid reproductive cycles and high mobility make them useful to identify early changes (Buchholz, 2010; Smith DiCarlo and DeBano, 2019). According to our results, spiders diversity (Shannon's and Simpson's) and community composition tended to respond significantly to the evaluation of grassland restoration strategies and fire (Malumbres-Olarte et al., 2013a), while species abundance and richness responded significantly to the assessment of grazing intensity (Horváth et al., 2009), but also mowing and disturbance, which makes them compatible with the assessment of multiple management practices. They have also been used as indicators of land use changes (Perner and Malt, 2003),

On the other hand, ants also have several characteristics that make them reliable indicators: they are one of the most dominant groups, both in terms of biomass and abundance of individuals (Agosti et al., 2000), they are easy to sample, and they occupy high trophic levels (Whitford et al., 1999). Ants play a key role in the ecosystem and affect grasslands biodiversity through their activity as consumers and seed dispersers (Helms et al., 2020; Wills and Landis, 2018). In addition, ants are one of the most relevant groups of soil ecosystem engineers, affecting soil physical properties (Lavelle et al., 2006), and they are ubiquitous and rely on a high variety of resources (Bagyaraj et al., 2016). The diversity of ant functional groups can be useful to assess the different ecosystem processes taking place (Gerlach et al., 2013), and they are relevant generalist predators of other terrestrial arthropods (Tiede et al., 2017). Ants have been widely used as grassland bioindicators of grazing (Okrutniak and Grześ, 2019), mowing (Dekoninck et al., 2007), burning (Underwood and Christian, 2009), restoration strategies (Wodika et al., 2014) and disturbances like mining (Andersen et al., 2004). Our results revealed that after Coleoptera, ants were the second most used indicator in number of studies to assess grazing, land use or disturbance, although they were not that commonly used for monitoring restoration plans or fire. Analyses showed that ants' species richness and community composition tended to respond significantly to restoration processes, while Shannon's diversity was closely associated to the assessment of abandonment, and Simpson's diversity and biomass, to the type of land use.

Some of the management practices used in these ecosystems, like mowing, grazing, or the use of prescribed fire, have been identified as the most important direct drivers of biodiversity change in grasslands (Blair et al., 2014; Fay, 2003; Keith et al., 2020). Our review documents the existence of a wide variety of responses depending on the taxonomic group employed and the indices chosen to evaluate the effects. Mowing can negatively affect arthropods with reduced mobility or no flying capacity, while the effects of grazing are quite dependent on the intensity (Mazalová et al., 2015). Our results showed that a very small percentage of the studies analysed the effects of mowing on arthropods with reduced or no potential ability to fly (e.g., Coleoptera, Araneae and Formicidae) and these effects were both significant and non-significant in a similar proportion. Regarding the impacts of grazing, we found that for some groups of arthropods the response was significant in a higher number of cases, but those with some flying ability like orthopterans did not follow this pattern. Mobility, which is linked to functional traits like body size (Beckers et al., 2020), may be a key factor when assessing the effect of environmental changes on grassland biodiversity.

Moreover, collecting information about mesofauna communities can be a useful reference when trying to restore or recover semi-natural grasslands (Gulvik et al., 2008). According to our review, macroarthropods were preferred over micro-arthropods to evaluate restoration strategies, probably due to taxonomical difficulties related to identification of the latter, although the proportion of significant vs no significant responses was very similar for all the orders. The diversity and community composition of spiders and grasshoppers showed significant responses to restoration assessment, as did mites' diversity and ants' species richness. Considering the diversity of responses, using several indicators or descriptors from different groups seems a sensible strategy when approaching the assessment of a restoration process.

4.3. Future challenges in grassland conservation status monitoring and research

Despite the increasing research addressing the use of arthropods as ecological indicators of temperate grasslands in the last decades, our review highlighted the need to overcome some challenges, based on the biases and gaps we found: (i) to increase the number of studies in certain temperate regions, (ii) to identify, within the groups of arthropods that have been overlooked due to taxonomical or methodological difficulties, those that may be useful to assess ecological change and, (iii) to select indices and properties that include community composition or functional diversity indices, as opposed to information only on species diversity and abundance.

First, considering the vast extension covered by the grassland biome in temperate regions, additional research is needed to fill current geographical gaps, particularly with respect to grasslands of central and eastern Europe, which are important biodiversity hotspots (Feurdean et al., 2018; Nita et al., 2019), and Eurasian steppes, which besides playing an important role in global carbon sequestration, are suffering critical degradation from the combined effects of climate change and human activities (Zhang et al., 2021).

Second, given the fact that there are some taxonomic groups, especially those of bigger size, receiving more attention than others, it is important to further analyse the response of other less commonly investigated arthropods to grassland changes. For example, Homoptera have already been used as soil quality indicators (Gardi et al., 2002; Ruiz et al., 2011) or to assess the impacts of land use or grazing on the invertebrate community (Gibson et al., 1992). Moreover, Dermaptera species were assessed during the evaluation of the effects of a restoration strategy (Liu et al., 2014), but the response of these orders was not the main target of the study.

Third, indices to quantify not only diversity or abundance, but how species functioning affects ecosystems are essential. The determination of functional diversity can be used to study ecological processes as well as the response of different organisms to the disturbance of these processes (Cadotte et al., 2011). Considering the important role of terrestrial arthropods in several ecosystem processes and services, a trait-based approach can improve the understanding of changes (Wong et al., 2019) affecting ecosystems like temperate grasslands.

Finally, we found that it is difficult to determine the type of response that different grassland management practices will cause in each arthropod group. Whether the effects are positive or negative will depend on many factors, including the taxonomic resolution being looked at (family or species level), the properties or indices chosen to be measured, or the initial ecological status of the communities. The prevalence in the use of species richness and abundance over other indices or traits should be tackled by including properties that allow a better understanding of the community ecological functioning.

5. Conclusions

This study provides novel evidence about the useful role of ground-dwelling arthropod communities as ecological indicators that help to understand the changes temperate grasslands face. Our results highlight that the bigger arthropod groups, such as Coleoptera, and especially the Carabidae family, are receiving remarkably more attention than others as indicators of temperate grasslands worldwide. Spider communities, along with ants and grasshoppers, responded significantly to a variety of grassland management practices like prescribed fire, grazing, mowing or fertilization, although the response was dependent on the index determined. Micro-arthropods like mites and springtails were especially sensitive to the assessment of land use types. Also, this review highlighted the need to overcome some challenges, based on the biases and gaps found: (i) to increase the number of studies in some temperate regions, (ii) to explore the potential of overlooked groups of arthropods, and (iii) to select indices or descriptors that include information on functional diversity.

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.

Data availability

Data will be made available on request.

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Appendix. Supplementary data

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