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Review article

Effects of uncut refuge management on grassland arthropods – A systematic review

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ABSTRACT

European semi-natural grasslands are often managed by mowing. These habitats have species-rich fauna, but mowing threatens arthropods' abundance and diversity. Leaving some part of the vegetation uncut can play a crucial role in their survival during and after mowing. The effectiveness of such uncut refuges for the conservation of arthropods has been studied, but the results are contradicting and partial. We conducted a systematic review of 22 articles encompassing 66 observations to synthesise existing knowledge. Overall, 69 % of abundance observation data and 64 % of species richness observation data showed positive responses to uncut refuges. In comparison, the remaining observations showed negative (25 % for abundance, 26 % for species richness) and neutral (6 % for abundance, 10 % for species richness) effects. We found several potential drivers behind these patterns, including refuge shape – most commonly strips or blocks – and refuge proportion, typically 10–25 % of the area. Results varied across study designs, which often involved sampling arthropods within and outside the refuges, before or after mowing, with or without independent control meadows. Additionally, research primarily focused on orthopterans with no negative responses to refuges, whereas other taxa received less attention. Although further research is needed on the assumed moderators (e.g. grassland habitat type, landscape structure) and understudied grassland taxa, based on the existing knowledge, we recommend leaving refuges where arthropod conservation is concerned.

1. Introduction

Species-rich semi-natural grasslands still exist in Europe but have declined dramatically in recent decades due to the pressure of intensification, abandonment, and land use changes (Keenleyside et al., 2010; Ustaoglu and Collier, 2018; Fartmann, 2024). Related to this, traditionally managed hay meadows also disappear at alarming rates (Nilsson et al., 2013) with a high number of plant and arthropod species associated with grassland habitats (Uchida and Ushimaru, 2014; Deák et al., 2021). In meadows, mowing operations are imperative to avoid vegetation succession and maintain the habitat open in the long term (Grime, 1973; Milberg et al., 2017;

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Bochniak et al., 2024).

The effects of mowing on arthropods have been studied by conservationists for a long time (Morris and Lakhani, 1979) and are found to threaten their diversity and abundance (Chisté et al., 2016, Chisté et al., 2018). Hence, there is a conflict between the need for regular mowing for plant conservation and habitat maintenance and the need for uncut vegetation for arthropod communities (Cattin et al., 2003; Schmidt et al., 2008). The management regime can often substantially affect them more than other local environmental parameters and surrounding land structures (Frenzel and Fischer, 2022). Higher cutting frequency directly leads to decreasing arthropod species richness due to the higher disturbance rate (Everwand et al., 2014; Fumy et al., 2023). Besides direct mortality (Humbert et al., 2010), mowing removes food resources and vegetation structures for habitation and oviposition sites or hiding places from predators (Kennedy and Otter, 2015). Thus, the recently mown matrix is generally unsuitable for many arthropod species, which may even go locally extinct when large areas are mown simultaneously (Braschler et al., 2009). In this context, leaving refuges has been recommended as a measure of mitigation (e.g. Piqueray et al., 2019; Berger et al., 2024).

Leaving some sort of undisturbed refuges as microhabitats for arthropods in different ecosystems as a conservation management is spreading. For example, in agroecosystems, several agri-environmental programs support the seeding of wildflower and grass strips (Tschumi et al., 2016; Toivonen et al., 2018) or so-called 'beetle banks' (MacLeod et al., 2004) to favour predatory arthropods and enhance biocontrol (Judt et al., 2023). These perennial fallow areas provide an overwintering site and a 'source' habitat for arthropods (Lemke and Poehling, 2002). Similarly, but within grassland fields, arthropods may utilise any form of intact vegetation as a refuge, such as isolated small fragments (Dittrich and Helden, 2012; Zschokke et al., 2000), rotational fallows (Schmidt et al., 2008) and uncut strips on hay meadows (Révész et al., 2024). These provide a spatio-temporal mosaic of mown and unmown areas that may combine ecological benefits to both plants and arthropods (Schmidt et al., 2008; Cizek et al., 2012).

Management regimes that create more heterogeneous environmental conditions than fully mown fields can support diverse arthropod communities (García, Fraser, 2019). Providing cut and uncut microhabitats leads to more diverse arthropod assemblages (Gathmann et al., 1994; Pech et al., 2015). Besides the obvious benefits of the left vegetation, such as food, shelter and oviposition site, uncut refuges also offer buffered microclimatic conditions (Gardiner, 2009; Révész et al., 2024). The litter layer, left in the uncut refuge, can also be an essential habitat element for overwintering insect larvae with low-temperature fluctuations. Uncut areas favour species that prefer abandoned or extensively managed grasslands (e.g., some declining butterfly species, such as *Erebia medusa* and *Euphydryas aurinia)* (Stuhldreher and Fartmann, 2014; Scherer and Fartmann, 2024). Rotational cutting with several years of rotations in irregularly shaped mosaics may maximise the benefits to invertebrates and associated wildlife (Cattin et al., 2003; Sanderson et al., 2020). As further benefits, heterogeneous grasslands usually benefit higher trophic levels, such as birds and reptiles (Stevens et al., 2010, Zahn et al., 2010).

Agri-environment schemes (AES) were launched in 1992 to respond to the increasing concern over biodiversity loss in agricultural landscapes (Batáry et al., 2015). These schemes compensate farmers financially for any loss of income associated with measures aimed at benefiting biodiversity. By 2002, about 25 % of all agricultural land in the EU was under AES agreements (Primdahl et al., 2010). Conservation management needs evaluation to estimate their efficiency for further consolidation and improvement (Primdahl et al., 2010; Batáry et al., 2015). It can favour some taxa but threaten some others. Further, it can be effective in some countries, regions, and circumstances but useless or harmful in others. For example, the provision of tall vegetation throughout the breeding season for corncrakes in Scotland also benefitted the abundance of butterflies, bumblebees and the majority of foliar arthropod groups (Wilkinson et al., 2012). Swiss hay meadows under AES regulations that were cut at least once a year, but not before 15th June, favoured plants, grasshoppers and wild bees but was insufficient for spiders (Knop et al., 2006). The cuts in the spring and autumn required by AES (Landscape Protected Area, IUCN category V) in Czech reserves were interfering with the larval development of the butterflies *Colias myrmidone* (Konvicka et al., 2008) and *Phengaris arion* (Spitzer et al., 2009). AESs also recommend leaving uncut areas on hay meadows, not specifying the exact amount and the arrangement (European Commission, Directorate-General for Environment, 2019), which vary usually around 10 % of the grassland area, depending on the applying countries (Hungarian Government Decree, 2007; Buri et al., 2013). As such grassland AESs are spreading and getting more popular, improving their management practices might have an extensive effect on farmland biodiversity.

Since extensively managed grasslands still represent the most diverse farmland habitats, the main goal of this study was to provide a systematic overview of the different options when leaving uncut refuge to preserve species-rich arthropod communities of hay meadows. There is substantial variance among study outputs; thus, a synthesis of the effect of uncut refuges is needed. We raised the following questions: Are all sampling designs able to test adequately the ecological effectiveness of refuges? Does the shape of the refuge matter for arthropods? What proportion (% of the meadow) left uncut can maintain these communities well? Are responses consistent across arthropod taxa?

2. Materials and methods

2.1. Literature search

We conducted a systematic review of scientific articles examining the effects of leaving uncut refuges when mowing on the abundance or diversity of arthropods. We searched in the Web of Science (WoS) scientific database (Science Citation Index Expanded) for studies published until 11th January 2024. We included further data from the authors' own studies not identified by the systematic search to cover the topic thoroughly without causing a potential publication bias. Search terms were built following the PICO (Population, Intervention, Comparator, Outcome) approach to find all potentially appropriate articles (Higgins and Green, 2008). We chose grassland arthropods as population, uncut areas as intervention, left vegetation as comparator and abundance and biodiversity as outcome. We used the following search terms: beetle* , carabid* , orthoptera* , "leaf hopper* ", leafhopper* , grasshopper* , arthropod* , insect* , invertebrate* , spider* , bee, bees, bumblebee* , and butterfl* as population terms, combined with unmow* , mow* , uncut, cut, refuge as intervention terms and with biodiversity, diversity, "species number", "species richness", abundance, density as outcome terms. We used the * as a truncation symbol to allow other endings of the search terms. Quotation marks indicate that a search term consisting of multiple words should be treated as a single expression. Our search was applied to title, abstract and keywords with no limitation regarding the year of publication. We included only the relevant fields of science (WoS categories: Ecology, Entomology, Biodiversity Conservation, Environmental Sciences, Forestry, Agriculture Multidisciplinary, Zoology, Multidisciplinary Sciences, or Soil Science). We excluded document types that would not contain the needed information (Meeting Abstract, Note, Editorial Material or Review Article), i.e. we included only research articles with potential primary data. This resulted in a total of 2465 potential articles.

We screened the title and abstract of articles and then scanned the full text of each potentially relevant article to decide whether it matched our selection criteria (for the selection process, see the PRISMA diagram in Fig. A.1). The inclusion of a study in our systematic review was based on the following criteria: (i) arthropod taxa, (ii) grassland habitat (no crop refuges), (iii) some amount of vegetation left uncut minimum until autumn (not just delayed cut). We found 17 studies through this systematic search and added five more (Révész et al., 2024 via author Kitti Révész, Řezáč and Heneberg, 2018 and Müller and Bosshard, 2010 via Révész et al., 2024, Kühne et al., 2022 via the review of Humbert et al., 2018, Gallé et al., 2024, thanks to author Gallé Róbert), resulting in 22 articles at the end.

2.2. Analyses

Due to the relatively low number of studies, we were unable to conduct a formal meta-analysis on the topic. Therefore, we qualitatively summarised our findings and highlighted important knowledge gaps. To enhance the quality of our comparison, we extracted data from articles to calculate the relative changes as a semi-conductive solution.

We computed the relative changes for each response variable in areas of uncut refuges relative to cut controls as:

$$\text{Relative change (\%)} = [(\text{uncut} - \text{cut}) / \text{cut}] \times 100$$

to provide common units following the method of Litt et al. (2014)

Calculated relative change results under absolute 5 % were considered neutral responses. We summarised the data in Table 1 and considered one row of the table as one 'observation'. We averaged all useful data in studies where the authors performed multiple temporal samplings of arthropod populations after mowing. We used sampling data before mowing only where the researchers used it as a control vs. refuge in a one-year experiment (Schmidt et al., 2008) or where they used it to show the cumulative effect in multi-year experiments (e.g. van Klink et al., 2019).

3. Results

We summarised the results presented in 22 scientific articles with 66 observations that studied the effect of leaving uncut refuges on grassland arthropods (Table 1). All experiments were established in Europe and distributed across only six countries, leaving a knowledge gap for other geographical regions. Uncut refuges were most studied in Switzerland (11), followed by the Czech Republic (4), Germany (3), Hungary (2), Belgium (1), and United Kingdom (1). The articles used four different study designs: 1) sampled the refuge treatment (mixed in and out of refuge) and fully mown control meadow, 2) sampled in the refuge and within–field control, 3) sampled in the rotational fallow and within–field control, 4) sampled only in the refuge (before and after mowing) (Fig. 1). Size of the refuge varied from 2 to 2000 m^2 of uncut areas with cases where the attributes of the left vegetation were unknown, this means the proportion of the uncut area varied from 3 % to 50 % of the total experiment area respectively, with most articles (55 %) ranging between 10 % and 25 %. The shapes of refuges also varied from strips, blocks to circles. The summarised articles focused on several arthropod taxa: orthopterans (12), spiders (9), beetles (7), butterflies (6), bees (4), and other less-represented taxa.

From the 22 articles, we extracted 66 observations on arthropod taxa, containing data on abundance, species richness or both. 65 observations contained data about abundance or density of arthropods: 69 % found increases in the case of uncut refuges, whereas only 25 % found decreases, and 6 % remained neutral to the management changes. There was less data available for species richness (42 observations), with a similar ratio of responses as for abundance: 64 % of taxa increased with the application of uncut refuge treatment, whereas 26 % decreased and 10 % did not show change.

Study types were not represented equally. Type 1 covered 23 observations plus 19 observations, which measured the cumulative effect next year (referred as '1/c' in Table 1), altogether 42. Type 2 was used in 22 observations, whereas Type 3 and 4 occurred only in one study each. The three most significant effects that refuge strip management showed were a 2080 % and a 1335 % increase in grasshopper abundance and an 831 % increase in true-bug abundance, all measured in Type 2 studies.

Each study applied only one shape of refuge in their investigations. The five shape categories were distributed in the following way: seven studies used strips, one used strips and blocks mixed (because of special requests of farmers, Handke et al., 2011), four used blocks (with a maximum 1:5 ratio of width:length), two used circles, and eight did not defined the shapes of refuges, only focused on the proportion. The proportion of uncut areas compared to the total meadow area was 3–10 % in 4 observations, 10–25 % in 43 observations, 33–50 % in 13 observations, and undefined in 6 observations. In the case of the lowest category (proportion 3–10 %), there were not enough observations to make any conclusion. The middle category (proportion 10–25 %) contained 70 % increases, 23 % decreases in abundance, and 63 % increases, 27 % decreases in species richness of arthropods (the left considered neutral), in line

Table 1
Direction and magnitude of effects of uncut refuges on the abundance/density and species richness of arthropods. Study type refers to the spatially and temporally different sampling methods detailed in the footnotes, refuge shape refers to the geometrical form of the refuge, and refuge proportion (%) refers to the percentage left uncut compared to the entire meadow/experimental plot.

Reference	Country	Study type	Refuge shape	Refuge proportion (%)	Taxa	Abundance/ Density	Richness
Bruppacher et al., (2016)	Switzerland	1	not defined	10–20	butterflies	+ 6 %	+ 29 %
		1/c	not defined	10–20	butterflies	+ 148 %	n.a.
Buri et al., (2013)	Switzerland	1	not defined	10–20	orthopterans	+ 81 %	+ 29 %
		1/c	not defined	10–20	orthopterans	+ 95 %	n.a.
Buri et al., (2014)	Switzerland	1	not defined	10–20	wild bees	+ 11 %	+ 13 %
					honey bee	−16 %	n.a.
Buri et al., (2016)	Switzerland	1	not defined	10–20	true hoppers	−3 %	+ 15 %
		1/c	not defined	10–20	true hoppers	−18 %	
		1	not defined	10–20	spiders	−11 %	+ 11 %
		1/c	not defined	10–20	spiders	+ 5 %	
Gallé et al., (2024)	Hungary	1	strips (3 ×100 m)	10	grasshoppers	+ 12 %	+ 35 %
					true bugs	+ 721 %	+ 96 %
					vegetation-dwelling spiders	+ 191 %	+ 158 %
					ground-dwelling spiders	−37 %	−43 %
					ground beetles	+ 16 %	−33 %
Handke et al., (2011)	Germany	1	strips + blocks (5 ×100 or 20 ×25 m)	n.a.	butterflies	+ 148 %	−1 %
					orthopterans	+ 17 %	+ 34 %
					true weevils	+ 256 %	+ 109 %
					leaf beetles	−4 %	+ 34 %
					true bugs	+ 193 %	+ 89 %
					dragonflies	+ 321 %	+ 97 %
Humbert et al., (2012)	Switzerland	1	circle (16 m diameter)	10	orthopterans	+ 60 %	n.a.
Kaláb et al., (2020)	Czech Republic	1	circle (12 m diameter)	10	orthopterans	+ 1 %	+ 5 %
van Klink et al., (2019)	Switzerland	1/c	not defined	10–20	butterfly larvae	+ 200 %	+ 38 %
					sawfly larvae	+ 106 %	n.a.
					pteromalid wasps	+ 79 %	−6 %
					meadow moths	+ 10 %	+ 10 %
					meadow hoverflies	+ 117 %	+ 67 %
					parasitoid wasps	+ 21 %	+ 3 %
					ground-nesting bees	−23 %	−3 %
					rove beetles	+ 9 %	+ 9 %
					ground beetles	+ 100 %	+ 33 %
					wood-nesting bees	−44 %	−36 %
					detrivorous hoverflies	−32 %	−51 %
					tree-feeding moths	−45 %	−11 %
Kühne et al., (2022)	Switzerland	1	not defined	10–20	moths	−53 %	−14.4 %
		1/c	not defined	10–20	moths	−8 %	n.a.
Meyer et al., (2017)	Switzerland	1	not defined	10–20	wild bees	+ 63 %	+ 7 %
		1/c	not defined	10–20	wild bees	+ 23 %	n.a.
		1	not defined	10–20	hoverflies	+ 150 %	+ 106 %
		1/c	not defined	10–20	hoverflies	+ 173 %	n.a.
Řezáč and Heneberg, (2018)	Czech Republic	1	strips	3–10	spiders	+ 195 %	+ 32 %
Article	Country	Study type	Refuge shape	Refuge proportion (%)	Taxa	Abundance/ Density	Richness
Buri et al., (2013)	Switzerland	2	not defined	10–20	orthopterans	+ 424 %	n.a.
Gardiner and Hassall, (2009)	UK	2	blocks (20 ×20 m)	50	orthopterans	+ 400 %	n.a.
Humbert et al., (2012)	Switzerland	2	circle (16 m diameter)	10	orthopterans	+ 1335 %	n.a.
Kühne et al., (2015)	Switzerland	2	not defined	10–20	butterflies	+ 333 %	n.a.
Müller and Bosshard, (2010)	Switzerland	2	strips (5 ×20 m)	5–10	orthopterans	+ 767 %	n.a.
Nentwig, (1988)	Germany	2	strips (1 ×6 m)	36	spiders	−11 %	+ 63 %
					ants	+ 27 %	n.a.
					beetles	+ 23 %	n.a.
					centipedes	−20 %	n.a.

(continued on next page)

Table 1 (*continued*)

Reference	Country	Study type	Refuge shape	Refuge proportion (%)	Taxa	Abundance/ Density	Richness
					aphids	+ 113 %	n.a.
					thrips	+ 27 %	n.a.
					orthopterans	+ 23 %	n.a.
					collembola	+ 21 %	n.a.
Pech et al., (2015)	Czech Republic	2	blocks (2 ×2 m)	46	ants	n.a.	−42 %
					spiders	−33 %	−12 %
Révész et al., (2024)	Hungary	2	strips (3 ×100 and 9 ×100 m)	10 or 25	orthopterans	+ 64 %	+ 116 %
					true bugs	+ 831 %	+ 247 %
					vegetation-dwelling spiders	+ 273 %	+ 116 %
					ground-dwelling spiders	−7 %	−8 %
					ground beetles	+ 66 %	+ 37 %
Schwarz et al., (2023)	Germany	2	blocks (10 ×50 m)	4.5	orthopterans	+ 2080 %	n.a.
Šumpich, Konvička, (2012)	Czech Republic	2	blocks	50	moths	−11 %	−15 %
Schmidt et al., (2008)	Switzerland	3	strips (10 ×(35–50)m)	33	spiders	−9 %	+ 12 %
Lebeau et al., (2015)	Belgium	4	strips (3–5 m wide)	5–10	butterflies	+ 89 %	n.a.

Study type: 1) sampled the refuge treatment (mixed in and out of refuge) and fully mown control meadow; 1/c) cumulative effect in type 1: sampled the refuge treatment in the following year, before mowing and fully mown control meadow; 2) sampled in the refuge and within–meadow control; 3) sampled in the rotational fallow and within–meadow control; and 4) sampled only in the refuge (before and after mowing).
n.a.: there was no data available.

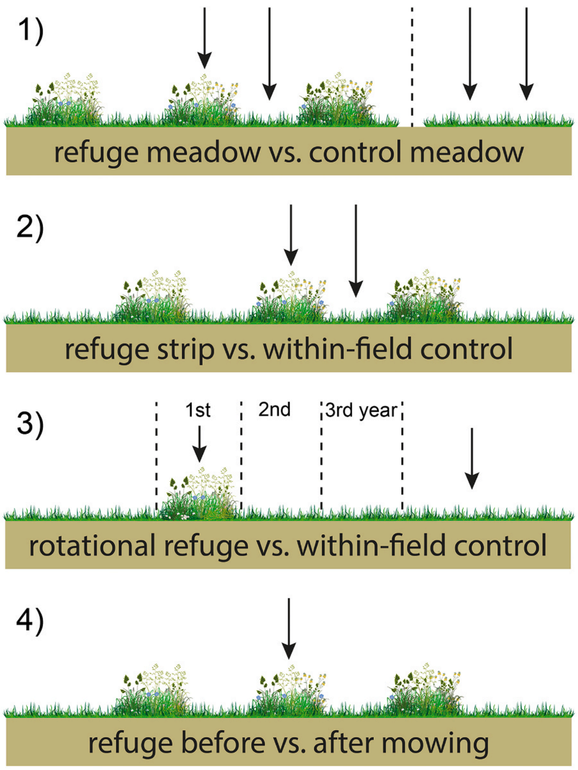

Fig. 1. The four different study designs used in the reviewed studies: 1) samples from the refuge treatment/meadow (mixed in and out of refuge) were compared to samples taken in fully mown control meadow, 2) samples taken in the refuge were compared to samples taken in the mown areas of the same meadow, which served as control, 3) samples taken in the rotational refuge changing its location every year were compared to samples taken in the continuously mown areas of the same meadow, 4) samples were taken in the refuge before mowing and compared to samples from the same refuge after mowing, as a temporal variation of type 2. Arrows show the location of the sampling at each study type.

with our main results of total observations. The highest category (proportion 33–50 %) was more balanced than the middle one regarding the results, but no sufficient observations were available to extract a pattern.

Orthopterans were the most studied taxa and benefitted the most from uncut refuges with no negative responses (just a few records under absolute 5 %, considered neutral). Spiders were well represented, but there were more negative results of their abundance than positive ones. Beetles were mainly supported by uncut refuges with only one negative species richness data (out of six observations). Butterflies were less studied than orthopterans but similarly without negative responses. Bees had some mixed responses in the six observations made on them. We found true bugs, with only three observations, and true hoppers, with only one observation, strongly understudied.

4. Discussion

Altogether, we identified 22 articles comprising 66 observations relevant to the focus of our review. Most records indicated that uncut refuges successfully achieved their objectives, with increased arthropod abundance and/or species richness observed in the refuges compared to the cut control. However, approximately one-quarter of the responses showed declines in both abundance and species richness in uncut refuges. Various factors likely act as potential drivers behind these patterns.

4.1. Comparison of study types

The main attributes of study designs might determine the study's outcomes and what the results can be used for (Fig. 1). Type 1 studies performed a complete sampling, i.e. sampled the refuge treatment (both in and out of refuge) and fully mown control meadow (s), which is thought to be the most appropriate method for measuring the effectiveness of the refuge treatment. When sampling was repeated in the following year of the treatment, before the next mowing, the positive cumulative effect of leaving a refuge over the years was evidenced for orthopterans (Buri et al., 2013), hoverflies (Meyer et al., 2017) and butterflies (Bruppacher et al., 2016). Type 2 studies sampled both within the refuge and in the control mown areas of the same meadow(s), primarily reflecting the local effects of the refuges. Obviously, this design can show very strong effects. It has the highest extremes in its results, with an increase of up to 2080 % in grasshopper abundance, possibly owing to a local concentration effect (Schwarz et al., 2023). Accordingly, when we compare Type 1 and Type 2 in one study, with the same circumstances (as in Humbert et al., 2012), we can see that the results of Type 1, i.e. the overall effectiveness of refuge strips on grasshopper abundance (+60 %) are more moderated compared to the results of Type 2 (+1335 %). We found only one study that used Type 3 sampling design and one that used Type 4, limiting our ability to draw firm conclusions. Type 3 showed a negative abundance response and positive species richness response, while Type 4 had only abundance data, which showed a strongly positive response to refuge strips. Among the four study types, Type 1 is the only design capable of rigorously evaluating the ecological effectiveness of uncut refuges for arthropod conservation. In contrast, results from other study types may merely reflect short-term concentration effects, as previously noted.

4.2. Comparison of refuge shapes

There are endless ways in what shape we can leave uncut refuges on a meadow. Among the reviewed studies, seven used strips, one used mixed strips and blocks, four used blocks, two used circles, and eight did not define the shapes of refuges, only focusing on the proportion. Leaving uncut refuges in any shape has the potential to promote grassland arthropods, but using geometric forms that enhance the ratio of edges makes it more accessible for arthropods searching for refuge on the field (Nentwig, 1988). Thus, we recommend to leave uncut refuges in elongated, strip-like shapes. Révész et al. (2024) showed that the width of refuges can affect the abundance and species richness of arthropods. When a lower proportion (10 %) of refuge is left on the meadow, wide (9 m) strips favour arthropods; when a higher proportion (25 %) is left uncut, narrow (3 m) strips can harbour more of them (Révész et al., 2024).

4.3. Comparison of refuge proportions

The proportion of uncut areas highly varied among the studies and was distributed unequally. In the case of the lowest category with 3–10 % proportion, there was not enough number of observations (only four) to reach any conclusion. The middle category with 10–25 % proportion– (43 observations) contained 70 % increases, and 23 % decreases in abundance and 63 % increases, 27 % decreases in species richness of arthropods (the left considered neutral), in line with our main results of total observations. The highest category, with 33–50 % proportion (13 observations), was more balanced than the middle one regarding the results, but no sufficient data were available to extract a pattern. The proportion that a farmer needs to leave uncut under AES can vary depending on the specific regulations of the country and the scheme they are participating in. However, the requirements usually are around 10 %, e.g. 3–10 % in the Czech Republic (Řezáč and Heneberg, 2018), 5–10 % in Hungary (Hungarian Government Decree, 2007) and Belgium (Lebeau et al., 2015), min. 10 % in Switzerland (Buri et al., 2013). The farmers also need to consider financial aspects, like how much hay they would lose, and practical aspects linked to the meadow shape, like where and how to leave uncut refuges. In a Hungarian case study, the proportion of uncut refuges had an interacting effect with the width of the refuge strips on some arthropods. The orthopterans' and spiders' abundance and the carabids' species richness were higher in wide strips in case of 10 % and in narrow strips in case of 25 % of uncut area (Révész et al., 2024), showing that the proportion might matter. Herbivores are sensitive to the amount of vegetation (Schowalter, 2022), thus also the proportion of left vegetation in a meadow. Predators are also affected by vegetation removal (Woodcock et al., 2009), because they need sward architecture for hunting and follow herbivores' patterns as a second trophic level (Tscharntke et al., 2005). Not specifying the proportion or only providing a broad interval in the studies addresses another knowledge gap regarding the role the proportion plays in the effect and effectiveness of uncut refuges.

4.4. Comparison of studied taxa

Arthropods responded dominantly positively to uncut refuges. Orthopterans and butterflies had no negative responses (just a few records under absolute 5 %, considered neutral), suggesting that uncut refuge treatments firmly enhance their abundance and species richness. The positive response might be stronger for herbivore taxa than predators, as they rely on the left vegetation not just for habitation but also for food resources (van Klink et al., 2019). Beetles were also mainly supported by uncut refuges with only one negative species richness data (out of six observations). Most beetles on hay meadows prefer uncut conditions, with a few exceptions, which are disturbance-tolerant species or other specialist species (Cizek et al., 2012). There were more negative results of spiders' abundance than positive, implying uncut refuges do not support but potentially decrease their numbers on hay meadows. Nentwig (1988) explains this phenomenon by addressing the sampling method of pitfall traps showing activity density rather than relative abundance. As prey gets denser in the refuges, they become more easily accessible to predators, resulting in less activity for them. In trait-based analyses uncut refuges had opposing effects on ground-dwelling and vegetation-dwelling spiders in both Type 1 (Gallé et al., 2024) and Type 2 (Révész et al., 2024) studies with vegetation-dwelling ones benefitting from refuge strips. The same pattern was found by van Klink et al., 2019 and Torma et al., (2023) on spiders and other groups of arthropods too. Responses of bees were also mixed in Buri et al. (2014) and Meyer et al. (2017), based on their traits. Domesticated honeybees did not profit from the uncut refuges, probably because they did not depend on the structures or the food resources they offered to build their colonies. On the other hand, wild bees reacted rapidly and sensitively to the introduction of refuges, just like other pollinators, because they may profit from the continuous provision of nectar and pollen in the uncut refuge at a time when flower resources are scarce in the landscape (Ammann et al., 2024). However, wild bee responses varied, and further investigation is necessary to better understand the reasons behind them. We found true bugs, with only three observations, and true hoppers, with only one observation (in Buri et al., 2016), are also strongly understudied. Both taxa are very abundant in extensively managed grasslands and are important sucking herbivores. Given their sensitivity to changes in grassland management (Torma et al., 2019), studying the responses of true bugs and true hoppers to vegetation removal is essential for advancing research on uncut refuges. More research on soil arthropods would provide interesting data about the indirect effects of establishing uncut refuges (e.g. changing abiotic conditions). Although this review did not include plants, it is important to state that leaving uncut refuges does not threaten the diversity of plants (van Klink et al., 2017) as long as the location where the refuge is left changes regularly (Rossier et al., 2023).

4.5. Further research directions for closing the knowledge gap

Based on the existing literature, we suggest that leaving uncut refuges on hay meadows can support arthropod populations during and after mowing and also in the long term, i.e. with populations progressively increasing over the years (van Klink et al., 2019). Generally, there is a meagre amount of data, which is especially incomplete among geographical regions and grassland arthropod taxa. Research is needed on whether global-, regional- and landscape-scale factors (climatic conditions, regional management intensity or species pool, landscape structure, grassland habitat type) modify the effect of uncut refuges and how.

The significance of local factors like proportion, shape, and location (whether on the edge or in the centre) of uncut refuges has not yet been investigated either. The microclimatic conditions of refuge strips need to be clarified to understand the abiotic drivers behind the biodiversity patterns of some taxa (e.g. orthopterans). Gardiner and Hassall (2009) found the cut area hotter and the shady grass strips cooler. On the contrary, Révész et al. (2024) found that the tall grass of the uncut strips functioned as windbreakers and kept the moist and hot air in the strips.

Furthermore, the timing of mowing and the following steps of hay harvest after mowing can be potential drivers of the ecological effectiveness of uncut refuges, too (Humbert et al., 2010b, 2012b). A later autumn cut can perform better results during summer, but might be detrimental for arthropods' overwintering (Schmidt et al., 2008). It matters what happens to the refuges after summer: are they later cut during autumn or left for next year, allowing arthropods to overwinter in it? If they are kept, it opens the opportunity to investigate multi-year studies' cumulative effects. Additionally, hay removal and other management practices can determine the effects of mowing modifications on arthropods (Noordijk et al., 2010, Hartlieb et al., 2024).

Specifying how to implement uncut refuges in hay meadows is critical because its effect can depend on many factors (e.g. location, proportion, shape, or the target taxa). In addition, practitioners need to consider other practical and financial factors besides conservation concerns, such as the cost-benefit of management actions, the practicality of the creation of refuges, and the potential loss of quantity and quality of hay. Finally, the research results should be considered in the establishment and development of agri-environmental schemes to be applied in the field (Báldi et al., 2023).

5. Conclusion

More and more research provides evidence about the beneficial effects of uncut refuges on the abundance and species richness of grassland arthropods, uncovering for which taxa and in what circumstances it can be suitable for conservation goals. This simple management modification can be the key to maintaining the high-value biodiversity of extensive grassland habitats and can be easily implemented in the current AES. It is shown to be well accepted by practitioners in Switzerland and Hungary. For appropriate management practices, we need a greater magnitude of research in this field, studying its local, immediate effects ass well as its field-level, cumulative effectiveness, supplemented with the core factors that might drive these effects.

Ethics Statement

Not applicable: This manuscript does not include human or animal research.

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.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.gecco.2024.e03381.

Data availability

Data will be made available on request.

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