

RESEARCH ARTICLE

Supportive effect of uncut refuge strips on grassland arthropods may depends on the amount and width of strips

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Abstract

1. Vast grassland areas disappear due to abandonment, conversion to arable fields or urban areas. Consequently, grassland species have declined dramatically during and since the last century. The majority of remaining European grasslands are managed, many of them by mowing, which, in general, decreases arthropods' abundance and species richness.
2. Here, we aimed to study the effects of width and proportion of refuge areas on local abundance and richness of arthropods in hay meadows. Within a ca. 4000 ha semi-natural grassland area of the Great Hungarian Plain, we established refuge strips of different widths (3 and 9 m) and proportion of total field area (10 and 25%) following a randomised block design with six replicates per treatment. We studied five arthropod groups (grasshoppers, true bugs, carabids and ground-dwelling and vegetation-dwelling spiders), which we sampled 2 weeks after mowing by sweep netting and pitfall traps.
3. Uncut strips were warmer and moister than the mown areas. The effects of refuge strips and their arrangement were stronger on the vegetation-dwelling than on ground-dwelling arthropods, although all taxa were affected in some way. We found more true bugs in mown areas between narrow strips than between wide strips. The interaction effect of width and proportion of refuge strips on the abundance of grasshoppers, ground-dwelling spiders and species richness of carabids showed that wider strips are more beneficial if their proportion is low and narrow strips are more beneficial with high proportion.
4. *Synthesis and applications*: Our findings provide evidence that uncut refuge strips can harbour diverse and abundant arthropod assemblages in hay meadows and mitigate the adverse effects of uniformly executed mowing on arthropods. Modifying attributes and considering farming practices, wide strips with a low (10%) proportion of total field area seem optimal for both conservation and practitioners.

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araneae, carabid, conservation practice, hay meadow, heteroptera, management, mowing, orthoptera

1 | INTRODUCTION

Vast areas of European grasslands disappear as a result of abandonment and conversion to agricultural fields or urban areas (Sutcliffe et al., 2015). Many semi-natural grasslands (e.g. semi-natural hay meadows) are now classified as vulnerable in Europe's red list of habitat types (Norderhaug & Johansen, 2011). The loss of species-rich grasslands results in a great loss of biodiversity (Littlewood et al., 2012). A high number of species associated with grassland habitats have also declined in the last century (Deák et al., 2021; Uchida & Ushimaru, 2014). Still, grasslands are diverse and important habitats for both native flora and fauna.

The majority of remaining European grasslands are managed. High mowing, grazing and fertilisation intensity negatively affect the diversity of the whole biota, especially arthropods (Chisté et al., 2016). Vegetation-dwelling arthropods are usually more severely affected than ground-dwelling ones (Hamřík & Košulič, 2021). Reducing the management intensity might help conserve invertebrate species richness and balance ecosystem functions (Diehl et al., 2013; Hudewenz et al., 2012). Therefore, low management intensity could help prevent future declines and extinctions (Löffler et al., 2020).

Mowing is among the most important and widespread management practices of grasslands. Mowing generally decreases arthropods' abundance and species richness (Lafage & Pétilon, 2014; Wagner et al., 2021). It reduces the microhabitat diversity of the grassland, which homogenises the available microclimatic conditions, and consequently, the distribution of arthropod taxa changes (Kormann et al., 2015). Besides its direct mortality effects (Humbert et al., 2010), it might change ecosystem functioning and dynamics, for example greater exposure of arthropods to vertebrate predators (Kennedy & Otter, 2015) or cause spillover of invertebrates (Rand et al., 2006). This latter process is well known between agricultural land and natural habitats (Madeira et al., 2016), but also recognised and documented between different natural habitats like forests and grasslands (Tölgyesi et al., 2018). Arthropods respond to mowing primarily by emigrating from mown habitat, which can result in the aggregation of arthropods in less disturbed habitats (Thorbeck & Bilde, 2004). This concentration or 'crowding' effect was documented for arthropod predators (Debinski & Holt, 2000).

Different meadow mowing techniques impact the fauna differently (Humbert et al., 2010). The most nature-friendly mowing is rotational and follows a mosaic design, which leads to different land areas being successively cut (Bubová et al., 2015). It creates spatial and temporal heterogeneity rather than uniformly cutting large grassland areas during a short period (Bonari et al., 2017). Leaving uncut areas preserves the habitat structure and might promote grassland arthropods' abundance and species richness (Kühne et al., 2015). For

instance, uncut refuges can harbour 10 times more grasshoppers than mown areas (Müller & Bosshard, 2010) and maintain the functional diversity of communities (Kaláb et al., 2020). Uncut refuges are successfully used to reach conservation goals in different grassland habitats (Gardiner, 2012; Mazalová et al., 2015) and for various arthropod groups (e.g. pollinators: Münsch et al., 2019; predators: Snyder, 2019).

Many agri-environment schemes (AES) aim to support the appropriate management for maintaining species-rich habitats (Báldi et al., 2013; Batáry et al., 2015). Their effectiveness was questioned in many ways, as different factors may influence how efficiently they can support biodiversity (Kleijn et al., 2011; Marja et al., 2019). Measures and evaluations can have a positive role in the development of AES (Carey, 2001). The outcome of the policy is the actual effect of policy-regulated farming practices on the environment (e.g. biodiversity) (Primdahl et al., 2003). These programmes suggest different management alternatives for the conservation of grasslands. For instance, they recommend leaving uncut areas, not specifying the exact amount and the arrangement (European Commission, Directorate-General for Environment, 2019), which is applied as 5%–10% (Müller & Bosshard, 2010) or 10%–20% (Buri et al., 2013) of uncut area on the meadow, depending on applying countries. The exact size, shape and arrangement of the uncut area vary highly between management interventions and their relative effects remain unknown.

To fill this knowledge gap in the case of species-rich semi-natural grasslands, we selected four arthropod groups to study the effect of mowing and the arrangement of uncut strips: grasshoppers, true bugs, ground beetles and spiders. All selected groups are species-rich and abundant in grasslands and have different roles in the ecosystem (Torma et al., 2023). Grasshoppers and true bugs are important herbivores in nearly all grassland ecosystems, and their diversity sensitively indicates the changes in the vegetation (Torma et al., 2019; Weiss et al., 2013). Spiders and ground beetles are among the prominent arthropod predators and are often used as bioindicators of environmental change because they are sensitive to microclimate, habitat structure and biological environment (Gallé et al., 2010; Mazalová et al., 2015). Since these groups have different functional roles, they may respond differently to various management practices. Therefore, our multitaxon analysis is capable of detecting various effects of management (Báldi et al., 2013).

Only a few studies assessed the arthropod diversity of refuge strips by comparing them to neighbouring mown strips (Cizek et al., 2012; Müller & Bosshard, 2010; Nentwig, 1988). Furthermore, we are not aware of any study comparing the effectiveness of refuge strip treatments with different mowing designs. Therefore, we aimed to test the effect of the width and proportion of refuge strips on local abundance and richness of arthropods.

We compared the effectiveness of narrow versus wide uncut refuge strips and also the low (10%) versus high (25%) proportion of refuge strips in conserving arthropod diversity. We conducted our study on vast, protected semi-natural grasslands in Southern Hungary. Our expectation was that (1) refuge strips harbour higher abundance and species richness of arthropods than mown areas (2) narrow uncut strips have higher abundance than wide uncut strips due to the concentration effect resulting from spillover from adjacent mown strips (Gallé et al., 2018; Tschardt et al., 2012); (3) uncut strips have a higher abundance when the proportion of uncut strips is higher, as it saves more individuals by the greater amount of untouched vegetation, and (4) the above effects are stronger on vegetation dwellers than on ground-dwellers, as the prior rely on vegetation more.

2 | MATERIALS AND METHODS

2.1 | Study region and design

We established uncut refuge strips in the Csanádi-pusztá (N46°22'11": E20°39'36") meadow complex in the Körös-Maros National Park (see Figure S1 in Supporting Information), managed within the Hungarian AES (Ángyán et al., 1999). We received permission for our fieldwork from Békés County Government Office, as the regional nature conservation authority, with permission number of BE/38/03931-8/2021. The area lies in the Southern part of the Hungarian Great Plain. Our study sites were located on two extensive grasslands, Kopáncs-pusztá and Montág-pusztá. The region is at 80–108 m a.s.l. and has a temperate continental climate, characterised by warm and dry summers with at least 1 month of drought and cold winters. The mean annual temperature is 10.3–10.5°C, and the mean yearly precipitation is 350–550 mm (Dövényi, 2010). Extensive grazing or mowing once a year is applied on these low-productivity grasslands; in the present study, we focused on hay meadows. The two main habitats in our study areas are Artemisian

salt steppe (characterised by short grasses, with *Artemisia santonicum* and *Festuca pseudovina*) and salt meadow (characterised by tall grasses, with *Alopecurus pratensis* as the most dominant species; Molnár et al., 2016).

We used a randomised block design. We left uncut strips with 3- and 9-m widths and 100-m lengths. The uncut strips covered 10% (low) or 25% (high) of the area. As a result, we had four types of refuge strip designs (1) narrow strips, high cover; (2) narrow strips, low cover; (3) wide strips, high cover; and (4) wide strips, low cover. We took samples from the uncut strips and the neighbouring mown strips, at 5 m distance from the uncut strips (Figure 1). We changed the locations of the uncut refuge strips in the two consecutive years of sampling, 2020 (see Appendix S1) and 2021 (see Appendix S2) and avoided successional effects.

2.2 | Arthropod sampling

We sampled vegetation-dwelling spiders, true bugs and grasshoppers by sweep netting with standard-sized nets of a 40 cm diameter. Sweep netting sampling was based on 25 sweeps along a 25 m long transect, 16–18 days after mowing. This post-mowing rest period was intended to allow the communities to recover. Sampling was done during 17–18 August 2020, and 26 July and 7 August 2021. The first year, 2020, was extremely dry in the study area. Thus, mowing was delayed from mid-July to the beginning of August. We collected 3 samples per transect $\times$ 2 management types (mown and uncut) $\times$ 2 widths of refuge strips (narrow: 3 m and wide: 9 m) $\times$ 2 proportions of refuge strips (10% and 25% of uncut) $\times$ 6 replicates = 144 samples. We placed the collected material in 70:30 alcohol/water solution in plastic bags.

We sampled carabids and ground-dwelling spiders with pitfall traps made from plastic cups with a diameter of 9.5 cm. We added a funnel to avoid vertebrate bycatches and increase trapping efficiency. We covered the traps with a brown plastic roof to prevent the dilution of the preservation fluid by rain. We filled traps with

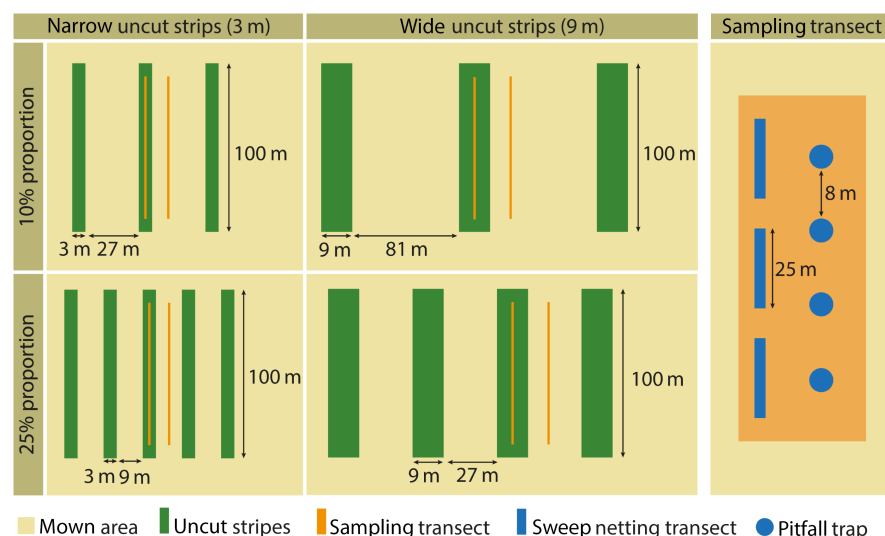


FIGURE 1 Four types of different arrangements combined of narrow/wide strips and 10%/25% proportion of refuge strips with sampling design within a sampling transect.

50:50 water/ethylene-glycol solution and added a few drops of detergent (Császár et al., 2018). We applied 4 traps per transect $\times$ 2 management types (mown and uncut) $\times$ 2 widths of refuge strips (narrow: 3 m and wide: 9 m) $\times$ 2 proportions of refuge strips (10% and 25% of uncut) $\times$ 6 replicates = 192 traps. Pitfall traps were exposed 16–18 days after mowing, for 10 days. Following the sweep net sampling, they were exposed on 17–27 August 2020 and 16–26 July (Kopáncsi puszta) and 27 July–6 August 2021 (Montág puszta).

We sorted the pitfall trap and sweep net samples for the focal taxonomic groups and identified all specimens to the species level. Voucher spider and grasshopper specimens were placed in the collection of the Centre for Ecological Research, whereas true bugs and carabid voucher specimens were placed in the collection of the University of Szeged. Juvenile individuals and larvae that could not be identified to species were identified to the lowest possible taxonomic level. Our study did not require ethical approval.

2.3 | Microclimate

We assessed microclimate conditions in the refuge strips and neighbouring mown areas, 2 m from the edge of the refuge strip. We measured the air temperature using data loggers (Optin ADL TH3-32) by installing one logger in the centre of each strip. We exposed data loggers on 16–26 July (Kopáncsi puszta) and 27 July–6 August 2021 (Montág puszta), in two rounds, parallel with pitfall traps. We recorded data every 20 min during exposure. We placed the equipment under a plastic roof to avoid direct sun radiation. We measured soil volumetric moisture content in the upper 20 cm at 10 random points in each site with a Field Scout TDR 350 soil moisture meter (resolution: 0.1 V/V% of water) on 26–28 July, 6–7 August and 6–7 September 2021. We averaged moisture data per sampling site.

2.4 | Data analyses

We used the R statistical software for all computations (R Core Team, 2021). We analysed the effect of the management, the proportion and the width of the refuge strips on species richness and abundance of study taxa (grasshoppers, true bugs, vegetation-dwelling spiders, carabids and ground-dwelling spiders separately) with generalised linear mixed-effects models (GLMMs; lme4, Bates et al., 2014). Both pitfall trap data and sweep net data were pooled per transect. We used Poisson error term for the species richness of arthropod groups. We detected overdispersion for abundance data; therefore, we ran models with negative binomial error term. We used (1) proportion of refuge strips ('10%' and '25%' of the given meadow), (2) width of the refuge strips ('narrow' and 'wide'), (3) management ('refuge' and 'mown') and (4) and their interactions as fixed effects as well as 'grassland' (Kopáncsi or Montág) and 'year' (2020 or 2021). Grassland and year were not included as focal variables in this study, we used them as covariates. We added the block and the width and proportion treatment combination, nested

in block as random factors to account for the spatial and temporal non-independence of samples. We carried out a manual backward model selection by omitting terms with the lowest ABS value of z -values until the minimum adequate model was obtained (the random effects were retained in all models as they were part of the study design). Model comparisons were based on inspection of likelihood ratio test values until the p -values became <0.05 (Table S1). We used Cook's D distance to measure the influence of an observation on the estimation of the coefficients. We regarded observations with $D > 1$ as influential observations (Zuur et al., 2007), but no observation had $D > 1$ value. To reveal the relationship between microclimate conditions (minimum [13.72–20.08°C] and maximum [37.03–49.64°C] temperature, mean humidity [48.09–73.95%]) and management, we used linear mixed-effects models with crossed random effects for round, and management nested in width and proportion treatment, nested in block, as we wanted to include a random intercept for individual transects for the repeated measures.

3 | RESULTS

3.1 | Vegetation-dwelling arthropods

We collected 947 grasshoppers, 1558 true bugs and 4558 vegetation-dwelling spiders by sweep netting, comprising 22 grasshopper species, 34 true bug species and 27 vegetation-dwelling spider species (see Table S2). We found higher species richness in the refuge strips than in the mown strips for all vegetation-related taxa, that is grasshoppers (estimate = -1.131 , $z = -3.111$), true bugs (estimate = -1.157 , $z = -7.899$) and vegetation-dwelling spiders (estimate = -1.003 , $z = -4.025$; see Table S3; Figure 2) and also higher abundance for true bugs (estimate = -1.531 , $z = -4.561$) and vegetation-dwelling spiders (estimate = -1.151 , $z = -5.307$).

The difference between narrow and wide strips was more pronounced in case of 10% proportion than in 25% for the abundance of grasshoppers (estimate = -1.317 , $z = -3.698$). There was a higher abundance of true bugs in the mown area when strips were narrow, not wide (estimate = -1.157 , $z = -2.287$; see Table S3; Figure 3).

3.2 | Ground-dwelling arthropods

We collected 1094 carabids and 2437 ground-dwelling spiders by pitfall traps, comprising 36 carabid species and 47 ground-dwelling spider species (Table S1). We detected higher species richness in the refuge strips than in the mown strips for carabids (estimate = -0.314 , $z = -2.423$), but not for ground-dwelling spiders. Proportion and width had an interacting effect on carabid species richness with more species in the wide strips in case of 10% proportion and more species in narrow strips in case of 25% proportion (estimate = -0.628 , $z = -2.419$). We found a higher abundance of ground-dwelling spiders in wide strips at 10% proportion and in narrow strips at 25% proportion (estimate = -0.661 , $z = -2.281$).

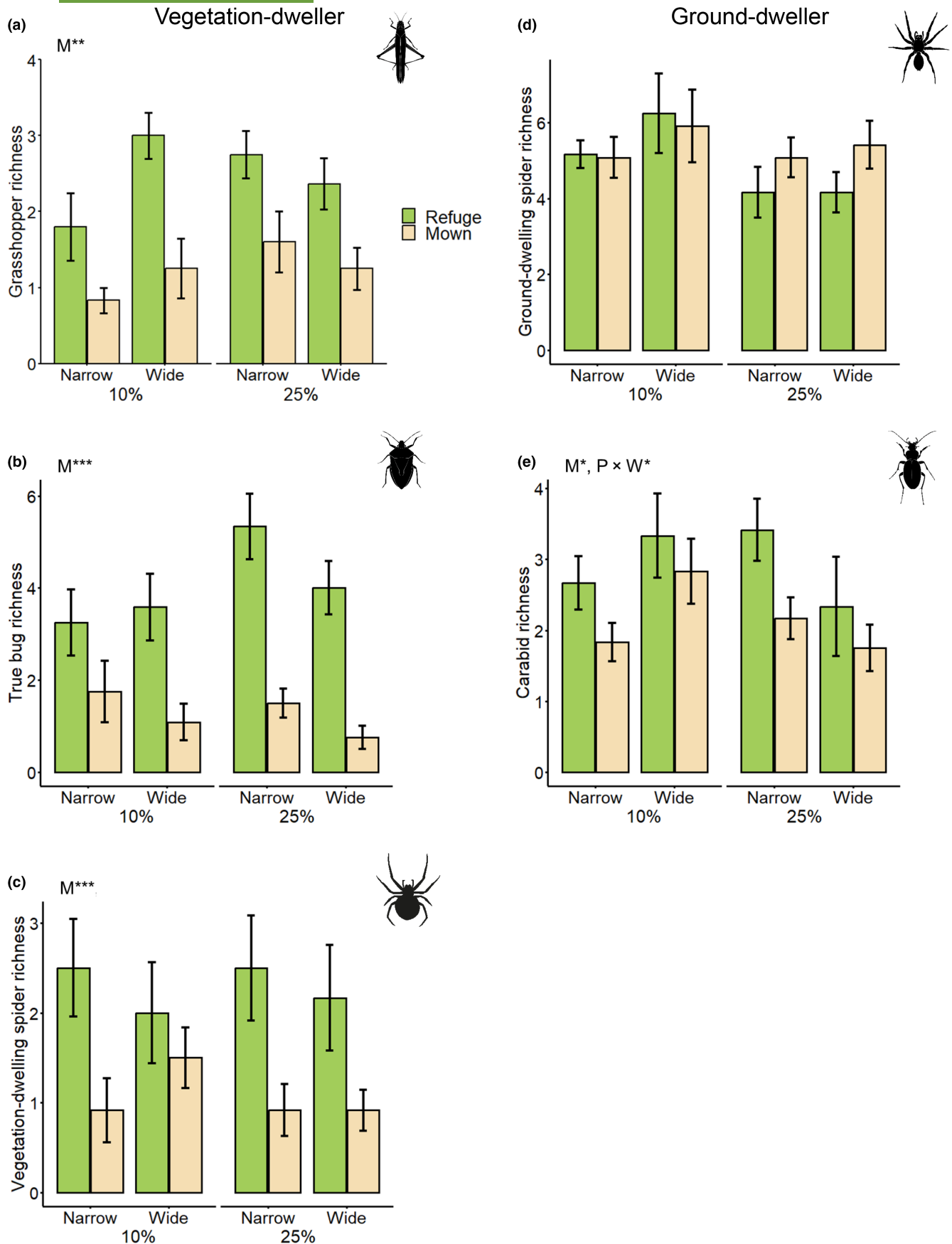


FIGURE 2 Species richness of investigated taxa (a) grasshoppers; (b) true bugs; (c) vegetation-dwelling spiders, (d) ground-dwelling spiders, (e) carabids, mean values $\pm$ SEM. M, management, R, ratio. Significance levels: *: <0.05 , **: <0.01 , ***: <0.001 .

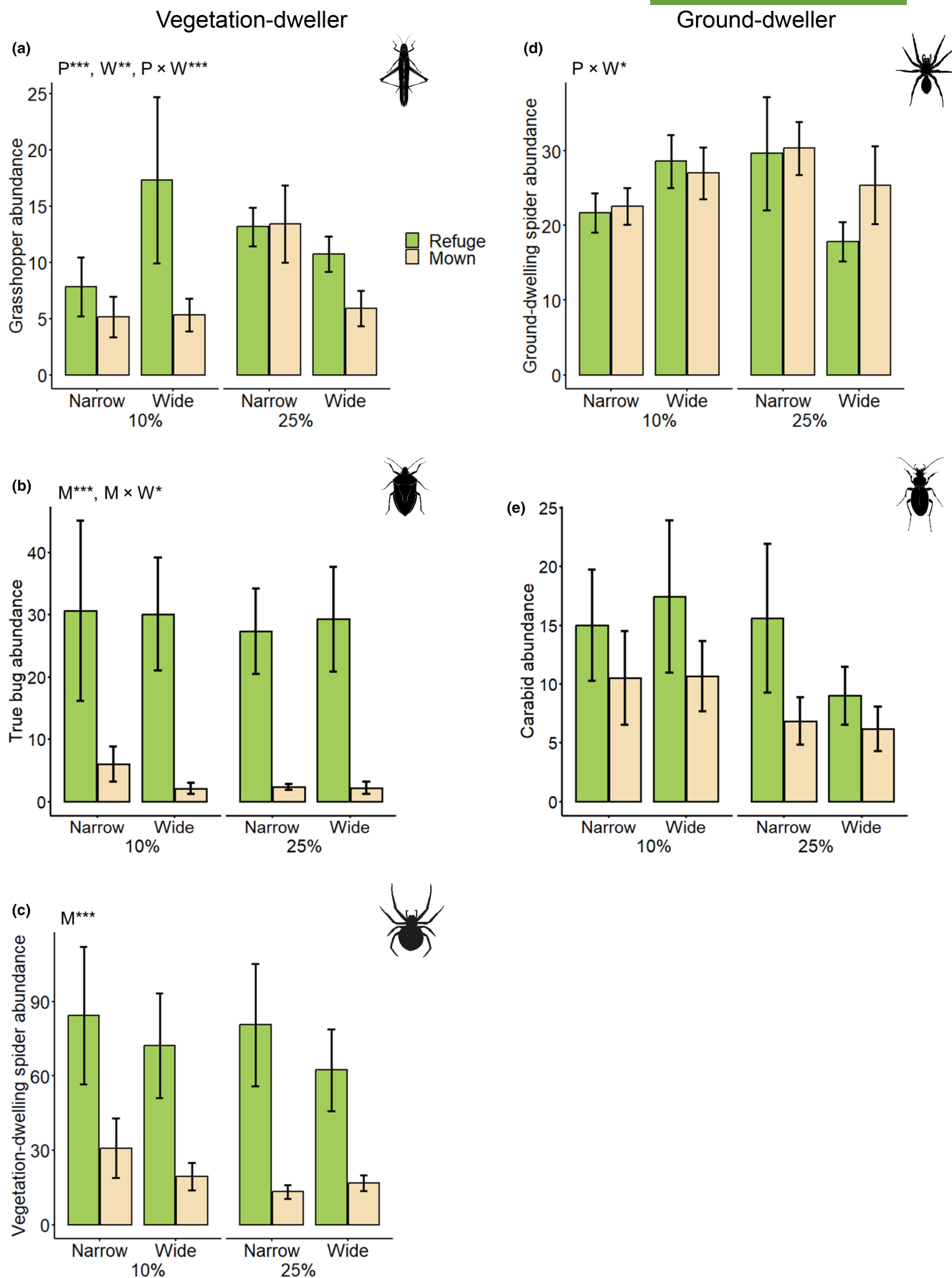


FIGURE 3 Abundance of all studied taxa (a) grasshoppers; (b) true bugs; (c) vegetation-dwelling spiders, (d) ground-dwelling spiders, (e) carabids, mean values $\pm$ SEM. M, management, R, ratio, W, width. Significance levels: *: <0.05, **: <0.01, ***: <0.001.

3.3 | Microclimate

We found different microclimate conditions in the refuge strips and the neighbouring mown strips, with a higher minimum, maximum temperature and mean humidity in uncut strips than in mown strips (see [Figure S2](#)).

4 | DISCUSSION

Our results showed that refuge strips harbour overall more arthropods than mown areas. Species richness was higher in the refuge strips than in the mown strips for all taxa associated with vegetation (grasshoppers, true bugs and vegetation-dwelling spiders) and for carabids. The abundance was higher in refuge strips for true bugs and vegetation-dwelling spiders. The abundance of true bugs was also higher in narrow than in wide mown strips. The interaction effect of width and proportion of refuge strips on the abundance of grasshoppers, ground-dwelling spiders and species richness of carabids showed that in case of 10% proportion, wider strips are more beneficial, but with 25% proportion, narrow strips are better.

4.1 | Vegetation-dwelling arthropods

The species richness of grasshoppers was doubled, and their abundance was higher with 60% in refuge strips than in mown strips. This is in line with a number of studies showing that hay meadows with refuge strips harbour higher grasshopper abundances than uniformly mown meadows. For instance, Müller and Bosshard (2010) found 10 times more individuals and significantly more grasshopper species when refuge strip management was applied (with 5%–10% proportion). Buri et al. (2013) found twice as high densities and 23% higher species richness of grasshoppers in meadows with 10%–20% refuge strips. Besides their obvious need for vegetation as food and shelter, moisture conditions and humidity requirements also shape the diversity pattern of orthopterans (Cizek et al., 2012). Temperature and moisture primarily affect the development and survival of grasshopper eggs and their oviposition behaviour (Wu et al., 2021). Typically, females start to lay eggs a few weeks after turning to adulthood, which lasts from early summer to fall for most species in Europe (Cherrill, 2002; Sardet et al., 2021). Mean humidity was higher in refuge strips than in mown areas. Therefore, moist and dense vegetation offered a high-quality ovipositing site and, presumably, a higher chance of survival and development for grasshoppers in the refuge strips. In the case of 10% proportion of refuge strips, we found higher abundance in wide ones than in narrow ones. We assume that the larger habitat size of wide strips benefitted invertebrates more. On the contrary, in the case of 25% proportion, there was a higher abundance in narrow strips than in wide ones. Here, narrow strips had only 9 m distance to the next refuge, thus invertebrates might have covered the area, as it did not pose a serious barrier for them.

In general, herbivores are sensitive to the amount and composition of vegetation (Schowalter, 2022). Mowing and the arrangement and quantity of uncut areas strongly affected the mainly herbivorous true bugs. We collected eight times more true bug individuals and three times more species in refuge strips than in mown areas, indicating the strong dependence of true bugs on uncut vegetation. True bugs are sensitive to changes in grassland management (Torma et al., 2019), and they are positively affected by the vegetation height of extensively managed grasslands (Kőrösi et al., 2012). Reduced plant biomass may directly reduce their population size (Gómez & González-Megías, 2002). Among mown areas, narrow strip arrangement favoured true bug abundance more than when there were wide strips and also wider distances between refuges. When refuge strips are closer to each other (e.g. 27 m instead of 81 m), true bugs can move more easily between them. This increased spillover effect could lead to a higher success of catches in narrow mown strips.

Vegetation-dwelling spiders were also positively affected by the refuge strips. We found twice more individuals in refuge strips than in mown strips. Rezác and Heneberg (2018) also found strip management to harbour three times more vegetation-dwelling spiders than homogeneously cut grasslands. The number of species was also doubled in refuge strips compared with mown strips. Although spiders do not depend on plants as a food resource, vegetation-dwelling spiders utilise the entire three-dimensional structure of grassland environments for web-attaching points, prey hunting and shelter (Cizek et al., 2012). Sward architecture is identified as the primary factor promoting increased species richness of predators (Woodcock et al., 2007, 2009). Therefore, vegetation-dwelling spiders are especially negatively affected by the removal of herbaceous vegetation.

4.2 | Ground-dwelling arthropods

Generally, ground-active arthropods were less affected by mowing than vegetation dwellers. Ground-dwelling spiders did not benefit from the establishment of refuge strips, as they are moderately affected by grassland management (Torma et al., 2023). Many ground-dwelling spiders, such as species in the family Gnaphosidae, are nocturnal, so they are less affected by the daily microclimatic differences between the strips and mown areas than diurnal species. Additionally, many of the collected spiders were xerophilous species, which were less dependent on the moist conditions of the refuge strips. Despite the toleration of mowing, the interaction of width and proportion of refuge strips caused a difference in the abundance of ground-dwelling spiders. This results in more individuals in wide strips than narrow ones in 10% proportion, and on the contrary, more individuals in narrow strips than in wide ones in 25% proportion. The mechanisms are similar to vegetation-dwelling arthropods with an addition that predators follow these patterns as a second trophic level (Tscharntke et al., 2005). Even though the maintenance mowing does not have a major influence on spider diversity, it is necessary to preserve the grassland spider diversity in Central-European hay meadows (Szmátóna-Túri et al., 2019). Low vegetation with an open

sward is the most beneficial to ground-dwelling arthropod diversity, and the more extensive management regimes can decrease ground-dwelling arthropod richness (Noordijk et al., 2010).

We detected 30% higher species richness of ground beetles in refuge strips than in mown areas, but we found no effect on their abundance. The interaction effect of refuge strip attributes also shaped carabid assemblages. Similarly, to the abundance of the ground-dwelling spiders, species richness of carabids was higher in wide refuge strips than in narrow ones in case of 10% proportion, and on the contrary, there was a higher species richness in narrow strips than in wide ones in case of 25% proportion. Uncut areas may serve as a high-quality habitat for ground beetles with higher diversity (Nentwig, 1988), and abundance (van Klink et al., 2019). The majority of ground beetles occurring on hay meadows prefer uncut conditions, with a few exceptions, which are species tolerating frequently disturbed, even ploughed environments or some other specialist species (Cizek et al., 2012). Ground beetles are sensitive to microclimatic factors, such as humidity and temperature (Buchholz et al., 2013). The changes caused by mowing made many species move from dry microhabitats of mown strips to the more humid refuge strips.

4.3 | Comparison of vegetation-dwelling and ground-dwelling arthropods

The effects of refuge strips were more substantial on the vegetation dwellers than on ground-dwelling arthropods. Rezác and Heneberg (2018) also confirmed that the uncut strips are associated with a higher abundance of common vegetation-dwelling spiders, but ground-dwelling spiders are less sensitive to strip management.

Onthogenic changes in habitat use might also drive this pattern. Arthropod species with vegetation-dwelling larvae benefit from leaving uncut refuge areas, in contrast to species whose larval development is independent of above-ground vegetation (van Klink et al., 2019). Therefore, vegetation-dwelling grasshoppers and true bugs are sensitive to mowing, as both larvae and adults mainly feed on the above-ground herbaceous vegetation (Kotze et al., 2011). Ground beetles and spiders might be more influenced by food availability and the differences in moisture conditions than vegetation height and cover. The relatively dry sampling years possibly also weakened the management effects on ground-dwelling arthropods, as strong abiotic stressors can partly override management effects on ground-dwelling arthropods (Torma et al., 2019). Weather conditions of the second sampling year favoured arthropod species richness and abundance similarly among vegetation-dwelling and ground-dwelling taxa.

4.4 | Conclusion and implication for conservation

Generally, more and more AES aims to maintain species-rich grassland habitats by leaving uncut refuge areas. Our results emphasise that refuge strips can greatly affect arthropod abundance, keeping up to eight times more individuals in refuge strips than beside. It is

crucial to leave uncut strips as refuges to arthropods during mowing. Besides raising the survival rate of arthropods in the critical time of mowing, it has further benefits with helping them to recolonise the wider field later.

Testing the different width and proportion of refuge strips, causing a different arrangements of uncut areas proved that all kinds of uncut strips could be beneficial to grassland arthropods. Even relatively narrow (3 m) and low proportion (10%) of refuge strips can be sufficient to mitigate some adverse effects of uniformly executed mowing. Although modifying attributes and considering farming practices, a low proportion (10%) with wide strips or high proportion (25%) with narrow strips seem to be the most efficient combinations for arthropods. The first one is probably the most acceptable by practitioners. It is easier to leave wide uncut strips or areas with the mowing machine than more detailed patterns. It is also more economical if the farmer needs to leave only 10% of the product and no more.

These well-distributed uncut areas during and after mowing play a simple but key role in optimising conservation practices for grassland arthropods. Our findings provide evidence that uncut refuge strips can harbour not just abundant but also diverse arthropod assemblages. We propose to have uncut refuge strips as obligatory part of AES for extensive hay meadow management, not just an optional choice of several possibilities. Finally, we strongly encourage all practitioners (e.g. National Park Directives) in charge of managing and maintaining high-value semi-natural grasslands to implement refuge strips in their practices.

AUTHOR CONTRIBUTIONS

Róbert Gallé conceived the ideas and designed methodology with support from Péter Batáry. Róbert Gallé, Nikolett Gallé-Szpisjak, Attila Torma, Márton Szabó, Lili Korsoveczky and Kitti Révész collected the data. Nikolett Gallé-Szpisjak, Attila Torma, Márton Szabó, Lili Korsoveczky and Kitti Révész identified the studied taxa. Róbert Gallé and Kitti Révész analysed the data. Kitti Révész wrote the manuscript with substantial input from Róbert Gallé and Péter Batáry. All authors contributed critically to the drafts and gave final approval for publication.

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CONFLICT OF INTEREST STATEMENT

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest. Péter Batáry is an Associate Editor

of the *Journal of Applied Ecology*, but took no part in the peer review and decision-making processes for this paper.

DATA AVAILABILITY STATEMENT

Data are available from the Zenodo Digital Repository <https://doi.org/10.5281/zenodo.11365756> (Révész et al., 2024).

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

Figure S1. A map showing the location of the study area, 'Csanádi puszták' in Hungary, Europe.

Figure S2. We found different microclimate conditions in the refuge strips and in the neighbouring mowed strips, minimum temperature ($t = -2.232$), maximum temperature ($t = -3.711$) and the mean humidity ($t = -3.807$) were higher in uncut strips than in mowed strips, however, the difference in soil moisture values was not significant.

Table S1. Summary table for df, χ^2 and p -values of manual model selection with Likelihood Ratio test with the variable's order of exclusion.

Table S2. Abundance of the studied taxa.

Table S3. Summary table for model estimates and z -values of final GLMM models on grassland arthropod species richness and abundance values.

Appendix S1. Arrangement of refuge strips in 2020.

Appendix S2. Arrangement of refuge strips in 2021.

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