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AGRI-ENVIRONMENT SCHEMES DO NOT SUPPORT BROWN HARE POPULATIONS DUE TO INADEQUATE SCHEME APPLICATION

Nikolett Ujhegyi[1,4*], Norbert Keller[2,4], László Patkó[3,4]
Zsolt Biró[4], Bálint Tóth[5,4] and László Szemethy[6,4]

[1]*Lendület Evolutionary Ecology Research Group, Plant Protection Institute, Centre for Agricultural Research, Eötvös Loránd Research Network, H-1022 Budapest, Herman Ottó út 15, Hungary*
*E-mail: ujhegyi.nikolett@atk.hu; https://orcid.org/0000-0001-9610-0353; *corresponding author*
[2]*Government Office of Baranya County, District Office of Komló*
Department of Foodchain-safety and Animal Health, H-7300 Komló, Berek út 3, Hungary
E-mail: kellernorbi88@gmail.com, https://orcid.org/0000-0003-2377-9267
[3]*WWF Hungary, H-1141 Budapest, Álmos vezér útja 69/A, Hungary*
E-mail: laszlo.patko@wwf.hu; https://orcid.org/0000-0002-4643-6411
[4]*Institute for Natural Resources Conservation, Department of Wildlife Biology, Szent István University, H-2100 Gödöllő, Páter Károly utca 1, Hungary*
E-mail: biro.zsolt@mkk.szie.hu; https://orcid.org/0000-0002-6046-5833
[5]*Government Office of Nógrád County, Department of Agriculture and Environmental Protection, H-3100 Salgótarján, Baglyasi út 2, Hungary*
E-mail: tr.balint@gmail.com; https://orcid.org/0000-0001-8104-0474
[6]*University of Pécs, Faculty of Sciences, Institute of Biology, H-7624 Pécs, Ifjúság u. 6, Hungary*
E-mail: laszlo.szemethy@gmail.com, https://orcid.org/0000-0001-7834-7619.

The goal of many agri-environment schemes (AES) is to increase biodiversity in agroecosystems. AES effects are often measured on invertebrates and birds; mammals as indicator species are infrequently targets of such researches. Our goal was to evaluate the local-scale effects of the Hungarian Agri-Environmental Measures (AEM) on the European brown hare (*Lepus europaeus*), which shows decreasing population trends across Europe. We compared hare abundances and their dropping numbers in AEM and control agricultural arable and grassland fields of 17 game management units in two seasons. We also examined the quality of arable fields based on their margin width and vegetation cover. We found that margin quality was higher in AEM than in the control fields. Control grasslands had higher vegetation quality than the AEM grasslands. We found a significant difference in hare counts between AEM and control arable fields in spring but no difference in autumn. The dropping densities did not differ in any season, treatment category or agroecosystem type. We conclude that the AEM program (2009-2014) in Hungary was not effective for the hare, and this might have been caused by the inadequate or weak application of AEM practices. We provide recommendations for future AEM programs to enhance biodiversity.

Key words: field margin, grassland, season, habitat-use intensity, Hungary, vegetation quality.

INTRODUCTION

Agri-environment schemes (AES) have been established in many countries of the European Union (EU) since the 1980s, which are intended to mitigate the biodiversity loss caused by intensive agriculture (de Sainte Marie 2014, Hodge *et al.* 2015). The monitoring of AES measures was mainly focused on compliance with regulations and supervision of processes, but the ecological effectiveness, specifically on the biodiversity, rarely played a significant role in the disbursement of subsidies. The projects' positive effects can be perceived, although its extent is subject to a severe scientific debate (Broughton *et al.* 2014, Pe'er *et al.* 2014, Batáry *et al.* 2015). The effects of many AESs were investigated mainly on birds or insects. For instance, Kleijn and Sutherland (2003), found that 32% of the assessment studies dealt with insect surveys and 47% of the studies investigated bird species, whereas only 2% of the studies investigated the response of mammal species to AES treatments.

The European brown hare (*Lepus europaeus*) is a vulnerable mammal species bound to agricultural areas. Its population density is sufficient yet, although its population size shows a falling trend all over Europe (Edwards *et al.* 2000, Smith *et al.* 2005*a*, Panek 2018). The primary cause of its population decline is habitat loss and decreased food supply due to agricultural intensification (Edwards *et al.* 2000, Kamieniarz *et al.* 2013). Other factors such as large field size, fast crop rotation, disappearing field margins, diversity loss of Poaceae species and forbs due to increased herbicide use, are all shown to have contributed to the decrease of hare populations (Haerer *et al.* 2001, Hackländer *et al.* 2002, Panek 2018). The availability of feeding and hiding places are likely decreasing, and the travel distance to reach these places is increasing due to the above-mentioned factors. The brown hare may indicate the impacts of several habitat-development projects due to its breeding strategy and population dynamics. This is because brown hares have more breeding seasons in a year, and they invest considerable energy in their offspring during the reproductive season, i.e. they are classified as income breeders (Hackländer *et al.* 2002, Schai-Braun *et al.* 2020). Females who live in good or heterogeneous habitats and have a higher survival rate and larger body weight are likely to produce larger litters more often (Hackländer *et al.* 2002, Smith *et al.* 2005*b*; Jennings *et al.* 2006, Langhammer *et al.* 2017). If the agriculture becomes too intensive, hare populations may decline and affect heterogeneity at farm scale, which means the agri-environment schemes may benefit hares, especially on intensively managed landscapes (Edwards *et al.* 2000, Vaughan *et al.* 2003, Báldi & Faragó 2007). The positive effects of habitat-management projects (e.g. "Conservation of *Otis tarda* in Hungary" LIFE program, or organic farming) on brown hare were demonstrated in several countries (Báldi & Faragó 2007, Reynolds *et al.* 2010, Santilli & Galardi 2016).

Generally, many AES's have the potential to improve habitats by increasing vegetation diversity and the availability of shrubby field margins and edge habitats important to the brown hare (Benton *et al.* 2003, Roedenbeck &

Voser 2008). Consequently, brown hare, as a common species, may be used as an indicator species on farmland landscapes. At the same time, the earlier long-term AES's could not provide noticeable, positive results related to the abundance of this species, supposedly due to the different AES's giving conflicting prescriptions amongst various directives of AES's (Zellweger-Fischer *et al.* 2011, Meichtry-Stier *et al.* 2014, Santilli & Galardi 2016). Our research aimed to analyse the relationship between the state of the brown hare populations and the AES in Hungary. In Hungary, AES programs for sustainable agriculture have been established since 2002 (Kovács Katona 2007, Hungarian Ministry of Agriculture and Rural Development 2015). The last completed AES cycle was the Agri-Environmental Measures (AEM), which was organised by the New-Hungary Rural Development Programme (NHRDP) between 2009–2014 (Batáry *et al.* 2015, Hungarian Ministry of Agriculture and Rural Development 2015). Thus, our main question was whether the intensity of local habitat use by brown hares was higher in AEM fields than in control arable fields. Because the field margins and the actual vegetation can also have a high impact on the hare habitat use intensity (Petrovan *et al.* 2012, Rodríguez-Pastor *et al.* 2016), for a better evaluation of our results, we also analysed the differences in the width of the field margins and the vegetation composition between control and AEM areas.

MATERIAL AND METHODS

Selecting study areas – We tested the effects of 13 management schemes for arable crop production lands and grasslands from the Hungarian AEMs' total 21 schemes. These schemes contained conservation-related directives mainly (Table 1), which were supposed to be beneficial for the brown hare.

The National Game Management Database (NGMD) collects and stores game population and hunting bag data for all game-management units (GMU) in Hungary (Csányi *et al.* 2011). For the analyses, we selected GMUs, where small game species management was the primary activity (based on harvest statistics) and had continuous management data between 2008 and 2014. To analyse the local-scale relationship between the brown hare and the AEM, we selected 17 GMUs with sufficient hare density (minimum 5 individuals/km^2, below this value, hare-hunting is not permitted in Hungary). We used the GIS database of agricultural fields from the National Food-chain Safety Office. From this database, with the Quantum GIS software (QGIS Development Team 2017), we selected AEM arable fields to the adjacent locations (mean ± SD: 4.68±1.52 km^2, Figs 1 & 2) that were part of relevant schemes (Table 1) and were sufficiently large enough for fieldwork (we did not sample small, isolated AEM arable fields). Furthermore, in parallel, we selected similar-sized control arable field groups that were not included in our 13 AEM schemes (mean±SD: 3.08±1.78 km^2, Figs 1 & 2) in each GMU. Whenever possible, we selected two types of AEM arable fields (one arable land and one grassland) and two types of control arable fields (one arable land and one grassland) in each GMU. Based on scientific literature, the brown hare's average home range is about 40 ha (Bray *et al.* 2007, Misiorowska & Wasilewski

Table 1. Our selected arable schemes and their important regulations: AA) integrated farming, AB) organic farming, AC) management of traditional homesteads ("tanya"), AD1) nature conservation purpose farming – great bustard, AD4) nature conservation purpose farming – red-footed falcon, AD2) nature conservation purpose farming – wild goose/crane, AD3) nature conservation purpose farming – bird / small game (grey partridge, pheasant, brown hare). Our selected grassland schemes and their important regulations: BA) extensive grassland management, CB) organic grassland management, BC1) nature conservation purpose farming – great bustard, BC2) nature conservation purpose farming – habitat management, BD1) environmental land-use change scheme, BD2) nature conservation purpose grassland establishment. We selected the compacted regulation from the Hungarian Ministry of Agriculture and Rural Development 2009 and the Hungarian Ministry of Agriculture and Rural Development 2015.

The main regulations of the selected schemes	AA	AB	AC	AD1	AD4	AD2	AD3	BA	CB	BC1	BC2	BD1	BD2
It is forbidden to plant rice and plants as biomass fuel (*Miscanthus spp*.)	x	x	x	x	x	x	x						
Compulsory crop rotation	x	x	x	x	x	x	x						
Crop structure max. 50% zea, wheat and sunflower	x	x	x										
Crop structure min. 10% *Medicago* species	x	x	x										
Crop structure min. 20% *Medicago* species				x	x	x	x						
Compulsory green fallow				x	x	x	x						
Crop structure min. 10% rapeseed				x	x								
Compulsory green manure min. once during the 5 yrs	x	x	x										
Compulsory use of environmentally friendly pesticides	x	x	x	x	x	x	x						
Mosaic cropping system	x	x	x										
It is forbidden to use wastewater and slurry					x	x	x	x	x	x	x		
It is forbidden to use rodenticide and soil disinfection				x	x	x	x						
Restrictions to the agricultural working hours or time					x	x				x	x		
Compulsory unmowed area				x	x	x	x			x	x		
Compulsory bird-friendly mowing (for example, using an alarming chain)				x	x	x	x			x	x		
Compulsory use of alarm-chain while mowing to protect wildlife				x	x	x	x			x	x		

Table 1 (continued)

The main regulations of the selected schemes	AA	AB	AC	AD1	AD4	AD2	AD3	BA	CB	BC1	BC2	BD1	BD2
It is forbidden to use chemicals at the border of the arable fields				×	×	×	×						
Compulsory removal of snow from the top of rapeseed				×	×								
Compulsory maise or wheat stubble				×	×	×	×						
Compulsory to report the date of mowing (at least 5 days prior)				×	×			×	×	×	×	×	×
It is forbidden to use herbicide						×	×	×	×	×	×	×	×

2008, Zaccaroni *et al.* 2013). The radius of a 40 ha circle is 720 m, so we used this minimum distance from AEM arable fields when selecting the control arable fields. We selected a total of 263 AEM and 297 control arable fields, which were visited in the autumn of 2013 and spring of 2014. In autumn, we walked 729 line transects on 208 arable fields (396 transects on 111 control and 333 transects on 97 AEM fields). In spring, we walked 1398 line transects on 388 arable fields (619 transects on 186 control and 605 transects on 166 AEM arable fields), which totalled approximately 820 km. We identified and added "X" and "Y" coordinates to the centre of the arable fields' polygons with QGIS software.

Surveying the number of hares and hare droppings – Flexible strip transects (Thompson *et al.* 1998) with 2 meters width were used for evaluating hare dropping density as the indicator of hare habitat use intensity (the actual width of the field we could evaluate was sometimes <2 m depending on the vegetation). We recorded the location and number of each hare dropping (total dropping number if we found a dropping group or the location of every single dropping) and the starting and ending point of the transect lines on Garmin 62 and 62st devices. We did not remove the droppings from the arable fields before the dropping counts, but we tried to reduce our sampling errors in two ways. First, we counted only the fresh-looking droppings (greenish, shiny, whole pellets that had not yet dried). Second, because a few tests showed that the region, the current weather conditions, and the habitat type have a significant influence on the dropping-decay rates (Prugh & Krebs 2004, Perry & Robertson 2012, Lioy *et al.* 2015), we tried to choose GMUs from the same region. All GMUs are part of the "Great Hungarian Plain region" (except for one, which neighbours it). We also tried to survey all of our arable fields in the shortest time possible. In autumn, we counted the hare and the hare dropping densities from 21st of November until the 19th of December (except for one GMU, which we visited on the 6th of January). In spring, the fieldwork started on the 7th of March and ended on the 13th of May. The median, minimum and maximum length of the transects were 330, 10 and 3500 m. Three transects were used in each arable field: the first, at the margins (0 m from the edge), because the edge or the vegetation of the field margins are important to communities of smaller mammals as well as hare (MacDonald *et al.* 2007, Petrovan *et al.* 2012, Rodríguez-Pastor *et al.* 2016). The second and the third transect lines were parallel to the margins at 50 and 100 meters (Fig. 2), as previous studies showed that the middle of the large fields was used less frequently than the areas closer to the field boundaries (Petrovan *et al.* 2012). For the statistical analyses, we calculated the surveyed area (m^2) we have seen on each line transect (the length of each transect × the width of each transect), then we summed up the surveyed area of the three transects for each field as "total surveyed area" (m^2). Finally, we converted the resulting value to hectares. This area was taken into account in the analysis of hare dropping counts, which we calculated for each arable field by summing up the numbers of hare droppings we have seen on the three line transects.

We also counted individual hares that were observed during transect walks on each field up to 250 m from the field margin. These counts were made by a third person who walked parallel with the field margin, keeping a 100 m from it, and we assumed 150 m visibility (Huysentruyt *et al.* 2018), thus evaluating a 100 m band from the field margin and a 150 m band on the opposite side. For the statistical analysis of hare counts, we calculated the surveyed area (m^2) for each arable field as follows: first, we used the longest length of the tree line transects (m), then multiplied this value by 250 m (if the width of the field was less than 250 m, we used the actual width value instead of 250 m); finally, we converted the resulting value to hectares.

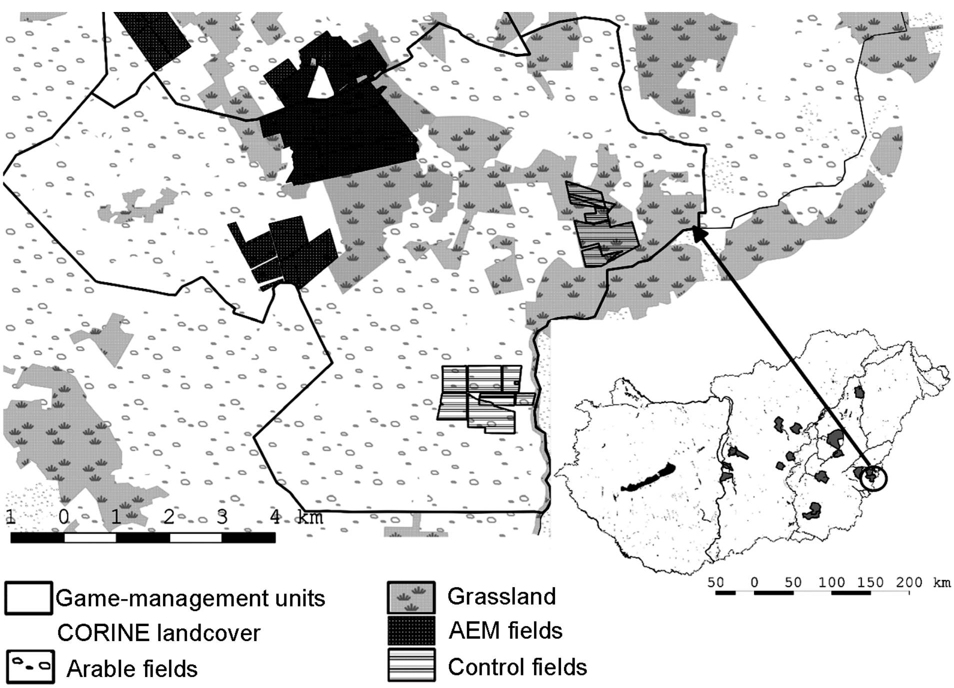

Fig. 1. Location of the studied game-management units in Hungary, shown by the grey patches on the small map in the bottom right corner, and an example of selected arable fields in one GMU showing AEM fields as dark grey areas and control fields as the light, striped grey areas. On the big map, the white area with the "rings symbol" shows the arable lands, and the light grey patches with the "grass symbol" show the grasslands

Categorising field margins and vegetation – During transect walks, we characterised the width, density and height of the margins. Because the margins provide a hiding place and feeding site to the animals, we gave higher scores to the broader and denser margins. We evaluated two margins per field, one parallel to the first transect and one adjacent (Fig. 2), based on vegetation characteristics as stated hereafter. First, we scored the average width of the margin as: (0) none, (1) narrow (<0.5 m), (2) medium (0.5–1 m), (3) wide (>1 m) (Figs 3 & 4). Second, we scored the plants' density in the margins with provided hiding place for the hare. To train our eyes, we used a wooden hare model to estimate what percentage of the animal's body is visible in vegetation with various densities. Based on this, we categorised the density and the height of the vegetation in the margins as: (0) none (100% visible), (1) sparse (more than 50% visible), (2) fair (less than 50% visible), (3) excellent (we could not see the hare) (Figs 3 & 4). We multiplied the width score with the density score of each margin (yielding a score between 0 and 9 for each margin), then we summed up each margin quality (range: 0–18).

During the fieldwork, we also collected data on the cultivated vegetation of the arable fields. Because the different arable lands are not equally beneficial to the hare in terms of the nutritional value of the crop species and the suitability of habitat they provide (Pelorosso *et al.* 2008, Schai-Braun *et al.* 2015), we gave different scores to the different vegetation types. First, we categorised the cultivated plants as follows: (0) no vegetation, (1) vegetation of lower quality for the hare (maise (*Zea mays*) (Sliwinski *et al.* 2019, Canova

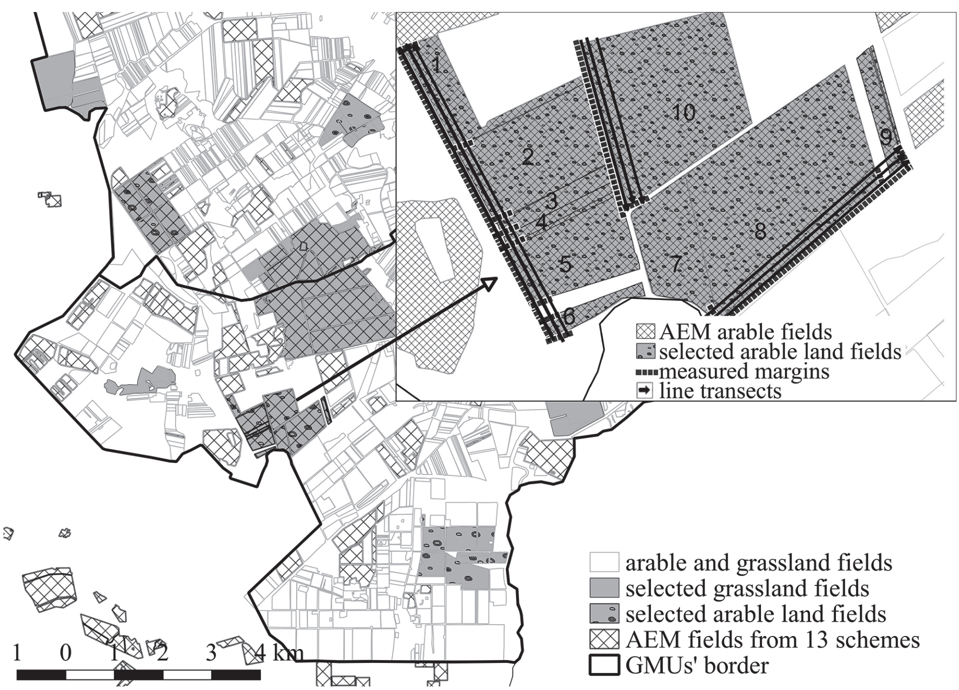

Fig. 2. An example of the selected and measured arable fields (which are indicated with numbers). On the small map in top right, the bold black arrows show the line transects: one on edge, and 2 in the field at 50 and 100 m from the edge; the dotted grey lines of the fields represented the measured margins

et al. 2020), sunflower (*Helianthus sp.*) (Reichlin *et al.* 2006, Schai-Braun *et al.* 2015), (2) vegetation of higher quality for the hare (grain (*Triticum sp.*), pasture, alfalfa (*Medicago sativa*), fallow field, rapeseed (*Brassica napus*), forage grasses (*Poaceae and Fabaceae*), beet (*Beta vulgaris*) (Reichlin *et al.* 2006, Schai-Braun *et al.* 2015, Sliwinski *et al.* 2019). Second, we also categorised the status of the vegetation. We gave a score of (0) if the vegetation height was under 5 cm or the soil had a flat smooth surface (land is prepared for sowing or heavily-

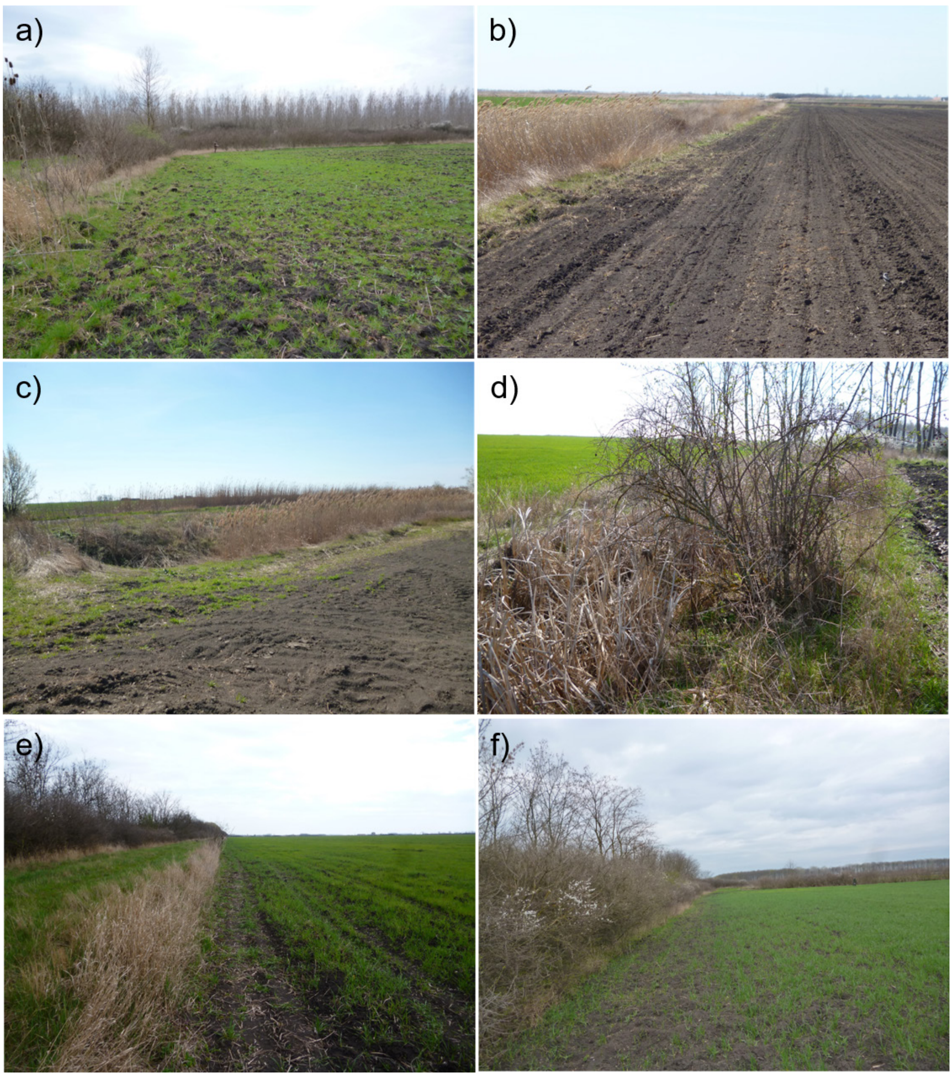

Fig. 3. Examples of the categorised low-score margins. These margins indicated a small ecological contrast on the field (a) none; b) narrow margin with bar field; c) medium margin with bare or sparse vegetation; d-f) wide margin with sparse vegetation)

grazed). We gave a score of (1) if the vegetation was higher than 5 cm, less nutritious or the vegetation phase was matured (forage plants decline in nutritional value as they advance in maturity, therefore crude proteins significantly decrease, and crude fibre, calcium, or phosphorus slightly increase) (George & Bell 2001), old and dry (stubble had been left after harvest), or the grassland had been mowed or under grazed, and the height of the vegetation was under 10 cm. Furthermore, we gave a score of (1) if the surface of the soil

Fig. 4. Examples of the categorised high-score margins. These margins indicated a larger ecological contrast on the field (a) narrow and excellent margin; b) medium and excellent margin; c–f) wide margin with excellent vegetation). E) and f) margins had the larger ecological contrast with hedge and woody vegetation

was not flat (the land had been ploughed), as the small clods may provide hiding spots for hares. We gave a score of (2) if the land was sowed, the vegetation phase was juvenile, or we saw pioneer/volunteer plants on the field. We summarised the plants' cultivation and vegetation status scores for each arable field (range: 0–4).

Statistical analysis – All analyses were run in the R 4.0.3 computing environment (R Core Team 2020), using the following packages: NBZIMM (Yi 2019), nlme (Pinheiro *et al.* 2018), MASS (Venables & Ripley 2003). To analyse the effect of AEM treatment on hare counts and hare dropping counts, we used negative binomial zero-inflated mixed models (NBZIMM). For both dependent variables, first, we built a full model containing the following effects. As fixed effects, we included treatment (AEM or control), season (spring or autumn), agroecosystem type (grassland or arable land), and all two-way interactions between these factors, as well as their three-way interactions, and we added the size of the surveyed area as a covariate. GMU was used as a random factor to take into account the non-independence of arable fields within the same GMUs (e.g. due to different hunting regimes). To control the spatial non-independence of sampling points, we incorporated a spatial autocorrelation structure, assuming exponential correlation because this function yielded the smallest residual variance among all correlation functions available for this type of model (Zuur *et al.* 2009). In the zero-inflation ("false zeros") part of the model, we assumed that the detection of the hares and their droppings depended on vegetation height (Wong & Hickling 1999), on the season due to seasonal changes in hare behaviour (Perry & Robertson 2012), and on the size of the surveyed area (e.g. hares and droppings may be missed more easily in larger areas). Additionally, in the hare counts model, we included margin density into the zero-inflation part because the detection failure probability may be higher in the denser margins (Perry & Robertson 2012, Lioy *et al.* 2015) and the hare can hide faster and easier in a dense margin. From each of these full models, we estimated the differences between AEM and control arable fields for each season × agroecosystem type combination by linear contrasts using the emmeans package (Lenth *et al.* 2020) in R.

To analyse the quality of vegetation and field margins, we used simple non-parametric methods, as these data are ordinal. Therefore the complex modelling framework that we used for counts cannot be applied to these semi-quantitative scores. We compared vegetation quality (0–4) and margin quality (0–18) between the AEM and control areas as well as between the two control areas with Mann-Whitney tests. Spearman rank correlation was used to test if the vegetation quality and margin quality were independent markers of the area. Finally, we used Spearman's rank correlation to test if hare counts or hare dropping counts correlated with margin quality and vegetation quality in different types of arable fields (AEM arable land, AEM grassland, control arable land, control grassland). For the latter correlations, we applied the false discovery rate (FDR) correction method (Pike 2011) to our P values to correct the significance level with the number of multiple tests.

RESULTS

Comparison of hare-dropping counts and hare counts between AEM and control fields

For the number of hare droppings, all interactions were non-significant, and AEM had no significant effect on the hare dropping quantity in any season or agroecosystem type (Table 2 & 3, Fig. 5). Dropping counts were smaller

Table 2. The statistics of the negative binomial zero-inflated mixed model of brown hare dropping counts (d.f. = 619).

Model parameters	Estimate±SE	Test statistic*	P Fixed effects
Fixed effect			
Intercept (autumn, grassland, control)	3.6±0.27	13.14	<0.001
Surveyed area (ha)	2.33±0.38	6.17	<0.001
Season (spring)	–0.39±0.31	–1.24	0.215
Agroecosystem type (arable land)	–1.46±0.31	–4.69	<0.001
Treatment (AEM)	–0.01±0.31	–0.02	0.98
Season (spring) × Agroecosystem type (arable land)	0.3±0.4	0.75	0.455
Treatment (AEM) × Agroecosystem type (arable land)	0.38±0.44	0.85	0.395
Season (spring) × Treatment (AEM)	0.05±0.41	0.14	0.89
Season (spring) × Treatment (AEM) × Agroecosystem type (arable land)	–0.15±0.57	–0.27	0.786
Zero inflation			
Intercept (autumn)	0.31±0.25	1.26	0.209
Vegetation height (cm)	–0.72±0.09	–7.61	<0.001
Season (spring)	0.34±0.27	1.29	0.196
Surveyed area (ha)	–2.27±0.73	–3.13	<0.001

*The test statistic is t-value for the fixed-effects parameters and z-value for the zero-inflation parameters. Covariates were not mean-centered, so the intercept estimates refer to the zero values of numeric covariates.

in spring than in autumn and lower in arable lands than in grasslands (Table 2, Fig. 5). It was also higher in larger surveyed areas (Table 2). The zero-inflation part of the model showed that the probability of not detecting hare droppings decreased with increasing vegetation height and the size of the surveyed area (Table 2).

For hare counts, we found a significant three-way interaction between season, agroecosystem type and treatment (Fig. 6, Table 3 & 4). We did not find different hare counts between AEM and control arable fields for either arable lands or grasslands in autumn. Still, in spring, the AEM arable lands had a significantly higher hare count than control arable lands (Table 3, Fig. 6). Grasslands showed the opposite: in spring, there were more hares in the control grasslands than in the AEM grasslands (Table 3, Fig. 6). On most occasions (74%), we did not see any hare on the field; the probability of "false zeros" was lower in larger survey areas, when the vegetation was higher, and the field margin was less dense but did not vary with the season (Table 4).

Table 3. Linear contrasts from the models in Tables 2 and 4, testing the difference between AEM and control fields in hare dropping counts or hare counts for each season and each agroecosystem type. P-values were FDR-corrected separately for each dependent variable.

Contrast	Estimate±SE	t	P
Dependent variable: Hare dropping count			
Control vs. AEM grassland in autumn	0.01±0.31	0.02	0.981
Control vs. AEM arable land in autumn	–0.37±0.32	–1.71	0.484
Control vs. AEM grassland in spring	–0.05±0.27	–0.18	0.981
Control vs. AEM arable land in spring	–0.27±0.23	–1.2	0.484
Dependent variable: Hare count			
Control vs. AEM grassland in autumn	0.11±0.24	0.5	0.843
Control vs. AEM arable land in autumn	0.03±0.2	0.14	0.891
Control vs. AEM grassland in spring	0.59±0.51	3.92	<0.001
Control vs. AEM arable land in spring	–0.56±0.18	–3.13	0.004

Quality of field margins and vegetation

We found a significant difference between the AEM and control grasslands in the margin quality (Mann-Whitney's W = 5316, P = 0.009): the AEM grassland fields had better margin quality than the control fields (Fig. 7).

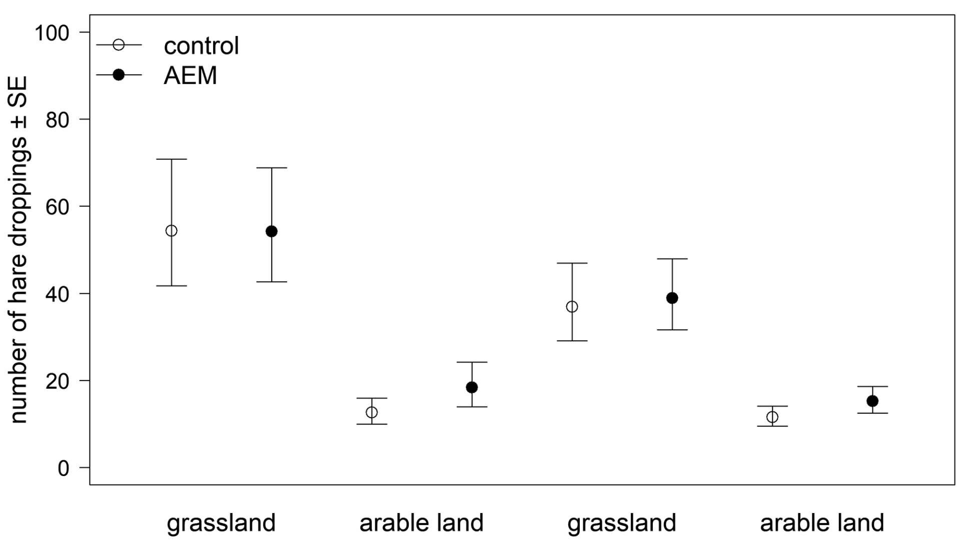

Fig. 5. Comparison of brown hare dropping counts between different treatments. Error bars show the mean ± SE values estimated from the negative binomial zero-inflated mixed model in Table 2, back-transformed to the original data scale

Table 4. The statistics of the negative binomial zero-inflated mixed model of brown hare counts (d.f. = 615).

Model parameters	Estimate±SE	Test statistic*	P Fixed effects
	Hare count		
Intercept (autumn, grassland, control)	–0.62±0.21	–2.82	0.005
Surveyed area (ha)	0.02±0.004	4.45	< 0.001
Season (spring)	1.22±0.21	5.89	< 0.001
Treatment (AEM)	–0.11±0.24	–0.48	0.632
Agroecosystem type (arable land)	0.35±0.22	1.59	0.11
Season × Agroecosystem type	–1.79±0.28	–6.37	< 0.001
Treatment (AEM) × Agroecosystem type	0.09±0.31	0.28	0.781
Season × Treatment	–0.48±0.28	–1.72	0.086
Season × Treatment × Agroecosystem type	1.07±0.38	2.78	0.006
	Zero inflation		
Intercept (autumn)	0.67±0.2	3.36	< 0.001
Vegetation height (cm)	–0.02±0.007	–2.93	0.003
Margin density score	0.16±0.08	1.2	0.049
Season (spring)	0.24±0.18	1.32	0.186
Surveyed area (ha)	–0.08±0.01	–6.91	< 0.001

*The test statistic is t-value for the fixed-effects parameters and z-value for the zero-inflation parameters.
Covariates were not mean-centered, so the intercept estimates refer to the zero values of numeric covariates.

However, this was not the case for arable land: although AEM arable fields had higher median margin quality, the control arable lands reached the highest scores (Fig. 7), and the difference between treatments was marginally non-significant (W = 18339, P = 0.091). Considering the vegetation cover scores, we did not find a significant difference between the AEM and control arable lands (W = 20300, P = 0.99), although there was a tendency that AEM fields had higher median vegetation quality scores (Fig. 7). In contrast, the AEM fields had significantly lower vegetation quality among grasslands than the control grasslands (W = 8668, P < 0.0001, Fig. 7). We found that the vegetation quality and margins quality were negatively correlated (N = 642, Rho = –0.12, P = 0.001). Among the control fields, the grasslands had significantly higher margins quality (W = 13733, P = 0.019) than the arable lands, whereas the vegetation quality did not differ between the two agroecosystem types without AEM (W = 12320, P = 0.538, Fig. 7).

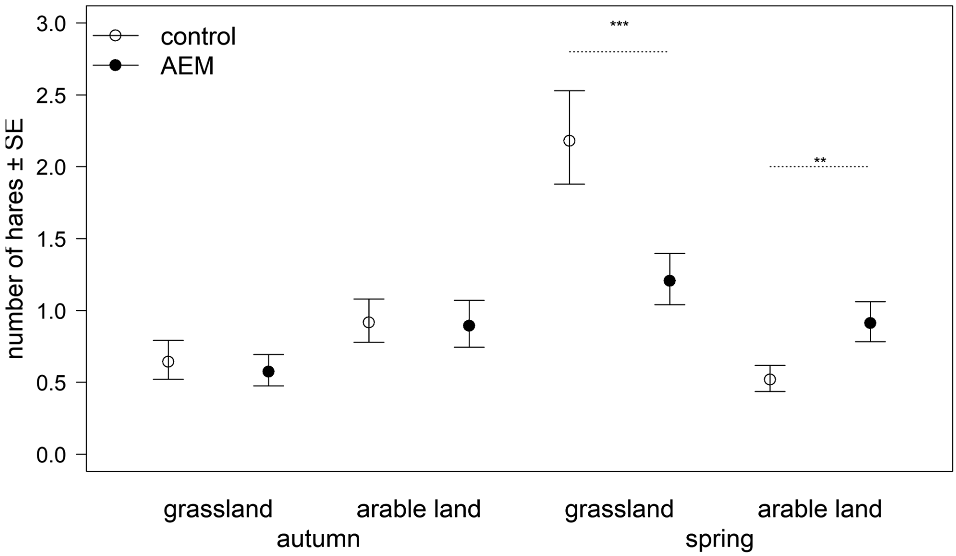

Fig. 6. Brown hare counts in different treatments. Error bars show the mean ± SE values estimated from the negative binomial zero-inflated mixed model in Table 4, back-transformed to the original data scale. Groups marked by asterisks differ from each other significantly (**P < 0.01, ***P < 0.001, after FDR correction)

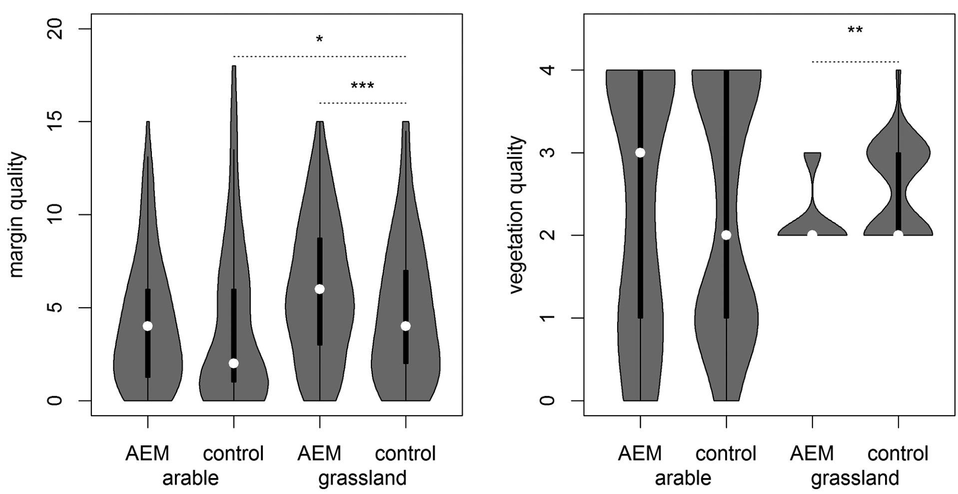

Fig. 7. Distribution of field margin quality and field vegetation quality in AEM and control fields. Each violin plot shows the probability density of the data at different values, smoothed by a kernel density estimator; the thick vertical line shows the interquartile range, and the white circle shows the median. Higher scores mean better quality for the hare. Groups marked by asterisks differ from each other significantly (*P < 0.05, **P < 0.01, ***P < 0.001, after FDR correction)

Table 5. Spearman rank-correlations testing the relationships of hare count or hare dropping count with vegetation quality (0–4) and margin quality (0–18) in each agroecosystem × treatment category. We applied FDR correction to the 4 P-values for each relationship.

Statistics	Control arable land	AEM arable land	Control grassland	AEM grassland
	Hare quantity and vegetation quality			
Rho	0.03	–0.03	–0.05	0.14
P	0.64	0.659	0.608	0.106
FDR–corrected P	0.659	0.659	0.659	0.426
N	239	170	99	134
	Hare dropping quantity and vegetation quality			
Rho	0.26	0.44	0.11	0.09
P	<0.001	<0.001	0.277	0.322
FDR–corrected P	<0.001	<0.001	0.322	0.322
N	239	170	99	134
	Hare quantity and margin quality			
Rho	–0.02	0.1	–0.1	0.07
P	0.81	0.215	0.311	0.443
FDR–corrected P	0.815	0.591	0.591	0.591
N	239	170	99	134
	Hare dropping quantity and margin quality			
Rho	–0.08	1.28	–0.08	–0.06
P	0.242	0.096	0.429	0.5
FDR–corrected P	0.483	0.385	0.5	0.5
N	239	170	99	134

The hare counts did not correlate with vegetation quality or margin quality scores in any treatment category (Table 5). The hare droppings count correlated significantly positive with the vegetation quality scores in both AEM and control arable lands, but not in grasslands (Table 5). The hare droppings count did not correlate significantly with margin quality in any treatment type (Table 5).

DISCUSSION

According to Zellweger-Fischer *et al.* (2011), many AES's may have positive effects on the abundance of the surveyed species. Contrary to this, our study did not find distinct positive effects related to the brown hare population quantity, such as those reported by previous studies in Italy (Cardarelli *et al.* 2011, Santilli & Galardi 2016). Even if the proportion of the AEM-related areas (with a total of 21 schemes) were high in Hungary (total 1 163 663 ha), those schemes which are relevant to the brown hare were fewer (percentage of the AEM affected areas of GMUs: mean±SD = 18.24±7.62%).

AEM effects on hare population in arable land

Although AES's, in general, have the potential to be a habitat-development project, in our local scale survey, we could not find any positive effects on brown hare incidences, even though the AEM arable lands had somewhat higher field margin and vegetation quality values than the control fields (Fig. 7). These small differences could be higher in a large scale survey. Therefore it would need further examination through future studies.

We did not see more hare on the AEM affected arable lands than in the controls in autumn. However, in spring, we saw a trend where more hares were found on the AEM arable lands. The breeding season for hares begin in spring, and because we found a slightly higher number of crop species on the AEM arable fields than on the controls (for example, beet), perhaps AEM arable fields have more diverse or more nutrient-rich vegetation, which is advantageous for the female hare (Pelorosso *et al.* 2008, Schai-Braun *et al.* 2015, Mayer *et al.* 2018). However, we did not find differences between the vegetation quality and the margin quality of the AEM and control arable lands, but AEM fields had higher medium height margins and favourable vegetation scrolls. Nonetheless, we found empty ploughed lands from autumn to spring on the AEM fields in many cases, which are avoided often by hares (Mayer *et al.* 2018).

Because all the AEM's arable land schemes demanded the field sizes be smaller than 75 ha (Hungarian Ministry of Agriculture and Rural Development 2009), we should have found more arable fields with maximum vegetation scores, or the vegetation taxa should have been more diverse. Perhaps we did not see more diverse vegetation in the AEM affected areas, due to the AEM legislation not having annual or seasonal requirements for the vegetation culture (for example, it required sowing legumes only once in five years), furthermore in that AEM regulation using "green manure" was prescribed minimum once during the five years (Table 1). Therefore, in many cases, we found the field to be bare during autumn, which may not be beneficial for brown hares' survival in winter as the vegetation quality is low or does not exist. The essential resources (such as food and shelter) are poor, mainly if the margin quality was low (Fig. 3). This led to reduced shelters in cover-rich structures, especially in field track edges (Schai-Braun *et al.* 2020). It could be restored in three ways: first, by sowing green-manure plants or other byproducts (biogas-digestate, pot-ale, rockdust and wood ash), which provide to the soil (Dahlin *et al.* 2015) and could yield alternative food sources to the small game species. Professionals should guide this decision since some plants, such as bioenergy crops, may cause unwanted effects, like increased home range (Petrovan *et al.* 2017), while others may be favourable, such as mixed-farming areas. At the same time, hares generally selected the shorter vegetation (1–50 cm) and remained further from field margins when the vegetation is under 50 cm. And hares avoided the high (>50 cm) and dense vegetation (e.g., brassicaceae, cereals, and maize), which is potentially a physical barrier inhibiting to the hare (Mayer *et al.* 2018). Secondly, suppose every scheme has a compulsory stubble (at least close to the permanent field boundary), not just the maize or wheat, in which case the stubble may provide good shelter for the hares, especially during winter when the fields are bare, with little to no margin scores (Fig. 3), taking into consideration that some research showed stubbles (especially maise) were avoided by the hares (Cardarelli *et al.* 2011, Mayer *et al.* 2018, Canova *et al.* 2020). Thirdly, if the vegetation cannot be improved, the field margins would need to be broadened (Fig. 4). On the one hand, the small flowering meadows near the field margins can help herbivores, insects and pollinators (Marshall *et al.* 2006, Sliwinski *et al.* 2019), on the other hand, the mosaic cropping system could also increase the arable lands' heterogeneity (Vasseur *et al.* 2013, Mayer *et al.* 2018). Any one of these solutions can improve the ecological contrast of the local area, even if the local arable lands had a simple landscape structure, resulting in a positive effect on hare and several other taxa, including pollinator species (Kleijn *et al.* 2011, Langhammer *et al.* 2017, Mayer *et al.* 2018, Marja *et al.* 2019).

AEM effects on hare population in grassland

The AEM affected grasslands had worse vegetation but higher margins quality than the control grasslands (Fig. 7). In spring, we counted the highest number of hares on the control grasslands. Among the grasslands, only the controls had the maximum vegetation score (higher than 10 cm vegetation), which may suggest that the AEM grasslands were more grazed upon than the controls, possibly leading to a negative impact on the abundance of the hare and some bird species (Schmidt *et al.* 2004, Báldi *et al.* 2005, Petrovan *et al.* 2012). The probability of a lower number in "false zeros" found in areas with more vegetation could be related to the hares avoiding open fields or areas with little vegetation (Neumann *et al.* 2011). The AEM legislation had directives to keep unmowed areas on the grassland (Table 1), so that the hares may have a proper resting place, but it seemed just the unmowed areas (if existent and not over-grazed by sheep or cows) were not enough for the hares. At the same time, in the spring breeding season, we saw more hares on the grasslands than the arable lands, which suggested that grasslands may have more diverse plant species (for example, grasses), which were possibly more favourable for the female hares and for some birds species (Piha *et al.* 2007, Pelorosso *et al.* 2008, Schai-Braun *et al.* 2015), or arable lands had high and dense vegetation, which tended to be avoided by the hares (Mayer *et al.* 2018).

AEM effects on the hare dropping density

The hare droppings indicated the resting area and habitat use of the hares (Cardarelli *et al.* 2011). We found much higher dropping density at the grasslands than at the arable lands (Fig. 5), suggesting that grasslands have more grass species that are favourable for hares (Schai-Braun *et al.* 2015) and available in every season. Because we counted more droppings on the grasslands (especially in autumn) (Fig. 5), it's suggested that the continuous plant cover may have a positive effect on the hares' winter survival. Even so, the high-graze fields are avoided by the hares (Schai-Braun *et al.* 2013). Because the increased surveyed area could reduce the "false zeros" of the counted droppings and grasslands had larger areas (in many cases with shorter vegetation height), perhaps finding droppings could have been easier on the grasslands. At the same time, we counted the highest number of hares on the control grasslands, which had the highest vegetation quality. Therefore the higher dropping quantity on grasslands can indicate species-rich grasslands with higher plant diversity and higher vegetation height which are important habitats for hares (Schai-Braun *et al.* 2013) and various bird species (Kovács-Hostyánszki & Báldi 2012).

We found a positive correlation between brown hare dropping densities and the vegetation quality on the arable lands. If the arable lands had a high vegetation quality score, the hares spent more time on the field (Neumann *et al.* 2011), resulting in more droppings (Table 5). Although the vegetation quality was tendentiously better in the AEM fields, we did not find significantly more droppings on the AEM arable lands (Fig. 5 & 7). Still, we would like to highlight that we saw a lot of bare AEM affected arable lands. Set-aside fields can be a solution for the continuous plant cover. More set-aside fields should increase the abundance of the brown hare and some bird species living in the agriculture ecosystem (Kovács-Hostyánszki & Báldi 2012, Mayer *et al.* 2018) and could also increase the proportion of green-agriculture areas, which could positively affect hare populations (Langhammer *et al.* 2017).

The hare droppings count did not correlate significantly with margin quality in any treatment type (Table 5). Though the AEM fields had higher margin scores than the controls in total, the quality of the margins was not high. More than a quarter of the arable fields had less than 9 scores of the margin quality, half of the maximum 18 scores (Fig. 7). We categorised two margins of each arable land. Many of the arable fields had no second margins (Fig. 3); perhaps this was the reason we found no relationship between margins and hare dropping quantity, even though a lot of research showed that margins are very important to hares (Benton *et al.* 2003, MacDonald *et al.* 2007, Petrovan *et al.* 2012, Rodríguez-Pastor *et al.* 2016). We only found a few second or perpendicular margins with larger ecological contrasts to the landscape (Fig. 4). Perhaps a grassy strip or a stubble between two arable fields could act the part of the second margin and positively affect several arthropod taxa (Birkhofer *et al.* 2014, Broughton *et al.* 2014, Marja *et al.* 2014).

IMPLICATIONS AND CONCLUSIONS

Altogether, we found that the Hungarian AEM's, from a conservation point of view, did not have a significant effect. In our study, AEM had a positive effect on the margin quality (or perhaps arable fields with higher margin quality were affected by AEM support, it would need to be measured in the future with a larger samples size). Still, AEM could not increase the vegetation quality on the arable lands and grassland. Moreover, AEM grasslands had significantly lower vegetation quality score, and in spring, we saw significantly less hare on the grassland fields. Brown hares' locomotor activity is more vigorous during the night (Zaccaroni *et al.* 2013), possibly explaining why we did not find a correlation between our hare density data. We counted the hares in the breeding season in spring, perhaps explaining why we saw more individuals as the hares' daytime activity changed. We think that counting the hares between seasons might not be a good indicator. Still, we believe it is a good indicator within a season, comparing the importance of the different treatment groups towards the hares.

Furthermore, most of the time, we did not see many hares on the arable fields, so we think that the counting of the hares during daytime (in the hares' inactive period) itself may not be a good indicator to examine the impact of the AEM. However, counting with indirect signs, for example, the number of droppings could be a better indicator. In the future, we need to use more accurate population estimation methods to see if the AEM can produce a positive effect on the population size (for example, the repetitive hunting bag data).

In many cases, AES-projects' weakness is the lack of result orientation, only the compliance with legislation is under control but without strict goals (Häring *et al.* 2005, Vepsäläinen *et al.* 2010). Therefore, our suggestion is to form the AEM – and most of the AESs too – into result-oriented projects, monitoring selected bioindicators (de Sainte Marie 2014), such as the brown hare. Similar AES's already exist in the United Kingdom and Switzerland (Concepción *et al.* 2020). In Germany, there are AES's whose primary goal is to provide diverse pastures in which to produce an outcome that is monitored on indicator species as well as other groups of species (Zabel & Roe 2009, Kaiser *et al.* 2010, Concepción *et al.* 2020). The French AES called "Flowering meadows" hopes to establish and conserve diverse, nature-related grasslands with dicotyledonous plants and wildflowers with a minimum species number of 20, including the required indicator species. These projects are focused on the results (de Sainte Marie 2014). Other projects may revolve around protecting keystone species, like the wolverines (*Gulo gulo*) in Sweden (Zabel & Holm-Müller 2008). The new cycle of VP-AEM in Hungary (Häring *et al.* 2005, Agriculture and Rural Development 2016) contains similar parts into result-oriented projects and emphasises protecting the field margins. Together with the "greening" of the common agricultural policy, it could provide significant beneficial effects to small game species (European Comission 2019, Concepción *et al.* 2020), which should be monitored in the future.

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