



Artificial field defects: A low-cost measure to support arthropod diversity in arable fields

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ARTICLE INFO

Keywords:

Agri-environmental schemes
Agroecosystems
Beneficial arthropods
Biodiversity
Insects
Non-crop habitats

ABSTRACT

Biodiversity is rapidly declining worldwide, with agricultural intensification being among the main drivers of this process. Effective conservation measures in agricultural landscapes are therefore urgently needed. Here we introduce a novel low-cost conservation measure called artificial field defects, i.e., areas where crop is not sown and spontaneous vegetation grows. To evaluate their biodiversity potential, we compared abundance and species richness of various arthropod taxa between artificially created field defects and control plots within oilseed rape (OSR) fields. The effectiveness of field defects to support biodiversity was examined using an experiment with a factorial design comparing OSR flowering and ripening phases, location of field defects (field edge vs interior) and field defect type (sown with a nectar-rich plant vs no sowing). Arthropod sampling was conducted by employing several complementary methods: pitfall trapping, pan trapping, sweep netting and individual counting. Butterflies, true bugs, bees and wasps were more abundant and species-rich in both types of defects than in OSR controls. In contrast, ground-dwelling taxa had more individuals and species in controls. Overall, arthropod abundance and species richness increased, and field defects became relatively more attractive, during OSR ripening compared to OSR flowering. Location of defects had little effect, with only butterfly and spider assemblages being more abundant and species-rich at field edges compared to interiors. Our data indicate that artificial field defects can provide a simple agri-environmental measure to support various arthropod groups. However, further studies are needed to assess their biodiversity value at the landscape scale, and evaluate the balance between costs and benefits for farmers.

1. Introduction

Biodiversity is rapidly decreasing across the globe (Dirzo et al., 2014; Wagner, 2020). This negative trend is thought to be accelerating and, in some regions, local extinctions occur now even in previously common and widespread species (Van Dyck et al., 2009; Konvicka et al., 2016). A multitude of causes, such as climate change, environmental pollution and biological invasion, are driving the ongoing biodiversity decline (Sanchez-Bayo and Wyckhuys, 2019). However, habitat loss and land-use change are probably the main drivers (Sanchez-Bayo and Wyckhuys, 2019; Chase et al., 2020). Indeed, biodiversity declines have

been especially severe in intensively managed agricultural landscapes, where changes in landscape structure in the last century have been particularly extreme (Newbold et al., 2015; Grab et al., 2019). As a result of socio-economic changes and agricultural industrialization, the historically fine-mosaic landscapes, composed of diverse small habitat patches, have gradually transformed into large arable fields with only limited amounts of non-crop areas and various linear elements (Sklenicka et al., 2009). These structural changes have resulted in the isolation of natural and semi natural habitats and limited landscape permeability (Stoate et al., 2009; Staley et al., 2012).

The biodiversity loss in agricultural landscapes can also pose a

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serious problem to agricultural production, as many crops depend on ecosystem services (e.g., pollination, pest control, decomposition) provided by wild organisms, among which arthropods are particularly relevant (Birkhofer et al., 2018; Noriega et al., 2018; Schowalter et al., 2018). Therefore, a significant effort has been paid to develop measures supporting biodiversity in intensively managed agricultural landscapes. Preservation of existing permanent non-crop habitats, and sometimes the creation of new ones, are among the most efficient biodiversity measures (Van Buskirk and Willi, 2004; Knapp and Rezac, 2015; Grab et al., 2019; Habel et al., 2019; Strobl et al., 2019; Gonzalez et al., 2020a). Unfortunately, the creation of permanent non-crop habitats is not very popular among farmers as it reduces the area that can be used for crop production, and is therefore, from a long-term perspective, considered economically risky (Siebert et al., 2010).

Several widely adopted alternatives rely on improvements directly applied on arable land. These alternatives include reductions in pesticide use, which benefits biodiversity but can significantly reduce crop yields at the same time (Seufert and Ramankutty, 2017). Another promising measure is to increase crop diversity at the field scale by growing several crops within a single field, e.g., using strip planting (two or more crops are planted in narrow and long strips) or intercropping (Brooker et al., 2015). A frequently applied alternative is also the temporary set-aside of arable land for habitat improvement, such as the sowing of nectar-rich plant species (Landis et al., 2000). This approach has, with variable success, been implemented in the European Union via agri-environmental schemes (Batary et al., 2011; Albrecht et al., 2020). Flower strips and other set-aside measures relatively efficiently support arthropod biodiversity and can result in only minimal yield losses at the farm scale (Pywell et al., 2015; Tschumi et al., 2016). A disadvantage of flower strips and other linear habitats is that they are commonly established at field margins and their positive effects on the provision of ecosystem services tend to be limited to only a small proportion of arable land (Kohler et al., 2008; Albrecht et al., 2020). Alternatively, non-crop habitats can be established in central parts of arable fields as in beetle banks used in the UK (MacLeod et al., 2004). Unfortunately, flower strip or beetle bank establishment and maintenance are costly operations (Venturini et al., 2017).

Our recent study was inspired by studies showing that natural processes, e.g., succession, can provide comparable results as human-driven processes, e.g., reclamation, in biodiversity support at a significantly lower cost (Knappova et al., 2017; Rehounkova et al., 2020). In our

previous studies, we have investigated a natural phenomenon called 'field defects'. Field defects are areas within arable fields where the crop is not growing well because of local environmental conditions, e.g., nutrient limitation or water deficiency (Gonzalez et al., 2020b; Seidl et al., 2020). Similar defects can also arise from operator error or machinery malfunction during crop seeding. Note, that in such cases local environmental conditions are suitable for crop growth, but the crop was not sown there. Field defects thus can also be easily created artificially, by intentionally stopping crop sowing anywhere within arable fields, providing a low-cost measure with a potential to support biodiversity on arable land.

In this study, we performed an experiment where artificial field defects were created within oilseed rape (OSR) fields (Fig. 1) in order to test their potential to support arthropod diversity. OSR was selected as a crop species as it is grown over a large area in Europe, and representing 16.7% of arable land in Czech Republic (ČSÚ, 2018) and over 6% of arable land in European Union in 2018 (EUROSTAT, 2018). Moreover, natural field defects are common in this crop, and it shows substantial fluctuation in resource provision – large green biomass and nectar amounts during mass blooming are followed by rapid disappearance of these resources afterwards (FAOSTAT, 2019; Seidl et al., 2020; Shaw et al., 2020). Specifically, we tested the following hypotheses: 1) Contrasting environmental conditions and vegetation structure between field defects and OSR crops will result in significant differences in arthropod abundance, species richness, and species composition; 2) Dispersal limitation will result in reduced abundance and species richness of arthropods in plots situated in field interiors compared to those at field margins (Boetzl et al., 2019); 3) Temporal changes in resource availability (OSR mass blooming in spring, increased flowering of wild plants in field defects in summer) will affect the spatial distribution of arthropods (Riedinger et al., 2014); 4) Addition of flower resources (sowing of nectar-rich plants in defects) will increase field defect attractiveness to flower-visiting arthropods (Rundloef et al., 2018). As particular taxa may strongly differ in their responses to local environmental conditions, the only robust approach to evaluate the effectiveness of conservation measures is to investigate diverse taxonomic groups in parallel in the same experimental setup (Kati et al., 2004; Billeter et al., 2008). In the present study, we investigated the effect of artificial field defects on eight arthropod taxa with varying resource requirements and dispersal abilities.

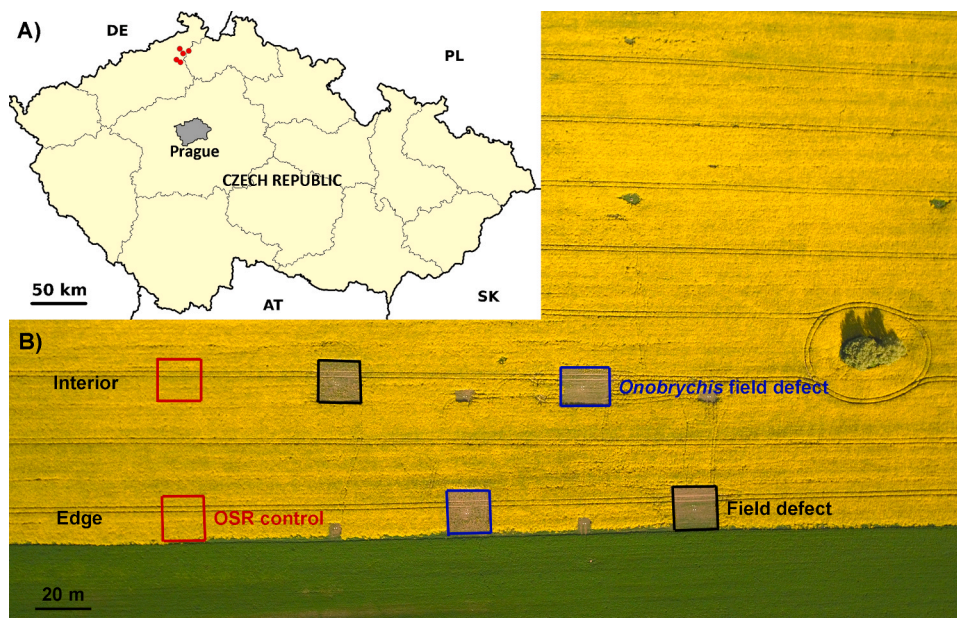


Fig. 1. Study sites location and experimental design. A) Location of investigated oilseed rape (OSR) fields (red dots) in Northwestern Czech Republic; B) Example of an OSR field showing the study design. Investigated plots (ca. 18 × 18 m) were situated at the field edge and interior (ca. 60 m from the field edge). Field defects (unsown) are shown in black, *Onobrychis* field defects in blue and OSR controls in red. (For interpretation of the references to colour in this figure, the reader is referred to the web version of this article.)

2. Materials and methods

2.1. Study area and sampling design

The study was performed in the northwestern part of the Czech Republic (Fig. 1A; 50.5468–50.5970°N, 14.2537–14.2989°E; ca. 20 km²), in an intensively cultivated lowland landscape at an altitude of ca. 330 m a.s.l., where non-crop habitats cover ca. 20–25% of the land area. In this region, the average annual rainfall is ca. 550 mm and the annual average temperature is around 9 °C (CHMI, 2020). In 2017, we selected five medium-sized arable fields (14.5–32.5 ha) sown with winter oilseed rape (OSR) in September. Within each field, we established four square plots (18 × 18 m; artificial field defects) where OSR was not sown. The size of artificial defects corresponds well to the size of natural field defect recorded in our previous study (Seidl et al., 2020). Of these, two field defects were located at the field edge and two in the field interior (ca. 60 m from the edge; Fig. 1B). Field defects at the edge were always neighbouring a natural or semi-natural habitat (4 × grassland and 1 × broadleaf forest). Furthermore, while half of the created field defects were left to be fully colonized by spontaneous vegetation, half of the created field defects ('*Onobrychis* field defects') were sown with common sainfoin (*Onobrychis viciifolia* Scop., Fabaceae) in early April 2018 (Fig. 1B; Appendix A1: Fig. A1). Common sainfoin is a nectar-rich perennial plant attractive to many pollinators, e.g., bees and butterflies, flowering continuously from May to September when sufficient precipitation is available (Gorenflo et al., 2017). Unfortunately, the extremely dry spring in 2018 resulted in only limited survival and growth of sown plants, and respective evidence must therefore be considered with caution. To compare arthropod communities in field defects with those in surrounding OSR crops, we established two control plots (18 × 18 m) within each investigated field (one plot at the edge and one in the interior; Fig. 1B). Note that both control plots and field defects were exposed to the same agricultural management (insecticide and herbicide application) from autumn 2017 to the end of arthropod sampling in late June 2018. The relatively small size of our artificial field defects made effective pesticide exclusion impossible anyway. However, no insecticide applications were performed during the two weeks before pan traps exposition, sweep-netting, and transect counting dates.

2.2. Arthropod sampling

To gain a better understanding of the effectiveness of artificial defects in supporting different arthropod communities, we used a multi-taxa approach (Kati et al., 2004; Billeter et al., 2008). Samples were collected for eight arthropod taxa: butterflies (diurnal Lepidoptera), bees and wasps (Hymenoptera: Aculeata), hoverflies (Diptera: Syrphidae), carabid beetles (Coleoptera: Carabidae), rove beetles (Coleoptera: Staphylinidae), true bugs (Hemiptera: Heteroptera), spiders (Araneae), and myriapods (Diplopoda and Chilopoda combined). These focal taxa differ widely in their functional traits, represent different trophic levels (herbivores, predators, decomposers, pollinators), have varying dispersal abilities (from sedentary to highly mobile taxa), sensitivity to environmental conditions, adult longevity, etc.

To obtain as representative samples as possible, we collected data using several sampling techniques in parallel (Rhoades et al., 2017; Strobl et al., 2019; Knapp et al., 2020). We used pitfall traps, yellow and white pan traps, sweep-netting, and timed butterfly surveys. Sampling was performed during two periods of OSR development. In particular, the first sampling was performed in mid-May (2018) when OSR was mass-flowering and field defects were dominated by bare ground. The second sampling took place in mid-June (2018), during ripening phase of the crop, when field defects were to a large extent covered by vegetation and flowering plants were present (see Appendix A1: Fig. A2).

During each sampling period and within each sampling plot (2 × field defect, 2 × *Onobrychis* field defect, and 2 × control plot per

field), we installed two pitfall traps, one white and one yellow pan trap, and performed sweep-netting and timed butterfly survey. Pitfall traps were placed ca. 2 m from each other in the central part of each plot and were exposed for ca. four weeks during each sampling period (starting on 29th April and 27th May). Traps were made of two transparent plastic cups (diameter 10 cm), covered with an aluminium roof (ca. 25 × 30 cm), and filled with 33% propylene glycol (diluted with water) as preservation fluid. One pan trap of each color was placed in the middle of each plot, on top of wooden poles that were adjusted at the height of the surrounding vegetation, and left exposed for 48 h in mid-May and mid-June 2018 during days with sunny and warm weather. Pan traps were made of plastic dishes (diameter 25 cm, depth 4 cm) filled with a saline solution with a few drops of detergent. During the same periods, sweep netting and visual counting were performed. Sweep netting (50 sweeps using a 35 cm diameter sweeping net) was performed evenly across the whole area of each sampling plot. For timed butterfly survey, all butterfly individuals were counted by an experienced lepidopterologist for 5 min per plot. Sweeping and butterfly surveys were performed during favorable weather conditions for insect activity (sunny days with no rainfalls or strong winds, between 9 am and 5 pm). Samples collected using pitfall traps were stored in a freezer, pan trap and sweep-netting samples were fixed using 70% ethanol prior to future processing.

In the laboratory, all stored samples were sorted into the eight above-mentioned focal higher taxa, individuals from other taxa were excluded. In the next step, all adult individuals of the focal taxa (also juveniles in the case of Myriapoda) were identified to species level by specialists. Finally, we pooled together the data for each taxon recorded by the different sampling techniques to obtain one sample per taxon per sampling plot and sampling period. For example, true bugs were collected mainly with pitfall traps and sweep-netting. For each group and sample, we calculated the species richness and abundance of each focal taxon for subsequent analyses, i.e., species richness and abundance were summed up across multiple methods.

2.3. Statistical analyses

Generalized linear mixed models (GLMMs) were applied to analyze the effects of experimental factors on the species richness and abundance of the studied arthropod groups. The explanatory variables in the models were habitat type (field defects, *Onobrychis* field defects, controls), field defect location (edge vs interior), sampling period (OSR flowering vs ripening phase), as well as paired interaction terms between these variables. Models for species richness were fitted assuming a Poisson error distribution, with a log link function, whereas those for abundance were fitted using a negative binomial error distribution instead due to overdispersion. To account for the nested structure of the study design, field identity was used as a random variable.

For model selection, we started with the full model that included habitat type, sampling period, field defect location and all interactions between these variables. Next, we simplified this model by removing all nonsignificant variables using likelihood ratio tests (χ^2 tests; $\alpha = 0.05$). To detect significant differences in the species richness and abundance of each arthropod group between habitats, Tukey's post hoc tests were performed with the package multcomp (Hothorn et al., 2008). All univariate analyses were performed with R software version 4.0.3 (R Development Core Team, 2020) using the package lme4 (Bates et al., 2015). We checked that all models met the validation criteria using the package performance (Lüdtke et al., 2021).

To analyse differences in community composition between habitat types, field defect location, and sampling periods, we performed redundancy analyses (RDA) in R, using the package vegan (Oksanen et al., 2007). RDAs were performed for each of the study groups separately, using habitat type, field defect location, sampling period and their paired interactions as independent variables. In these analyses, we used log-transformed data, and field ID was included as a conditional

factor to account for the nested design of the study. The best model for each study group was selected using a stepwise selection procedure (999 permutations; function ‘step’ in R) to identify the model with the lowest AIC value. Furthermore, an Indicator Species Analysis with the R package *indicspecies* (De Caceres and Legendre, 2009) was performed to determine if there were species associated with particular habitat type, phenological period, and/or field defect location. For each arthropod group, identified indicator species were plotted in the RDA figures. Finally, in order to explore differences among habitat types in detail, pairwise comparisons were performed using the package *RVAideMemoire* (Herve, 2020), which allows to compare factor levels with corrections for multiple tests.

3. Results

A total of 33 004 arthropod individuals from 388 species were collected in this study (Appendix A2). Great majority of the recorded species were common habitat generalist species, yet 26 species (i.e., 6.7%; 15 species in controls, 13 in field defects and 11 in *Onobrychis* field defects) are included in the Red List of Czech Republic (see Appendix A2, for details). Total arthropod species richness was similar in the three habitat types (field defects 247 species, *Onobrychis* field defects 245 species, OSR crop controls 241 species). However, individual taxa showed contrasting patterns of abundance and species richness across habitat types (see below).

3.1. Abundance

Most of the arthropod taxa that responded to habitat type were more abundant in both types of defects than in OSR controls (Table 1; Fig. 2; Appendix A1: Table A1). Bees and wasps were more abundant in both types of defects than in controls during both sampling periods, whereas the same was true for butterflies during OSR flowering and true bugs during OSR ripening (Fig. 2). Spider abundance was highest in field defects, intermediate in *Onobrychis* field defects, and lowest in controls (Fig. 2). By contrast, carabid beetles were more abundant in controls

than in defects. Rove beetle responses switched between sampling periods: during OSR flowering, abundance was lower in controls, intermediate in field defects, and higher in *Onobrychis* field defects, whereas during ripening controls had more individuals than both defect types (Fig. 2). Finally, myriapods and hoverflies had similar numbers of individuals across habitat types.

Most taxonomic groups clearly increased in abundance between OSR flowering and ripening periods, both in defects and control plots (Table 1; Fig. 2; Appendix A1: Table A1). The exceptions were myriapods, whose abundance did not differ between the two periods, and rove beetles which increased in abundance between the two periods only in controls (Fig. 2).

The abundance of most taxonomic groups did not differ between edge and interior plots (Table 1). Only butterflies and spiders were consistently more abundant at the field edges (Appendix A1: Table A1 and Fig. A3) and field interiors hosted higher abundances of myriapods during OSR flowering phase, and of bees and wasps during ripening phase (Appendix A1: Table A1 and Fig. A3).

3.2. Species richness

Habitat type had diverse effects on the species richness of arthropod groups (Table 1; Appendix A1: Table A1). Bees and wasps, true bugs, and butterflies were more species-rich in both types of defects than in control plots irrespective of sampling period (Fig. 3). Carabid beetles, rove beetles, and myriapods showed the opposite pattern, with more species in OSR controls. However, rove beetles had an intermediate richness in field defects and myriapods in *Onobrychis* field defects (Fig. 3). Neither spiders nor hoverflies showed differences in their richness among habitat types.

Species richness of most taxa – bees and wasps, true bugs, carabid beetles, butterflies, and hoverflies – increased between the two sampling periods, being lower during OSR flowering and higher during OSR ripening (Table 1; Fig. 3). By contrast, the species richness of spiders, rove beetles, and myriapods did not change between the two periods (Table 1; Fig. 3).

Table 1

Results of the likelihood ratio tests used for model selection for the effects of habitat type, sampling periods, and location of plots on the abundance and species richness of arthropods in oilseed rape fields. For each response variable and arthropod group, χ^2 and p values (in parentheses) for each independent variable and their interactions are shown. Significant variables are highlighted in bold.

Response variable	Group	Habitat type	Phenological stage	Location	Habitat * Phenological stage	Habitat * Location	Phenological stage * Location	Habitat * Phenological stage * Location	
Abundance	Lepidoptera	21.85 (<0.001)	134.38 (<0.001)	4.20 (0.04)	12.06 (0.002)	1.29 (0.52)	0.46 (0.50)	1.35 (0.51)	
	Hymenoptera	18.52 (<0.001)	71.84 (<0.001)	1.99 (0.16)	8.63 (0.005)	7.73 (0.02)	1.07 (0.58)	1.63 (0.44)	
	Syrphidae	2.36 (0.31)	79.12 (<0.001)	0.72 (0.40)	4.30 (0.12)	0.97 (0.62)	1.21 (0.17)	2.78 (0.25)	
	Carabidae	15.11 (0.001)	23.05 (<0.001)	0.11 (0.73)	0.99 (0.61)	0.04 (0.98)	0.01 (0.99)	0.92 (0.63)	
	Staphylinidae	1.51 (0.47)	2.81 (0.09)	0.47 (0.49)	21.79 (<0.001)	2.50 (0.29)	3.73 (0.06)	0.40 (0.82)	
	Heteroptera	35.55 (<0.001)	0.01 (0.99)	0.17 (0.68)	7.52 (0.02)	1.47 (0.48)	3.66 (0.06)	0.82 (0.66)	
	Araneae	8.30 (0.02)	21.68 (<0.001)	4.93 (0.03)	5.06 (0.08)	0.04 (0.98)	1.64 (0.20)	0.29 (0.87)	
	Myriapoda	2.75 (0.25)	0.04 (0.84)	1.03 (0.31)	2.31 (0.31)	3.19 (0.20)	4.30 (0.04)	0.34 (0.84)	
	Species richness	Lepidoptera	10.53 (0.005)	15.22 (<0.001)	6.84 (0.009)	1.93 (0.17)	0.64 (0.72)	0.58 (0.75)	0.14 (0.93)
		Hymenoptera	15.35 (0.001)	41.00 (<0.001)	0.05 (0.82)	2.19 (0.34)	0.95 (0.62)	0.05 (0.83)	0.98 (0.61)
Syrphidae		0.88 (0.64)	76.94 (<0.001)	0.01 (0.91)	3.98 (0.14)	3.20 (0.20)	3.21 (0.07)	1.56 (0.46)	
Carabidae		18.68 (<0.001)	11.28 (0.001)	1.43 (0.23)	0.70 (0.70)	0.33 (0.85)	0.67 (0.41)	1.02 (0.60)	
Staphylinidae		8.87 (0.01)	1.23 (0.27)	0.14 (0.71)	4.70 (0.10)	0.23 (0.89)	1.03 (0.31)	1.27 (0.53)	
Heteroptera		40.42 (<0.001)	106.9 (<0.001)	0.82 (0.36)	4.01 (0.13)	0.34 (0.85)	1.15 (0.28)	0.57 (0.75)	
Araneae		1.64 (0.44)	3.15 (0.08)	5.89 (0.02)	2.48 (0.29)	0.28 (0.87)	0.17 (0.68)	0.40 (0.82)	
Myriapoda		7.78 (0.02)	2.84 (0.09)	2.84 (0.09)	0.54 (0.77)	1.08 (0.58)	0.002 (0.97)	0.24 (0.89)	

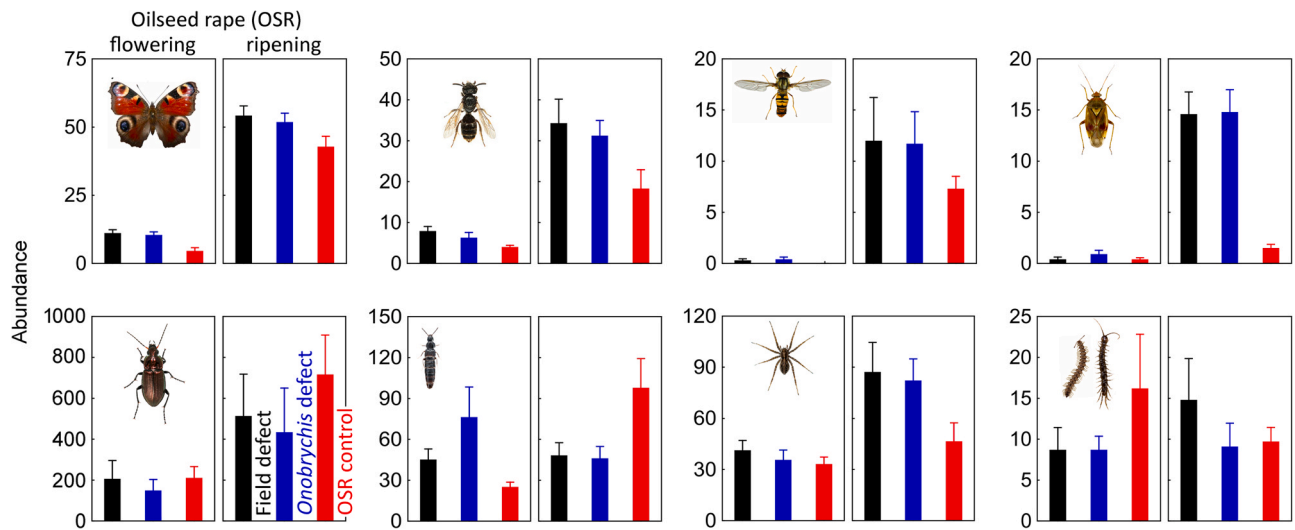


Fig. 2. Effects of habitat type and sampling period on arthropod abundance within oilseed rape (OSR) fields. Habitat types are shown with different colors: OSR controls in red, field defects in black, and *Onobrychis* field defects in blue. Data are shown separately for OSR flowering and ripening periods. Mean values and standard errors are shown separately for butterflies, bees and wasps (combined), hoverflies, true bugs, carabid beetles, rove beetles, spiders and myriapods. (For interpretation of the references to colour in this figure, the reader is referred to the web version of this article.)

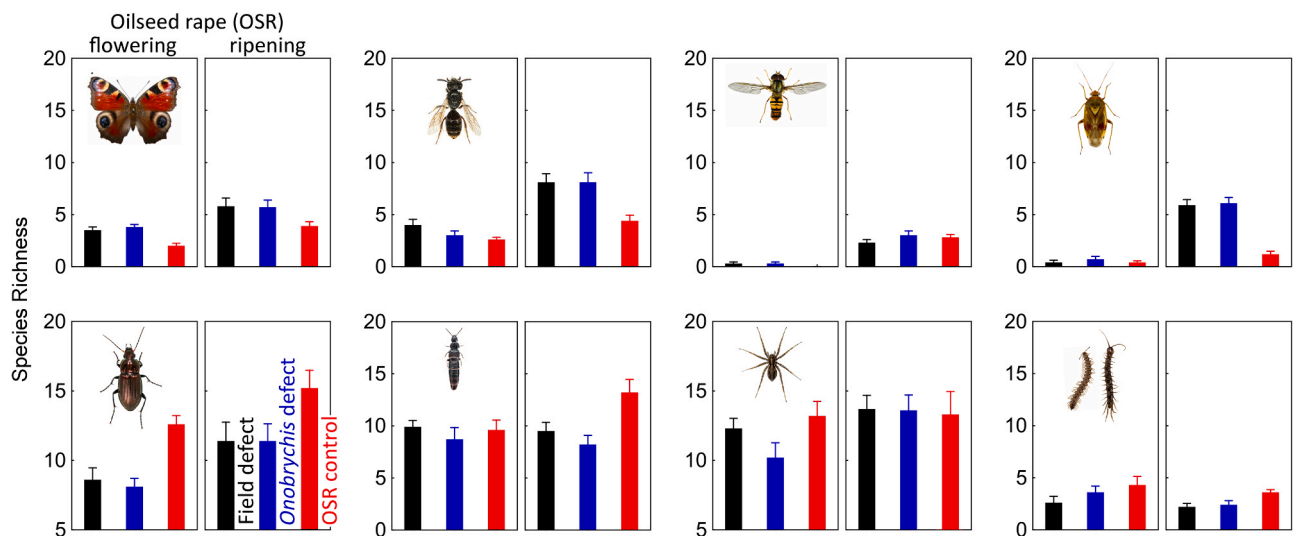


Fig. 3. Effects of habitat type and sampling period on arthropod species richness within oilseed rape (OSR) fields. Habitat types are shown with different colors: OSR controls in red, field defects in black, and *Onobrychis* field defects in blue. Data are shown separately for OSR flowering and ripening periods. Mean values and standard errors are shown separately for butterflies, bees and wasps (combined), hoverflies, true bugs, carabid beetles, rove beetles, spiders and myriapods. (For interpretation of the references to colour in this figure, the reader is referred to the web version of this article.)

Table 2

Results of the model selection process for the Redundancy Analyses (RDA) analyzing the effects of habitat type, sampling periods, and location of plots on the species composition of arthropods in oilseed rape fields. For each response variable and arthropod group, F and p values (in parentheses) for each independent variable and their interactions are shown. Significant variables are highlighted in bold.

Group	Habitat type	Phenological stage	Location	Habitat * Phenological stage	Habitat * Location	Phenological stage * Location
Lepidoptera	3.23 (0.01)	54.42 (0.001)	1.89 (0.12)	2.07 (0.05)	0.85 (0.68)	1.79 (0.11)
Hymenoptera	4.26 (0.004)	55.06 (0.001)	1.68 (0.15)	3.54 (0.002)	0.89 (0.46)	1.45 (0.20)
Syrphidae	1.27 (0.32)	55.62 (0.001)	0.37 (0.70)	0.59 (0.62)	0.37 (0.84)	0.66 (0.51)
Carabidae	9.39 (0.001)	20.75 (0.001)	1.35 (0.19)	1.57 (0.10)	0.50 (0.96)	0.88 (0.53)
Staphylinidae	3.41 (0.001)	4.65 (0.001)	1.50 (0.11)	3.95 (0.001)	1.18 (0.22)	1.04 (0.39)
Heteroptera	4.32 (0.002)	24.30 (0.001)	0.55 (0.73)	4.43 (0.002)	1.09 (0.31)	0.86 (0.43)
Araneae	5.30 (0.001)	2.27 (0.02)	16.85 (0.001)	2.48 (0.29)	1.19 (0.17)	0.95 (0.54)
Myriapoda	3.12 (0.001)	3.73 (0.003)	2.53 (0.02)	0.92 (0.52)	2.49 (0.006)	1.31 (0.22)

Location of plots had limited effect on the species richness in most studied groups (Table 1). As exceptions, spiders and butterflies were more species-rich at the edge (Appendix A1: Fig. A3).

3.3. Species composition

The species composition of most arthropod groups was influenced by habitat type (Table 2; Fig. 4; Appendix A1: Table A2), and several indicator species for particular habitat types could be identified (Fig. 4; see Appendix A1: Table A3, for details). The species composition of carabid beetles, spiders, bees and wasps, and rove beetles in both types of defects differed markedly from controls during both sampling periods (Fig. 4; Appendix A1: Table A2). In some groups, also the interacting effects of habitat type and sampling period or plot location on species composition appeared to be significant (Table 2; Appendix A1: Table A2). For example, the species composition of true bugs in both defect types differed from OSR controls during OSR ripening, whereas the three habitat types shared a similar species composition during OSR flowering (Fig. 4; Appendix A1: Table A2). Myriapod species composition differed between control plots and both defect types at the edge but not in the field interior (Fig. 4; Appendix A1: Table A2). Field defects and controls differed strongly in the species composition of butterflies especially during OSR flowering (Fig. 4; Appendix A1: Table A2). Hoverflies were the only group in which the species composition was similar across the three habitat types irrespective of location or OSR phenological stage (Fig. 4; Appendix A1: Table A2).

Species turnover between the two sampling periods occurred in all investigated taxa (Table 2). The shift in species composition was especially pronounced in hoverflies, butterflies, bees and wasps, carabid beetles and spiders (Fig. 4).

The effects of within-field location of plots on species composition were quite limited. Only spider and myriapod assemblages differed between field edges and interiors (Table 2; Fig. 4).

4. Discussion

Although agricultural fields are commonly spatially heterogeneous in many aspects and have areas where the crop performs poorly, the relevance of features such as field defects for biodiversity is poorly understood. This study investigated the response of a wide array of arthropod groups to artificial field defects created within oilseed rape fields. Our results provide evidence that artificial field defects represent a promising measure to increase environmental heterogeneity within arable land and benefit various arthropod groups. However, the taxon-specific responses observed highlight the importance of considering multiple focal taxa to fully evaluate the effectiveness of particular biodiversity measures in agricultural landscapes.

Overall, artificial field defects increased local abundance and species richness of these arthropod taxa that are closely associated with plants, whereas ground-dwelling taxa (carabid beetles in particular) did not benefit from field defect creation. Ground-dwelling taxa are frequently sensitive to microclimatic conditions and many species prefer humid microhabitats over dry ones (Holland et al., 2007). As vegetation cover increases soil humidity and decreases its surface temperature, field defects with their sparser vegetation cover (and bare ground early in the season) are likely to be a suboptimal habitat for such species. This explanation is strongly supported also by our previous study investigating carabid assemblages in natural field defects, where carabid species richness was found to increase with vegetation cover (Seidl et al., 2020).

Despite a sparser vegetation cover, field defects usually have higher plant species richness than the surrounding crop monoculture. This may explain why plant-associated arthropod taxa, e.g., butterflies, bees, and true bugs, benefited from artificial field defects. Indeed, it is well known that plant species richness is an important driver of pollinator, and especially herbivore species richness (Hudewenz et al., 2012; Lin et al.,

2015). Theoretically, sowing nectar-rich plants in field defects should increase habitat attractiveness for both ground-dwelling and pollinator taxa, as it will increase total plant cover and will provide additional resources for nectar- and pollen-feeding species (Batory et al., 2011; Albrecht et al., 2020). However, *Onobrychis* sowing had almost no effect on arthropod abundance or species richness in this study, even not on flower-visiting taxa. The most likely explanations for this result are methodological: limited seedling recruitment of *Onobrychis* resulting from extremely dry spring and early summer of 2018, and plant grazing as a consequence of high *Onobrychis* attractiveness to large herbivores like roe deers. As a result, *Onobrychis* defects and spontaneously vegetated defects did not differ much in their flowering resources (Appendix A1: Figs A1 and A2). In addition, unsown field defects may provide more suitable habitat for naturally occurring weed species, including rare and threatened species (Fried et al., 2009). Nevertheless, an important argument in favour of unsown field defects is also the ease of their creation: establishing sown field defects requires additional agricultural operations that makes them economically less affordable.

Arthropod distribution within arable fields commonly changes during the season and mass flowering crops can strengthen this pattern (Geslin et al., 2016; Knapp et al., 2019). During flowering, OSR offers huge amounts of green biomass as well as extensive pollen and nectar resources for diverse arthropod groups, especially for pollinators, parasitoids, and herbivores (Alford, 2003). By contrast, during ripening, OSR provides only limited resources to arthropods, as OSR flowers for only a few weeks and above-ground biomass rapidly dries up (Alford, 2003). This rapid deterioration of resources contrasts with the situation in field defects, where plant cover persists and nectar availability increases throughout the growth season (Appendix A1: Fig. A2). Interestingly in this light, in absolute terms, abundances of nearly all taxa increased from spring to summer in both field defects and OSR crops. However, this pattern is likely to be driven by species phenologies rather than increasing habitat quality of investigated arable fields, as for many arthropod species summer individuals represent the offspring of the spring generation and are thus more abundant (Chapman et al., 2012). Moreover, the significant species turnover between sampling periods indicates that different species occurred in spring and in summer. Nevertheless, the relative distribution of individuals among habitat types appeared to shift between the two phenological periods: with the season progressing, field defects became more attractive than OSR for several arthropod taxa, with the interesting exception of rove beetles, which showed the opposite pattern. As rove beetle assemblages in arable fields are dominated by ground-dwelling and topsoil layer inhabiting species with specific microclimatic demands (Krooss and Schaefer, 1998), high summer temperatures may exacerbate microclimatic unsuitability of field defects for this group.

We found only a minor effect of within-field location of plots on arthropod assemblages, which is in some contradiction with the presumed effects of dispersal limitation. In fact, only the abundance and species richness of spiders and butterflies were higher on field edges compared to field interiors. In case of spiders, dispersal limitation is likely to be invoked (Picchi et al., 2016; Kolb et al., 2020), which is also supported by existing species turnover between field edge and interior. However, butterflies are known for their good dispersal abilities, and tens of meters wide crop separating interior plots from field edges would no way present a significant barrier for this insect group (Stevens et al., 2010; Viljur and Teder, 2018). Instead, a more plausible explanation for the observed pattern is the lack of suitable food plants in field defects. Most open-habitat butterflies are rather specialized in their resource use, and suitable resources are typically associated with semi-natural grasslands in arable landscapes rather than with early-successional vegetation typical for first-year field defects. Increased butterfly abundance and species richness in field edges thus likely resulted from a spillover effect from neighbouring semi-natural habitats (Ockinger et al., 2012). A difference in abundance and species richness between edge and interior plots was hypothesized for a wide range of arthropod taxa investigated

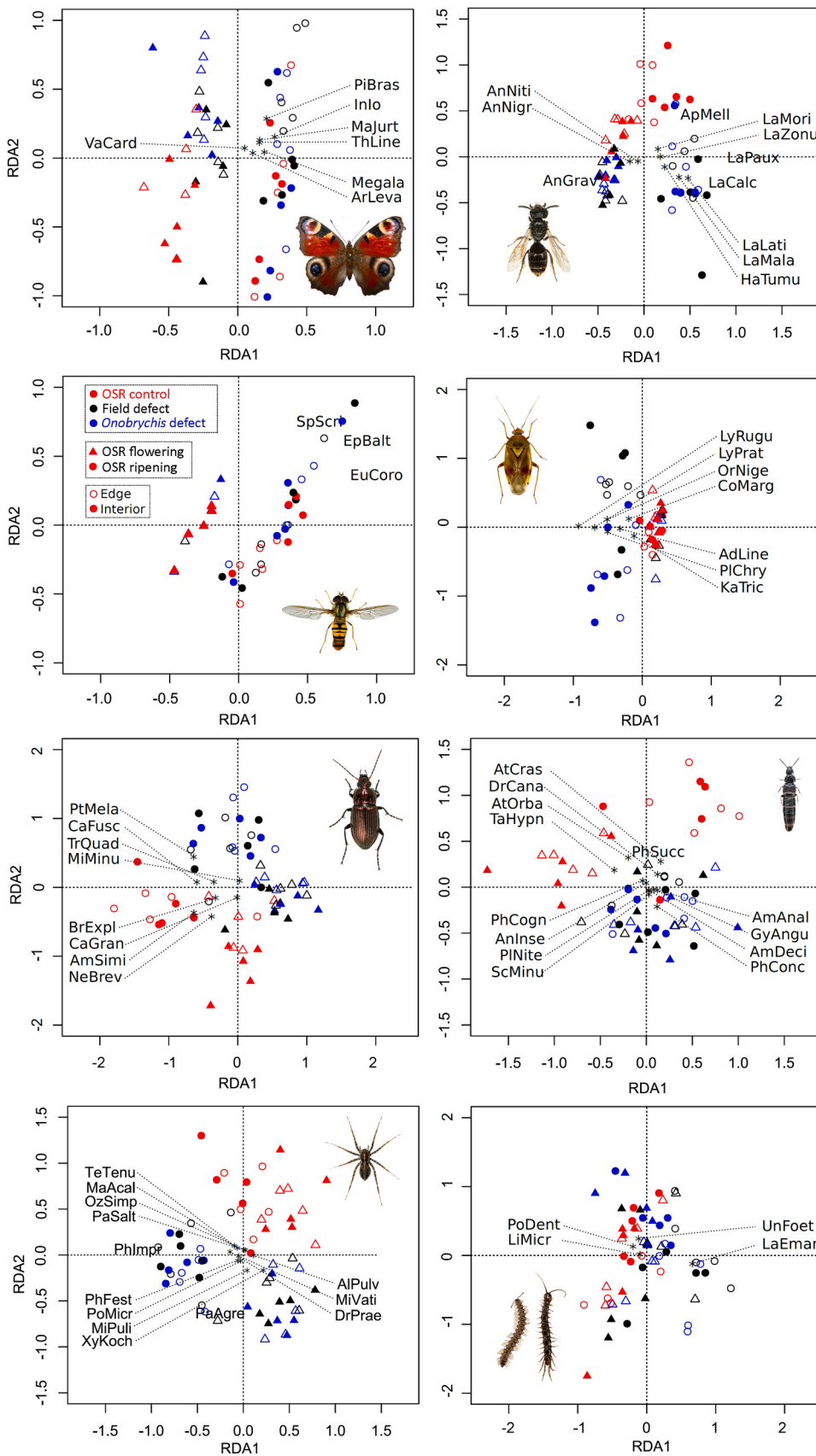


Fig. 4. Ordination plots showing the effects of habitat type, sampling period, and location of plots on arthropod species composition within oilseed rape (OSR) fields. Habitat types are shown with different colors: OSR controls in red, field defects in black, and *Onobrychis* field defects in blue. Samples from OSR flowering period are shown with triangles and samples from OSR ripening with circles. Samples from field edges are shown with empty symbols and samples from field interiors with filled symbols. Indicator species from the Indicator Species Analysis are shown using stars and lines connecting each star with the species abbreviation. For complete species names corresponding to each abbreviation, please see [Appendix A1: Table A2](#). (For interpretation of the references to colour in this figure, the reader is referred to the web version of this article.)

in this study but even arthropod taxa including species with limited dispersal abilities, e.g., myriapods (David and Handa, 2010), were equally abundant or even more abundant in field interiors than at edges. This may indicate that distances of this magnitude are not limiting for arthropods inhabiting arable land (Woodcock et al., 2016) or field interiors represent source rather than suboptimal habitats for some arthropod groups (Knapp and Rezac, 2015). In such case the creation of field defects within arable fields can be equally efficient as at their edges. This would nicely complement the existing agri-environmental schemes, e.g., flower strips, which are commonly established at field margins (Albrecht et al., 2020).

To further evaluate the potential of artificial field defects for biodiversity conservation within arable land, future research investigating long-term effects at larger spatial scales is needed. Farm-scale studies, comparing fields with and without artificial field defects across different crops and considering also wild plants and vertebrates as focal taxa, may provide further insight. Moreover, attention should also be provided on agricultural management within field defects as well as their size. The small field defects (18 × 18 m) employed in this study were exposed to routine field management, i.e., pesticide applications that may strongly compromise their conservation potential (Brittain et al., 2010). Ephemeral defects exposed to disturbances (e.g., tillage) later in the growing season may function as an ecological trap, i.e., attractive pieces of habitat in early summer where arthropods will suffer high mortality later (Ganser et al., 2019). Establishing perennial defects persisting for longer periods in the same location may help to partly overcome this problem. Moreover, perennial defects can host more developed plant communities that can support more diverse arthropod assemblages (Hudewenz et al., 2012; Requier et al., 2015; Seidl et al., 2020). Field defects in our study supported taxa of high conservation priority, such as butterflies and bees, that are widely known to decrease in agricultural landscapes (Ollerton et al., 2014; Habel et al., 2016; Wagner, 2020). By contrast, taxa that were more abundant within arable land, e.g., carabid beetles, were dominated by agrobiont species that are commonly found in crops, even at higher numbers than in neighbouring non-crop habitats (Knapp and Rezac, 2015).

We are aware that arthropod sampling is prone to various methodological issues that can obscure real biodiversity patterns (O'Connor et al., 2019; Knapp et al., 2020). For example, OSR mass flowering can reduce pan trap efficiency (O'Connor et al., 2019), and may result in an underestimation of abundance and richness in control plots during OSR flowering period. However, additional analyses comparing the performance of pan traps and vegetation sweeping for bees and wasps in our study show similar patterns for both methods, and do not invalidate qualitative conclusions (Appendix A1: Fig. A4). Moreover, pan trap efficiency should be relatively higher within control patches (OSR crop) during OSR ripening, but the relative difference between habitats decreased during that period for bees and wasps (Appendix A1: Fig. A4). Different sampling methods can help to record species with different traits (Knapp et al., 2020), and limitations of particular sampling methods can be overcome by using a combination of several complementary methods to sample focal arthropod groups (Rhoades et al., 2017; O'Connor et al., 2019). For example, a detailed inspection of our data revealed that the decrease in spider abundance in control plots during OSR ripening was caused mainly by the increased abundance of plant utilizing species for both field defect types (Appendix A1: Fig. A4).

The creation of artificial field defects is an easily applicable measure compared to existing agri-environmental measures relying on set-asides. Farmers do not need additional mechanisation, agricultural operations, or material inputs (seeds, fuel, etc.): they just need to stop sowing to create field defects. Although more persistent defects can be more beneficial for biodiversity, even long-term field defects still represent habitat patches that can be easily converted back into arable land. Artificial field defects can also provide farmers with benefits related to increased ecosystem services (pollination, pest control); however, at the same time other ecosystem services, mainly pest predation related to

carabid beetle activity, can be lower in field defects compared to the surrounding crops (Gonzalez et al., 2020b), and future studies should investigate this issue in more detail. Artificial field defects may provide an efficient measure for conservation of threatened weed species (Fried et al., 2009) but, at the same time, a potential source of annoying common weeds for farmers who aim to minimize weed spread to cropped areas (Marshall, 2002). We observed that some pest species (aphids and pollen beetles) occurred in our field defects during OSR ripening period, which indicates that future studies investigating field defects should focus also on pest populations and related ecosystem disservices. Finding a balance between conservation benefits and agronomic problems associated with artificial field defects thus represents a major research challenge that may need to be solved before the adoption of this conservation measure in common agricultural practice. Finally, as herbicides can negatively affect the establishment of wild plants in field defects, the supporting role of field defects for biodiversity could be improved in organically managed fields. Therefore, future studies could also compare field defect performance under various management approaches.

5. Conclusions

In conclusion, the creation of artificial field defects, i.e., quite small non-crop patches, within cultivated fields might have considerable positive effects on arthropod diversity. These patches represent a low-cost measure that can be easily adopted by a wide range of farmers and help to fulfil biodiversity targets of the EU Common Agricultural Policy. However, field defects benefited mainly arthropod groups that feed on plants, e.g., pollinators and herbivores and improvements might be needed to support ground-dwelling arthropods. Furthermore, further studies are needed to evaluate their biodiversity effects at the landscape scale, as well as to assess the value of artificial field defects to farmers by measuring their influence on the provision of ecosystem services and disservices under various agricultural management regimes.

Funding

This study was supported by the Czech Science Foundation (grant number 18-26542S), the Technology Agency of the Czech Republic (grant number SS02030018 – DivLand), the Internal Grant Agency of Faculty of Environmental Sciences, Czech University of Life Sciences Prague (grant number 42110/1312/3118) and by the Estonian Research Council (grant number PRG741).

Declaration of Competing Interest

There are no conflicts of interest.

Data availability

The raw data used in the article are available through Mendeley Data (will be uploaded after the acceptance).

Acknowledgments

We would like to thank the farm ZD Liběšice (namely Václav Grindler) for collaboration during artificial field defect creation and for the permission to perform fieldworks in their arable fields, Michal Řericha, Tomáš Jor, Helena Antošová and others for their help in data collection. We also thank Pavel Moravec, Karel Tajovský, Antonín Kůrka, Jiří Hadrava, Antonín Hlaváček and Tomáš Jászay for help with arthropod identification. Finally, we also thank Ben Woodcock and an anonymous reviewer for their helpful comments on the first version of the manuscript.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.agee.2021.107748.

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