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Size of fragments of woodland in rural landscapes affects assemblages of ground dwelling invertebrates

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Abstract. Due to intensive farming fragments of woodland and hedgerows were almost eliminated and the diversity of invertebrates in agriculture landscapes decreased. The aim of this study was to evaluate the effect of the size of fragments of woodland and hedgerows on the distribution of ground dwelling invertebrates in agricultural landscapes in southern Moravia. Invertebrates were collected using pitfall traps, which were set for three weeks in fragments of woodland during the vegetative seasons in 2016–2017. We focused on the patterns in the distributions of ground beetles (Carabidae), spiders (Araneae) and harvestmen (Opiliones). The dominant species were those that prefer open habitats. We found that small patches of woodland were inhabited by more diverse assemblages than the large ones. Our findings highlight that not only large fragments of woodland, but also small fragments and hedgerows deserve more attention as they are important in maintaining a high diversity of ground dwelling invertebrates.

Key words. Agricultural landscape, Araneae, Carabidae, Opiliones, species richness.

INTRODUCTION

The agricultural landscape consists of a heterogeneous and dynamic mosaic of landscape elements (Petit & Usher 1998, Diekötter et al. 2007). In addition to crop fields, different types of uncultivated natural habitats are present. Such landscape elements like forests, meadows, hedges, ponds, marshes, ditches, tree lines, solitary trees, groups of trees and stone walls play major roles as refuges, corridors or shelters for species (Peña et al. 2003, Aviron et al. 2005, Diekötter et al. 2007). Woodland features such hedgerows are among the most stable parts of such landscapes (Petit & Usher 1998). They are shaped by human activity and fulfil ecological and cultural functions in the landscape, as in such fragments there many species of ground dwelling invertebrates, which make up an important part of the biodiversity in an area (Diekötter et al. 2007). The physical structure of this network can also protect open landscapes against wind and water erosion (Baudry et al. 2000). Continuous changes in landscape structure due to human activity (intensification of farming and land-use, fragmentation, deforestation) can affect the availability of these habitats, especially for species that are generally restricted to uncultivated patches (Peña et al. 2003, Aviron et al. 2005, Burel & Baudry 2005, Diekötter et al. 2007). As a result of the consolidation and enlargement of fields, the size of the fragments of woodland is reduced; the quality of the vegetation decreases and the remaining areas of woodland are fragmented. The amount of suitable habitat that ground dwelling invertebrates can colonize is decreasing and the ability of these species to disperse in this landscape is reduced. Consequently, the survival of their populations is threatened (Charrier et al. 1997, Petit & Usher 1998, Peña et al. 2003), which results changes in the species composition of invertebrates. By decreasing the size of the fragments woodland, the species composition

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of forest specialists is changing towards generally widespread species that prefer open habitats (Peña et al. 2003, Oates et al. 2005).

Many species of invertebrates' act as a natural protection against pests of agricultural crops; they contribute to the decomposition of organic matter and are a source of food for many vertebrates (Diekötter et al. 2007). Their conservation, protection of suitable habitats and their proper management play an increasingly important role in the context of land use. Based on this, the aim of our research was to clarify the relationship between the size of fragments of woodland and the species composition and abundance of ground dwelling invertebrates.

MATERIALS AND METHODS

We studied the distribution of model groups of ground dwelling invertebrates (spiders, harvestmen and ground beetles) in an intensively cultivated landscape in the vicinity of the towns Čejč, Stavěšice and Šardice (in southern Moravia). We selected 40 fragments of woodland varying in size from 0.04 to 11 hectares and differing in tree composition. These included remains of forests, orchards (largely colonized by blackthorn) or patches with self-seeding trees, where acacia (*Robinia pseudacacia*) and elderberry (*Sambucus nigra* L.) predominate. Other types were artificially planted fragments of woodland, mostly consisting of pine trees, walnut trees and supplemented by wild trees or hedgerows with a predominance of poplars. Invertebrates were sampled during summer in 2016 and 2017. Five pitfall traps were set in each fragment woodland. They consisted of a plastic cup of a volume of 3 deciliters, which was buried with the rim aligned with the surface of the soil, filled with a fixative solution of 4% formaldehyde and covered with a roof that prevented leaves falling into the traps. Traps were set for a period of three weeks and the ground beetles (Carabidae), spiders (Araneae) and harvestmen (Opiliones) caught were sorted and if possible identified to species level.

Patterns in the distributions of more than 120 species belonging to Carabidae, Araneae and Opiliones were analyzed. For some analyses we used only those species whose abundance exceeded 1%. Abundances of species were the dependent variables and the size of fragments of woodland the independent environmental variable. Linear redundancy analysis (RDA) and generalized additive models (GAM) were used to evaluate the abundances of the different species, and the numbers of animals and species trapped in the different fragments of woodland. Analyses were created using the program CANOCO 5.

RESULTS AND DISCUSSION

Altogether, ca. 47 thousand individuals of 15 higher taxa were sampled, including 6,700 ground beetles (60 species), over 2,200 spiders (ca. 50 species) and almost 900 harvestmen (nine species, Table 1). The most abundant species of ground beetle were *Pseudoophonus rufipes* (21% of all ground beetles), *Anchomenus dorsalis* (19%), *Trechus quadristriatus* (14%) and *Calathus fuscipes* (10%), all species typical of open sunny habitats such as meadows, fields, forest edges and hedgerows (Hůrka 1996). Among the spiders, juveniles of the genus *Pardosa* (22% of all spiders) and *Diplostyla concolor* (19%) dominated (typical species of fields and meadows) as well as *Ozyptila praticola* (16%), which usually occurs in forests and at their edges (Buchar & Růžička 2002). Most abundant harvestmen were *Astrobunus laevipes* (44% of all harvestmen), juveniles of the family Phalangiidae (31%) and *Nelima semproni* (14%), which is typical of forest habitats (Šilhavý 1954).

The relationship between the size of the fragments of woodland and species composition of assemblages of soil surface dwelling macrofauna (Fig. 1) was significant ($F=2.1$, $p=0.032$). To suppress the effect of accidentally caught species and to improve the clarity of the graphical output, only species with a dominance greater than 1% were included in the analysis. Many of the species occurred independently of the area, but there were also species that prevailed in small and thin fragments of woodland. These species, like e.g. *Opilio saxatilis*, *Ozyptila praticola*, *Brachinus crepitans*, and *A. dorsalis* are typical of agricultural landscapes (Šilhavý 1954, Thiele 1977, Hůrka 1996; Fig. 1). They are mostly habitat generalists, which are usually agile and can easily overcome obstacles and travel great distances. Therefore, they are not so affected by the decrease in the size of their habitat (Oates et al. 2005).

On the other hand, large forest species are more susceptible to disturbance and require more stable environments, which can be disrupted by intensive farming (Aviron et al. 2005). They are less able to spread and are much more affected by fragmentation and reduction of their habitat and, therefore, are declining in agricultural landscapes (Burel 1992, Niemelä 2001, Oates et al. 2005, Fujita et al. 2008). This was also the case in this study, as the abundance of the large forest species *Carabus coriaceus* (Thiele 1977, Hůrka 1996) was positively associated with the size of the fragment of woodland (Fig. 1). That of some other forest species (e.g. *Carabus scheidleri* or *Abax parallelepipedus*) was independent of the size of the patch of woodland and they were relatively abundant even in small hedgerows (Niemelä 2001) with a dense canopy of trees and bushes (Aviron et al. 2005).

The dominant species of harvestmen (*A. laevipes* and *N. semproni*) were most abundant in large fragments of woodland (>3 ha) with a dense canopy. Nevertheless, they were also abundant in some small patches of woodland. These species are usually classified as forest species (Šilhavý 1954).

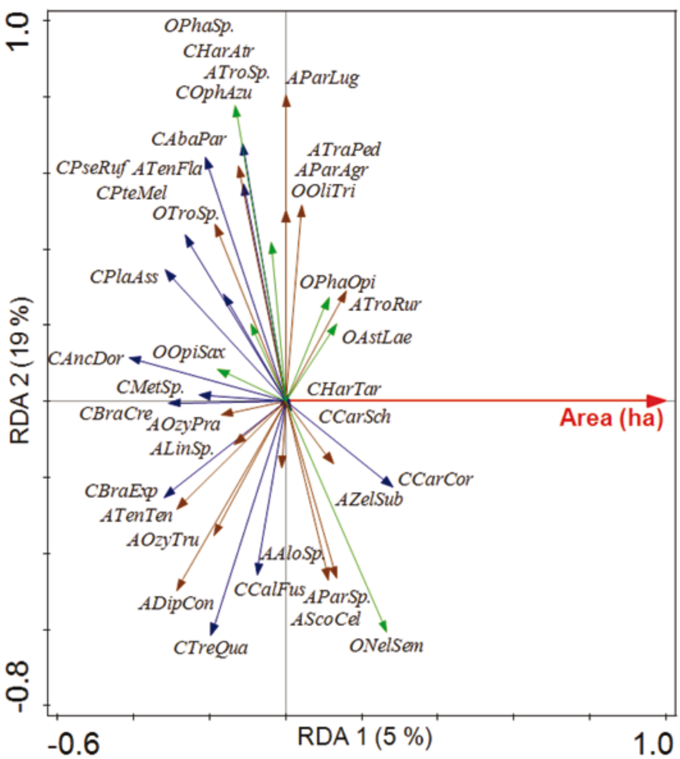

Fig. 1. RDA analysis of the patterns in the distributions of dominant species at sites with different areas. Blue arrows indicate Carabidae, brown arrows Araneae and green arrows Opiliones. Numbers in brackets indicate the percentages of the variability explained. For codes of the species see Table 1.

Table 1. List of the ground beetles, spiders and harvestmen caught

	taxon	code	individuals
	Coleoptera: Carabidae		6725
1	*Abax parallelepipedus* (Piller et Mitterpacher, 1783)	*CAbaPar*	355
2	*Amara anthobia* Villa et Villa, 1833		2
3	*Amara aulica* (Panzer, 1796)		6
4	*Amara cursitans* Zimmermann, 1831		3
5	*Amara eurynota* (Panzer, 1796)		1
6	*Amara familiaris* (Duftschmid, 1812)		32
7	*Amara ovata* (Fabricius, 1792)		37
8	*Amara similata* (Gyllenhal, 1810)		21
9	*Anchomenus dorsalis* (Pontoppidan, 1763)	*CAncDor*	1251
10	*Anisodactylus signatus* (Panzer, 1796)		1
11	*Badister bullatus* (Schrank, 1798)		4
12	*Badister lacertosus* Sturm, 1815		2
13	*Bembidion lunulatum* (Fourcroy, 1785)		18
14	*Bembidion lampros* (Herbst, 1784)		1
15	*Bembidion quadrimaculatum* (Linnaeus, 1761)		1
16	*Brachinus crepitans* (Linnaeus, 1758)	*CBraCre*	103
17	*Brachinus explodens* Duftschmid, 1812	*CBraExp*	146
18	*Calathus erratus* (Sahlberg, 1827)		2
19	*Calathus fuscipes* (Goeze, 1777)	*CCalFus*	663
20	*Carabus coriaceus* Linnaeus, 1758	*CCarCor*	119
21	*Carabus granulatus* Linnaeus, 1758		6
22	*Carabus hortensis* Linnaeus, 1758		18
23	*Carabus scheidleri* Panzer, 1799	*CCarSch*	125
24	*Carabus ullrichi* Germar, 1824		4
25	*Carabus violaceus* Linnaeus, 1758		53
26	*Cylindera germanica* (Linnaeus, 1758)		1
27	*Dolichus halensis* (Schaller, 1783)		2
28	*Harpalus affinis* (Schrank, 1781)		2
29	*Harpalus atratus* Latreille, 1804	*CHarAtr*	216
30	*Harpalus latus* (Linnaeus, 1758)		8
31	*Harpalus luteicornis* (Duftschmid, 1812)		1
32	*Harpalus serripes* (Quensel, 1806)		6
33	*Harpalus tardus* (Panzer, 1797)	*CHarTar*	102
34	*Laemostenus terricola* (Herbst, 1784)		3
35	*Leistus ferrugineus* (Linnaeus, 1758)		29
36	*Licinus depressus* (Fabricius, 1792)		7
37	*Metophonus* sp.	*CMetSp.*	257
38	*Microlestes maurus* (Sturm, 1827)		4
39	*Nebria brevicollis* (Fabricius, 1792)		1
40	*Notiophilus biguttatus* (Fabricius, 1779)		3
41	*Notiophilus palustris* (Duftschmid, 1812)		5
42	*Notiophilus pusillus* Waterhouse, 1833		1
43	*Notiophilus rufipes* Curtis, 1829		1
44	*Ophonus azureus* (Fabricius, 1775)	*COphAzu*	72
45	*Oxypselaphus obscurus* (Herbst, 1784)		4
46	*Panagaeus bipustulatus* (Fabricius, 1775)		9
47	*Platynus assimillis* (Paykull, 1790)	*CPlaAss*	298
48	*Poecilus cupreus* (Linnaeus, 1758)		33
49	*Poecilus sericeus* Fischer von Waldheim, 1824		3
50	*Pseudoophonus rufipes* (De Geer, 1774)	*CPseRuf*	1414
51	*Pterostichus melanarius* (Illiger, 1798)	*CPteMel*	265
52	*Pterostichus niger* (Schaller, 1783)		37
53	*Pterostichus oblongopunctatus* (Fabricius, 1787)		1

54 *Stomis pumicatus* (Panzer, 1796)		3
55 *Syntomus obscuroguttatus* (Duftschmid, 1812)		5
56 *Syntomus pallipes* (Dejean, 1825)		3
57 *Synuchus vivalis* (Illiger, 1798)		2
58 *Trechus austriacus* Dejean, 1831		1
59 *Trechus quadristriatus* (Schrank, 1781)	*CTreQua*	949
60 *Zabrus tenebrioides* (Goeze, 1777)		3
Araneae		2240
1 *Agroeca brunnea* (Blackwall, 1833)		16
2 *Agroeca cuprea Menge*, 1873		11
3 *Agyneta rurestris* (Koch, 1836)		9
4 *Alopecosa pulverulenta* (Clerck, 1757)		9
5 *Alopecosa* sp.	*AAloSp.*	24
6 *Aulonia albimana* (Walckenaer, 1805)		6
7 *Centromerus sylvaticus* (Blackwall, 1841)		2
8 *Clubiona diversa* Cambridge, 1862		1
9 *Clubiona terrestris* Westring, 1851		2
10 *Diplocephalus cristatus* (Blackwall, 1833)		4
11 *Diplocephalus latifrons* (Cambridge, 1863)		1
12 *Diplostyla concolor* (Wider, 1834)	*ADipCon*	397
13 *Drassodes* sp.		10
14 *Drassyllus praeficus* (Koch, 1866)		17
15 *Dysdera hungarica* Kulczyñski, 1897		2
16 *Ebrechtella tricuspidata* (Fabricius, 1775)		1
17 *Eratigena agrestis* (Walckenaer, 1802)		1
18 *Erigone atra* Blackwall, 1833		1
19 *Ero furcata* (Villers, 1789)		2
20 *Euophrys frontalis* (Walckenaer, 1802)		4
21 *Euryopis flavomaculata* (Koch, 1836)		9
22 *Gnaphosa bicolor* (Hahn, 1833)		8
23 *Harpactea lepida* (Koch, 1838)		2
24 *Harpactea rubicunda* (Koch, 1838)		14
25 Linyphiidae sp.	*ALinSp.*	36
26 *Marpissa muscosa* (Clerck, 1757)		2
27 *Mermessus trilobatus* (Emerton, 1882)		1
28 *Micrargus herbigradus* (Blackwall, 1854)		10
29 *Microneta viaria* (Blackwall, 1841)		5
30 *Neon reticulatus* (Blackwall, 1853)		1
31 *Oedothorax apicatus* (Blackwall, 1850)		53
32 *Ozyptila praticola* (Koch, 1837)	*AOzyPra*	337
33 *Ozyptila trux* (Blackwall, 1846)	*AOzyTru*	30
34 *Palliduphantes pallidus* (Cambridge, 1871)		4
35 *Pardosa agrestis* (Westring, 1861)	*AParAgr*	77
36 *Pardosa lugubris* (Walckenaer, 1802)	*AParLug*	143
37 *Pardosa* sp.	*AParSp.*	461
38 *Phrurolithus festivus* (Koch, 1835)		15
39 *Porrhomma microphthalmum* (Cambridge, 1871)		5
40 *Robertus arundineti* (Cambridge, 1871)		13
41 *Scotina celans* (Blackwall, 1841)	*AScoCel*	96
42 *Scotophaeus scutulatus* (Koch, 1866)		1
43 *Tegenria* sp.		10
44 *Tenuiphantes flavipes* (Blackwall, 1854)	*ATenFla*	59
45 *Tenuiphantes tenuis* (Blackwall, 1852)	*ATenTen*	52
46 *Titanoeca schineri* Koch, 1872		1
47 *Trachyzelotes pedestris* (Koch, 1837)	*ATraPed*	23
48 *Trochosa ruricola* (De Geer, 1778)	*ATroRur*	95

49 *Trochosa terricola* Thorell, 1856		7

Table 1. (continued)

taxon	code	individuals
50 *Trochosa* sp.	*ATroSp.*	96
51 *Walckenaeria acuminata* Blackwall, 1833		3
52 *Xysticus* sp.		3
53 *Zelotes subterraneus* (Koch, 1833)	*AZelSub*	41
54 *Zora spinimana* (Sundevall, 1833)		7
Opiliones		866
1 *Astrobunus laevipes* (Canestrini, 1872)	*OAstLae*	376
2 *Lacinius dentiger* (Koch, 1848)		1
3 *Leiobunum rupestre* (Herbst, 1799)		1
4 *Nelima semproni* Szalay, 1951	*ONelSem*	123
5 *Oligolophus tridens* (Koch, 1836)	*OOliTri*	24
6 *Opilio saxatilis* Koch, 1839	*OOpiSax*	32
7 *Phalangiidae* sp.	*OPhaSp.*	271
8 *Phalangium opilio* Linnaeus, 1761	*OPhaOpi*	12
9 *Trogulus* sp.	*OTroSp.*	26

The relationship between area of woodland and total abundance of invertebrates (Fig. 2) was also significant (F=4.1, p=0.025). It is clear, that assemblages in large fragments of woodland are more similar in terms of the number of invertebrates trapped than the assemblages in small fragments of woodland. In some of the small patches of woodland the abundance invertebrates (sample size) is several times higher than in large patches (Fig. 2). We conclude that as the assemblages inhabiting small patches of woodland vary in their abundance they are less stable

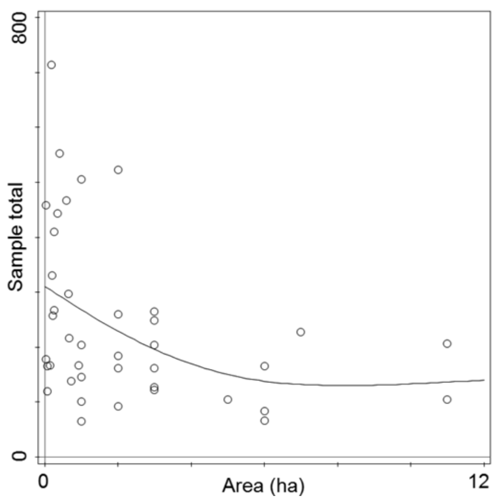

Fig. 2. GAM plot evaluating size of fragments of woodland (x-axis) and number of animals trapped (y-axis). Circles on diagram represent individual fragments of woodland.

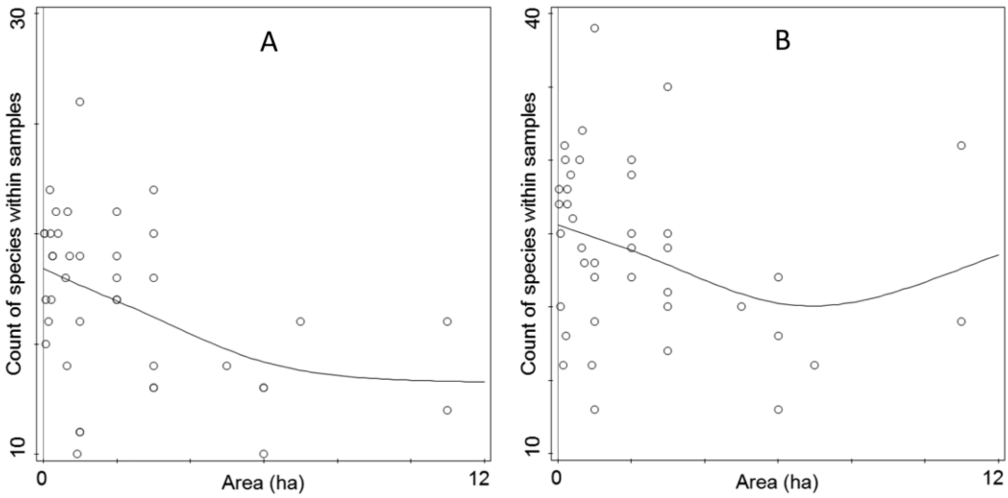

Fig. 3. GAM plot of species diversity. A) GAM plot of the diversity of species with a more than 1% degree of dominance in relation to the size of the fragments of woodland. B) GAM plot of species diversity in relation to the size of the fragments of woodland. Circles on diagram represent individual fragments of woodland.

and may be more influenced by changing environmental conditions or landscape structure (Petit & Usher 1998).

We also tested the relationship between species diversity and the size of fragments of woodland using two models (Fig. 3A, B). Included in the first model were only those species with a dominance greater than 1% and this model was significant ($F=4.4$, $p=0.019$). It is apparent, that most of the small patches of woodland are inhabited by a high number of species and with increasing size of the patches, the number of species decreases (Fig. 3A). This may be because small patches are frequently visited by open habitat preferring species (Niemela 2001). This is supported by Fujita et al. (2008), whose study indicates that species richness of non-forest species does not increase with the size of the woodland.

In the second model, we included all the species captured, and this model was not significant ($F=2.6$, $p=0.091$). In this case, the number of species also decreased with increase in the area of woodland, but there was a higher species richness in the largest patches (Fig. 3B). The higher number of species in large fragments of woodland can be explained by the presence of species typical of forest habitats, which are rare in the total catch due to the low number of large woodlands sampled.

Diversity of invertebrates in small fragments of woodland can also be affected by the edge effect. This hypothesis generally indicates that the interface of two habitats is characterized by highly diverse assemblages of species (Magura et al. 2017). Ecotones are distinguished from their surroundings by specific microclimatic conditions that positively affect the invertebrates and also have habitats suitable for recolonization from surrounding habitats (Magura et al. 2001, Molnár et al. 2001).

The presence of small fragments of woodland and hedgerows in the landscape significantly increases the proportion of ecotones; Lövei et al. (2006) stress that edge-preferring species can further distort the expected relationship, as smaller fragments have larger edge:core ratios. Mader

(1984) mentions that an area of less than 0.5 ha is practically only an ecotone, and areas with a tree canopy smaller than 2–3 ha is an assemblage of ecotones. These patches, therefore, are important in preserving species diversity in agricultural landscapes (Horváth et al. 2002).

The importance of ecotones is that they are inhabited by many ecotone specialists. In the case of ground beetles the ecotone specialists include in particular the numerous *Carabus coriaceus*, which prefers the edges of forests, but due to his great mobility has also spread deeper into forests (or open landscapes). Among the other ecotone specialists trapped were *C. hortensis* (Magura et al. 2001, Molnár et al. 2001, Veselý & Šarapatka 2008) and *Ophonus azureus*, which Duelli et al. (1990) refers to as a grass ecotone specialist that occur in fields and semi-natural habitats. That ecotones have a positive effect on spiders is mentioned by Bedford & Usher (1994), Downie et al. (1996) and Horváth et al. (2002). We captured the ecotone specialist *Pardosa lugubris*, which prefers sunny forest edges, but is also abundant deep in forests and in open habitats (Bedford & Usher 1994, Buchar & Kůrka 1998).

Species of open habitats (e.g. *Pterostichus melanarius*, *P. rufipes* and *Synuchus vivalis*) colonize small fragments of woodland with less dense canopies in search of food or for reproduction or overwintering (Bedford & Usher 1994, Downie et al. 1996, Magura et al. 2001). This may also contribute to an increase in diversity in these areas (Van de Poel & De Smedt 2016).

CONCLUSIONS

We can conclude that fragments of woodland and hedgerows considerable increase the richness of ground dwelling invertebrates. Their presence in the landscape provides stable habitats and interconnections between local populations, ensuring their long-term survival. They can also play an important role as "stepping stones" in the case of species that are spreading or colonizing an area (Petit & Usher 1998). Vasas et al. (2009) demonstrate the importance of these fragments and their connectivity in preserving biodiversity at the landscape scale. Small patches of woodland are important in supporting biodiversity due to their higher edge density and higher quantity of overwintering sites (Lövei et al. 2006, Gallé et al. 2018). The network structure of these fragments of woodland and hedgerows is also vital in supporting biodiversity as pointed out by Jordán et al. (2007).

The results of this study can be considered, like the Territorial System of Ecological Stability (TSES, or ÚSES in Czech), to be an ecological network in the Czech Republic. This concept is part of environmental legislation and is a system of bio centers, bio corridors, buffer zones and interacting elements that are ecologically important segments of the landscape (Mackovčin 2000). Biocentres at the local level are areas of a minimum size of 3 hectares in which populations and assemblages of species can permanently survive (Kubeš 1996). However, this study has shown that there is a greater abundance and species richness of ground dwelling invertebrates in hedgerows and small fragments of woodland, often of less than 3 hectares, than in large fragments of woodland. Based on this, it is recommended that bio centers should include some areas of less than 3 hectares if future studies support this. Nevertheless, the protection or creation of these landscape elements is desirable in order to preserve biodiversity.

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