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Effects of roads and adjacent areas on diversity of terrestrial isopods of Hungarian highway verges

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Abstract: Transportation infrastructure may be the most important driver of social and economic development, but it is a major cause of environmental change in landscapes. The main objective of this paper is to report road edge effects on isopods of Hungarian highway verges. We examined the isopod diversity along five highways (M0, M1, M3, M5, M7) while accounting for road edge proximity and the adjacent areas. Double-glass pitfall traps were set in a total of 15 sites and at three distances from the edge of the roads next to different types of adjacent areas. We found differences between ecological parameters of isopod communities in relation to adjacent areas as well as to road edge proximity. The highest diversity was observed near urban areas, while the lowest was near the arable fields. Isopod diversity increased with decreasing distance from a road. Species diversity of different types of verges based on adjacent areas varied strongly in relation to road edge proximity. A medium distance (40 m) from roads had a positive effect on species richness, while verges next to arable fields were the most species-rich habitats. The general conclusion of this study is that highway verges provided suitable environment conditions for generalist isopod species but may be a limiting factor for specialist isopods. Moreover, highway verges function as corridors for isopods. The proximity of roads and urban areas positively affected isopods, and verges close to roads and urban areas are considered as an attractive environment for isopods in heterogeneous roadside verges.

Key words: linear infrastructure; species richness; road edge proximity; vegetation structure

Introduction

Terrestrial isopods are widely distributed and are easily identified soil-dwelling macrodecomposers. In the temperate regions, they represent dominant saprophagous members of the soil macrofauna (Hassall et al. 1987; Paoletti & Hassall 1999). Isopods can adapt well to modified habitats and have successfully colonised the majority of continental areas (Schmidt 2008). Terrestrial isopods are potential bio-indicators of environmental quality in polluted, disturbed and natural habitats (Dallinger et al. 1992; Paoletti & Hassall 1999). The temperature and the humidity of the environment is a limiting factor for them and they are confined to microhabitats where suitable conditions such as food sources, detritus, and the temporal continuity of the area are available (Spencer & Edney 1954). Despite this, they also widely tolerate dry habitats (Smigel & Gibbs 2008).

Large-scale transportation infrastructure such as highways contribute to the creation of roadside ditches, grassland corridors and roadside verges, where endangered, native, exotic and invasive species can adapt successfully (Ries et al. 2001; Tikka et al. 2001; Brisson et al. 2010; Holderegger & Di Giulio 2010; Noordijk et al. 2011; Vona-Túri et al. 2013, 2015, 2016). In modified habitats, invasive species have a chance to adapt and spread along roadsides (Alaruikka et al. 2002), but invaders alter community structure through resource use and other species interactions that lead to a reduction in the distribution of other native species and, ultimately, species extinctions (Charles & Dukes 2007). Highway verges may function as connecting ecological corridors among natural habitats for several arthropod species (Hawbaker et al. 2006). Verges can be refuges for species which are sensitive to extensive disturbances caused by agricultural management (Ries et al. 2001; Purtauf et al. 2005; Noordijk et al. 2008). Beside the positive effects of roads on organisms, their negative effects are known, such as habitat destruction, altering the physical environment, road mortality, shifting animal behaviour, chemical pollution, acting as physical barriers and increasing the dispersal of invasive species (Trombulak & Frissell 2000; Forman et al. 2002; Knapp et al. 2013). Roads do not have the same effect on all organisms. Higher trophic levels such as predatory arthropods are more sensitive to fragmentation (Bolger et al. 2000), while roads in-

Table 1. Characteristics of the sampling sites.

Types of adjacent areas		Highway	Sampling site	Distance from the road (~)
Natural and semi-natural	Grasslands	M5	Röszke	20 m
		M0	Ferihegy	40 m
		M7	Táska	90 m
	Forest	M5	Örkény	20 m
		M3	Kisbag	40 m
		M1	Óbarok	90 m
Disturbed	Urban	M0	0 km	20 m
		M7	Budaörs	40 m
		M0	Csepel	90 m
	Orchard	M3	Ecséd	20 m
		M1	Turul	40 m
		M7	Velence	90 m
	Arable	M7	Szegerdő	20 m
		M3	Polgár	40 m
		M5	Kecskemét	90 m

crease mortality rates and injuries in reptiles, amphibians and carrion-feeding animals (Daigle 2010). Roads change the flows of water from the sub-soil drainage system (Andrews 1990) that may affect ground-dwelling arthropods. Roads also contribute to the creation of new artificial habitats which have impacts on adjacent areas at various distances (Bennett 1991; Reijnen et al. 1997). The larger the size of a road, the higher the expected impact on both dispersal patterns and landscape structure (Trombulak & Frissell 2000; Holderegger & Di Giulio 2010). In Hungary, the total road network length is 200,961 km and 211 km of road is located per 100 km^2, and as such, represents the fourth densest road network among the member states of the European Union (www.ksh.hu). At present, the length of the Hungarian highway network is 1,481 km and is increasing yearly to satisfy human needs (Tari 2010). The verges of Hungarian highways represent more than 2,000 hectares of green surfaces (Kozár 2009).

In the present study, we focused on road effects on isopod diversity in highway verges. We investigated the variability of the ecological characteristics of isopod assemblages such as species richness, diversity, evenness and species composition, and the contribution of species differentiation (beta diversity) among habitat types. Firstly, we examined the differences in diversity between different types of adjacent areas to verges. Our hypothesis was that high isopod diversity occurs near urban habitats because of the spatial and temporal heterogeneity of the environment (McIntyre et al. 2001). We also studied differences between habitats at three distances from the edge of the roads to analyse the effect of the presence of a highway on isopods. Our hypothesis was that verges at medium distances from a road are more diverse than verges in close proximity and larger distance from roads, because the proximity of a road causes disturbance of habitats (Delgado et al. 2013b).

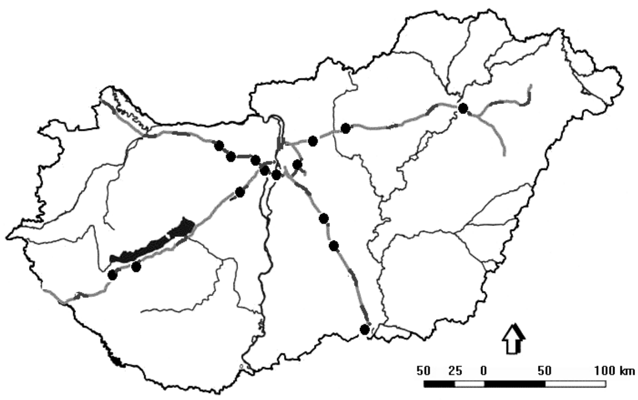

Fig. 1. Map of sampling sites in Hungary.

Material and methods

Sampling areas and methods

The study was carried out along five Hungarian highways (M0, M1, M3, M5, M7) between 2011−2013. The highway M0 is considered as a main road but is managed as a highway in Hungary. Highways M1 and M5 represent the Hungarian sections of the Brussels-Athens axis. The highways M7 and M3 are the Hungarian sections of the Rome-Kiyev axis. On the crossing point of the two highway axes, the M0 ring road located around the capital city of Hungary can be found. On the highway verges, we selected 15 sampling points that were located next to different types of adjacent areas: landscape type: G − grasslands, F − forest, U − urban habitats, O − orchards, A − arable land) (Figs 1, 2; Table 1). In order to analyse the effects of road edge proximity, we selected sampling sites at three distances from the edge of the roads (close: 20 m, medium: 40 m, and large: 90 m) for all adjacent area types. Habitats in all verges were represented by uncharacteristically dry and semi-dry grasslands or closed sand steppes. Double-glass pitfall traps made of 3 dl plastic cups filled with 65% aqueous solution of ethylene glycol were enclosed by fencing. Six traps were set at a distance of 4–5 m along a transect in each site. The traps were deployed three times (spring, summer, autumn) over

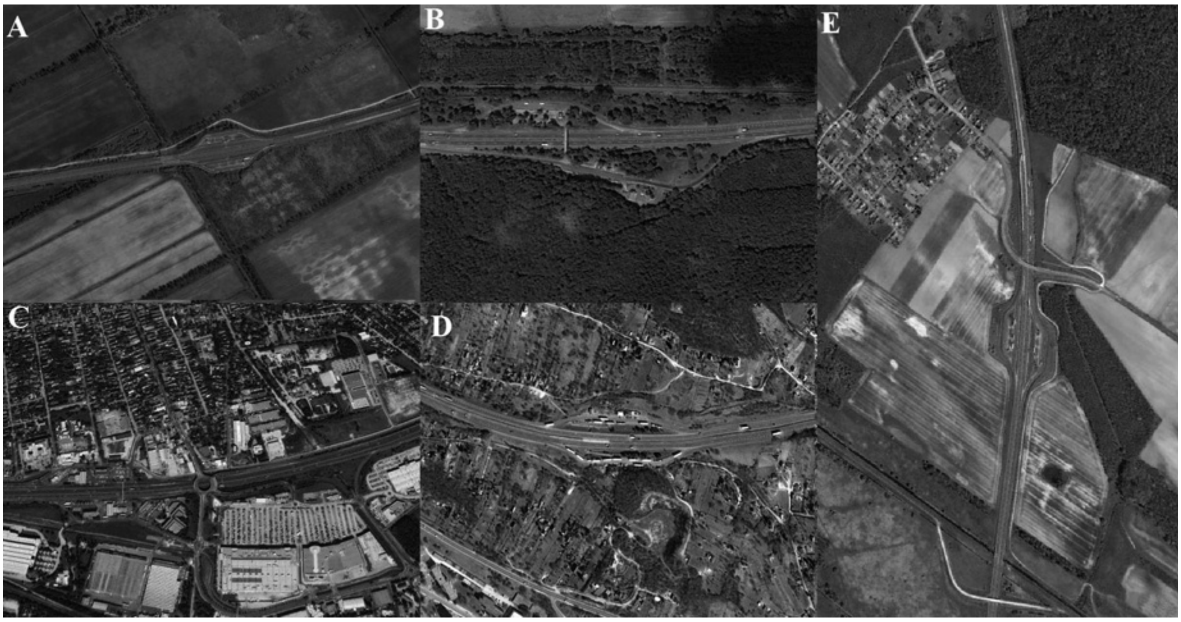

Fig. 2. Satellite images of sampling sites representing the five landscape types. A – grasslands (Táska), B – forests (Kisbag), C – urban areas (Budaörs), D – orchards (Turul), E – arable land (Szegerdő).

Table 2. The list of isopod species with their habitat preference, ecomorphotypes and origin.

Species	Habitat preference	Ecomorphotypes	Origin
Trichoniscus pusillus Brandt, 1833,	G	C	N
Porcellium collicola (Verhoeff, 1907)	G	S	N
Trachelipus nodulosus (C. Koch, 1838)	G	S	N
Trachelipus rathkii (Brandt, 1833)	G	S	N
Lepidoniscus minutus (C. Koch, 1838)	NF	S	N
Platyarthrus hoffmannseggii Brandt, 1833	G	C	N
Protracheoniscus politus (C. Koch, 1841)	NF	S	N
Orthometopon planum (Budde-Lund, 1885)	NF	S	N
Porcellio scaber Latreille, 1804	G	S	K
Porcellionides pruinosus (Brandt, 1833)	G	S	K
Armadillidium vulgare (Latreille, 1804)	G	S	K
Armadillidium nasatum Budde-Lund, 1885	DR	S	I
Armadillidium opacum (C. Koch, 1841)	NR	S	N

Explanations: G – generalists, DR – disturbed-rare species, NF – natural-frequent species, NR – natural-rare species, C – creeper, S – surface active, N – native, I – introduced, K – cosmopolitan.

a three-week period each year. We used the keys of Hopkin (1991), Schmidt (1997), Berg & Wijnhoven (1998) and Farkas & Vilisics (2013) for identification of woodlice specimens. Species names were applied according to Schmalfuss (2003). The habitat preference (generalist, natural-frequent species, disturbed-rare species and natural-rare species) and ecomorphotypes (creeper and surface active) are based on classification by Hornung et al. (2007, 2009) and Vilisics & Hornung (2010). The origin of species (native, cosmopolitan and introduced) is based on Vilisics & Hornung (2008).

Statistical analyses

We used the PAST Paleontological Statistic suite for data analysis (Hammer et al. 2001). Besides number of individuals and species richness we computed Shannon-Wiener diversity and evenness (Pielou's index) in order to examine the diversity of isopods. The Shannon-Wiener index is more sensitive to the frequency of rare species (Nagendra 2002; Hill et al. 2003; Magurran 2003). The Pielou's evenness index shows the evenness of the distribution of species and is sensitive to changes in rare species (Hill et al. 2003; Magurran 2003). Margalef's richness index was used as a simple measure of species richness (Margalef 1958). We used the Wilson & Shmida's Beta diversity index (βT) in order to evaluate the value of species turnover between habitat types. The level of complementarity of habitats within the study habitats was characterized with Whittaker's β-diversity index (βW) (Magurran 2003). We used the Jaccard similarity index for pairwise comparison of similarities of areas based on species composition. This index calculates the similarity based on the absence and presence of the species (Schmera & Erős 2008). Friedman's test was applied to compare the ecological indices using XLSTAT 14.0.7182.5000 version software (https://www.xlstat.com). Community separation was represented with Detrended Correspondence Analysis using XLSTAT 14.0.7182.5000 version software.

Results

A total of 13 isopod species comprising 22,430 individuals were collected at 15 sampling sites (Table 2). We

Table 3. The differences between ecological parameters of verges in relation to adjacent areas and distance from the road by Friedman-test (Alpha = 0.05).

	In relation to adjacent areas	In relation to distance from the road
Q (Observed value)	2.785	0.500
Q (Critical value)	9.488	5.991
DF	4	2
P-value (Two-tailed)	0.594	0.779

Table 4. Number of isopod species (S), number of individuals (N), Shannon-Wiener diversity (H), Margalef's richness index (DMg) and the evenness (E) in the verges in relation to types of adjacent areas.

	Grasslands	Forests	Urban areas	Orchards	Arable land
S	5	4	9	8	9
N	3714	458	2233	1690	14335
H	0.2976	0.3137	0.8853	0.4144	0.0751
DMg	0.4866	0.4896	1.0370	0.9418	0.6269
E	0.2693	0.3421	0.2693	0.1892	0.1540

Table 5. Number of isopod species (S), number of individuals (N), Shannon-Wiener diversity (H), Margalef's richness index (DMg) and the evenness (E) in the verges located at different distances (20 m, 40 m and 90 m) from roads.

	20 m from roads	40 m from roads	90 m from roads
S	7	10	7
N	3181	14776	4590
H	0.8838	0.1329	0.2743
DMg	0.7440	0.9374	0.7116
E	0.3457	0.1142	0.1879

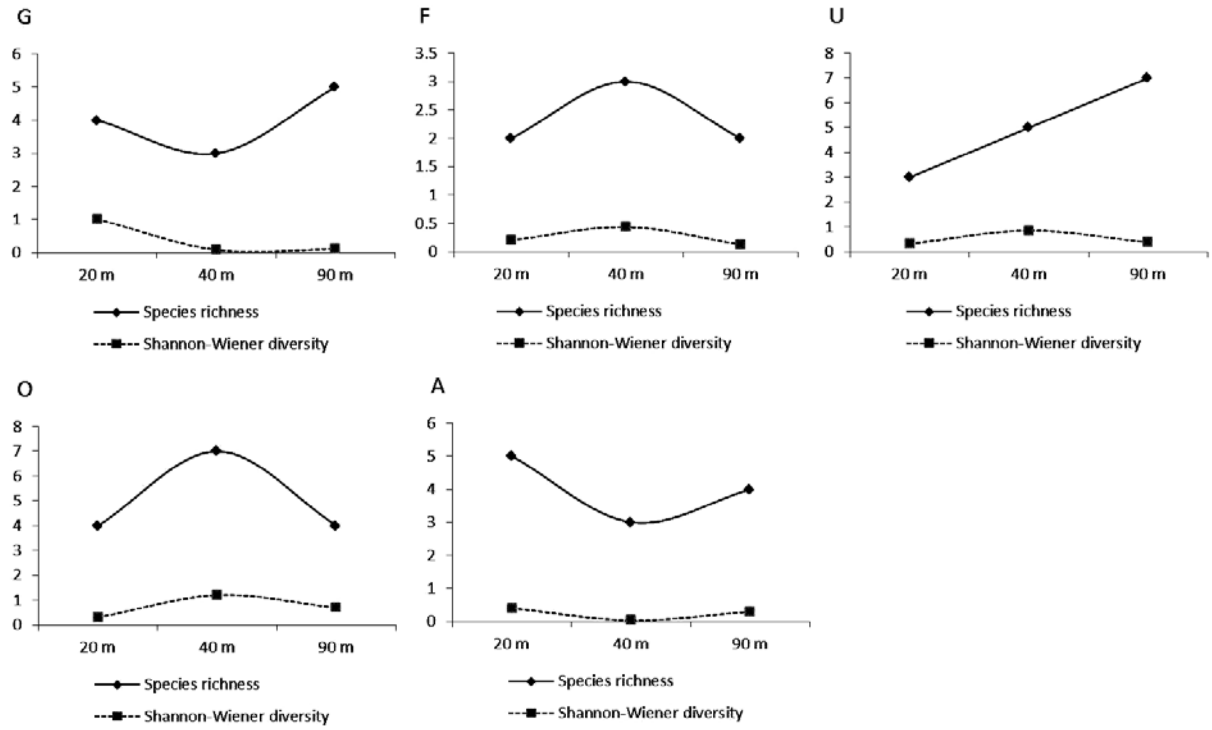

Fig. 3. Isopod species richness (S) and the values of Shannon-Wiener index (H) in verges 20 m, 40 m and 90 m from the edge of road relation to the different adjacent areas (G – grasslands, F – forest, U – urban areas, O – orchards, A – arable land).

found no significant differences between ecological parameters of isopod communities in relation to types of adjacent areas of verges (Table 3). The verges next to urban areas were characterized by the highest species

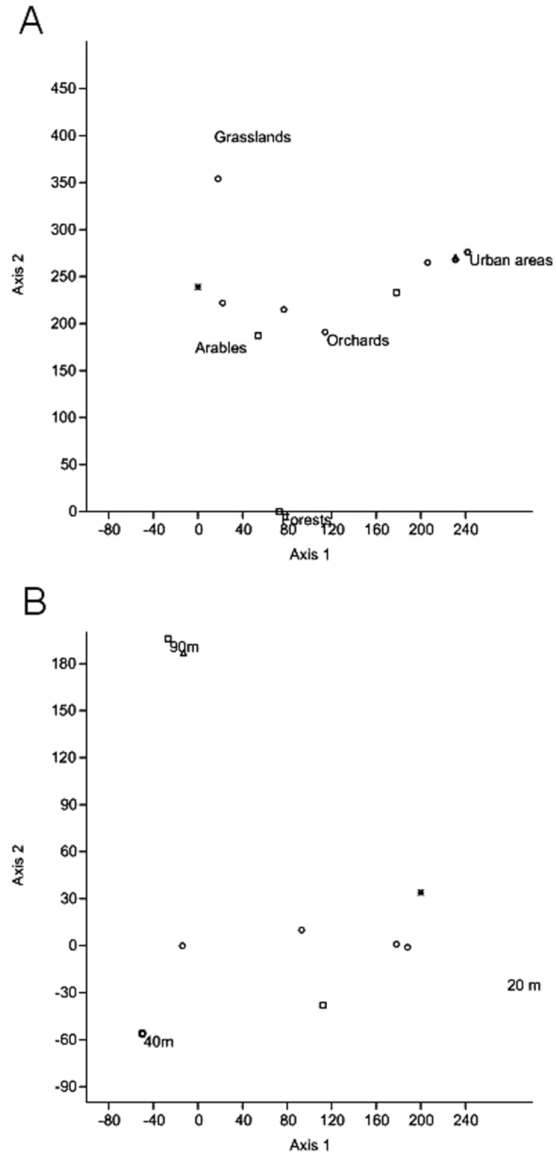

Fig. 4. The separation among the verges in relation to (A) adjacent area and (B) distance from the roads using Detrended Correspondence Analysis (○ – generalists, □ – natural-frequent species, ▲ – disturbed-rare species ∗ – natural-rare species).

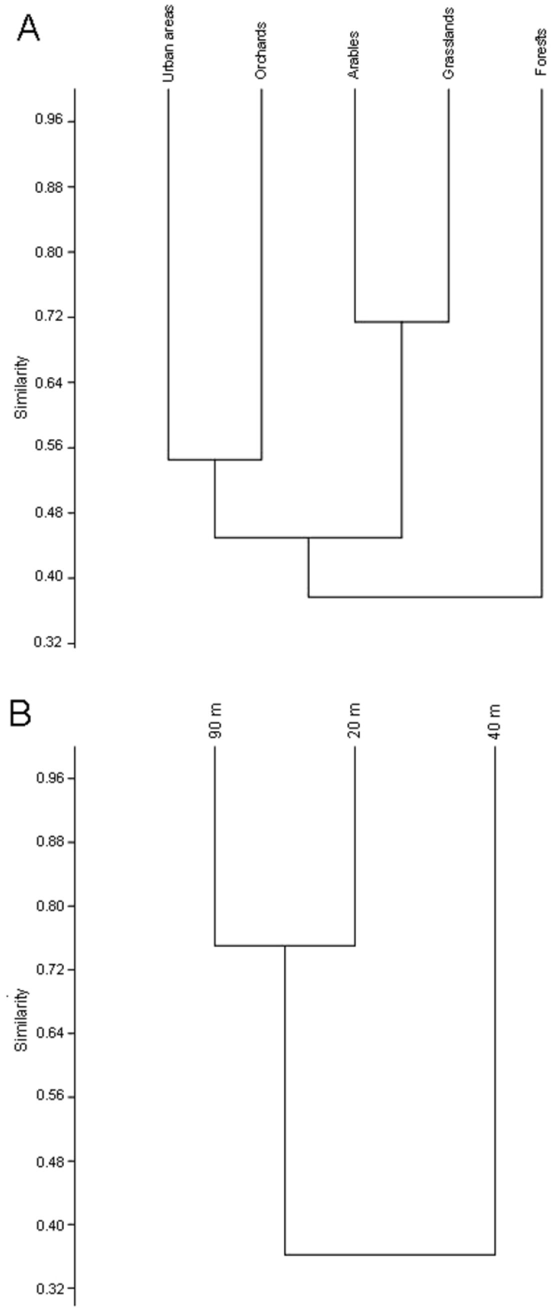

Fig. 5. Similarity of verges in relation to (A) adjacent area and (B) distance from the roads using Jaccard' similarity index.

richness and diversity. The lowest species richness was found in verges next to forests, and the lowest diversity was observed next to arable land (Table 4). No significant differences were found between ecological parameters of isopod communities in relation to road edge proximity (Table 3). Species richness was the highest at a distance of 40 m from the road, but isopod diversity was the highest at 20 m distance from the highway (Table 5). Species diversity in different types of verges (based on adjacent areas) varied strongly in relation to road edge proximity. Diversity was higher 20 m from the road in case of verges located near grassland and arable land. In verges next to forests, orchards and urban areas diversity was higher at a 40 m distance from the road (Fig. 3).

The highest number of individuals was found in verges next to arable land and the lowest number occurred in verges near forests. Differences were observed in verges according to the habitat-preferences of isopod species. In verges next to arable land all types of species (generalists, natural-frequent, disturbed-rare and natural-rare) were found. In verges next to semi-natural habitats only two types of species were found, dominated by generalists. The ordination statistics demonstrated that species in verges are separated from each other based on adjacent areas. The disturbed areas (Table 1.) are situated closer to each other, whereas the semi-natural habitats are located far from the other areas and from each other (Fig. 4A). Regarding the road edge proximity, the occurrence of isopod species in verges varied. Only natural-rare species were present

Table 6. Isopod species turnover between assemblages in verges in relation to different adjacent areas.

	Wilson & Shmida's Beta diversity index (βT)			
	Grasslands	Forests	Urban areas	Orchards
Forests	0.333	0	0.538	0.500
Urban areas	0.428	0.538	0	0.294
Orchards	0.384	0.500	0.294	0
Arables	0.1666	0.454	0.375	0.333

Table 7. Isopod species turnover between different habitats in relation to the distance from a highway.

	Wilson & Shmida's Beta diversity index (βT)	
	20 m from roads	40 m from roads
40 m from roads	0.411	0
90 m from roads	0.142	0.529

in verges at a distance of 20 m and 90 m from the road.

Regarding adjacent areas, we observed the highest species turnover between verges near forests and urban areas, and the lowest turnover between verges next to grasslands and arable land (Table 6). Regarding road edge proximity, the Wilson & Shmida's Beta diversity index was highest between verges at distances of 40 m and 90 m from the roads (Table 7). According to Jaccard's similarity index, the highest similarity was observed between verges next to grasslands and arable land (0.71), followed by urban habitats and orchards (0.54), and forests and grasslands (0.50). There was a distinct difference among verges in relation to road edge proximity, showing the highest similarity between 20 m and 90 m (0.75) (Fig. 5). We found high complementarity of species between these habitats which was demonstrated by high Whittaker's β diversity (0.96).

Discussion

In this study, impacts of adjacent habitats of highway verges and their distance from highways on isopod communities were analysed. Few publications provide data about isopods of roadside verges, but several studies have shown the effects of roads on ground-dwelling arthropods (Noordijk 2006, 2008; Knapp et al. 2013) and litter invertebrates (Delgado et al. 2013a, b). We found significant differences between isopod communities in verges, depending on the characteristics of the adjacent areas. In contrast, Noordijk et al. (2008) did not observe differences between arthropod communities in roadside verges and the adjacent areas because of the similar vegetation in both areas.

Highway verges with adjacent urban areas can be characterised based on their complexity and heterogeneity. The urban fauna can be very diverse in many microhabitats (Riedel at al. 2009) due to the presence of exotic species (Jedryczkowsky 1981). Similar to Hornung et al. (2007) and Korsós et al. (2002), we observed the presence of a new invader exotic species, *Armadillidium nasatum,* in urban verges. In Hungary, this species was found to occur in greenhouses and big cities, but recently increasingly more outdoor occurrences were recorded, e.g. in the Transdanubian Hills (Vilisics & Hornung 2010). The heterogeneous structure of synanthropic habitats provides suitable microhabitats and protection for the organisms from extreme weather conditions (Horváth 2012).

One of the key factors in the development of diversity is the structure of the landscape, in which the more complex configuration of a patch, the more habitat sources are available for organisms (Allik 2014). This may explain the highest isopod biodiversity next to urban areas. Thus, urban habitats are likely to be more important to the maintenance of biodiversity than other habitat types (Forman & Alexander 1998; Alaruikka et al. 2002; Niemelä et al. 2002). Riedel et al. (2009) showed that urban soil provides substrate for native species typical of natural and semi-natural habitats in cities.

Highways can considerably change the local assemblages of ground-dwelling arthropods in Central Europe (Knapp et al. 2013). The potencial decrease in biodiversity is caused by the extinction of sensitive species, habitat damage (Henle et al. 2004) and the impacts of invasive species (Charles & Dukes 2007). There is evidence that biodiversity of wildlife communities is significantly affected by roads (Bissonette 2002). Saunders et al. (2002) recorded that a road-effect is observed to a 300 m distance. Regarding road edge proximity, our data showed that isopod species diversity was significantly higher in verges than at more distant locations. This can be explained by the dominance of generalist species. These isopod species have a good colonizing ability and increased tolerance to habitat disturbances (Krauss et al. 2003). Delgado et al. (2013a) studied litter invertebrate species responses to road edges, and similar to our results, they showed that these species were found most frequently and in higher population densities at distances between 10 and 20 m from the roads. Delgado et al. (2013b) also observed that litter invertebrate species diversity was the highest at a distance of 10 m from the edge of the road, which was explained by alteration of habitat structure due to roads, and the predictions of general niche theory. For all types of adjacent areas, we found the highest isopod diversity in verges situated 20 m or 40 m from the road. Thus, we can conclude that isopod diversity was less influenced by the type of adjacent areas than by the distance from the road.

Our results show that highway verges provide suitable environmental conditions mainly for generalist isopod species. Isopods are quite sensitive to low humidity, unstable temperatures and high insulation (Lee 2006). However, roadside verges function as green corridors which contribute to the spread of species, especially generalists with wide tolerance. Habitat loss and alteration, and the high abundance of generalist species, may be a limiting factor for specialist isopods along roads. Isopod diversity is influenced by road edge proximity and the landscape type. The proximity of roads and urban areas increases the species richness resulting in a high diversity of isopods along highways. The high species turnover between communities and the 96% of complementarity highlighted the heterogeneity of highway verges.

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