Scientific Review Engineering and Environmental Sciences (2023), 32 (3), 238–254

Sci. Rev. Eng. Env. Sci. (2023), 32 (3) https://srees.sggw.edu.pl

ISSN 1732-9353 (suspended) eISSN 2543-7496 DOI 10.22630/srees.4931

Received: 05.06.2023
Accepted: 01.08.2023

Izabela STAWSKA
Izabela DYMITRYSZYN https://orcid.org/0000-0001-8059-4838
Axel SCHWERK✉ https://orcid.org/0000-0002-2284-3776
Warsaw University of Life Sciences – SGGW, Institute of Environmental Engineering, Poland

Potential of a linear woodland landscape element as ecological corridor for carabid beetles (Coleoptera: Carabidae): a case study from Poland

Keywords: Carabidae, forest, ecological corridor, habitat connectivity, biological diversity, landscape management

Introduction

Fragmentation of landscapes and habitats has been identified as a main driver of biodiversity loss (Hanski, 2005; European Environmental Agency [EEA], 2011). Small habitat fragments can only support small populations, which are more vulnerable to extinction (Millennium Ecosystem Assessment [MEA], 2005). Species with a low dispersal power are especially endangered because for many species which are unable to fly, the transfer between suitable habitats may be hampered or even impossible and population extinctions cannot be compensated by refoundings (den Boer, 1990). Forests are among those habitat types which are especially threatened by fragmentation (Millennium Ecosystem Assessment, 2005). A solution to counteract the problem of landscape fragmentation are the so-called ecological corridors,

✉axel_schwerk@sggw.edu.pl

i.e. linear landscape elements, which connect individual habitat patches (Soulé & Gilpin, 1991). Ecological corridors belong to measures, which support the conservation of biota in fragmented landscapes due to enhanced habitat connectivity (Bennett & Saunders, 2010) and can be planned and established on different spatial levels (Ćurčić & Đurđić, 2013). Other ecological benefits from such structures have been reported, like their capability as seed sources or contribution in limiting soil loss due to wind and water erosion (Ćurčić & Đurđić, 2013). Recently, ecological corridors have also been viewed from the perspective of being important means to achieve regional sustainable development (Shi et al., 2018). For example, in cities the green infrastructure, including ecological corridors, is being increasingly promoted as part of the broader sustainability agenda (Norton, Evans & Warren, 2016).

Studies on the function of linear landscape elements as ecological corridors have been carried out, amongst others, on linear grassland strips as corridors for butterflies (Öckinger & Smith, 2008), secondary forests as corridors for small mammals (Pardini, de Souza, Braga-Neto & Metzger, 2005), woody sites along rivers, railways and roads as corridors for garden shrews (Vergnes, Kerbiriou & Clergeau, 2013), hedgerows and roadside verges as corridors for carabid beetles (Eversham & Telfer, 1994; Vermeulen, 1994; Plat, Kuivenhoven & van Dijk, 1995) and railway edges for plants, Orthoptera and snails (Pujols & Panone, 2013). The studies demonstrate that linear elements may serve as corridors and buffer habitat fragmentation, but the effectivity is influenced by diverse factors, such as for example vegetation characteristics and corridor length.

Hence, in order to plan and establish such corridors successfully, we must understand the factors crucial for their effectiveness. Aiming to improve our knowledge in this regard, we initiated a study on a selected linear landscape element along a railway line using carabid beetles as indicators. Railways are important linear elements crossing different habitat types in the landscape. Their vegetated edges can play a positive role as ecological corridors, especially where the respective green areas are scarce (Pujols & Panone, 2013). Carabid beetles are suitable indicators for the quality of linear landscape elements as ecological corridors, because they are known to react to landscape-level phenomena (Koivula, 2011) and many species characteristic for woodlands and forests are unable to fly. Because their dispersal ability is restricted to walking activity, these species are particularly useful for assessing the effectivity of ecological corridors. Moreover, carabids are useful model organisms, so that they can give insights on the responses of other organisms to ecological corridors. Knowledge about the relationships between its characteristics and functionality as an ecological corridor is fundamental for successful planning. Therefore, the selected landscape element was described by several parameters, including both spatial characteristics and ecological indicator values. Potential habitats located at both ends of the study area have been investigated regarding their carabid beetle fauna in earlier studies (Błaszkiewicz & Schwerk, 2013; Schwerk & Dymitryszyn, 2015, 2017) which provided the possibility of a more complex assessment of apparent species migrations.

The aim of our study was to analyze the potential of the selected linear woodland landscape element in detail as ecological corridor for carabid beetles. We wanted to study if (1) the study area has potential as ecological corridor for some forest species, and (2) which environmental factors are of major importance for the occurrence of carabid beetle species in the linear landscape element. The results of the study are discussed from the perspective of designing ecological corridors as elements of landscapes.

Material and methods

Study area and field methods

The study area was an about 650 m long woodland strip of a width between about 15 and about 70 m along a railway line located in the Wałecki district in the West of Poland (Fig. 1). The strip is bordered to the North and the South mainly by agricultural fields. In the West it is connected to a pine forest with an age of about 49 years in 2020. In the East a patch of young trees, an older forest patch and a property with a cluster of tress, among them a couple of old fruit trees, are located.

Eight sampling plots were installed: the first sampling plot (sampling plot 1) was located in the pine forest in the West of the woodland strip, the second sampling plot (sampling plot 2) was located close to the border of the pine forest in the center of the woodland strip about 120 m to the West from the first plot, and sampling plots 3–8 were located in the center of the woodland strip at distances of about 90 m from each other to the East (Fig. 1).

Based on a value of 0 m for sampling plot 1, for each sampling plot the distance from this plot to the East was measured. At sampling plots 2–8 the width of the woodland strip was measured. For sampling plot 1 an “effective” width of 200 m was defined as based on information about movement distances and home ranges of big sized carabid beetles (Riecken & Raths, 1996; Skłodowski, 1999).

At each sampling plot an area of 25 × 25 m was marked in order to elaborate a phytosociological survey, with exception of sampling plot 3, where an area of 14 × 15 m was studied. The surveys were elaborated in the second week of July 2019 by recording the species and describing their occurrence using the cover-abundance scale of Braun-Blanquet (1964).

For each phytosociological survey the values of coverage of the plant species were transformed to a value of mean percentage cover according to Braun-Blanquet (1964): ±0.1%, 1 – 5%, 2 – 17.5%, 3 – 37.5%, 4 – 62.5%, and 5 – 87.5%. Next, for each sampling plot ecological indicator values of vascular plants were calculated, according to Zarzycki et al. (2002). The ecological values according to Zarzycki are a modification of the method of ecological values of vascular plants according to Ellenberg (1974) adapted to the conditions of the Polish climate. Ecological indicator values for light, temperature, soil moisture, trophy (fertility), soil acidity (pH), soil granulometric composition, and organic matter content (humus) were calculated as an average value.

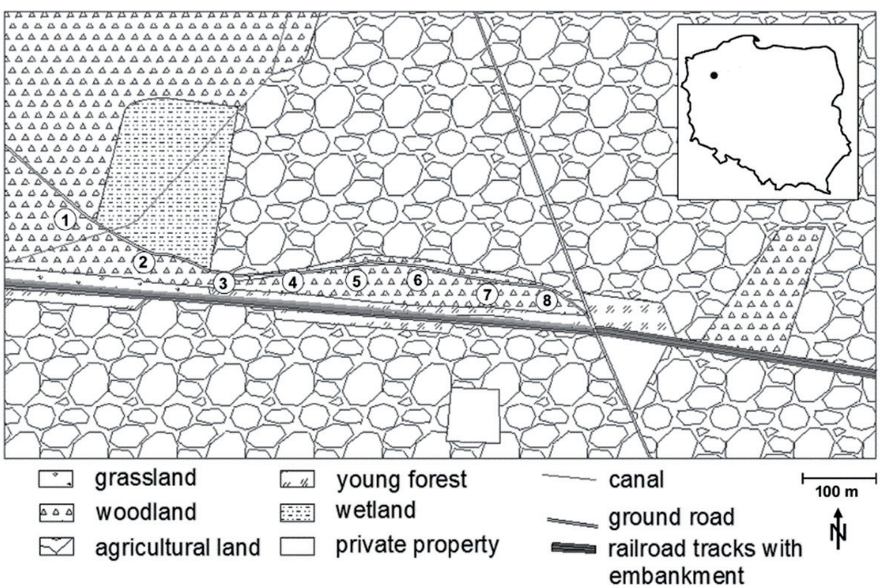


FIGURE 1. Map showing the location of the study area and the surrounding landscape. The small figure in the upper right indicates the location of the study area in Poland

Source: own elaboration.

Carabids were collected using pitfall traps (Barber, 1931). At each sampling plot three traps were installed about three m apart from each other. Traps were glass jars topped with a funnel (upper diameter of about 10 cm) set flush with the soil surface. A roof was suspended a few cm above the funnel and ethylene glycol was used as a killing agent and preservative. Carabids were sampled in 2019 from 02.06.2019 to 14.09.2019, with a replacement of the traps on 26.07.2019. Thus, carabid samples were taken two times during the whole collection period. Determination and nomenclature of the individuals collected was carried out according to Freude et al. (2004).

Statistical methods

For each sampling plot the catches of the three traps were pooled. For each species, the total number of individuals per sampling plot and the dominance value (percentage share of the individuals of the respective species on the total number of individuals collected at the sampling plot) were calculated. The characteristic forest species among the recorded species were identified based on literature (Larsson, 1939; Lindroth, 1945; Burakowski, Mroczkowski & Stefańska, 1973; Burakowski, Mroczkowski & Stefańska, 1974; Lindroth, 1986; Hurka, 1996; Freude, Harde, Lohse & Klausnitzer, 2004).

Correlations between selected parameters and selected species of the carabid fauna (forest species with low dispersal power of the tribes Carabinae and Cychrini and species collected with more than 50 individuals) and environmental parameters of the sampling plots were tested using Spearman rank correlation with IBM SPSS Statistics ver. 25.0.0.1.

In order to test the significance of the impact of the individual environmental variables on the whole species data set, we carried out a constraint ordination using CANOCO for Windows ver. 4.56 (ter Braak & Šmilauer, 2002). DCCA was first used to select the appropriate statistical model based on the longest gradient (Lepš & Šmilauer, 2003) and then redundancy analysis (RDA) with the Monte Carlo permutation tests (unrestricted, 1999 permutations) was carried out, first for each variable separately and then using automatic forward selection of variables (reduced model). The analysis was performed using inter-species correlations and dividing by standard deviation and unweighted data for each of the species. Because dominance values were used, the data were not transformed. CanoDraw for Windows ver. 4.14 was used to create a triplot with species fit range adjusted in such a manner that the 10 species with the highest fit into the ordination space were displayed (ter Braak & Šmilauer, 2002).

Results and discussion

Characterization of the sampling plots

The width of the woodland strip (sampling plots 2–8) varied between 14 m (sampling plot 3) and 70 m (sampling plot 6). Regarding the ecological indicator values, only rather slight differences between the sampling plots could be detected. The sampling plot in the forest (sampling plot 1) showed higher values compared to the sampling plots in the woodland strip (sampling plots 2–8) for soil moisture, trophy, soil acidity and organic matter content (Table 1).

TABLE 1. Characterization of the sampling plots by distance from sampling plot 1, width, and ecological indicator values according to Zarzycki et al. (2002) for light, temperature, soil moisture, trophy, soil acidity, soil granulometric composition, and organic matter

Parameter	Sampling plot							
	1	2	3	4	5	6	7	8
Distance [m]	0	115	232	327	421	511	605	698
Width [m]	200	64	14	38	66	70	53	40
Light	3.219	3.750	3.886	3.154	3.500	3.235	3.542	3.750
Temperature	3.594	3.542	3.477	3.000	3.529	3.294	3.500	3.542
Soil moisture	3.281	3.042	3.023	2.462	3.147	2.971	3.000	3.042
Trophy	3.656	3.000	3.136	2.462	3.294	3.206	3.375	3.000
Soil acidity	3.813	3.333	3.636	2.808	3.647	3.441	3.750	3.333
Soil granulometric composition	3.625	3.542	3.636	3.038	3.529	3.500	3.708	3.542
Organic matter	2.031	1.917	1.932	1.692	1.941	1.824	1.958	1.917

Source: own elaboration.

Carabid beetle inventory

Altogether, 1,646 individuals of carabid beetles, belonging to 39 species, were collected (Table 2). Among them the species *Amara communis* outstood with 1,170 individuals. The numbers of individuals collected at the sampling plots ranged from 72 (sampling plot 4) to 418 (sampling plot 7), with a very high share of individuals from species characteristic for forests at sampling plot 1 (Fig. 2a). The numbers of species collected at the individual sampling plots ranged from 9 (sampling plot 4) to 22 (sampling plot 7). Particular high numbers of forest species were collected at sampling plot 1 (14 species) and sampling plot 7 (13 species), the lowest number of forest species was collected at sampling plot 3 (2 species) – Figure 2b.

TABLE 2. Numbers of carabid beetles collected at the sampling plots

Species	Sampling plot							
	1	2	3	4	5	6	7	8
Agonum gracilipes			1					
Amara brunnea				1	3	3	17	4
Amara communis	3	109	41	34	235	316	293	139
Amara lunicollis							1	
Amara plebeja		1				1		
Amara similata		1	3	1	1	1	1	
Badister bullatus				1	1		1	
Badister lacertosus	4				1	2	2	1
Calathus cinctus						1		
Calathus fuscipes			1	2		2	2	2
Calathus melanocephalus						1	1	
Calathus micropterus			2	12	6		16	1
Calathus rotundicollis							2	
Carabus coriaceus	1					1		
Carabus hortensis	3				1		1	
Carabus nemoralis	3	1			1	5	6	
Cychrus caraboides	4							
Harpalus froelichii			1					
Harpalus laevipes	1	1					2	
Harpalus latus	9	4	1		3	7	3	2
Harpalus rubripes			1					
Harpalus rufipes			39	10	1	7	4	4
Harpalus tardus	1	1						
Leistus ferrugineus					1			
Leistus rufomarginatus	9					1	3	
Leistus terminatus	1	1						
Licinus depressus			4				3	1
Limodromus assimilis	1							
Nebria brevicollis							1	
Notiophilus biguttatus	1							
Notiophilus palustris	3	1			2	4	35	1
Panagaeus bipustulatus			1		1			1
Pterostichus melanarius	1							1
Pterostichus niger	13	6	11	6	21	3	2	5
Pterostichus oblongopunctatus	14	1		5	12	7	20	10
Pterostichus strenuus	9				1	1	2	
Stenolophus teutonus			1					
Synuchus vivalis						2		1
Zabrus tenebrioides		1	1					
Number of individuals	81	128	108	72	291	365	418	173
Number of species	18	12	14	9	16	18	22	14

Source: own elaboration.

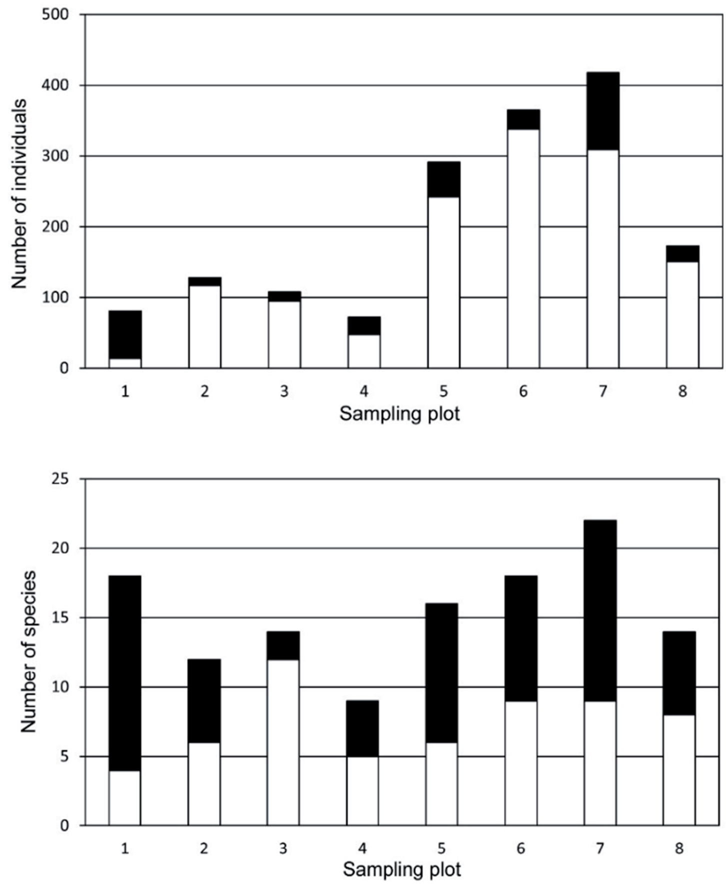
a b


FIGURE 2. Numbers of individuals (a) and species (b) of carabid beetles collected at the sampling plots. Black parts of the bars indicate the share of forest characteristic individuals and species

Source: own elaboration.

Four characteristic forest species of the Carabinae and Cychrini tribes (*Carabus coriaceus*, *Carabus hortensis*, *Carabus nemoralis*, *Cychrus caraboides*) were collected. All of them were collected in the forest site (sampling plot 1). The three *Carabus* species were collected also in the woodland strip. However, only *Carabus nemoralis* was collected there regularly (at four of the seven sampling plots). Another big sized species with low dispersal power, *Pterostichus niger*, was collected at all sampling plots. Regarding other species (collected with more than 50 individuals), the forest species *Pterostichus oblongopunctatus* was collected at the forest site (sampling plot 1) and also regularly in the woodland strip (sampling plots 2, 4–8). Two non-forest species were collected with more than 50 individuals. *Amara communis* was collected at all sampling plots, but in much higher numbers at the sampling plots in the woodland strip (sampling plots 2–8) than at the forest site (sampling plot 1). *Harpalus rufipes* was collected only in the woodland strip at sampling plots 3–8 (see Table 2).

Number of species, number of forest species, number of forest individuals, *Carabus hortensis*, *Carabus nemoralis*, the sum of individuals from *Carabus* and *Cychrus* and *Pterostichus oblongopunctatus* showed a significant positive correlation with trophy. Except for *Carabus nemoralis* and *Pterostichus oblongopunctatus*, they were also significantly positively correlated with soil acidity, and *Carabus hortensis* was also significantly positively correlated with soil organic matter. Number of forest species, *Carabus coriaceus* and the sum of individuals from *Carabus* and *Cychrus* showed a significant positive correlation with the width of the sampling plots. *Amara communis*, however, showed a significant positive correlation with the distance from the forest site (sampling plot 1) and *Harpalus rufipes* was significantly negatively correlated with temperature and soil moisture (Table 3).

TABLE 3. Spearman rank correlation coefficients (*r*) and significance values (*p*) for correlations between selected parameters and selected species of the carabid fauna and environmental parameters of the sampling plots (statistically significant values are printed bold)

Species	*r*/*p*	Distribution	Width	Light	Temperature	Moisture	Trophy	pH	Granulation	Organic matter
Species	*r*	0.265	0.566	–0.115	0.176	0.176	**0.903**	**0.830**	0.467	0.648
	p	0.526	0.143	0.786	0.677	0.677	**0.002**	**0.011**	0.244	0.082
Individuals	*r*	0.690	0.262	0.252	–0.036	–0.084	0.395	0.299	0.204	0.180
	p	0.058	0.531	0.548	0.933	0.844	0.333	0.471	0.629	0.670
Forest species	*r*	0.024	**0.814**	–0.398	0.494	0.470	**0.855**	**0.759**	0.253	0.687
	p	0.955	**0.014**	0.329	0.213	0.240	**0.007**	**0.029**	0.545	0.060
Forest individuals	*r*	0.214	0.500	–0.551	0.048	0.096	**0.790**	**0.710**	0.192	0.575
	p	0.610	0.207	0.157	0.910	0.821	**0.020**	**0.045**	0.649	0.136
Carabus coriaceus	*r*	–0.252	**0.756**	–0.507	0.127	0.127	0.507	0.380	–0.127	0.127
	p	0.547	**0.030**	0.200	0.765	0.765	0.200	0.353	0.765	0.765
Carabus hortensis	*r*	–0.192	0.577	–0.346	0.484	0.581	**0.871**	**0.871**	0.401	**0.871**
	p	0.648	0.134	0.402	0.224	0.131	**0.005**	**0.005**	0.325	**0.005**
Carabus nemoralis	*r*	0.086	0.700	–0.266	0.117	0.031	**0.747**	0.624	0.266	0.438
	p	0.840	0.053	0.525	0.782	0.942	**0.033**	0.098	0.525	0.277
Cychrus caraboides	*r*	–0.577	0.577	–0.415	0.581	0.581	0.581	0.581	0.249	0.581
	p	0.134	0.134	0.307	0.131	0.131	0.131	0.131	0.552	0.131
Carabus + *Cychrus*	*r*	–0.146	**0.830**	–0.393	0.344	0.319	**0.884**	**0.785**	0.295	0.638
	p	0.729	**0.011**	0.336	0.405	0.441	**0.004**	**0.021**	0.479	0.089

TABLE 3 (cont.)

Species	*r*/*p*	Distri-bution	Width	Light	Temper-ature	Mois-ture	Trophy	pH	Granu-lation	Organic matter
Pterostichus niger	*r*	–0.647	0.156	–0.090	0.319	0.645	0.151	0.247	–0.090	0.331
	p	0.083	0.731	0.831	0.441	0.084	0.722	0.555	0.831	0.423
Pterostichus oblongopunctatus	*r*	0.333	0.524	–0.371	0.371	0.323	**0.731**	0.659	0.275	0.635
	p	0.420	0.183	0.365	0.365	0.435	**0.040**	0.076	0.509	0.091
Amara communis	*r*	**0.738**	0.190	0.180	–0.252	–0.275	0.180	0060	–0.060	–0.108
	p	**0.037**	0.651	0.670	0.548	0.509	0.670	0.888	0.888	0.799
Harpalus rufipes	*r*	0.313	–0.699	0.085	**–0.849**	**–0.764**	–0.400	–0.352	–0.145	–0.497
	p	0.450	0.054	0.842	**0.008**	**0.027**	0.326	0.393	0.731	0.210

Source: own elaboration.

None of the environmental parameters showed a significant impact on the formation of the total carabid assemblages (both when tested separately and using forward selection). However, the most important factors were "width" and "distance" when tested separately and "width" when using forward selection (Table 4).

TABLE 4. Results of the Monte Carlo permutation tests of the environmental variables tested separately and using automatic forward selection of variables (reduced model). During forward selection of variables "Trophy" and "Soil granulometric composition" were not added to the model due to collinearity. Lambda-1 – variance explained by the environmental variables separately; Lambda-A – additional variance explained when included in the model using forward selection

Variable	Tested separately			Forward selection		
	Lambda-1	*F*	*p*	Lambda-A	*F*	*p*
Width	0.34	3.14	0.124	0.34	3.14	0.124
Distance	0.34	3.10	0.095	0.17	1.66	0.221
Trophy	0.11	0.71	0.451	–	–	–
Light	0.10	0.67	0.479	0.03	0.00	1.000
Organic matter	0.09	0.57	0.507	0.12	0.44	0.329
Soil acidity	0.07	0.43	0.585	0.16	6.50	0.169
Soil moisture	0.06	0.37	0.628	0.05	0.44	0.590
Temperature	0.04	0.23	0.759	0.13	1.37	0.367
Soil granulometric composition	0.03	0.17	0.803	–	–	–

Source: own elaboration.

The first two RDA axes explained 95.6% of the total variance. The ordination diagram separated sampling plot 1 (forest site) from the other sampling plots along the first ordination axis and also sampling plots P3 and P4 along the second ordination axis. These were the sampling plots with a low width of the corridor. The factor with the highest impact was "width" which (together with most other factors) points towards sampling plot 1 (forest site). The "light" factor was negatively correlated with "width". "Distance", however, pointed in the opposite direction from sampling plot 1 along the first ordination axis. Characteristic forest species (e.g. *Carabus hortensis*) were located close to sampling plot 1 (forest site) in the diagram, species characteristic for open areas (*Amara similata*, *Harpalus rufipes*) were located close to sampling plot 3, and *Amara communis* was correlated with "distance" (Fig. 3).

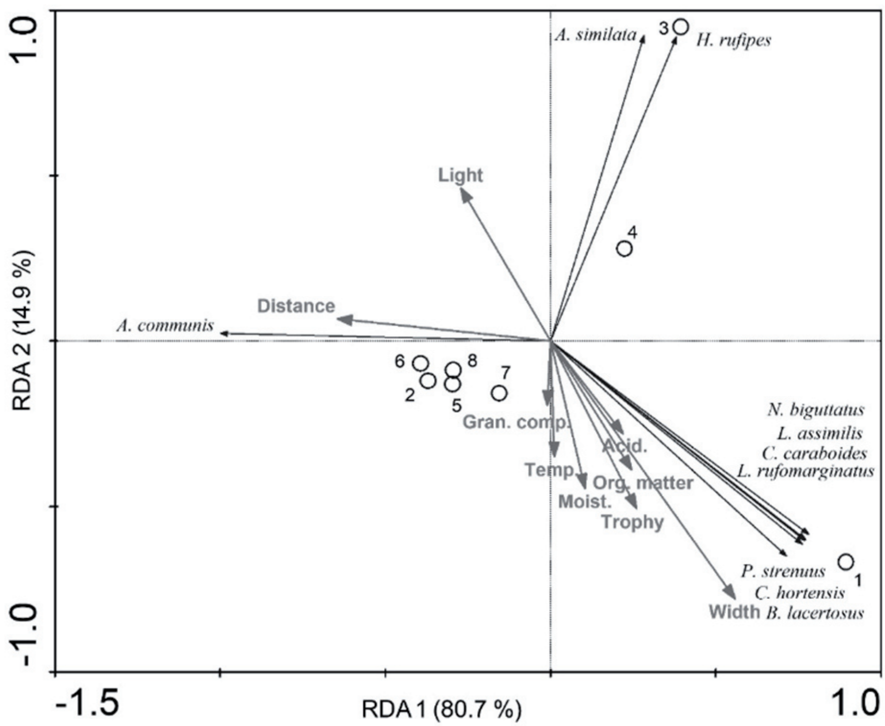


FIGURE 3. Ordination plot based on redundancy analysis (RDA) of the results for sampling plots (open circles) and species (thin arrows) and environmental variables (strong arrows). All species were included in the analysis, but only 10 species with the highest fit into the ordination space are displayed

Source: own elaboration.

Potential corridor function of the study site

The studied area indicated potential as an ecological corridor what is corroborated by data on the carabid fauna of adjacent habitats. The carabid fauna in the forest located west of the woodland strip has already been studied by Błaszkiewicz and

Schwerk (2013) and Schwerk and Dymitryszyn (2017), showing that with exception of *Cychrus caraboides* the forest species of the tribes Carabinae and Cychrini and also *Pterostichus niger* and *Pterostichus oblongopunctatus* were detected in this forest in earlier years, even if not all species in every year. As additional forest species of these tribes *Carabus violaceus* was proven. Schwerk and Dymitryszyn (2015) detected *Carabus nemoralis* and *Pterostichus niger*, both forest species unable to fly, in the insulated habitat located close to the East of the studied area (private property, see Fig. 1). These results underline that the woodland strip has a potential as an ecological corridor for some of the forest species with low dispersal power, though particularly for more eurytopic species (i.e. species able to tolerate wider ranges of ecological conditions), such as *Carabus nemoralis* and *Pterostichus niger*. An effectivity of linear landscape elements as corridors for these two species was shown by Gruttke, Kornacker and Willecke (1998), who studied a newly created habitat strip of hedge like plantations.

The results indicate that spatial (landscape) factors, i.e. the physiognomy of the corridor, are of higher importance than habitat parameters at the individual sampling plots for the formation of the carabid assemblages. However, individual species showed significant relations to the habitat parameters at the sampling plots. This indicates that both aspects are important for a proper functioning of a woodland strip as the ecological corridor. Plat et al. (1995), who studied the suitability of hedgerows as corridors for forest carabid species, concluded that the hedgerows should be as wide as possible. They should have a vegetation similar to the adjacent forest, thus being at least partly a potential habitat for target species. According to Soulé and Gilpin (1991), the effectivity of ecological corridors depends on the degree of edge effects, linearity and shape of the corridor. Shi et al. (2018) emphasize that the function of railways and expressways for connecting natural areas depends significantly on the width of undisturbed native vegetation along the verge.

However, linear woodland elements as ecological corridors for forest species might cause a barrier effect on species moving perpendicular to the respective corridor. Therefore, the idea of semi-open corridors was discussed (Eggers et al., 2009). Even if not statistically significant, *Harpalus rufipes*, a species characteristic for open areas, occurred in our study most frequently in the narrow part of the woodland strip (sampling plots 3 and 4), indicating that the varying width of the corridor is an important factor. The narrow parts seem to be permeable for at least some species of open habitats. In this part of the woodland strip no species from the tribes Carabinae and Cychrini were collected. However, the occurrence of species as *Carabus coriaceus* and *Carabus hortensis* at the sampling plots in the woodland strip more distant from the forest indicates that the narrow part does not hinder migration of these species along the strip. These two species are strongly connected to forest habitats and it can be excluded to a very high degree that they entered the respective parts of the woodland strip from the agricultural fields.

The results of our study provide some pieces of information regarding the rules for the construction of woodland strips as corridors for carabid beetles. Short narrow parts seem not to hinder migration through the corridor, but to enable permeability for species of neighboring habitats and higher soil trophy (fertility) and pH seem to be beneficial for some species. We assume that some of these rules also apply to other taxonomic groups of invertebrates. However, in order to guarantee the functionality as ecological corridor technical aspects have to be considered, too. Pujols and Panone (2013) raise the issue of construction solutions for overpasses, because they may interrupt some biological fluxes.

Today, ecological corridors have to also fulfil targets of sustainable regional development. Ćurčić and Đurđić (2013) recommend a set of strategies concerning this matter when implementing ecological corridors. Besides benefits related to species conservation this set also includes aspects concerning relationships in the local community, human resources and education. This implies that another important aspect involves the maintaining of such areas. Pujols and Panone (2013) formulated management and maintenance goals for railway vegetation, including the use of mechanical techniques and herbicides as well as the handling of invasive species. They conclude that long-term strategic plans incorporating economical, sustainable and multi-year integrated approaches for vegetation management are necessary. Villemey et al. (2018) identified a lack in studies dealing with the influence of management or surrounding landscape on insect dispersal along infrastructure verges. We conclude that studies towards this research direction are necessary to improve the strategies for constructing and using such landscape elements as ecological corridors.

Conclusions

The paper provided a case study regarding the potential of a linear woodland landscape element as ecological corridor for carabid beetles. The following conclusions can be outlined:

– The research area provides appropriate conditions which facilitate the migration of species from one habitat to another.
– The results indicate that spatial (landscape) factors, i.e. the physiognomy of the corridor (e.g. width, length), are more important than habitat parameters.

- The study indicates that the value of an individual site for biodiversity conservation should be assessed in the context of the landscape in which it is embedded. It is necessary to identify the kind of landscape features that are missing in order to exploit its full potential.
- Not only the individual elements of the landscape are important, but also its structure.

Acknowledgements

This paper is Communication 535 in the tradition of the Laboratory of Evaluation and Assessment of Natural Resources, Warsaw University of Life Sciences – SGGW.

References

Barber, H. S. (1931). Traps for cave inhabiting insects. *Journal of the Elisha Mitchell Scientific Society*, *46* (2), 259–266.

Bennett, A. F. & Saunders, D. A. (2010). Habitat fragmentation and landscape change. In N. S. Sodhi, P. R. Ehrlich (Eds.), *Conservation biology for all* (pp. 88–106). Oxford: Oxford University Press.

Błaszkiewicz, M. & Schwerk, A. (2013). Carabid beetle (Coleoptera: Carabidae) diversity in agricultural and post-agricultural areas in relation to the surrounding habitats. *Baltic Journal of Coleopterology*, *13* (1), 15–26.

Boer, P. J. den (1990). Density limits and survival of local populations in 64 carabid species with different powers of dispersal. *Journal of Evolutionary Biology*, *3* (1–2), 19–48. https://doi.org/10.1046/j.1420-9101.1990.3010019.x

Braak, C. J. F. ter & Šmilauer, P. (2002). *CANOCO reference manual and CanoDraw for Windows user's guide: software for Canonical Community Ordination (version 4.5)*. Ithaca, NY: Microcomputer Power.

Braun-Blanquet, J. (1964). *Pflanzensoziologie; Grundzüge der Vegetationskunde* [*Plant sociology. Fundamentals of vegetation science*]. Berlin: Springer Verlag.

Burakowski, B., Mroczkowski, M. & Stefańska, J. (1973). *Katalog fauny Polski (Catalogus faunae Poloniae). Część XXIII, tom 2. Chrząszcze (Coleoptera). Biegaczowate (Carabidae), część 1* [*Catalogue of Polish fauna. Part XXIII, volume 2. Beetles (Coleoptera). Ground beetles (Carabidae), part 1*]. Warszawa: Państwowe Wydawnictwo Naukowe.

Burakowski, B., Mroczkowski, M. & Stefańska, J. (1974). *Katalog fauny Polski (Catalogus faunae Poloniae). Część XXIII, tom 3. Chrząszcze (Coleoptera). Biegaczowate (Carabidae), część 2* [*Catalogue of Polish fauna. Part XXIII, volume 3. Beetles (Coleoptera). Ground beetles (Carabidae), part 2*]. Warszawa: Państwowe Wydawnictwo Naukowe.

Ćurčić, N. B. & Đurđić, S. (2013). The actual relevance of ecological corridors in nature conservation. *Journal of the Geographical Institute "Jovan Cvijic" SASA*, *63* (2), 21–34. https://doi.org/10.2298/IJGI1302021C

Eggers, B., Matern, A., Drees, C., Eggers, J., Härdtle, W. & Assmann, T. (2009). Value of semi-open corridors for simultaneously connecting open and wooded habitats: a case study with ground beetles. *Conservation Biology*, *24* (1), 256–266. https://doi.org/10.1111/j.1523-1739.2009.01295.x

Ellenberg, H. (1974). Zeigerwerte der Gefäßpflanzen Mitteleuropas [Indicator values of the vascular plants of Central Europe]. *Scripta Geobotanica*, *9*, 1–97.

European Environmental Agency [EEA] (2011). *Landscape fragmentation in Europe. Joint EEA-FOEN report.* Luxembourg: Publications Office of the European Union. https://doi.org/10.2800/78322

Eversham, B. C. & Telfer, M. G. (1994). Conservation value of roadside verges for stenotopic heathland Carabidae: corridors or refugia? *Biodiversity and Conservation*, *3*, 538–545. https://doi.org/10.1007/BF00115159

Freude, H., Harde, K. W., Lohse, G. A. & Klausnitzer, B. (2004). *Die Käfer Mitteleuropas. Bd. 2, Adephaga 1, Carabidae (Laufkäfer) (2. (erweiterte) Aufl.)* [*The beetles of Central Europe. Vol. 2, Adephaga 1, Carabidae (ground beetles) (2nd (extended) ed.)*]. Berlin: Spektrum--Verlag.

Gruttke, H., Kornacker, P. M. & Willecke, S. (1998). Effizienz eines neu angelegten Biotopstreifens als Ausbreitungskorridor in der Agrarlandschaft – Ergebnisse einer Langzeitstudie [Effectiveness of a newly created habitat strip as dispersal corridor in an agricultural landscape – results of a longterm study]. *Schriftenreihe für Landschaftspflege und Naturschutz*, *58*, 243–290.

Hanski, I. (2005). Landscape fragmentation, biodiversity loss and the societal response. *EMBO reports*, *6*, 389–392. https://doi.org/10.1038/sj.embor.7400398

Hurka, K. (1996). *Carabidae of Czech and Slovak Republics*. Zlín: Kabournek.

Koivula, M. J. (2011). Useful model organisms, indicators, or both? Ground beetles (Coleoptera, Carabidae) reflecting environmental conditions. *ZooKeys*, *100*, 287–317. https://doi.org/10.3897/zookeys.100.1533

Larsson, S. G. (1939). Entwicklungstypen und Entwicklungszeiten der dänischen Carabiden [Development types and times of development of the Danish carabids]. *Entomologiske Meddelelser*, *20*, 277–562.

Lepš, J. & Šmilauer, P. (2003). *Multivariate Analysis of Ecological Data using CANOCO.* Cambridge: Cambridge University Press.

Lindroth, C. H. (1945). *Die Fennoscandischen Carabidae: I Spezieller Teil* [*The Fennoscandian Carabidae: I Special part*]. Göteborg: Elanders Boktryckeri Aktiebolag.

Lindroth, C. H. (1986). *The Carabidae (Coleoptera) of Fennoscandia and Denmark. Fauna Entomologica Scandinavica. Volume 15, Part II*. Klampenborg: Scandinavian Science Press.

Millennium Ecosystem Assessment [MEA] (2005). *Ecosystems and human well-being: biodiversity synthesis.* Washington, DC: World Resources Institute.

Norton, B. A., Evans, K. L. & Warren, P. H. (2016). Urban biodiversity and landscape ecology: patterns, processes and planning. *Current Landscape Ecology Reports*, *1*, 178–192. https://doi.org/10.1007/s40823-016-0018-5

Öckinger, E. & Smith, H. G. (2008). Do corridors promote dispersal in grassland butterflies and other insects? *Landscape Ecology*, *23* (1), 27–40. https://doi.org/10.1007/s10980-007-9167-6

Pardini, R., Souza, S. M. de, Braga-Neto, R. & Metzger, J. P. (2005). The role of forest structure, fragment size and corridors in maintaining small mammal abundance and diversity in an Atlantic forest landscape. *Biological Conservation*, *124* (2), 253–266. https://doi.org/10.1016/j.biocon.2005.01.033

Plat, S., Kuivenhoven, P. & Dijk, T. S. van (1995). Hedgerows: suitable corridors for ground dwelling forest carabid beetles? *Proceedings of the Section Experimental and Applied Entomology of the Netherlands Entomological Society*, *6*, 73–75.

Pujols, J. P. & Penone, C. (2013). *Railway edges, ecological corridors: how to conciliate biodiversity and economic management of vegetation?* Retrieved from: https://railknowledgebank.com/Presto/content/Detail.aspx?ctID=MTk4MTRjNDUtNWQ0My00OTBmLTllYWUtZWFjM2U2OTE0ZDY3&rID=MjMwNQ==&qrs=RmFsc2U=&q=UHVqb2xz&ph=VHJ1ZQ==&bckToL=VHJ1ZQ==&rrtc=VHJ1ZQ==

Riecken, U. & Raths, U. (1996). Use of radio telemetry for studying dispersal and habitat use of *Carabus coriaceus* L. *Annales Zoologici Fennici*, *33* (1), 109–116.

Schwerk, A. & Dymitryszyn, I. (2015). Epigeic and soil carabid fauna (Coleoptera: Carabidae) in relation to habitat differentiation of an insulated semi-natural habitat in Western Poland. *Baltic Journal of Coleopterology*, *15* (1), 47–56.

Schwerk, A. & Dymitryszyn, I. (2017). Carabid beetle (Coleoptera: Carabidae) distribution in a rural landscape based on habitat diversity and habitat characteristics. *Baltic Journal of Coleopterology*, *17* (2), 107–118.

Shi, H., Shi, T., Yang, Z., Wang, Z., Han, F. & Wang, C. (2018). Effect of roads on ecological corridors used for wildlife movement in a natural heritage site. *Sustainability*, *10* (8), 2725. https://doi.org/10.3390/su10082725

Skłodowski, J. (1999). Movement of selected carabid species (Col. Carabidae) through a pine forest-fallow ecotone. *Folia Forestalia Polonica, Series A – Forestry*, *41*, 35–41.

Soulé, M. E. & Gilpin, M. E. (1991). The theory of wildlife corridor capability. In D. A. Saunders, R. J. Hobbs (Eds.), *Nature conservation 2: the role of corridors* (pp. 3–8). Sydney: Surrey Beatty & Sons.

Vergnes, A., Kerbiriou, C. & Clergeau, P. (2013). Ecological corridors also operate in an urban matrix: a test case with garden shrews. *Urban Ecosystems*, *16* (3), 511–525. https://doi.org/10.1007/s11252-013-0289-0

Vermeulen, H. J. W. (1994). Corridor function of a road verge for dispersal of stenotopic heathland ground beetles Carabidae. *Biological Conservation*, *69* (3), 339–349. https://doi.org/10.1016/0006-3207(94)90433-2

Villemey, A., Jeusset, A., Vargac, M., Bertheau, Y., Coulon, A., Touroult, J., Vanpeene, S., Castagneyrol, B., Jactel, H., Witte, I., Deniaud, N., Flamerie De Lachapelle, F., Jaslier, E., Roy, V., Guinard, E., Le Mitouard, E., Rauel, V. & Sordello, R. (2018). Can linear transportation infrastructure verges constitute a habitat and/or a corridor for insects in temperate landscapes? A systematic review. *Environmental Evidence, 7*, 5. https://doi.org/10.1186/s13750-018-0117-3

Zarzycki K., Trzcińska-Tacik H., Różański W., Szeląg Z., Wołek J. & Korzeniak U. (2002). Ekologiczne liczby wskaźnikowe roślin naczyniowych Polski [Ecological values of vascular plants of Poland]. In Z. Mirek (Ed.), *Różnorodność biologiczna Polski* [*Biodiversity of Poland*]. Kraków: Instytut Botaniki im. Władysława Szafera Polskiej Akademii Nauk.

Summary

Potential of a linear woodland landscape element as ecological corridor for carabid beetles (Coleoptera: Carabidae): a case study from Poland. Fragmentation of landscapes and habitats has been identified as the main driver of biodiversity loss. Ecological corridors may support the conservation of biota in fragmented landscapes due to enhanced habitat connectivity. We conducted a study in order to assess the potential of a linear woodland landscape element along a railway line as ecological corridor using carabid beetles as indicators. The results showed that for some forest species the studied woodland strip has potential as an ecological corridor. Trophy and soil acidity were most often significantly correlated with parameters and species, but width of the woodland strip and distance from the forest site were of highest importance for the formation of the whole carabid assemblages. The results of our study provide with information regarding rules for the construction of woodland strips as ecological corridors. Management strategies should integrate such areas in concepts of sustainable regional development.